Response to:

'Draft import risk analysis report for fresh ginger from Fiji'

Prepared by the Australian Ginger Industry Association

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AUSTRALIAN Ginger
Pure Local Flavour

Summary

The Australian Ginger Industry Association believes that the 'Draft import risk analysis report for fresh ginger from Fiji' (Draft IRA) has underestimated the risks associated with the following aspects of importation of fresh ginger from Fiji.

- Many pests and diseases are carried in soil adhering to ginger rhizomes and often this is the primary method by which these problems are spread. However, the Draft IRA does not take full account of the risks associated with importing soil on rhizomes. Ginger is a particularly difficult plant to clean. In fact, because of the nature of its morphology, it is considered almost impossible to remove all soil adhering to rhizomes. There are crevices between the fingers on many rhizomes that can hold soil, and the soil cannot be removed without breaking the rhizome apart to separate the fingers. This means that there is a greater risk of transporting soil with ginger than with other root crops, which have a much more even surface. The AGIA believes that additional measures need to be taken to mitigate the risks of transporting soil. If soil is not removed, the risk of importing *any* organism that is carried in soil is high.
- As stated in the Draft IRA, many of the pests and pathogens on ginger rhizomes, such as yam scale, nematodes and latent fungal and bacterial infections, may escape detection during a visual inspection. This means that inspection is not a sufficient phytosanitary measure for ensuring that rhizomes are suitable for export, and it is not sufficient for assessments on arrival in Australia. Therefore, the risk of importing *any* organism that is not easily detected on the rhizome is high.
- Fresh ginger rhizomes are essentially planting material. Every piece of fresh ginger that is imported for human consumption can be used as planting material at any time of the year. Furthermore, a single hand can be split and used to produce several plants. It is a major omission of the Draft IRA that it does not consider the risks associated with consumers and growers unintentionally or intentionally planting imported rhizomes. Many consumers grow ginger in their backyards by planting pieces purchased in shops, and commercial ginger growers currently purchase ginger from the market to use as planting material on their farms. The Draft IRA discounts these avenues of spread because they 'cannot be effectively regulated'. Without more rigorous assessment of this infection pathway, the risk must be assumed to be high.
- In categorising organisms as quarantine pests, the Draft IRA does not take sufficient account of the wide and varied host ranges of particular pests and pathogens, and the genetic diversity of these organisms. The AGIA has identified five further organisms that are of particular concern because of the likelihood of importing biotypes that are not currently in Australia. We present new evidence of differences in host range and pathogenicity between an Australian and a Fijian isolate of *Radopholus similis* (burrowing nematode). We also present new evidence of differences between an Australian and a Fijian isolate of *Pythium vexans* (soft rot fungus). Even though, in most cases, the variants of these organisms do not have distinct published names, it is well documented that they have variable host ranges and pathogenicity; importing these organisms would be equivalent to importing new pest species. These organisms threaten the ginger industry, as well as other major crops and nursery plants, including citrus, bananas, sweet potatoes, pineapples and a wide range of popular ornamental garden plants.
- The Draft IRA grossly underestimates the potential consequences for the natural environment. Many native plants are closely related to ginger and grow close to commercial

ginger crops. These are at high risk of damage by imported pests and pathogens. The flow-on effects of any impact on native plants have not been addressed. Any plant or animal in the same ecosystem as a plant species affected by one of these pathogens is also likely to be affected, thereby causing imbalance in the ecosystem. However, in nearly every case, the Draft IRA suggests that little information is available about the host range and potential damage to native plant species and that, therefore, the consequences are 'indiscernible'. On the contrary, in the absence of reliable data, the AGIA believes that a *higher* risk should be assumed and a precautionary approach must be adopted. This lack of consideration of the potential consequences places the natural environment at a high risk of damage.

- In view of the risks described above:
- the unrestricted risk for ring nematodes is revised to 'low', which exceeds Australia's ALOP. Therefore, specific risk management measures are required for these pests.
- the unrestricted risk for spiral nematodes is revised to 'low', which exceeds Australia's ALOP. Therefore, specific risk management measures are required for these pests.
- the unrestricted risk for *Sphaeronema* sp. is revised to 'moderate', which exceeds Australia's ALOP. Therefore, specific risk management measures are required for this pest.

The AGIA agrees that the unrestricted risk for *Aspidiella hartii* is 'low', which exceeds Australia's ALOP. Therefore, specific risk management measures are required for this pest.

Additional organisms have been categorised as quarantine pests and their unrestricted risk estimates are as follows:

- The unrestricted risk estimate for *Radopholus similis* is 'moderate'.
- The unrestricted risk estimate for *Rotylenchulus reniformis* is 'moderate'.
- The unrestricted risk estimate for *Pythium vexans* and *P. graminicola* is 'moderate'.
- The unrestricted risk estimate for *Fusarium oxysporum* f.sp. *zingiberi* is 'moderate'.
- The unrestricted risk estimate for *Ralstonia solanacearum* is 'high'.
- *Verticillium albo-atrum* is categorised as a quarantine pest but a risk estimate has not been made in this response.

All of these unrestricted risk estimates exceed Australia's ALOP. Therefore, specific risk management measures are required for these organisms.

1 General

The Australian Ginger Industry Association (AGIA) is the peak body of the Australian ginger industry and as such is providing the industry response to the 'Draft import risk analysis report for fresh ginger from Fiji' (hereafter referred to as the Draft IRA). The information presented in this response has been gathered from detailed consultations with ginger growers, ginger agronomists and both Australian and overseas scientific experts in ginger entomology, nematology and plant pathology.

DAFF Biosecurity released the Draft IRA in April 2012 and comments were requested by 15 June 2012 to comply with the 60-day consultation period.

AGIA notes that the Draft IRA proposes that the importation of fresh ginger be permitted from all areas of Fiji.

1.1 Australian ginger industry

Ginger (*Zingiber officinale*) is a perennial rhizomatous herb, the underground rhizome of which is the source of an important spice. It belongs to Zingiberaceae, which is a distinct family of aromatic tropical plants that yield spices, dyes, perfumes and medicines. Other well-known members of this family include turmeric and cardamom, while a number of ornamental species are cultivated for their showy flowers (Smith 2004).

The Australian ginger industry is predominantly located throughout Queensland in the Sunshine Coast and Wide Bay – Burnett regions. The Sunshine Coast produces approximately 6075 tonnes of ginger annually, while Wide Bay – Burnett is the second largest growing region with production estimated at 1837 tonnes per year. The current farm-gate value of the Australian ginger industry is approximately A$15.6 million. Ginger is also used as a vital ingredient in a wide range of semi-processed products for the food manufacturing sector and processed products for the retail sector. The value of these products, in which Australian ginger is a key ingredient, is estimated at over A$80 million.

The Australian fresh markets take over 40% of the ginger produced domestically, but this market fluctuates according to supply and demand. The processing sector takes 55% of Australian production, and this market offers immediate growth potential for growers. Approximately 40% of the world's supply of confectionery ginger is processed and sold by one company, Buderim Ginger Limited on Queensland's Sunshine Coast, just over an hour north of Brisbane (Smith 2004).

The Australian ginger industry is mechanised, standardised and centralised with approximately half of its produce sold on the fresh market and the other half processed. Ginger production in Australia is a capital- and labour-intensive industry, and maximum yields are obtained in well-drained friable coastal soils using high inputs of good-quality water, fertiliser and organic matter. A high capital outlay is incurred in irrigation, specialised planting and harvesting equipment, and planting materials (Smith 2004). Australian ginger has approximately 40 commercial growers who employ around 200 full-time farmhands and 385 casual staff during peak harvesting periods.

Today the Australian ginger industry has some of the most efficient producers and processors in the world (Smith 2004).

2 Method of import risk analysis

This response to the Draft IRA is based on sound scientific advice and published evidence from many scientists who are specialists in their fields with many years of experience. It is also informed by the results of a four-year ACIAR project that studied farming systems and pests and diseases on ginger in Fiji and Australia (Smith *et al* 2012). Before that project, much of the information on soilborne pathogens of ginger in Fiji was to be found only in annual reports that were difficult to access and, in many cases, were poorly documented. That ACIAR project has provided information from extensive farm surveys and from experiments conducted in the field, as well as under more closely controlled conditions in the laboratory and glasshouse. Conclusions and recommendations are based on sound science. Results of the project have been published in peer-reviewed journals and proceedings. Together with the unpublished trip reports, this ACIAR project gives a thorough account of the pest and disease problems confronting the industry in Fiji and the AGIA believes that it should be used by DAFF Biosecurity to assess pest risks.

2.1 Provision of relevant information by DAFF Biosecurity

- **Draft Import Risk Analysis**

The extent and quality of the information and science in Section 3 (pp. 15–20) of the Draft IRA makes it difficult to assess the risk involved with importing fresh ginger from Fiji. It requires significantly more detail in almost every subsection.

For example, there is insufficient information about the location and climatic conditions of ginger production areas in Fiji (p. 15). The AGIA recommends including a thorough description of the location, surrounding vegetation and climatic conditions under which ginger is produced in Fiji. This should include:

- a map of ginger production areas in Fiji
- maps or detailed descriptions of key climatic parameters, such as rainfall, humidity and temperature, for each of the production areas
- descriptions of soil types in each major production area
- details of vegetation types near to production areas: for example, rainforest containing numerous other *Zingiber* or closely related species; close to urban areas; or within a large area of mainly commercial agriculture.

The Draft IRA (p. 16, para. 2) states that 'The importation of fresh ginger for further processing is currently permitted into Australia, subject to specific import conditions'. It is unclear from this statement whether the term 'fresh ginger' refers to ginger 'imported into Australia for processing in a Quarantine Approved Premises' as mentioned in Section 1.2.3, para. 2. If so, this should specified be more clearly. If this statement does not refer to 'Quarantine Approved Premises', the 'specific import conditions' should be described.

Section 3.2.1, para. 1 states that 'Both cassava and taro are poor hosts of parasitic nematodes such as *Radopholus similis, Rotylenchulus reniformis* and *Meloidogyne* spp. (Smith *et al.* 2012), so this practice helps suppress pest nematode populations'. This statement is incorrect and has been misunderstood and misquoted from the original source. A plant that is a poor host of a

particular nematode species does not 'suppress' the population of that species. A poor host merely prevents reproduction of that nematode species on that plant. On the other hand, suppression of a nematode species occurs when the chemical, physical or biological characteristics of the soil kill the nematodes or prevent them from infecting a host plant.

A further statement in Section 3.2.1, 'In addition to the crop rotation, a fallow period of about six months is usually included in the program'. This is an inadequate description of what appears to be the main pest and disease control measure used in Fijian ginger production. The description should state what program is being referred to, how long the program runs for and what else is included in the program.

The statement that 'Ginger production is very labour intensive, with much of the land preparation and harvesting done by hand (Buresova and McGregor 1990)' (Section 3.2.1, para. 1) relies on an old reference. Being more than 30 years old, it is difficult to be confident that this paper describes current farming practices. More recent studies should have been referred to, such as ACIAR project no. PC/2004/049 (Smith *et al.* 2012) and the trip undertaken by DAFF Biosecurity officers in 2007. This statement also omits the fact that at least two large ginger producers in Fiji are becoming increasingly mechanised and that at least one of these is following similar practices to those used in Australia.

Section 3.2.1, para. 1 states that 'Sourcing planting material from previous crops lessens the risk of pests and diseases being introduced from infected farms to new areas'. While this statement may be true, it ignores the fact that this practice can also increase levels of infection on farms where pests and diseases are currently present. Both effects of the same practice need to be considered. Research highlighted in the annual reports of ACIAR project no. PC/2004/049 (Smith *et al.* 2012) shows that most of the disease and pest problems in Fiji were introduced on planting material; therefore, the rhizome inspection and disinfestation treatment of planting material used in Fiji are ineffective. In fact, the longer the crop remains in the ground, as is the case for fresh ginger exports and for planting material, the more pathogens will build up in the soil and greater the levels of disease and pest infection will be in rhizomes.

When discussing hot-water treatment, Section 3.2.1 (para. 2) states that, with 'the apparent absence of diseases affecting the planting material, some farmers have bypassed this process'. This statement is misleading. ACIAR project no. PC/2004/049 (Smith *et al.* 2012) demonstrated that most pest and disease problems in Fiji are introduced on planting material. The Draft IRA should describe how the apparent absence of disease is assessed and by whom. In addition, there is no description of the efficacy of this hot-water treatment on various pests and pathogens. Section 4.5.1 of this response provides references to studies on the efficacy of various hot-water treatments on some nematodes. These suggest that treatment at 51 °C for 10 minutes would not be sufficient to eliminate those nematode species. Furthermore, it is notoriously difficult to maintain the prescribed water temperature for the required time. The Draft IRA does not describe the apparatus used in Fiji for hot-water treatment and makes no assessment of how well those farmers who do treat rhizomes are able to do this.

The Draft IRA (Section 3.2.1, para. 3) then states that 'The seed pieces are left to dry for a few days before planting, further reducing the risk of introducing nematodes to the soil'. There is no evidence to support this statement and the AGIA and its consultants are unaware of any research that shows that air drying seed pieces reduces the risk of introducing nematodes to soil. Some evidence is needed for this statement. ACIAR studies have shown that nematodes and *Pythium* continue to cause damage in seed even after air drying (Smith *et al.* 2012).

The statement (Section 3.2.1, para. 3) ‘Shrivelled material is discarded’ should describe what is meant by ‘shrivelled material’ and where it is discarded.

In Section 3.2.1 of the Draft IRA, significantly more detail is required on the cultivation practices for ginger in Fiji. For example:

- How are ginger crops in Fiji irrigated?
- Are chemical treatments applied to crops and, if so, how?
- What fertiliser or nutrients are applied to crops?
- What is the standard pest and disease management program used?
- Smith *et al.* (2012) found that few chemicals are used other than herbicide. Many growers plant more or larger blocks to offset expected losses caused by soilborne pathogens. Fertilisers tend to be organic materials such as poultry manure, but the larger producers use inorganic fertiliser. Rotation is the most important way of limiting losses to the ginger crop; however, some growers use vegetables and herbs in their rotations, which present greater potential for soilborne pathogens on exported rhizomes.

The statement ‘Immature ginger is harvested within 6 to 6.5 months’ (Section 3.2.2 of the Draft IRA) is unclear. If it means ‘within 6 to 6.5 months of planting’, then this should be stated. The reference used for harvesting dates is more than 30 years old and a more recent reference should be used to support a description of current practices.

The statement that ‘ginger rhizomes are washed individually’ (Section 3.2.2) is misleading and incorrect, particularly when taken in conjunction with Figure 3.4 in the Draft IRA. That photo shows rhizomes stacked up on top of one another in many places, and they are so closely packed that comprehensive cleaning of the whole surface of individual pieces would not be possible. A more accurate statement would be that ‘ginger rhizomes are spread out on wire racks and hosed thoroughly’.

More information is needed on postharvest handling of ginger in Fiji. For example:

- There should be a description of the location and conditions of the drying area. If it is close to the washing area, rhizomes could be splashed with soil from the next batch of rhizomes washed.
- What is the quality of the water used for washing? Is it clean or recycled water? Is it chlorinated or disinfected in some other way?
- What happens to the soil–water mix that is washed off the rhizomes?
- Who grades and inspects the root removal process?
- What grading scale is used to determine that rhizomes are free of roots?
- What grading scale is used to determine that rhizomes are free of soil?
- Who decides which pieces are ‘unsuitable for export’ and by what criteria?
- Is the ginger packed into boxes by hand or machine? How much ginger is packed into each box, and are any other packing materials included? Is only one type of box used?
- What are the packing boxes made of? Are they clean or reused?

2.1.2 Basis for the Draft Import Risk Analysis

The basis for estimating unrestricted risk in the draft Import Risk Analysis was stated to be a report on a trip by two DAFF Biosecurity officers to Fiji for four days in September 2007 (Draft IRA p. 15, para. 2). That trip report (entitled 'Field visit report, Ginger production and processing in Fiji, September 23–29 2007') was classed by DAFF Biosecurity as an internal working document and not intended for wider distribution. A request was made in Senate Estimates on 21 May 2012 to provide the report to the AGIA. The AGIA received the report on 25 May 2012. At a meeting with DAFF Biosecurity officers on 31 May 2012, it was stated that, contrary to the claim in the Draft IRA, the trip report did not form the basis of the Draft IRA but instead formed 'the basis for further work'. However, even though it seems that this further work has not been done yet, DAFF Biosecurity still considered that there was enough information to write the Draft IRA.

The trip report did not describe the experience and expertise of the two DAFF Biosecurity officers; therefore it is difficult for the AGIA to assess how well the pest and disease situation would have been investigated, especially as so little information was supplied in the report. In addition, the travel program was not provided with the report so it is not possible to determine how much time was spent visiting ginger farms and facilities and how much was spent on other stated tasks, including visiting 'production areas for fruit fly commodities' and 'the High Temperature Forced Air treatment facility in Nadi'.

Unfortunately, the trip report is very limited in its scope. Given the limited information provided in the Draft IRA (as described in Section 2.1.1 of this response), even taken together there is insufficient information for the reviewers of the Draft IRA to assess the pest and disease risks associated with importing fresh ginger rhizomes from Fiji. The trip report raises many more questions and contradictions that the AGIA needs solved before it can be confident that the situation related to importation of fresh ginger from Fiji is understood.

- Contrary to the claim on p. 2 of the trip report, a systems approach does *not* adequately mitigate the pest and pathogen risk associated with ginger. Smith *et al.* (2012) found numerous problems associated with preparation of seed material, and farm practices were recorded as contributing to pest and disease problems. Of particular concern is how the DAFF Biosecurity officers arrived at the assessment that the 'systems approach' can adequately mitigate the pest and pathogen risk when the pests and diseases have not even been identified (p. 7 of the trip report). The risk management measures have not been technically or practically demonstrated. Given the lack of evidence to support the risk management measures, a systems approach is not technically feasible or sustainable.
- On pp. 2 and 13 of the trip report, the problem of bacterial wilt is acknowledged and seen as an ongoing issue and to be 'investigated further'; however, this has been dismissed in the Draft IRA. Before it can be confident that the bacterial wilt situation in Fiji is understood, the AGIA needs to know which crops have been tested and from which areas, how many isolates from each crop have been identified, what the host ranges of those isolates are and what tests were used to identify the isolates.
- The trip report repeatedly confuses the end uses of mature ginger with 'baby' or immature ginger. Fiji already exports brined and confectionery products to Australia; this is harvested immature and does not pose a biosecurity risk. It is the mature ginger destined for the fresh market that poses a risk and, because it grows in the soil for a longer time, it also has a greater chance of infection and is more likely to harbour diseases and pests.

- Figure 2 of the trip report shows a farm at Waibau in the Natasiri highlands. The authors of the trip report claim that pests and diseases have a low likelihood of establishment on ginger on these slopes. This is incorrect. Smith *et al.* (2012) did extensive surveys of farms in the highlands, including a field trial on the farm shown in Figure 2, and showed that rhizome rot caused by *Pythium* was a major problem and several species of plant-parasitic nematodes were routinely found on ginger and in soils used for ginger cultivation (Smith *et al*. 2012).
- Figure 6 of the trip report shows a farm at Navua on the river flats. Again rhizome rot caused by *Pythium* was responsible for extensive losses following heavy rainfall on this farm, and a number of plant-parasitic nematode species were consistently extracted. Smith *et al*. (2012) also recorded heavy losses due to *Erwinia* sp. and *Rhizoctonia* sp. at various times on this farm.
- The statement that 'individual high pressure washing of rhizomes at the pack house will remove any soil and other materials of quarantine concern' (p. 13 of the trip report) contradicts the photos in the report showing rhizomes two to three layers deep in the trays being washed. Figures 8 and 9 of the trip report show ginger stacked and collectively washed. The shape and density of the rhizomes shown mean that it is impossible to wash away all soil. If rhizomes were washed individually, it should be explained how this was done. The statement on p. 2, para. 5 says that there was soil remaining on rhizomes after washing, so the previous washing procedure was not sufficient. The report does not, however, describe how the 'remaining soil' was removed.
- The trip report (p. 13) makes an assumption that all nematodes are considered primarily as external feeders or ectoparasites. This is incorrect. *Radopholus* and *Sphaeronema* are found inside the rhizome.
- The trip report (p. 6) states that hot-water treatment was used 'to address any nematodes carried on the seed material'. However, it does not state which nematode species are included in 'any nematodes'. The AGIA needs to know how efficacious this treatment was for different nematode species, whether it was also effective for nematodes inside the rhizome and how this was tested. The last point is particularly important because it is extremely difficult to detect low numbers of nematodes. To be sure that all nematodes have been eliminated from a rhizome, it would be necessary to plant it in sterile soil and extract nematodes after the rhizome has developed for some time. Without information about the effectiveness of the hot-water treatment, it should not be used as a risk mitigation measure.
- On p. 7 of the trip report, the question is raised 'of whether factors other than nematodes are affecting ginger'. This is an admission that DAFF Biosecurity, Fijian growers and Fiji authorities did not know at that time what pests and diseases were associated with ginger in Fiji. Has this been determined yet? Which nematodes are known to affect ginger? How widespread are these nematode problems?
- Dot point 3 on p. 8 of the trip report states that nematodes are 'not likely to be prevalent in the highland areas'. Why are they not likely to be prevalent? Which nematode species does this refer to? Why would the soil conditions be unfavourable for nematodes (dot point 4)?
- The DAFF officers were 'not able to observe any seed and land preparation' (trip report p. 6). Therefore, they were not able to assess the risk in this area.
- There is little scientific justification in the trip report to support the risk assessments made in the IRA. In fact, there is not even a mention of any insect pests in the trip report, even though yam scale is the only pest identified in the Draft IRA as being above the ALOP. This raises the question of what information was used to assess the risk in the Draft IRA. If no

information is available for a particular pest, then it is not possible to estimate the risk and this should be stated explicitly.

- If 'flat land commercial farmers face a difficult task in maintaining well drained soils', and 'rotting appeared to be the major problem' (p. 5), and investigations by staff at the Koronivia research station were ongoing to determine the cause, what was the result of the investigations that were commenced in 2007? Was the cause of the problem a pest, a disease or waterlogging?
- Baby ginger is 'not affected by any significant pests and diseases' (p. 8, last para. of trip report). How was this assessed? The trip report also states that baby 'rhizomes are soft and not hardy, they are not likely to germinate'. The report says that this requires further verification. Has this verification been done?
- The trip report does not describe the inspection process for ginger being exported to, for example, New Zealand. Do the Fijian staff inspect the ginger with hand lenses or microscope facilities, and do they have adequate lighting?

2.2 Assumptions used in estimating unrestricted risk

This section discusses important aspects related to importation of fresh ginger from Fiji that the AGIA believes were not addressed adequately in the Draft IRA. These are all fundamental points that relate to all pests and diseases that might be imported into Australia, and all affect their pest risk assessments.

2.2.1 Efficacy of washing rhizomes

The AGIA believes that the Draft IRA did not take full account of the risks associated with soil adhering to ginger rhizomes. This is a very concerning infection pathway that was not discussed in the Draft IRA.

Ginger is a particularly difficult plant to clean. In fact, because of the nature of their morphology, it is effectively impossible to remove all soil adhering to rhizomes; there are many crevices that can hold soil, and the soil cannot be removed without breaking the rhizome apart. This means that there is a greater risk of transporting soil with ginger than with other root crops, which have a much more even surface.

Section 3.2.3 states that 'The ginger rhizomes are washed individually with water using a high pressure hose to remove soil and external contaminants (Figure 3.4)'. However, Figure 3.4 in the Draft IRA does not show rhizomes being washed individually. Even if each rhizome was washed individually, additional measures would still be needed to remove soil from between fingers. Even then, it would still not be possible to remove all the soil from larger rhizomes, where parts overlap, without breaking the rhizome apart. No reference to these difficulties was made in the Draft IRA.

Australian ginger growers who produce rhizomes for export grow their crops using additional cultural practices to reduce contact with soil to a minimum. It appears that these measures are not used in Fiji; the Draft IRA does not refer to it and it was not seen by Smith *et al*. (2012) during their four-year ACIAR project in Fiji.

For the purpose of this response to the Draft IRA, and in order to quantify the risk of rhizomes carrying soil, Dr Mike Smith conducted a simple experiment, as described in Appendix 1 (This

article will be presented at the Australasian Soilborne Diseases Symposium in Fremantle in September 2012). This experiment revealed that, even after thorough washing (see Figure 2.1), similar to that shown in Figure 3.4 of the Draft IRA, an average of 0.88 grams of soil (range = 0.05–4.51 g, SD = 1.28) was still adhering to each rhizome (see Figure 2.2).

Figure 2.1 Washing of ginger rhizomes

The average weight of rhizomes was 275 g. Extrapolation enables estimation of the quantity of soil (potentially carrying serious ginger pathogens) that may be found in average consignments of ginger destined for the fresh market. For instance, a 10 kg carton may be expected to contain 32 g of soil. Even if only 70% of the rhizomes contain traces of soil, this still means 22.4 g of soil would be found on rhizomes in a 10 kg carton. Take this further and 2.24 kg of soil could be found in a 1-tonne air-freight consignment and 22.4 kg in a 10-tonne sea-freight consignment.

The numbers of nematodes extracted from soil adhering to these rhizomes after thorough washing (see Table A.1 in Appendix 1) illustrates that even very small quantities of soil can harbour significant numbers of nematodes. Nematode counts revealed that amounts of soil over 5 g contained hundreds of nematodes; 1–5 grams contained between 2 to 50 nematodes; and soil less than 1 gram contained up to 17 nematodes. In fact, 82% of the soil residues weighing less than 1 gram contained at least one nematode. Of those samples where more than 1 gram of soil was found on a rhizome, an average of 31 nematodes were extracted per gram of soil.

Extrapolation of nematode numbers from Table A.1 in Appendix 1 means that a 1-tonne air-freight consignment could contain nearly 70,000 nematodes and a 10-tonne sea-freight consignment could contain about 700,000 nematodes. Nematodes are generally about 0.5 mm long and can easily go undetected even in these small amounts of soil. However, nematodes are very large in comparison with fungal and bacterial spores, which can be less than one-tenth of

this size. The numbers of fungal and bacterial spores in such consignments are likely to be many orders of magnitude greater than this.

The Draft IRA (Section 3.2.3, p. 17), refers to the use of a high-pressure hose to remove soil and external contaminants'. However, there is no guideline for what the water pressure should be or for how long the rhizomes should be washed. In fact, it may not be possible to stipulate such guidelines. Ginger rhizomes at different times of the year (that is, at different stages of maturity) have softer or more resilient surfaces, making it necessary to adjust the water pressure accordingly. Without such guidelines, it is impossible to be sure that washing is done to a set standard.

In contrast to the preparation of ginger rhizomes as described in the Draft IRA, Figure 2.3 shows the rigour that is required for taro corms imported into Australia. Taro corms are much easier to clean because of their smooth surfaces. On arrival in Australia, AQIS requires that corms be free of soil, and be topped and tailed, with the root end clean.

The AGIA believes that additional measures need to be taken to mitigate the risks of transporting soil on ginger rhizomes into Australia. The risk of importing *any* soilborne organism on ginger rhizomes is high.

On arrival in Australia, AQIS imposes one or more of the following post-entry treatments if imported goods are inspected and found to contain soil (or other contaminants). The goods may be:

- cleaned and re-inspected. As described earlier, this is not feasible for any but very small consignments.
- treated with chlorine solution. This is not suitable for commodities intended for human consumption.
- destroyed or re-exported. These are the most likely scenarios for most consignments of ginger imported into Australia.
- Although the Draft IRA does not address the problem of trash, it presents an additional significant problem. For example, grass and weed stems may be caught in crevices and between the fingers of rhizomes, as is seen in produce in Australian markets currently. This could not be removed by washing. Also, it may be a similar colour to the rhizome and therefore unlikely to be detected as easily as dark-coloured soil.

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Figure 2.2 (a) An example of a ginger rhizome after thorough washing (b) The same rhizome after being pulled apart to extract soil from between fingers. The soil adhering to the rhizome after thorough washing is shown in the Petri dish.

Figure 2.3 Taro corms prepared for export to Australia (photos courtesy of AQIS)

The AGIA assumes that AQIS is thorough in its inspections. However, it would never be possible to eliminate all soil and trash from a consignment of ginger rhizomes. Even very small amounts of soil can harbour significant numbers of nematodes and would also carry very high numbers of bacteria and fungi. The AGIA recommends that enhanced visual inspection using a lens or microscope be undertaken, both pre-export and on arrival, to ensure that pests, soil and other contaminants will be detected on rhizomes.

2.2.2 Risks of growing imported rhizomes

A significant flaw in the Draft IRA is that it does not consider that the risks associated with consumers and growers unintentionally or intentionally planting imported rhizomes are significant.

The report states that 'The intentional importation of fresh ginger for the purposes of propagation (for example, by farmers) under an import permit for human consumption is a breach of import permit conditions, and liable to prosecution under the *Quarantine Act 1908*' (p. 2, para. 3). However, it is not a breach of the Act to purchase ginger for human consumption from the market and use it for planting material. In fact, many consumers grow ginger in their backyards, and it is known that growers currently purchase ginger from the consumer market to grow commercially. Currently, about 10–20% of the ginger planting material used commercially is sourced from outside of the farm (Hall and Ekman 2012); see Appendix 2 for a copy of an invoice issued from a consumer market to a ginger grower for ginger rhizomes that were subsequently used as planting material on a commercial farm.

Section 3.3 of the Draft IRA claims that southern Australia provides the bulk of the market for Fijian ginger. However, Biosecurity Queensland has confirmed that there are no restrictions on ginger that has been imported into markets in 'southern Australia' moving north to Queensland, where the main ginger-production region is located. Imported rhizomes could be moved to consumer markets in more northern parts of Australia, and may also be bought by ginger growers to use as planting material.

Risks associated with planting infected rhizome material from Fiji include spread from farms or backyards to other host plants, including other ginger crops, pineapple and banana crops grown close to the ginger-production region and native forest plants. Native forests are another important avenue of impact. Figure 2.4 illustrates that ginger crops are currently grown directly adjacent to native forests; any pest or disease in the ginger crop is very likely to spread to native host plants.

Figure 2.4 A ginger crop in Southeast Queensland growing adjacent to a native rainforest

Section 1.2.2 states that 'It is expected that volumes of ginger diverted to growing purposes by consumers would be small'. However, the Draft IRA does not describe the basis for this statement. Informal surveys by the AGIA have revealed that the incidence of consumers growing edible ginger and native ginger in their backyards is not small. A survey in Southeast Queensland revealed 40% of residents growing ginger in their backyards and 25% growing various species of native ginger. A rough survey in Murwillumbah (northern New South Wales) found 50% of rural residential blocks with ginger plants; in addition, residents regularly swap or give away plants or rhizomes as plants grow and need to be reduced to a manageable size.

Figure 2.5 shows a typical ginger rhizome that is no longer usable for cooking but is producing green shoots. Many people would plant such material in their gardens in order to grow their own ginger, thereby increasing the risk of establishing exotic pests and diseases that may be present in the rhizome. Increasing the extent of infected ginger increases the risk of spreading pests and diseases away from the ginger-growing region.

Edible ginger is planted in an increasing number of backyards as a healthy food plant. There are also many types of ornamental ginger in several genera, including *Hedychium* and *Etlingera*, that are grown for their flowers and attractive foliage, and these are also commonly planted in gardens in both new and established gardens.

Figure 2.5 Ginger rhizome withered and no longer usable for cooking, but producing green shoots. Some consumers would plant such material in their gardens.

In addition to consumers and growers planting ginger rhizomes, there is a significant risk associated with consumers distributing imported rhizome material, as stated in the Draft IRA (p. 23, dot points 12 and 13):

- Individual consumers could carry small quantities of ginger rhizomes to urban, rural and natural localities. Small amounts of ginger waste could be discarded in these localities.
- Small amounts of ginger waste will be discarded into domestic compost.

The movement around Australia in the nursery trade of ginger and other plants that are hosts of ginger pests and diseases (see Figure 2.6) has been underrated in the Draft IRA. This is yet another pathway for the spread of exotic pests and diseases that might enter Australia via fresh ginger imports. In addition, ginger and related plants are collected by people who swap, buy and sell plants via websites such as eBay (see Figure 2.7). This would contribute to the rapid spread of these pests and diseases.

The use of imported fresh ginger as planting material and spread by consumers reduces enormously the difficulties faced by pests and diseases in becoming established in Australia. It also increases the risk of ginger pests and diseases reaching other crops, nursery plants and native forests. Therefore, the probabilities of establishment in the Draft IRA are likely to be higher than those stated. In particular, the Draft IRA needs to re-assess all probabilities and consequence ratings in consideration of this risk.

Figure 2.6 An example of movement of ginger plants via the nursery trade

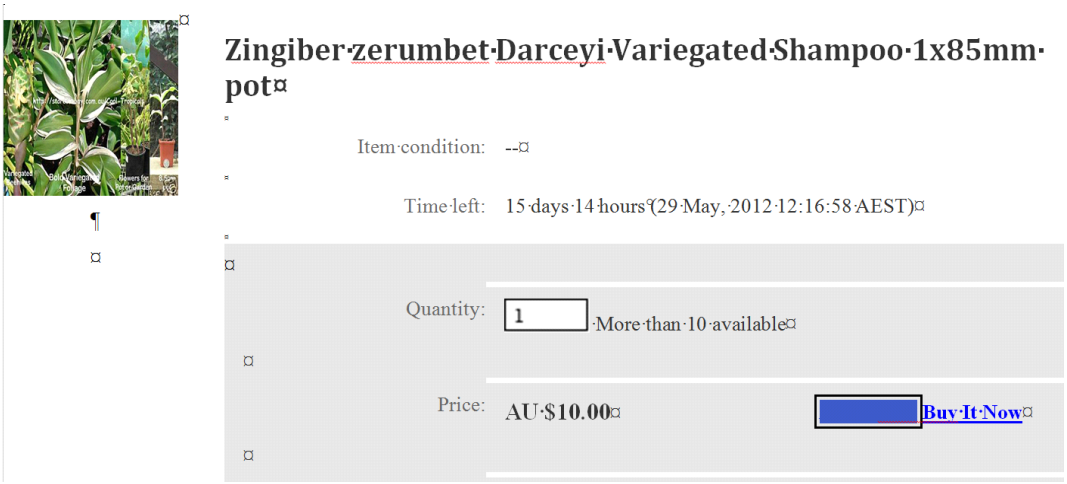


Figure 2.7 An example of movement of ginger plants via eBay

It is not sufficient to discount movement of ginger planting material simply because it 'cannot be effectively regulated' (Draft IRA, p. 2, para. 3). Without more rigorous assessment of this infection pathway, the risk must be assumed to be high. If no information is available, then it is not possible to estimate the risk and this should be stated explicitly.

2.2.3 Variability in host range and pathogenicity

The Draft IRA (p. 5, para. 2) defines a pest as 'any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products'. However, the report does not then consider this variability when categorising pests and pathogens as quarantine pests.

All pests, including disease-causing organisms, are inherently diverse. Much time is spent by plant pathologists, entomologists, nematologists etc. in identifying variation between populations of a pest species for the purpose of ascertaining their host range and pathogenicity and to develop

control measures, such as the use of resistant cultivars, crop rotation and biological control, all of which rely on accurate identification of the pest.

Identification of a pest organism can usually be done to the species level quite readily. However, this captures only a small amount of the diversity in that species. Populations within a species can vary markedly, and in only a few cases has enough work been done to classify this variation as subspecies, races, pathotypes etc. Even for species where such classification has not been made, a large amount of diversity has often been identified but the species has not yet been divided into smaller named groups. Understandably, this makes it difficult for quarantine authorities to form a basis on which to restrict certain commodities in order to protect Australia's agriculture and its unique environment.

Serious consequences can result from importing exotic isolates of pests or pathogens that have different a host range or pathogenicity from Australian isolates. For example, if an organism of species X is imported into Australia and it has a different host range from populations of species X already present in Australia, it may establish on and significantly affect crops and other plant species that have not previously been affected by species X. In addition, the imported organism may be more pathogenic to crops already known to be hosts of Australian isolates of species X. Either situation would result in more damage to crops and may render current control measures (such as resistance and crop rotation) inadequate.

In recent decades, considerable work has been done to differentiate populations of organisms on the basis of differences in DNA sequences. This is a very sensitive technique and, in fact, such molecular studies will reveal genetic differences between nearly all populations of organisms. Therefore, it could be claimed that all isolates of a pest organism are different and so we should prevent importation of isolates of all organisms. However, that is not the purpose of the discussion here. The AGIA merely maintains that, where significant diversity (genetic, physiological, biochemical etc.) has been found between isolates of pest organisms, it is vital to ascertain the host range and pathogenicity of Fijian isolates of those organisms before we risk importing them into Australia.

Because of the diversity within species of pest organisms, this response challenges the categorisation of some of the organisms listed in Appendix A of the Draft IRA. The AGIA concentrates on the pests that are of particular concern to the ginger industry, other significant industries or the natural environment; where there is well-documented evidence of host range and pathogenicity variation within that species; and where there is a legitimate basis for excluding Fijian isolates of those pests until their host range and pathogenicity are compared with those of Australian isolates.

This is discussed in more detail for specific pests in Section 3 of this response.

2.2.4 Reliability of visual inspection

As stated in the Draft IRA, it is very difficult to detect many of the pests and pathogens, such as yam scale and nematodes, on ginger rhizomes.

The Draft IRA (dot point 5, p. 33 and dot point 7, p. 45) explains that, because of their small size, nematodes 'would escape detection during a visual inspection'. Fungal and bacterial spores are at least ten times smaller than nematodes so would be even more likely to escape detection. Also, fungi and bacteria can survive as latent infections (Verhoeff 1974; Ishikawa 2004) and this would not be seen without culturing the organisms.

In addition to the problem of the microscopic nature of pests and disease organisms is the fact that ginger rhizomes have very uneven surfaces. Any of these indentations and crevices could harbour important organisms, in addition to soil. Furthermore, any organism that may be found inside a rhizome, including weevils, nematodes, fungi and bacteria, would also escape detection by visual inspection (Draft IRA, dot point 6, p. 23).

This means that there is a high risk of importing *any* organism that is carried by the rhizome and that is not easily detected visually. Furthermore, visual inspection is not a sufficient phytosanitary measure for ensuring that rhizomes are suitable for export from Fiji. It is vital that additional measures are taken in Fiji to ensure that rhizomes are free of pests and diseases before there are ready for export.

2.2.5 Risks to natural environment

The Draft IRA grossly underestimates the potential consequences for the natural environment.

Many native plants are closely related to ginger and these are at high risk of damage by imported pests and pathogens. For example, Stanley and Ross (1989) have recorded two species of native ginger (family Zingiberaceae) in Southeast Queensland: *Alpinia caerulea* and *A. arundelliana*; both of these are endemic to rainforests of the Moreton and Wide Bay districts (Australia's ginger-growing region) with the former species described as widespread and the latter as rarer. They both have attractive foliage and blue berries and are cultivated in home gardens. Edible ginger (*Zingiber officinale*) is often grown within metres of these rainforest areas (see Figure 2.4).

Appendix 3 is a report by Dr Jonathon Lidbetter on the risks presented by edible ginger imported from Fiji to Australian native flora. Edible ginger is closely related to many native plants including *Alpinia, Strelitzia, Canna, Maranta* and *Heliconia*. It is also closely related to genera that are grown as commercial crops, including banana (*Musa*) turmeric (*Curcuma*), cardamom (*Elettaria* and *Amomum*) and galangal (*Alpinia* and *Kaempferia*). It seems from the Draft IRA (Section 3.3) that the largest market for ginger from Fiji would be the southern states of Australia. It might also be considered that the climate in those states would not be conducive to consumers growing ginger in home gardens. However, that is not the case; ginger and its relatives are grown widely in those areas, as evidenced by many on-line forums shown in Appendix 3.

Contrary to the Draft IRA's assessment of environmental risks, there is a high risk of exotic pathogens introduced on imported ginger coming into contact with these native species, particularly through home gardens but also from commercial farms that use planting material sourced from the market. Furthermore, when a garden or farm is close to a forest, sick and diseased plants found in the garden or paddock are likely to be disposed of in adjacent natural habitats. This presents a likely infection pathway for pests and diseases, and it poses a high environmental risk as introduced pathogens found on ginger may attack native species.

These species of native ginger attract native birds and insects. They are also important as bush tucker and bush medicine; their value has been recognised recently as an inclusion in European diets (such as an addition to salads) as well as for their medicinal benefits. For instance, He *et al.* (2012) have found that the berries contain a compound zerumin A, which has anti-angiogenic properties; that is, it restores health by controlling or inhibiting blood vessel growth and has therefore been useful in treating cancers etc.

In many instances, the Draft IRA gives an impact score of A (indiscernible at the local level) for risks related to the environment. This appears to be based on the lack of information available. However, the AGIA believes that, if no information is available to assess the risk of a particular pest on the environment, then it is not possible to estimate the risk and this should be stated explicitly.

In the absence of reliable data, we must assume a *higher* risk. This lack of consideration in the Draft IRA of the potential risks from all pests and diseases results in a much reduced 'unrestricted risk estimate' and places Australia's unique plant life and ecosystems at high risk of damage.

2.2.6 On-farm practices in Fiji

The AGIA believes that the Draft IRA overestimates the efficacy of on-farm practices in Fiji in reducing pest and pathogen populations.

The report (Section 3.2.1, para. 2) cites the example of growers not using hot-water treatment for ginger seed material in 'the apparent absence of diseases'. If this is exemplary of the lack of stringency in on-farm hygiene, it gives the Australian ginger industry no confidence that rhizomes imported from Fiji would be free of important pest organisms.

In addition, hot-water treatment tends not to be reliable because it is notoriously difficult to regulate the temperature. If the correct temperature cannot be maintained for the prescribed time, treatment is ineffective and cannot be relied on to reduce target organisms. In addition, most guidelines for hot-water treatment are aimed at reducing pest populations rather than eliminating them. For most pests, protocols have not been developed to eliminate organisms; this would likely require higher temperatures or longer treatment times, and these may affect the resultant quality of ginger rhizomes. Where required for particular organisms, methods must be developed to achieve elimination without affecting the quality of ginger rhizomes intended for human consumption.

Also in Section 3.2.1, the Draft IRA states that 'The seed pieces are left to dry for a few days before planting, further reducing the risk of introducing nematodes to the soil'. However, the report gives no evidence to support this statement. It may be true of some nematodes species, but this practice would have minimal effect on nematodes within the rhizome tissue, such as *Radopholus similis*, and would have no effect on species that survive by anhydrobiosis (survival without water and in a dormant state). *Rotylenchulus reniformis*, for example, tolerates extreme temperatures and survives extended periods in dry soil without a host through anhydrobiosis (Radewald and Takeshita 1964; Lehman 2004). Populations can survive for two years in fallow soil as eggs or as second-stage juveniles (Sipes *et al*. 2005).

On p. 43, para. 1, the report states that 'seed rhizomes may have some roots still attached'. This further indicates poor on-farm practices; seed rhizomes should not have *any* roots attached.

Although the Draft IRA gives some description of how nematodes are managed in Fiji, it does not discuss how insect pests, and *Aspidiella hartii* in particular, are controlled. The AGIA can only conclude that there are no effective control measures.

The lack of disease-free planting material is a key impediment to the success of Fiji's ginger industry (SPC 2011). If it is difficult to produce disease-free planting material for use within Fiji, it seems unlikely that the AGIA can be assured that imported fresh ginger rhizomes will be free of pests and disease-causing organisms.

2.2.7 Uncategorised pests

While the categorised pests are of most concern, fresh ginger rhizomes could also harbour other organisms on the importation pathway, as described on pp. 51–52 of the Draft IRA. Furthermore, Table 5.1 of the Draft IRA identifies the ant species *Pheidole fervens* as an actionable organism likely to be intercepted on fresh ginger from Fiji. Although consignments will be inspected on arrival in Australia, there is no certainty that these other organisms will be detected, especially as they are likely to be concealed within the uneven surface of ginger rhizomes.

In addition, it appears from Figure 3.6 of the Draft IRA that there are no slip sheets in boxes packed ready for export. The boxes have many entry points where 'hitchhikers', such as frogs, spiders, lizards and ants, could find their way in. The packing sheds are not described in the Draft IRA. If they are not enclosed, they cannot prevent insects flying in and entering boxes ready for export.

2.2.8 Chemical residues

Another issue related to importing fresh ginger from Fiji is that of chemical residues. On pp. 16–17, the Draft IRA describes the use of Sundomil for treatment of planting material. However, the report does not mention any other use of chemicals to control pests or diseases.

The Fijian Ministry of Primary Industries recommends chemical treatment of crops for ginger rhizome rot caused by *Pythium* species:

> When disease symptoms appear ... apply fungicide (Sundomil at 50g in 1 Litre of water) to plants and surrounding areas.
>
> Use Sundomil by spraying the soil around the plant ...

Sundomil contains 640 g/kg mancozeb and 80 g/kg metalaxyl. Australia has a residue limit set for the use of metalaxyl in ginger. However, the ginger industry does not have a use permit for mancozeb, and no residue limits have been set.

In Australia, each crop requires a product registration, a minor use permit or an emergency use permit. Registrations and minor use permits require residue analysis work to ensure safety. Emergency use permits do not always require residue analysis; however, if this is not available, the APVMA sets use guidelines that ensure that chemical residues fall below the intake food basket for consumption of that product. The problem with setting use guidelines would be the difficulty of calculating the application rates and, therefore, the residues when high-volume backpack sprayers are used, as recommended by the Fijian Ministry of Primary Industries.

2.2.9 Comparison with other importing countries

Section 3.2.4 of the Draft IRA states that 'Fresh mature ginger, produced and prepared as described above, is currently exported to New Zealand and the United States without additional treatments'. While this may be true, it is not a valid comparison because it does not take into account the wide differences between the situations in those two countries and that in Australia.

Firstly, there is no commercial production of ginger in New Zealand or the United States (except in Hawaii).

Secondly, many of the target organisms that the Australian ginger industry seeks to prevent being imported are already present in those countries, particularly in the Hawaiian ginger

production areas, including *Radopholus similis*, *Rotylenchulus reniformis*, *Pythium vexans* and *P. graminicola*, *Fusarium oxysporum* f.sp. *zingiberi* and *Ralstonia solanacearum* (Trujillo 1964; Nishina *et al.* 1992; Wang *et al*. 2002). *Rotylenchulus reniformis* is the major nematode pest of pineapple in Hawaii. *Fusarium oxysporum* f.sp. *zingiberi* is probably the most serious problem of ginger in Hawaii (Trujillo 1964). The Hawaiian ginger industry is also severely affected by bacterial wilt, which has been reported from most areas where ginger is grown commercially (Trujillo 1964).

2.2.10 Transshipping and importation

It is common practice worldwide to transship horticultural produce (either legally or illegally); that is, produce is imported from another country and exported as if it has been grown in the exporting country. If supplies of exportable ginger in Fiji were low, it may be profitable to supply Australia with produce that has been grown outside of Fiji. The AGIA has anecdotal evidence of this occurring from Thailand through New Zealand to Fiji, and directly from China to Fiji. This is an issue that the AGIA cannot ignore.

Fijian ginger growers have close ties with China and India. Both China and India have a range of pests and pathogens of ginger that are of concern to Australia. For example, bacterial wilt (*Ralstonia solanacearum*) is a serious ginger disease in both China and India (Kumar and Hayward 2005). India also has serious problems with *Aspidiella hartii* (Devasahayam and Abdulla Koya 2005), *Pythium vexans*, *Fusarium oxysporum* f.sp. *zingiberi*, *Radopholus similis* and *Rotylenchulus reniformis* (Dohroo 2005). There are likely to be many other organisms of concern in these and other countries that might be sources of ginger for export to Australia.

Transshipping presents serious risks to the viability of Australia's ginger industry. There may be no legal process for preventing this from happening and, therefore, it is vital to be sure of the pest and disease risks that it presents. It is also vital to develop protocols in Fiji to ensure that ginger rhizomes are rendered free of pests and diseases before they are exported to Australia. This should include an external audit of registered packing house procedures in Fiji.

3 Categorisation of quarantine pests

The Australian ginger industry considers that the organisms listed in Table 3.1 present a significant risk to ginger production and to other industries.

Table 3.1 Quarantine pests for fresh ginger from Fiji

Organism	Common name	Status
Arthropods		
Aspidiella hartii	Yam scale	Present in Fiji and not present in Australia
Nematodes		
Discocriconemella discolabia; *Mesocriconema denoudeni*	Ring nematodes	Present in Fiji and not present in Australia
Helicotylenchus egyptiensis; *H. indicus*; *H. mucronatus*	Spiral nematodes	Present in Fiji and not present in Australia
Sphaeronema sp.	Cystoid nematode	Present in Fiji but unidentified and one report in Australia but unidentified
Radopholus similis	Burrowing nematode	Present in Fiji and in Australia but there is strong evidence for pathogenicity differences between biotypes in the two countries and worldwide
Rotylenchulus reniformis	Reniform nematode	Present in Fiji; present in parts of Australia but absent from the major ginger- and pineapple-production areas in the Southeast Queensland Region
Bacteria		
Ralstonia solanacearum	Bacterial wilt	Present in Fiji but the biovar has not been identified (could be biovar 3 or 4); biovar 3 present in Australia but biovar 4 has been eradicated
Fungi		
Pythium vexans and *P. graminicola*	Soft rot	Present in Fiji and in Australia but strong evidence for pathogenicity differences between biotypes in the two countries
Fusarium oxysporum f.sp. *zingiberi*	Rhizome rot	Present in Fiji and in Australia but strong evidence for pathogenicity differences between biotypes in the two countries
Verticillium albo-atrum	Rhizome rot	Present in Fiji and not present in Queensland, New South Wales, Northern Territory, Australian Capital Territory or Western Australia

3.1 Yam scale (*Aspidiella hartii*)

The Draft IRA categorised *Aspidiella hartii* as a quarantine pest.

3.2 Ring nematodes (*Discocriconemella discolabia* and *Mesocriconema denoudeni*)

The Draft IRA categorised *Discocriconemella discolabia* and *Mesocriconema denoudeni* as quarantine pests.

3.3 Spiral nematodes (*Helicotylenchus egyptiensis*, *H. indicus* and *H. mucronatus*)

The Draft IRA categorised *Helicotylenchus egyptiensis*, *H. indicus* and *H. mucronatus* as quarantine pests.

3.4 Cystoid nematode (*Sphaeronema* sp.)

The Draft IRA categorised *Sphaeronema* sp. as a quarantine pest.

3.5 Burrowing nematode (*Radopholus similis*)

The Draft IRA considers that *Radopholus similis* does not require a pest risk assessment because it has been recorded in Australia (p. 64). While this nematode species does occur in Australia, and is a major pest of banana crops, this argument fails to take account of the considerable literature on the nematode's variability and wide host range among different isolates of this nematode both within Australia and around the world. Importing an isolate of *R. similis* from Fiji that has a different host range or greater pathogenicity than already present in Australia would present significant risks to the ginger and other industries.

Recent studies with *R. similis* on ginger have shown that a Fijian isolate of the nematode reproduces and causes damage very rapidly to ginger in Fiji, killing plants and destroying rhizomes, with secondary organisms playing little role in symptom development (Turaganivalu *et al.* 2012; Smith *et al.* 2012); it can cause severe damage and can increase ten-fold in nematode numbers within 20 weeks. In contrast, an isolate of *R. similis* from Queensland caused very little damage after 16 weeks and did not reproduce beyond the initial inoculum (see Appendix 4 for an article to be presented to the Australasian Soilborne Diseases Symposium in Fremantle in September 2012); that is, it appears that ginger is *not* a host of the Australian isolate of *R. similis*. To illustrate that differences between the Australian and Fijian isolates of *R. similis* more clearly, the relevant results of the two trials are shown in Tables 3.2 and 3.3.

While it was not possible to use the same ginger cultivar in these two trials, the methods used and the environmental conditions were similar. The results suggest, therefore, that the Fijian isolate of *R. similis* would be much more damaging to Australian ginger than isolates already in Australia.

Table 3.2 Effect of *Radopholus similis* on ginger and numbers of a Fijian isolate of *R. similis* recovered 20 weeks after plants growing in potting mix were either inoculated with 1500 nematodes or left uninoculated (Turaganivalu *et al.* 2012)

Treatment	Dry wt. shoots (g)	Fresh wt. seed piece (g)	Fresh wt. rhizome (g)	No. *R. similis* females		
				per seed piece	per rhizome	per pot (soil + roots)
Control	79.2 a	52.8 a	54.4 a	0	0	0
R. similis	7.5 b	23.7 b	24.5 b	397	884	15,628

Numbers in the same column followed by different letters are significantly different ($p = 0.05$).

Table 3.3 Effect of *Radopholus similis* on ginger and numbers of an Australian isolate of *R. similis* recovered 16 weeks after plants growing in potting mix were either inoculated with 2000 nematodes or left uninoculated (Cobon *et al.* 2012; see Appendix 4)

Treatment	Fresh wt. shoots (g)	Fresh wt. seed piece (g)	Fresh wt. rhizome (g)	No. *R. similis*		
				per 100 g seed	per 100 g rhizome	per 100 g seed + rhizome + roots
Control	130.5	30.4	202.1	0	0	0
R. similis	114.0	34.9	220.0	11	19	428

Results were not significantly different ($p = 0.05$).

R. similis has never been recorded in ginger in Australia, although *R. similis* frequently occurs in other crops such as banana, which are grown commercially in Southeast Queensland between Caboolture and Bundaberg. Both banana and ginger farms occur in Southeast Queensland and, in some cases, on neighbouring properties. Also ginger, a shade-loving plant, has been intercropped with banana on some small farms and by some organic producers.

Although banana is not a major commercial crop in Southeast Queensland today, it was important prior to about 1990. It was also widely planted in home gardens (and still is today). *R. similis* was known to be an important pest of banana, and, since ginger and banana were grown in the same general area for more than 50 years, the fact that the nematode was not recorded on ginger suggests that its capacity to attack ginger is limited. While the absence of *R. similis* on ginger in Australia may be due in part to the use of hot water to obtain clean planting material, hot-water treatment was never used by all growers and was not introduced until the 1960s. Given that *R. similis* has never been reported from ginger in Australia, despite being grown in close proximity to infested bananas for many years, it would not be responsible to threaten the Australian ginger and banana industries by importing ginger rhizomes that may be infested with a more virulent race of the nematode before tests have determined the host range and pathogenicity of Fijian and Australian isolates on these crops.

Furthermore, Smith *et al*. (2007b) did not find *R. similis* in banana roots or soil in Fiji, despite extensive sampling of crops growing adjacent to severely infected ginger blocks. This raises questions about the host preference of *R. similis* in Fiji and suggests that there is a major risk of introducing a pest that is adapted to, and has a preference for, feeding on ginger roots and rhizomes.

Two races of *R. similis* have been named (DuCharme and Birchfield 1956); the 'banana race' is pathogenic to banana but not citrus, and the 'citrus race' is pathogenic to both citrus and banana. In 1984, a taxonomic change was made and the citrus race was named *R. citrophilus*. Subsequent studies, however, suggested that previous work was not convincing and that both the banana and citrus races belong to *R. similis* (Kaplan and Opperman 1997, 2000; Kaplan *et al*. 1997, 2000; Elbadri *et al.* 2002).

Spreading decline of citrus, caused by the 'citrus race' of *R. similis*, is a severe disease in Florida (Duncan 2005). Within the citrus race, biotypes are known to have broken the resistance of all burrowing nematode-resistant citrus rootstocks released since 1958 (Kaplan and O'Bannon 1985). Therefore, even within this race, significant host range variability is known.

Aside from this race classification, there is significant biodiversity within the banana race of *R. similis*. Biological diversity of *R. similis* attacking banana was first described on populations from Central America and the Caribbean (Edwards and Wehunt 1971; Pinochet 1979, 1988; Tarté *et al.* 1981; Sarah 1993). Sarah *et al*. (1993) also found large variability between geographically isolated populations of *R. similis* in both their ability to reproduce on banana and their ability to cause damage. Several studies have revealed wide diversity in pathogenicity to banana plants directly related to the multiplication rate in the root tissue (Sarah and Fallas 1995) and provide some explanation for the considerable differences in the economic impacts of this nematode in different banana production areas worldwide (Sarah 1993).

Various isolates of *R. similis* have been shown to exhibit different levels of pathogenicity on different host species, and clear differences in reproductive potential and the degree of host response have been demonstrated. For example, in a study comparing the pathogenicity of nine different isolates of *R. similis* from throughout the world, it was found that a Queensland isolate from Tully was one of the least pathogenic (Fallas *et al.* 1995), and this ranking was *not* related to temperature during the experiment (Fallas and Sarah 1995). Cobon and Pattison (2003) studied seven Australian isolates of *R. similis* from banana crops. They found significant variation between some isolates, but this difference was very small compared with that found by Fallas *et al.* (1995). In the study by Cobon and Pattison (2003), the Tully population was from the same farm as the Queensland isolate studied by Fallas *et al.* (1995); this Tully isolate was the most pathogenic of the Australian isolates, suggesting that Australian isolates are generally less pathogenic than most of those studied by Fallas *et al.* (1995).

Hahn *et al.* (1996) found significant differences between ten isolates of *R. similis* (including one from Fiji) in their ability to reproduce on banana, with up to 35-fold differences in reproduction. Koshy and Jasy (1991) identified ten races among 28 isolates of *R. similis* in south India on the basis of their multiplication on 17 host differentials. In another study of host ranges with isolates of *R. similis*, Edwards and Wehunt (1971) found evidence of more than one banana race in Central America. Quiros and Araya (2008) identified correlations between the pathogenicity of a number of isolates from Costa Rica and Belize and the genetic distance between those isolates.

R. similis was first reported on banana in Queensland by Tryon (1902). Since the nematode was first described on banana in Fiji by Cobb (1893), it has sometimes been assumed that the Australian isolate was introduced from Fiji. However, there is no evidence that this actually occurred. It is more likely that the nematode was introduced from Asia, given that thousands of people moved from Asia to north Queensland during the mining boom of the late 19th century. This possibility is supported by data from Tan *et al*. (2010), who indicated that *R. similis* was probably introduced from a single source population, most likely from South-East Asia. Given that Tan *et al*. (2010) also confirmed the lack of diversity of *R. similis* within Australia, any

further introduction is likely to add to that diversity. The risk from Fijian isolates is particularly high, given that its host range and pathogenicity appear to differ from those of *R. similis* strains elsewhere in the world.

3.6 Reniform nematode (*Rotylenchulus reniformis*)

The Draft IRA (p. 64) states that *Rotylenchulus reniformis* has been recorded in Northern Territory, Queensland and Western Australia. It therefore states that a pest risk assessment is not required and that it cannot be categorised as a quarantine pest.

Neither the *Import Risk Analysis Handbook 2011* nor the *Quarantine Act 1908* stipulates how the term 'quarantine pest' should be identified. In categorising quarantine pests, the Draft IRA uses the following FAO (2010) definitions:

- **Quarantine pest:** 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
- **Pest:** Any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products
- **Endangered area:** An **area** where ecological factors favour the establishment of a pest whose presence in the area will result in economically important loss
- **Area:** An officially defined country, part of a country or all or parts of several countries

Even though the Draft IRA does not describe any restriction of the FAO (2010) definition of 'quarantine pest', it appears to confine the categorisation of quarantine pests to those organisms where a species or a named variant is present on ginger in Fiji but is not present anywhere in Australia.

However, the definitions refer not to Australia but to the endangered area. Therefore, in order to categorise *R. reniformis* as a quarantine pest, it is necessary to determine the endangered area.

In the case of *R. reniformis*, the endangered area is the Southeast Queensland Region, which contains the ginger-production region and a large proportion (about 65%) of the pineapple-production region. The Southeast Queensland Region is an officially defined region (Office of Economic and Statistical Research) and, therefore, it is 'an officially defined ... part of a country'. The nearest presence of *R. reniformis* to the Southeast Queensland Region is in north Queensland, about 500 kilometres away. Because of the ginger and pineapple production in the Southeast Queensland Region, it is also 'an area where ecological factors favour the establishment of [*R. reniformis*] whose presence in the area will result in economically important loss'.

Therefore, *R. reniformis* is 'a pest of potential economic importance to the area endangered [Southeast Queensland Region] thereby and not yet present there'. This nematode fits the definition of 'quarantine pest' and, therefore, should be categorised as a quarantine pest.

3.7 Bacterial wilt (*Ralstonia solanacearum*)

The Draft IRA (p. 65) says that the bacterial wilt strain affecting ginger is not known to be present in Fiji, and therefore *Ralstonia solanacearum* is not considered as a quarantine pest.

However, for three main reasons, the AGIA contends that there is still a significant risk of importing *R. solanacearum* into Australia with fresh ginger from Fiji.

- *R. solanacearum* has been found affecting a range of vegetable crops in Fiji.
- A full picture of the biovars present in Fiji and their host ranges is not known.
- There is significant variation between the pathogenicity of biovars in different countries, indicating that there is not a complete correlation between biovar classification and pathogenicity.

In Fiji, many growers rotate their ginger crops with vegetables (such as eggplant, tomatoes, bok choy and Asian lettuce) that are hosts of *R. solanacearum* (Smith *et al*. 2007a; Smith pers. comm.), and there is also movement of ginger planting material between growers. Furthermore, *R. solanacearum* can survive as latent infections on ginger rhizomes. Even though *R. solanacearum* has not been reported on ginger in Fiji, there is a significant risk that it could be transported to Australia in rhizomes or in soil adhering to rhizomes.

McKenzie *et al*. (2003a) reported that bacterial wilt of solanaceous crops (chilli pepper, tomato, eggplant and tobacco) caused by *R. solanacearum* is widespread and destructive in Fiji. Although they did not find the ginger strain (biovar 4) of *R. solanacearum*, they surveyed in early crops in only one season, and four months later only in some locations on Viti Levu. They advised that surveillance should continue. Weeds in the family Asteraceae (Compositae) are also alternate hosts of *R. solanacearum* (McKenzie *et al*. 2003b). Jackson (1995) also reported that biovar 4 isolates can infect solanaceous crops and many weeds.

DNA-based evidence suggests that *R. solanacearum* biotype 4 was probably introduced to Southeast Queensland from China in the 1950s as a latent infection in ginger rhizomes (Xu *et al.* (2009). This resulted in a severe outbreak of bacterial wilt in ginger in the mid 1960s, causing heavy losses (Pegg *et al*. 1974). A very large proportion of the ginger industry was devastated, which resulted in the ginger industry moving further north from Nambour. Subsequently, biovar 4 has been eradicated and is no longer believed to be present in Australia.

R. solanacearum has been described as a species complex (a cluster of closely related isolates whose individual members may represent more than one species). It does not behave as a single bacterium with a uniform biology and host range, but as a complex of variants, variously described as races, biovars and later as phylotypes and sequevars. The different classifications of *R. solanacearum* may be confusing to those not familiar with the literature.

Buddenhagen *et al*. (1962) distinguished races 1, 2 and 3 on the basis of pathogenicity. Hayward (1964) distinguished four biovars (biotypes) by their ability to produce acid from several disaccharides and sugar alcohols. However, these biovars do not correlate with the races of Buddenhagen *et al*. (1962), although race 3 is equivalent to biovar 2 (Hayward 1983). Further work has classified the species into five races on the basis of differences in host range, and into six biovars on the basis of biochemical properties.

Races and biovars have also been classified into two main groups according to an analysis of restriction fragment length polymorphisms (RFLP) (Cook and Sequeira, 1988, 1994; Cook *et al*. 1989). Asian strains of race 1 (biovars 3, 4 and 5) form one group and American strains of race 1 (biovar 1), race 2 (biovar 1) and race 3 (biovar 2) form the other. Two additional races affecting *Zingiber officinale* and mulberries (*Morus* spp.), respectively, have also been distinguished (Buddenhagen 1986), but their status is still unclear.

Fegan and Prior (2005) further revealed that the *R. solanacearum* species complex comprises four broad genetic groups (phylotypes) corresponding to geographic origin. Within these phylotypes, there are subgroupings (sequevars), which correspond to clusters of isolates with similar pathogenicity or isolates of common geographic origin. Phylotype 1 (biovars 3, 4 and 5) is widespread in the South Pacific, Oceania, Australasia and South-East Asia (McKenzie *et al.* 2003a).

As more isolates are tested, it is expected that greater genetic diversity will be revealed (Fegan and Prior 2005). It is difficult to gather information on the biological, ecological and epidemiological properties of strains, and, without this, it is impossible to use taxonomic information to predict pathogenicity (Fegan and Prior 2005).

Almost all isolates from ginger have proven to be biovar 3 or biovar 4; these show variable degrees of pathogenicity to ginger. For example, in Australia, biovar 3 is widespread, but it affects very few plants in a crop and causes a slow wilt of minor significance. In the mid 1960s, biovar 4 spread through ginger crops very quickly, killing large areas (Hayward *et al*. 1967; Jackson 1995). In contrast, however, biovar 3 causes rapid wilt in India (Kumar and Hayward 2005) and in Indonesia (Jackson 1995). This indicates that biovars are not reliable indicators of pathogenicity. There is no definite correlation between biovars and races (Jeong *et al*. 2007). Therefore, identification of the biovar of an isolate of *R. solanacearum* does not define its host range.

Therefore, there is a significant risk that a strain of *R. solanacearum* potentially pathogenic to Australian ginger is present in Fiji. If so, given the cropping systems, it is highly likely that it would come into contact with ginger rhizomes in soil. It could then be carried within rhizomes as a latent infection or in soil adhering to rhizomes. This would likely devastate the Australian ginger industry as it did in the mid 1960s following the introduction of seed material from China.

A further concern is the origin of ginger planting material. Because there is often a shortage of disease-free planting material in Fiji (SPC 2012), there is a risk that it might be acquired from a country (such as China) where biovar 4 is present. Australia must be satisfied that Fijian authorities can control where growers acquire their planting material.

Before fresh ginger is imported into Australia from Fiji, it is very important that a thorough survey be done over several seasons to ensure that strains of *R. solanacearum* able to cause serious disease of Australian ginger are not present. This will require accurate identification of the bacterium as well as pathogenicity and host range testing.

3.8 Soft rot (*Pythium vexans* and *P. graminicola*)

The Draft IRA (p. 66) says that *Pythium vexans* and *P. graminicola* have been recorded in Australia and so they are not considered as quarantine pests. However, there is strong evidence that isolates of both *P. vexans* and *P. graminicola* that are present in Fiji have different pathogenicity from those in Australia. This was demonstrated by Duy Phu Le in an *in-vitro* trial at the University of Queensland by comparing a single isolate of *P. vexans* from Australia with an isolate from Fiji. The results are shown in Appendix 5. Although, this *in-vitro* test is not a good predictor of pathogenicity of in living plants (Duy Phu Le pers. comm.), the trial clearly demonstrated that *P. vexans* in Fiji is significantly different from that in Australia. It cannot be predicted from this trial how these isolates would behave under different environmental conditions, on living plants or on different hosts. Nor is it possible to predict how isolates other

than the two tested would behave under various conditions. The clear message from this small trial is that *P. vexans* in Fiji is a different organism from that in Australia; as this type of *P. vexans* is not known to be present in Australia, it should be categorised as a quarantine pest.

Soft rot caused by *Pythium* spp. was recorded in Fiji as long ago as 1935 (Parham 1935, cited by Dohroo 2005) but it was first encountered in Australia during the wet summer of 2007–08 (Stirling *et al.* 2009). Although soft rot of ginger causes serious damage in both Fiji and Australia, it is important to distinguish between the causal organisms in the two countries.

Molecular and morphological studies have identified *Pythium myriotylum* as a causal species on ginger in both Australia and Fiji (Fiji Ministry of Primary Industries; Smith *et al*. 2012; Stirling *et al.* 2009). However, isolates obtained from additional surveys have indicated that several other *Pythium* species are responsible for rhizome rot of ginger.

There are two other significant *Pythium* species present on ginger in Fiji — *P. graminicola* and *P. vexans* — and they both cause rhizome rot (Fiji Ministry of Primary Industries; Lomavatu *et al.* 2009). In Fiji, Lomavatu *et al.* (2009) isolated and identified *P. graminicola* and *P.vexans* from infected rhizomes in the Waibau and Navua ginger-growing districts, respectively.

Pythium soft rot is currently regarded as the most serious fungal pathogen affecting ginger in Fiji, where *P. myriotylum*, *P. graminicola* and *P. vexans* are all pathogenic. Severe crop losses were observed in some blocks in the Navua and Veikoba districts (Stirling *et al*. 2009); serious losses have been observed in other areas when disease epidemics occur.

The three *Pythium* spp. found on ginger in Fiji have different host ranges and environmental tolerances. For example, Dohroo (2005) noted that *P. myriotylum* is most active at temperatures above 34 °C (with a maximum tolerance limit of 40 °C), whereas *P. vexans* has a lower temperature requirement (with a maximum tolerance limit of 34 °C). Therefore, *P. vexans* may be more destructive on ginger grown in Southeast Queensland, Australia's main ginger-growing region, than it is in Fiji. This finding also suggests that *P. vexans* imported from Fiji would be more pathogenic on ginger in Southeast Queensland than *P. myriotylum* is.

P. graminicola has been recorded in north Queensland, New South Wales and Victoria on rice, sugarcane and wheat (Australian Plant Pest Database). *P. vexans* has been recorded in Brisbane and Tully on papaya, custard apple, avocado and durian (BRIP database) and in lucerne, safflower, lettuce, subterranean clover, Chinese gooseberry and eggplant in New South Wales, Northern Territory and north Queensland (Australian Plant Pest Database).

Although *P. vexans* and *P. graminicola* have been recorded on a number of plant species in Australia, they have never been recorded on ginger. In a survey of ginger rhizomes from Southeast Queensland, Le *et al.* (2010) extracted *P. myriotylum* and *P. spinosum* but did not find *P. graminicola* or *P. vexans*.

P. graminicola is widespread in sugarcane in Southeast Queensland and is the most common pathogenic fungus found in sugarcane. However, ginger grown on old sugarcane land has not developed symptoms of *Pythium* rot (Pegg 1996). This is very strong evidence of the existence of different pathotypes in *P. graminicola*. Therefore, it is very likely that Fijian and Australian isolates of *P. graminicola* differ genetically and in their host ranges and pathogenicity.

P. vexans has a wide host range, including papaya, custard apple, avocado, durian, lucerne, safflower, lettuce, subterranean clover, Chinese gooseberry, eggplant, onion, apple, orange, passionfruit, papaya, wheat, *Pinus radiata*, many Australian native plants and many nursery

plants (BRIP database; Australian Plant Pest Database; USDA–ARS database). *P. graminicola* also has a wide host range, including rice, sugarcane, wheat (Australian Plant Pest Database), pineapple, many grasses and cereals, capsicum, cotton, lupins, peas, sugarcane and faba bean (USDA–ARS database). Importation of ginger poses a risk not only to the ginger industry but also to other crop, ornamental and forestry species.

P. graminicola strains vary widely in their pathogenicity on turf grasses (Kageyama *et al.* 2005), and this may explain why *P. graminicola* is a pathogen of ginger in Fiji but not in Queensland. Although it is possible that environmental or cultural factors may explain, at least in part, the observed differences in pathogenicity of *P. graminicola* and *P. vexans* in Australia and Fiji, it would be irresponsible to import new pathogens before sufficient research has been done to ensure that these *Pythium* spp. will not cause crop losses in Australia similar to those in Fiji and threaten the viability of the Australian ginger industry. Before importing fresh ginger planting material, it is essential to compare the pathogenicity of Australian and Fijian isolates of *P. vexans* and *P. graminicola*. Given the amount of variability in other species of *Pythium*, it is likely that *P. vexans* and *P. graminicola* from Fiji have different pathogenicity from Australian isolates.

(Note: *Pythium graminicolum* is a synonym of *Pythium graminicola* (MycoBank).)

3.9 Rhizome rot (*Fusarium oxysporum* f.sp. *zingiberi*)

The Draft IRA (p. 67) says that *Fusarium oxysporum* f.sp. *zingiberi* (*Foz*) is present in ginger rhizomes (Pappalardo *et al* 2009) and widespread in Australia (Weiss 2002; Pappalardo *et al.* 2009). It is therefore not considered as a quarantine pest. While there are strains of *Foz* in Australia, different isolates of *Foz* are variable in their pathogenicity, with mortality ranging from 60 to 100% (Dohroo and Sharma 1992). As demonstrated clearly in Section 3.8 for *Pythium vexans*, the presence of a species in both Australia and Fiji does not imply that there is no difference between the two organisms. Within a species, there can be marked variability in pathogenicity and host range. These must be known for both countries to ensure that Australia does not import new organisms.

Fusarium oxysporum is a soilborne fungal species that includes both pathogenic and non-pathogenic forms (Chakrabarti *et al.* 2011). Overall, this species causes wilt disease on a wide range of plant species; however, individual isolates have narrow host ranges and can be classified, mainly on host range, at the subspecies level as formae speciales (f.sp.). For example, the form that causes tomato wilt is classified as *F. oxysporum* f.sp *lycopersici* (*Fol*) and the form that causes cotton wilt is *F. oxysporum* f.sp. *vasinfectum* (*Fov*). Many studies have focused on the molecular basis of pathogenicity and host range; this work is most advanced for *Fol*, where large-scale investigations based on genome sequencing have identified pathogenicity genes (e.g. Ma *et al* 2010).

Races are well documented in other forms of *Fusarium oxysporum.* For example, Chakrabarti *et al.* (2011) used DNA fingerprints to distinguish Australian isolates of *Fov* from non-Australian isolates, supporting the hypothesis that Australia *Fov* is different from *Fov* in other countries. Therefore, it is highly likely that races also exist in *Foz*. Pappalardo *et al*. (2009) assessed genetic variation among 29 isolates of *Foz* from ginger in Queensland and identified three haplotypes. Two of these haplotypes were very similar but the other was quite distinct. Given the genetic diversity within *Foz*, it is highly likely that more pathogenic isolates occur in Fiji.

Little specific information is available on variability within *Foz*. However, pathogenicity genes have been identified in other forms of *F. oxysporum*, such as *Fol* (Ma *et al*. 2010), *Fov* (Chakrabarti *et al*. 2011) and *F. oxysporum* f.sp. *cubense* (Meldrum *et al*. 2012). It has also been demonstrated that these pathogenicity genes can move between isolates by horizontal transfer.

The pathogenicity genes in *F. oxysporum* are associated with one or more dispensable chromosomes. When hyphae of *F. oxysporum* anastomose, the chromosome may move past the anastomosis. This exchange of pathogenicity genes can change a non-pathogenic isolate into a pathogen, or may increase the pathogenicity of a mildly pathogenic isolate.

Horizontal transfer of pathogenicity genes has been demonstrated experimentally. For example, Ma *et al*. (2010) showed that two lineage-specific chromosomes carrying pathogenicity genes passed from a pathogenic strain of *Fol* to a non-pathogenic strain, converting the non-pathogenic strain into a pathogen.

Before importing ginger, it is essential to compare the complements of pathogenicity genes in Australian and Fijian isolates of *Foz*. If there are pathogenicity genes in Fiji that are not already present in Australia, it would be equivalent to a new species of pathogen. Isolates of *Foz* from Fiji are very likely to be more pathogenic than Australian isolates. In addition, those Fijian isolates may transfer foreign pathogenicity genes to less pathogenic isolates in Australia, increasing their pathogenicity.

3.10 Rhizome rot (*Verticillium albo-atrum*)

The Draft IRA (p. 69) says that *Verticillium albo-atrum* is present in South Australia, Tasmania, Victoria and Queensland, and it is therefore not considered as a quarantine pest. However, work by Walker (1990) authenticated the records only for potato from South Australia, Tasmania and Victoria. In some of the unauthenticated records, the fungus can now be identified as *V. dahliae*; in others, the identity of the fungus cannot be determined. Much of the earlier literature failed to distinguish between *V. albo-atrum* and *V. dahliae*. Sometimes diseases were reported as verticillium wilt and the causal fungus was assumed to be *V. albo-atrum* but not identified.

V. albo-atrum is a quarantine pest in Europe (OEPP/EPPO 2011), the United States (Washington State Department of Agriculture) and New Zealand (Biosecurity New Zealand MAF 2010). Walker (1990) stated that '*Verticillium albo-atrum* must be regarded as a pathogen of major significance for Australia and stringent measures taken to exclude it'. This fungus is present on ginger rhizomes in Fiji, although it appears to be of minor importance to ginger. However, it is a major pathogen of lucerne, hops and some vegetables including tomato, potato and cucurbits (Burgess *et al*. 2008).

Interestingly, Australian Plant Pest Database record no. VPRI-21357a shows spread to a native species, *Lepidozamia* sp., which would not be predicted from its pathogenicity on the known crop hosts.

V. albo-atrum infects roots, colonises the xylem tissue and grows through the stem and leaves. Therefore, imported rhizomes of infected ginger plants are likely to contain this fungus. It is not in the scope of this response from the AGIA to provide information for assessment of the pest risk of this fungus for crops other than ginger. However, the AGIA recommends that such an assessment be done for the risk of importation of fresh ginger from Fiji to these other crops.

4 Pest risk assessments for quarantine pests

4.1 Yam scale

Aspidiella hartii

4.1.1 Probability of entry

Probability of importation

The AGIA agrees that the likelihood that *Aspidiella hartii* will arrive in Australia with the importation of fresh ginger from Fiji is: **HIGH**. This probability should not be reduced.

Probability of distribution

The AGIA agrees that the likelihood that *Aspidiella hartii* will be distributed within Australia in a viable state, as a result of the processing, sale or disposal of fresh ginger from Fiji, is: **HIGH**. This probability should not be reduced.

Probability of entry (importation × distribution)

The AGIA agrees that the likelihood that *Aspidiella hartii* will enter Australia and be transferred in a viable state to a susceptible host, as a result of trade in fresh ginger from Fiji, is: **HIGH**. This probability should not be reduced.

4.1.2 Probability of establishment

The AGIA recommends that the likelihood that *Aspidiella hartii* will establish within Australia, based on a comparison of factors in the source and destination areas considered pertinent to its survival and reproduction, be revised to: **HIGH**.

- The Draft IRA (p. 27) describes *A. hartii* as reproducing sexually. However, it is also able to reproduce parthenogenetically (Devasahayam and Abdulla Koya 2005). Therefore, just a single female scale insect could lead to the introduction and establishment of this species in Australia.

4.1.3 Probability of spread

The AGIA agrees that the likelihood that *Aspidiella hartii* will spread within Australia, based on a comparison of those factors in the source and destination areas considered pertinent to the expansion of the geographic distribution of the pest, is: **HIGH**. This probability should not be reduced.

4.1.4 Probability of entry, establishment and spread

In view of the recommended probability of establishment, the likelihood that *Aspidiella hartii* will be imported as a result of trade in fresh ginger from Fiji, be distributed in a viable state to a susceptible host, establish and spread within Australia, is: **HIGH.**

4.1.5 Consequences

The AGIA agrees with the analysis in the Draft IRA that the assessment of the consequences (direct and indirect) of *Aspidiella hartii* for Australia is: **LOW**. This assessment should not be reduced.

- However, the AGIA considers that an important aspect of the biology of *A. hartii* has not been adequately addressed. This scale insect is a pest of ginger both in the field and in storage. Ginger is generally stored for a considerable time and as a result provides the opportunity for insects such as scale insects not only to survive but also to reproduce and multiply.
- The mobile crawlers potentially can infest other ginger rhizomes within the same consignment while in transit and through the marketing chain. A further opportunity to infest other plant hosts exists when ginger is stored adjacent to other suitable host material such as sweet potatoes.

4.1.6 Unrestricted risk estimate

The AGIA agrees that the unrestricted risk for *Aspidiella hartii* is: **LOW**. This risk should not be reduced.

The unrestricted risk estimate for *Aspidiella hartii* of 'low' exceeds Australia's ALOP. Therefore, specific risk management measures are required for this pest.

4.2 Ring nematodes

Discocriconemella discolabia; *Mesocriconema denoudeni*

4.2.1 Probability of entry

Probability of importation

The AGIA recommends that the likelihood that these ring nematodes will arrive in Australia with the importation of fresh ginger from Fiji be revised to: **HIGH**.

- As explained in Section 2.2.1 of this response, there is a high risk of soil adhering to rhizomes imported from Fiji and there is a high risk of that soil carrying nematodes.
- As stated in the Draft IRA (p. 43), ring nematodes are migratory ectoparasites and free-living in the soil. Therefore, they can be carried by soil adhering to ginger rhizomes.

Probability of distribution

The AGIA recommends that the likelihood that these ring nematodes will be distributed within Australia in a viable state, as a result of the processing, sale or disposal of fresh ginger from Fiji, be revised to: **HIGH**.

- Imported ginger will be distributed to many localities within Australia by wholesale and retail trade, and by individual consumers (Draft IRA p. 43).
- Individual consumers could carry small quantities of ginger rhizomes to urban, rural and natural localities. Small amounts of ginger waste could be discarded in these localities (Draft IRA p. 44).
- Some ginger rhizomes may be distributed to areas where host plants are grown (Draft IRA p. 44).
- Imported ginger will be used by ginger growers as planting material (see Section 2.2.2 of this response). This would introduce the nematode into soil on commercial farms.
- Consumers could use ginger rhizomes as planting material in gardens (see Section 2.2.2 of this response), which would introduce the nematode into the soil. Once roots form and the ginger plant becomes established, the nematodes would feed on the roots and establish a population.
- As explained in Section 2.2.1 of this response, there is a high risk of soil carrying nematodes adhering to rhizomes. Therefore, any planting of ginger rhizomes is likely to introduce nematodes into the soil.

Probability of entry (importation × distribution)

In view of the recommended probabilities of importation and distribution, the likelihood that these ring nematodes will enter Australia and be transferred in a viable state to a susceptible host, as a result of trade in fresh ginger from Fiji, is: **HIGH**.

4.2.2 Probability of establishment

The AGIA agrees with the analysis in the Draft IRA that the likelihood that these ring nematodes will establish within Australia, based on a comparison of factors in the source and destination areas considered pertinent to their survival and reproduction, is: **HIGH**. This probability should not be reduced.

4.2.3 Probability of spread

The AGIA agrees with the analysis in the Draft IRA that the likelihood that these ring nematodes will spread within Australia, based on a comparison of those factors in the source and destination areas considered pertinent to the expansion of the geographic distribution of the pests, is: **HIGH**. This probability should not be reduced.

4.2.4 Probability of entry, establishment and spread

In view of the recommended probability of entry, the overall likelihood that these ring nematodes will be imported as a result of trade in fresh ginger from Fiji, be distributed in a viable state to a susceptible host, establish and spread within Australia, is: **HIGH**.

4.2.5 Consequences

The AGIA agrees with the analysis in the Draft IRA that the assessment of the consequences (direct and indirect) of these ring nematodes for Australia is: **LOW**. This assessment should not be reduced.

4.2.6 Unrestricted risk estimate

In view of the recommended probabilities of importation and distribution, the unrestricted risk for ring nematodes is: **LOW**. This risk should not be reduced.

The unrestricted risk estimate for ring nematodes of 'low' exceeds Australia's ALOP. Therefore, specific risk management measures are required for this pest.

4.3 Spiral nematodes

Helicotylenchus egyptiensis; *H. indicus*; *H. mucronatus*

4.3.1 Probability of entry

Probability of importation

The AGIA recommends that the likelihood that these spiral nematodes will arrive in Australia with the importation of fresh ginger from Fiji be revised to: **HIGH**.

- As explained in Section 2.2.1 of this response, there is a high risk of soil adhering to rhizomes imported from Fiji and there is a high risk of that soil carrying nematodes.
- As stated in the Draft IRA (p. 37, para. 3), all life stages can be found in the soil.
- The Draft IRA (p. 39, dot point 1) states that spiral nematodes are most likely to occur in rhizomes accompanied by moist soil. It is true that spiral nematodes are dispersed in this way. However, they are just as likely to be dispersed in dry soil by entering the dauer stage (as described on p. 38, dot point 10) and surviving for long periods through anhydrobiosis in dry soil.

Probability of distribution

The AGIA recommends that the likelihood that these spiral nematodes will be distributed within Australia in a viable state, as a result of the processing, sale or disposal of fresh ginger from Fiji, be revised to: **HIGH**.

- Imported ginger will be distributed to many localities within Australia by wholesale and retail trade, and by individual consumers (Draft IRA p. 43).
- Individual consumers could carry small quantities of ginger rhizomes to urban, rural and natural localities. Small amounts of ginger waste could be discarded in these localities (Draft IRA p. 44).
- Some ginger rhizomes may be distributed to areas where host plants are grown (Draft IRA p. 44).
- Imported ginger will be used by ginger growers as planting material (see Section 2.2.2 of this response). This would introduce the nematode into soil on commercial farms.
- Consumers could use ginger rhizomes as planting material in gardens (see Section 2.2.2 of this response), which may introduce the nematode into the soil. Once roots form and the ginger plant becomes established, the nematodes would feed on the roots and establish a population.
- As explained in Section 2.2.1 of this response, there is a high risk of soil carrying nematodes adhering to rhizomes. Therefore, any planting of ginger rhizomes is likely to introduce nematodes into the soil.

Probability of entry (importation × distribution)

In view of the recommended probabilities of importation and distribution, the likelihood that these spiral nematodes will enter Australia and be transferred in a viable state to a susceptible host, as a result of trade in fresh ginger from Fiji, is: **HIGH**.

4.3.2 Probability of establishment

The AGIA agrees with the analysis in the Draft IRA that the likelihood that these spiral nematodes will establish within Australia, based on a comparison of factors in the source and destination areas considered pertinent to their survival and reproduction, is: **HIGH**. This probability should not be reduced.

4.3.3 Probability of spread

The AGIA agrees with the analysis in the Draft IRA that the likelihood that these spiral nematodes will spread within Australia, based on a comparison of those factors in the source and destination areas considered pertinent to the expansion of the geographic distribution of the pests, is: **HIGH**. This probability should not be reduced.

4.3.4 Probability of entry, establishment and spread

In view of the recommended probability of entry, the overall likelihood that these spiral nematodes will be imported as a result of trade in fresh ginger from Fiji, be distributed in a viable state to a susceptible host, establish and spread within Australia, is: **HIGH**.

4.3.5 Consequences

The AGIA agrees with the analysis in the Draft IRA that the assessment of the consequences (direct and indirect) of these spiral nematodes for Australia is: **LOW**. This assessment should not be reduced.

4.3.6 Unrestricted risk estimate

In view of the recommended probabilities of importation and distribution, the unrestricted risk for spiral nematodes is: **LOW**. This risk should not be reduced.

The unrestricted risk estimate for spiral nematodes of ‘low’ exceeds Australia’s ALOP. Therefore, specific risk management measures are required for this pest.

4.4 Cystoid nematode

Sphaeronema sp.

4.4.1 Probability of entry

Probability of importation

The AGIA recommends that the likelihood that *Sphaeronema* sp. will arrive in Australia with the importation of fresh ginger from Fiji be revised to: **HIGH**.

- On p. 43, para. 1 of the Draft IRA states that 'No nematodes had been detected in the soil prior to planting, so it appears that the nematodes were introduced into prepared plots on *seed* that had been insufficiently hot-water treated'. However, in Section 4.5.1, dot point 3 states that 'The nematodes are likely to be present in the *roots and root base*, rather than the rhizome itself. Roots should be removed during postharvest processing prior to export'. The latter point is *not* correct; *Sphaeronema* sp. was, in fact, found on seed pieces (i.e. in the rhizomes) in Fiji by Smith *et al*. (2007b).
- As explained in Section 2.2.1 of this response, there is a high risk of soil adhering to rhizomes imported from Fiji and there is a high risk of that soil carrying nematodes.
- As stated in the Draft IRA (p. 42, para. 3), *S. sasseri* is found within the rhizosphere. Furthermore, after hatching, juveniles of *S. sasseri* migrate to roots (p. 42, para. 4). Therefore, as they are found in the soil, particularly in the rhizosphere, it is highly likely that *Sphaeronema* sp. would be found in soil imported with fresh rhizomes from Fiji.

Probability of distribution

The AGIA recommends that the likelihood that *Sphaeronema* sp. will be distributed within Australia in a viable state, as a result of the processing, sale or disposal of fresh ginger from Fiji be revised to: **HIGH**.

- In addition to the points raised in the Draft IRA on pp. 43–44, it is highly likely that ginger rhizomes imported from Fiji will make their way to the ginger-growing region (as discussed in Section 2.2.2 of this response). This changes the emphasis on dot points 2 and 8 on p. 44 of the Draft IRA: 'Some ginger rhizomes may be distributed to areas where host plants are grown' and 'Consumers could attempt to use ginger rhizomes as planting material in a garden'. In fact, ginger rhizomes are highly likely to be planted in consumers' gardens and also used to produce commercial ginger crops. As ginger is a good host of *Sphaeronema* sp., this nematode is highly likely to become established.
- Soil adhering to imported rhizomes will also be introduced to the planting site, thereby inoculating the soil with any nematodes present in the imported soil.

Probability of entry (importation × distribution)

In view of the recommended probabilities of importation and distribution, the likelihood that *Sphaeronema* sp. will enter Australia and be transferred in a viable state to a susceptible host, as a result of trade in fresh ginger from Fiji, is: **HIGH**.

4.4.2 Probability of establishment

The AGIA agrees with the analysis in the Draft IRA that the probability of establishment of *Sphaeronema* in Australia is: **HIGH**. This probability should not be reduced.

4.4.3 Probability of spread

The AGIA agrees with the analysis in the Draft IRA that the probability of spread of *Sphaeronema* in Australia is: **HIGH**. This probability should not be reduced.

4.4.4 Probability of entry, establishment and spread

In view of the recommended probability of entry, the likelihood that *Sphaeronema* sp. will enter Australia as a result of trade in fresh ginger from Fiji, be distributed in a viable state to a susceptible host, establish and spread within Australia, is: **HIGH**.

4.4.5 Consequences

Assessment of the potential consequences (direct and indirect) of *Sphaeronema* sp. for Australia is: **MODERATE**.

Criterion	Estimate and rationale
Direct	
Plant life or health	**Impact score**: D – significant at the district level The AGIA agrees with this assessment.
Other aspects of the environment	**Impact score**: D – minor significance at the regional level The AGIA recommends that the impact score be revised to D. *Sphaeronema* sp. as assessed in the Draft IRA has not yet even been identified, so its host range, pathogenicity etc. are not yet known. It is vital, therefore, to identify this organism before an estimate of the consequences of its importation can be made. The host ranges of various *Sphaeronema* spp. includes *Arctostaphylos* sp., *Umbellularia californica*, *Zantedeschia* sp., citrus, *Abies fraseri*, *Picea rubens*, Pear, *Liquidambar styraciflua* (Nemabase). It is not yet known which native plants would be hosts to this nematode. It is likely to reach nursery plants in backyards and native forests near ginger crops established by planting rhizomes from Fiji.
Indirect	
Eradication, control etc.	**Impact score**: E – significant at the regional level The AGIA agrees with the analysis in the Draft IRA that *Sphaeronema* sp. on ginger would have minor significance at the district level. However, if it reached and multiplied on one or more native hosts, it could have significant consequences at the regional level. However, this risk is still unknown because the organism has not even been identified.
Domestic trade	**Impact score**: B – minor significance at the local level The effect of *Sphaeronema* sp. on ginger production is likely to be minor.
International trade	**Impact score**: B – minor significance at the local level Australia's export trade in ginger is small. *Sphaeronema* sp. is unlikely to have a major effect on international trade.

Environmental and non-commercial	**Impact score**: unknown This is unknown but there are many native plants in forests adjacent to the ginger-growing region. If *Sphaeronema* sp. becomes established in the ginger-growing region, and one or more native plants are hosts of this nematode, it is likely to spread to those forests. There are likely to be both direct effects on host plants and indirect effects on their ecosystem, including both plants and animals.

4.4.6 Unrestricted risk estimate

In view of the recommended probabilities of importation and distribution, the unrestricted risk for *Sphaeronema* sp. is: **MODERATE**.

The unrestricted risk estimate for *Sphaeronema* sp. of 'moderate' exceeds Australia's ALOP. Therefore, specific risk management measures are required for this pest.

4.5 Burrowing nematode

Radopholus similis

Radopholus similis was first associated with a disease of ginger in Fiji in the early 1970s. It caused stunting and chlorosis, and yields were reduced (Vilsoni *et al.* 1976). Extensive surveys conducted during an ACIAR project from 2006 to 2010 found burrowing nematode affecting ginger in the Veikoba and Muanaweni districts. Surveys revealed that 10% of planting material was infected with *R. similis* (Smith *et al.* 2012).

The nematode was found in infected planting material, initially in small sunken lesions that could easily go undetected. Turaganivalu *et al.* (2012) found that the nematode first feeds on outer parts of the rhizome and, as more tissue is destroyed, lesions extend further into the rhizome. The plants eventually die and the rhizome is destroyed.

While the importation of Fijian isolates of *R. similis* is clearly a high risk for ginger, it is also a high risk for the banana industry, which is worth $450 million per year to the Australian economy. Currently, *R. similis* is widespread in banana production areas and has been difficult to control using systemic nematicides. However, additional strategies are now used to manage this nematode on bananas, including crop rotation with non-host plants. Importation of Fijian isolates of this nematode may make it even more difficult to control on bananas. The current methods of managing *R. similis* on bananas in Australia may not be effective against an imported isolate that is more pathogenic or has a different host range.

4.5.1 Probability of entry

Probability of importation

The likelihood that *Radopholus similis* will arrive in Australia with the importation of fresh ginger from Fiji is: **HIGH**.

- The nematode is carried in ginger rhizomes (Smith *et al.* 2012) and so is very likely to be present in imported rhizomes (see Figure 4.1).
- All stages of the lifecycle are found within the rhizome.
- Few studies have been done on the control of *R. similis* on ginger, but hot-water treatment could help to reduce the yield loss it causes (Koshy *et al*. 2005); however, this would not be sufficient to ensure nematode-free rhizomes for export to Australia.
- Okwuowulu (2005) found that hot-water treatment at 48 °C for 20 minutes reduced number of *R. similis* in ginger rhizomes but did not eliminate them.
- Vadhera *et al*. (1998 in Koshy *et al*. 2005) found that hot-water treatment at 45 °C for 3 hours was needed to disinfest ginger rhizomes of root-knot nematodes.
- Other examples of hot-water treatment required to eliminate nematodes from root crops include:
    - 47 °C for 65 minutes to eliminate *Meloidogyne* (root-knot nematode) from potatoes (Scurrah *et al*. 2005)

    - 50–51 °C for 30 minutes to eliminate *Meloidogyne* from yam tubers (Bridge *et al.* 2005).
    - 50 °C for 15 minutes to eliminate *Helicotylenchus miticausa* from taro corms (Bridge *et al.* 2005).
- Detecting low numbers of nematodes in hot-water treated material is very difficult. The only way to confirm that a treatment was effective is to grow treated rhizomes in sterile soil for at least one season and then extract nematodes from the rhizome and soil.
- A ginger industry survey in Fiji showed that hot-water treatment equipment provided by the extension service was seldom used and, even when hot-water treatment of ginger planting material was practised, it was done incorrectly and at temperatures that were insufficient to kill nematodes (Smith *et al.* 2012).
- The Draft IRA (p. 16) says that Fijian ginger growers treat rhizomes at 51 °C for 10 minutes but does not provide any information about how effective this is or how the assessment was done. Previous studies suggest that this treatment is unlikely to produce ginger rhizomes free of *R. similis*. Therefore, more work is required to determine the temperature and duration of hot-water treatment needed to produce clean planting material, without damaging rhizomes intended for human consumption.
- As explained in Section 2.2.1 of this response, there is a high risk of soil adhering to rhizomes imported from Fiji and there is a high risk of that soil carrying nematodes.

Figure 4.1 Lesions caused by *Radopholus similis* inside ginger rhizome

Probability of distribution

The likelihood that *Radopholus similis* will be distributed within Australia in a viable state, as a result of the processing, sale or disposal of fresh ginger from Fiji, is: **HIGH**.

- Imported ginger will be distributed to many localities within Australia by wholesale and retail trade, and by individual consumers (Draft IRA p. 43).

- Individual consumers could carry small quantities of ginger rhizomes to urban, rural and natural localities. Small amounts of ginger waste could be discarded in these localities (Draft IRA p. 44).
- Some ginger rhizomes may be distributed to areas where host plants are grown (Draft IRA p. 44).
- Small amounts of ginger waste will be discarded into domestic compost (Draft IRA p. 44).
- Imported ginger will be used by ginger growers as planting material (see Section 2.2.2 of this response). This would introduce the nematode into soil on commercial farms.
- Consumers could use ginger rhizomes as planting material in gardens, which may introduce all stages of the nematode into the soil. Once roots form and the ginger plant becomes established, the nematodes would feed on both the roots and the rhizome.
- *R. similis* has a known host range of more than 350 plant species. In addition to ginger and banana, other primary hosts include palm, avocado, coffee, black pepper, sugarcane, tea, vegetables and various grasses, weeds and nursery plants. The host range among Australian native plants is unknown but at least one common native species, *Indigofera hirsuta*, is also a host of *R. similis* (Nemabase). With such a wide host range, it is likely that introduced nematodes would locate suitable alternate hosts.

Probability of entry (importation × distribution)

The likelihood that *Radopholus similis* would enter Australia and be transferred in a viable state to a susceptible host, as a result of trade in fresh ginger from Fiji, is: **HIGH**.

4.5.2 Probability of establishment

The likelihood that *Radopholus similis* would establish within Australia, based on a comparison of factors in the source and destination areas considered pertinent to its survival and reproduction, is: **HIGH**.

- Climatic conditions in parts of Australia match those in the ginger production areas in Fiji (Draft IRA p. 34).
- *R. similis* lives in the roots, the rhizosphere and the rhizome, so it is likely that, if nematodes were introduced on fresh rhizomes, they may be numerous, which would increase the likelihood of establishment.
- The most likely scenario for this nematode to successfully establish would be through the use of infested rhizomes as planting material in a garden or a commercial crop. The nematode would reproduce on the plant, resulting in establishment of the Fijian isolate of *R. similis* in Australia.
- Introduction of just one gravid female is enough to establish a new population (O'Bannon 1977).

4.5.3 Probability of spread

The likelihood that *Radopholus similis* would spread within Australia, based on a comparison of those factors in the source and destination areas considered pertinent to the expansion of the geographic distribution of the pest, is: **HIGH**.

- Plant-parasitic nematodes require at least a film of water to enable locomotion, and so the soil water content is a primary ecological factor.
- *R. similis* is most likely to be spread through the movement of infested planting material and soil (Smith *et al*. 2012).
- *R. similis* may remain undetected for some time in small sunken lesions in the rhizome, causing little damage, and be inadvertently spread via planting material.
- Spread of *R. similis* is also likely by transfer to alternate host plants, particularly banana.

4.5.4 Probability of entry, establishment and spread

The likelihood that *Radopholus similis* will be imported as a result of trade in fresh ginger from Fiji, be distributed in a viable state to a susceptible host, establish and spread within Australia, is: **HIGH**.

4.5.5 Consequences

Assessment of the potential consequences (direct and indirect) of *Radopholus similis* for Australia is: **HIGH**.

Criterion	Estimate and rationale
Direct	
Plant life or health	**Impact score**: F – major significance at the regional level Yield losses to *R. similis* would be significant for the ginger industry, but there could be a much greater threat to the banana industry.
Other aspects of the environment	**Impact score**: E – significant at the regional level *R. similis* isolates from Fiji are likely to have a significant effect on native plant species. *Alpinia purpurata*, *Heliconia humilis* (Vilsoni *et al*. 1976) and *Indigofera hirsuta* are known hosts of *R. similis*, which suggests that the risk to native plant species is high. Current use of systemic nematicides to control *R. similis* on bananas is a major concern for the environment and for the health of farm workers.
Indirect	
Eradication, control etc.	**Impact score**: F – major significance at the regional level Once established, eradication of this nematode would be difficult in both ginger and banana. Control measures in ginger would be aimed at ensuring nematode-free planting material. Control of *R. similis* in bananas would require the development of new management practices, which would take many years.
Domestic trade	**Impact score**: C – minor significance at the district level Some ginger rhizomes are likely to be affected by *R. similis* and be unsalable on the domestic market; yields may also be affected, reducing the amount of ginger available.
International trade	**Impact score**: D – significant at the district level Ginger has been exported to Japan, which is seen as a potential market for export. Quarantine regulations require that the consignment is inspected and found to be free of *R. similis*. An isolate of *R. similis* that was aggressive on ginger would threaten these export markets. Carrot is another host of *R. similis*. Export of carrots to Taiwan requires that

	designated production sites be free of *R. similis*. If the nematode is found on those sites, it would prevent export of carrots to Taiwan and affect its significant potential to increase. It would also prevent the development of further international trade.
Environmental and non-commercial	**Impact score**: unknown This is unknown but there are many native plants in forests adjacent to the ginger- and banana-growing areas in Southeast Queensland. It is possible that, if Fijian isolates of *R. similis* are introduced to this region, they could spread to native host plant species. There are likely to be both direct effects on host plants and indirect effects on their ecosystem, including both plants and animals.

4.5.6 Unrestricted risk estimate

The unrestricted risk for *Radopholus similis* is: **HIGH**.

The unrestricted risk estimate for *Radopholus similis* of 'high' exceeds Australia's ALOP. Therefore, specific risk management measures are required for this pest.

4.6 Reniform nematode

Rotylenchulus reniformis

While *R. reniformis* has been recorded in some parts of Australia, geographic isolation has resulted in it not being found in the Southeast Queensland Region, which is where the major ginger and pineapple industries are based.

4.6.1 Probability of entry

Probability of importation

The likelihood that *Rotylenchulus reniformis* will arrive in Australia with the importation of fresh ginger from Fiji is: **HIGH**.

- The nematode is carried in ginger rhizomes and in soil so it is very likely to be present in imported rhizomes. Adult females are embedded in roots (Sipes *et al*. 2005) and rhizomes (Smith *et al.* 2007a).
- *R. reniformis* is almost always present on ginger throughout Fiji and was found in high numbers, particularly on mature ginger used for the fresh market (Smith *et al*. 2012).
- *R. reniformis* is a quarantine pest in the United States and has been intercepted in California on imported ginger rhizomes between 1988 and 1994 (University of California Davis).
- Adult females produce egg masses of about 60 to 200 eggs in a gelatinous matrix (Sipes *et al*. 2005). Eggs hatch as second-stage juveniles.
- *R. reniformis* tolerates extreme temperatures and survives extended periods in dry soil without a host through anhydrobiosis (Radewald and Takeshita 1964; Lehman 2004). Populations can survive for two years in fallow soil as eggs or as second-stage juveniles (Sipes *et al*. 2005).

Probability of distribution

The likelihood that *Rotylenchulus reniformis* will be distributed within Australia in a viable state, as a result of the processing, sale or disposal of fresh ginger from Fiji, is: **HIGH**.

- Imported ginger will be distributed to many localities within Australia by wholesale and retail trade, and by individual consumers (Draft IRA p. 43).
- Individual consumers could carry small quantities of ginger rhizomes to urban, rural and natural localities. Small amounts of ginger waste could be discarded in these localities (Draft IRA p. 44).
- Some ginger rhizomes may be distributed to areas where host plants are grown (Draft IRA p. 44).
- Small amounts of ginger waste will be discarded into domestic compost (Draft IRA p. 44).
- Imported ginger will be used by ginger growers as planting material (see Section 2.2.2 of this response). This would introduce the nematode into soil on commercial farms.

- Populations can survive for years as eggs or as second-stage juveniles (Sipes *et al*. 2005). Consumers are likely to plant ginger rhizomes in gardens, which would distribute any imported eggs and second-stage juveniles of the nematode into the soil.
- Once roots form and the ginger plant becomes established, *R. reniformis* would feed on both the roots and the rhizome.
- *R. reniformis* has been reported on more than 300 host species in 74 plant families, including pineapple, soybean, cotton, pigeon peas, beans and taro (Robinson *et al*. 1997; Sipes *et al.* 2005; Bridge *et al*. 2005), increasing the likelihood that introduced nematodes could locate a suitable host.

Probability of entry (importation × distribution)

The likelihood that *Rotylenchulus reniformis* would enter Australia and be transferred in a viable state to a susceptible host, as a result of trade in fresh ginger from Fiji, is: **HIGH**.

4.6.2 Probability of establishment

The likelihood that *Rotylenchulus reniformis* would establish within Australia, based on a comparison of factors in the source and destination areas considered pertinent to its survival and reproduction, is: **HIGH**.

- Climatic conditions in parts of Australia match those in the ginger production areas in Fiji (Draft IRA p. 34).
- *R. reniformis* live in the roots, the rhizosphere and the rhizome, so it is likely that, if nematodes were introduced on fresh produce, they may be numerous, which would increase the likelihood of establishment.
- The most likely scenario for this nematode to establish successfully would be if infested rhizomes were used as planting material in a crop or in a garden, and subsequently sprouted. This would greatly increase the likelihood of reproduction occurring, resulting in establishment of *R. reniformis* on ginger and pineapple in Southeast Queensland.
- Egg hatch is stimulated by root exudates of host plants. Second-stage juveniles hatch from the eggs and moult to the adult stage. Adult females enter the root system, become sedentary and produce an egg mass of about 60 to 200 eggs in a gelatinous matrix. Amphimixis is most common but parthenogenesis has been reported in Japan (Sipes *et al*. 2005).

4.6.3 Probability of spread

The likelihood that *Rotylenchulus reniformis* would spread within Australia, based on a comparison of those factors in the source and destination areas considered pertinent to the expansion of the geographic distribution of the pest, is: **MODERATE**.

- Plant-parasitic nematodes require at least a film of water to enable locomotion, and so the soil water content is a primary ecological factor.
- These nematodes are most likely to be spread through the movement of infested planting material (Smith *et al*. 2007b) and in soil adhering to rhizomes, footwear and planting equipment.
- It is possible that, if these nematodes became established in the ginger- and pineapple-production areas, they could remain undetected for some time, causing little damage, until

populations build up. During that time, they could easily be inadvertently spread further via planting material.

- Spread is also likely by transfer to alternate hosts. *R. reniformis* has a host range of more than 300 plant species, including pineapple, soybean, cotton, pigeon peas, beans (Sipes *et al*. 2005), bananas, cabbage, sweet potato, sweetcorn, palm, cucumber, tomato, eggplant (Dropkin 1980; Robinson *et al*. 1997).
- *R. reniformis* has also been found to reproduce on the palm species *Acoelorrhaphe wrightii* and *Washingtonia robusta*, two commonly grown ornamental plants (Inserra *et al.* 1994).

4.6.4 Probability of entry, establishment and spread

The likelihood that *Rotylenchulus reniformis* will be imported as a result of trade in fresh ginger from Fiji, be distributed in a viable state to a susceptible host, establish and spread within Australia, is: **MODERATE**.

4.6.5 Consequences

Assessment of the potential consequences (direct and indirect) of *Rotylenchulus reniformis* for Australia is: **MODERATE.**

Criterion	Estimate and rationale
Direct	
Plant life or health	**Impact score**: C – minor significance at the district level *R. reniformis* is an important pest on ginger in the Pacific Islands (Bridge 1988) and was found to be pathogenic on ginger in west Bengal (Rama and Dasgupta, cited in Dohroo 2005).
Other aspects of the environment	**Impact score**: E – major significance at the district level *R. reniformis* from Fiji is likely to have significant effects on pineapple and sweet potato crops in Southeast Queensland. *R. reniformis* is a major nematode problem on pineapples in Hawaii, the Philippines, the Caribbean, in some areas of Thailand and Mexico and in north Queensland. In Hawaii, infected pineapple plants are smaller and roots are poorly developed. Heavy infestations result in plant collapse and death (Sipes *et al*. 2005). *R. reniformis* is the most important nematode pest of pineapple in Hawaii (University of California). This is of particular concern because pineapples are grown very close to the ginger-production region in Southeast Queensland. Spread to pineapples in Queensland could devastate an iconic industry. While *R. reniformis* can significantly reduce yield of sweet potato (Clark and Wright 1983; Walters and Barker 1993), its most important effect is causing cracks in tubers (Clark and Wright 1983; Thomas and Clark 1983) making them unsalable. *R. reniformis* has also been found to reproduce on the palm species *Acoelorrhaphe wrightii* and *Washingtonia robusta*, two commonly grown ornamental plants (Inserra *et al.* 1994).

Indirect	
Eradication, control etc.	**Impact score**: E – major significance at the district level Once established in the pineapple and sweet potato industries in Southeast Queensland, significant measures would be need to control *R. reniformis*. No pineapple cultivars are resistant to *R. reniformis*. Currently, *R. reniformis* is controlled on pineapple in Hawaii by fallowing for six to 12 months, fumigating before planting and then applying post-plant, non-fumigant nematicides (Apt and Caswell 1988). However, dry fallow may be ineffective as a means of control since *R. reniformis* can survive by anhydrobiosis, reviving when environmental conditions are favorable (Apt 1976).
Domestic trade	**Impact score**: D – significant at the district level Pineapple yield is likely to be affected significantly by *R. reniformis*, reducing the amount of pineapple available for the domestic market. The quality of sweet potato is likely to be affected significantly, with cracking of tubers caused by *R. reniformis*, reducing the amount of sweet potato available for the domestic market.
International trade	**Impact score**: B – minor significance at the local level Australia's export trade in ginger is small. *R. reniformis* is unlikely to have a major effect on international trade.
Environmental and non-commercial	**Impact score**: unknown This is unknown but there are many native plants in forests adjacent to the ginger- and pineapple-growing areas in Southeast Queensland. It is possible that, if *R. reniformis* is introduced to this region, it could spread to native host plant species.

4.6.6 Unrestricted risk estimate

The unrestricted risk for *Rotylenchulus reniformis* is: **MODERATE**.

The unrestricted risk estimate for *Rotylenchulus reniformis* of 'moderate' exceeds Australia's ALOP. Therefore, specific risk management measures are required for this pest.

4.7 Bacterial wilt

Ralstonia solanacearum

Bacterial wilt caused by *Ralstonia solanacearum* has become a severe problem on ginger in China, and there are no effective measures to control this disease (Yang and Guo 2010).

All isolates from ginger have proven to be biovar 3 or biovar 4, and these show variable degrees of pathogenicity to ginger. In Australia, biovar 4 was a much more serious pathogen; however, the reverse situation has been reported in India (Kumar and Hayward 2005) and Indonesia (Jackson 1995).

4.7.1 Probability of entry

Probability of importation

The likelihood that *Ralstonia solanacearum* will arrive in Australia with the importation of fresh ginger from Fiji is: **LOW**.

- *R. solanacearum* spreads via rhizomes, contaminated farm implements and running water. It is spread by contaminated surface water used for irrigation; control requires strict hygiene and water disinfestation (Janse *et al*. 2004).
- Heavy rainfall events in the ginger-growing areas in both Australia and Fiji are common (Stirling *et al.* 2009). Therefore, run-off water could carry *R. solanacearum* from areas of infestation to ginger crops.
- The bacterium is commonly found on a range of vegetable crops in Fiji; these include chilli pepper, tomato, eggplant and tobacco (McKenzie *et al.* 2003b). These may be grown in rotation, or may grow as weeds, with ginger in Fiji; for example, tomato has been seen growing as a weed in ginger crops (Smith pers. comm.). This means that there is a significant risk of soil planted to ginger becoming infested and the bacterium being exported to Australia in rhizomes or soil adhering to rhizomes.
- The bacterium can invade roots of non-hosts and resistant cultivars without showing any symptoms. It can survive and be transmitted in ginger rhizomes because of their high moisture content. Rhizomes used as planting material may show no obvious symptoms and can serve as a means of disease spread (Kumar and Hayward 2005; Xue *et al*. 2011).
- Latently infected planting material is the major means of dispersal of *R. solanacearum* between locations, states, countries and continents (Hayward 1991; Huang *et al*. 2012).
- *R. solanacearum*, intercepted from ginger rhizomes exported to Europe for cut flower production, caused serious economic losses when severe quarantine measures had to be taken (Elphinstone 2010).
- Hot-water treatment at 50 °C for 10 minutes is the usual preplant treatment for ginger rhizomes in Hawaii (Kumar and Hayward 2005). However, this would not be sufficient to ensure that rhizomes were free of *R. solanacearum* for export. Studies have shown that treatment in hot air so that the *internal* temperature of the rhizomes reached 49 °C for

30 minutes was required to ensure that the rhizomes were free of *R. solanacearum* (Kumar and Hayward 2005).

- There is strong DNA-based evidence that the biovar 4 strain that devastated the ginger industry in the mid 1960s originated from China in latently infected rhizomes. That particular strain has been found in a number of provinces in China (Xu *et al.* 2009; Xue *et al*. 2011).
- A possible extension to the infection pathway includes ginger planting material imported into Fiji from another country where biovar 4 is present. Phylotype 1 (which comprises biovars 3, 4 and 5) is widespread in the South Pacific, Oceania, Australasia and South-East Asia (McKenzie *et al*. 2003a).

Probability of distribution

The likelihood that *Ralstonia solanacearum* will be distributed within Australia in a viable state to a susceptible part of a host, as a result of the processing, sale or disposal of fresh ginger from Fiji, is: **HIGH**.

- Imported ginger will be distributed to many localities within Australia by wholesale and retail trade, and by individual consumers (Draft IRA p. 43).
- Individual consumers could carry small quantities of ginger rhizomes to urban, rural and natural localities. Small amounts of ginger waste could be discarded in these localities (Draft IRA p. 44).
- Some ginger rhizomes may be distributed to areas where host plants are grown (Draft IRA p. 44).
- Small amounts of ginger waste will be discarded into domestic compost (Draft IRA p. 44).
- Imported ginger will be used by ginger growers as planting material (see Section 2.2.2 of this response). This would introduce *R. solanacearum* into soil on commercial farms.
- *R. solanacearum* has an unusually wide host range, including ginger, with susceptible host plants occurring in over 50 different plant families (Kumar and Hayward 2005).
- The host range of biovar 4 of *R. solanacearum* includes tomato, potato, capsicum, eggplant, peanut and tobacco, as well as the following weeds that are commonly found in ginger crops in Australia: *Solanum nigrum, S. mauritianum, Crassocephalum crepidioides*, *Physalis minima*, *P. peruviana* and *Ageratum houstonianum* (Pegg and Moffett 1971).

Probability of entry (importation × distribution)

The likelihood that *Ralstonia solanacearum* will enter Australia and be transferred in a viable state to a susceptible host, as a result of trade in fresh ginger from Fiji, is: **LOW**.

4.7.2 Probability of establishment

The likelihood that *Ralstonia solanacearum* will establish within Australia, based on a comparison of factors in the source and destination areas considered pertinent to their survival and reproduction, is: **HIGH**.

- Climatic conditions in parts of Australia match those in the ginger production areas in Fiji (Draft IRA p. 34).
- *R. solanacearum* is known to overwinter in temperate zones and to survive the dry season in tropical areas (Kumar and Hayward 2005).

- The bacterium can persist in soil for a long time (Okwuowulu 2005) in the absence of host plants. Alternative weed hosts and non-host plants play an important role in survival.
- *R. solanacearum* can survive on non-host plants and plant debris. There is evidence of both saprophytic and parasitic survival of the bacterium in the rhizosphere of certain weeds in Queensland (Moffett and Hayward 1980, Pegg and Moffett 1971).
- Biovar 4 of *R. solanacearum* can survive on many weed species including *Solanum nigrum*, *S. mauritianum, Crassocephalum crepidioides*, *Physalis minima*, *P. peruviana* and *Ageratum houstonianum* (Pegg and Moffett 1971).

4.7.3 Probability of spread

The likelihood that *Ralstonia solanacearum* will spread within Australia, based on a comparison of those factors in the source and destination areas considered pertinent to the expansion of the geographic distribution of the pest, is: **HIGH**.

- Root-to-root spread has been recorded but there is little evidence of long-distance spread between fields except in circumstances where floodwater moves infested soil or infested plant debris (Kumar and Hayward 2005).
- *R. solanacearum* in Kenya is spread by contaminated surface water used for irrigation; control requires strict hygiene and water disinfestation (Janse *et al*. 2004).
- Heavy rainfall events in the ginger-growing areas in both Australia and Fiji are common (Stirling *et al.* 2009). Therefore, run-off water could carry *R. solanacearum* away from ginger grown from imported rhizomes.

4.7.4 Probability of entry, establishment and spread

The likelihood that *Ralstonia solanacearum* will be imported as a result of trade in fresh ginger from Fiji, be distributed in a viable state to a susceptible host, establish and spread within Australia, is: **LOW**.

4.7.5 Consequences

Assessment of the potential consequences (direct and indirect) of *Ralstonia solanacearum* for Australia is: **EXTREME**.

Criterion	Estimate and rationale
Direct	
Plant life or health	**Impact score**: E – major significance at the district level Bacterial wilt caused by *R. solanacearum* is a serious disease of ginger in Hawaii (Ishii and Aragaki 1963). The disease ranks as one of the most serious and damaging bacterial diseases in the world. It causes losses of up to 100% in many ginger-growing regions of India (Kumar and Hayward 2005). Symptoms are wilting and yellowing of lower leaves. Wilting extends up to younger leaves. Stems become water-soaked and leaves separate easily from the stem (Okwuowulu 2005). Bacterial wilt of ginger is widespread and exceedingly destructive in several countries, a situation made worse by the ease with which the pathogen is carried within the planting material (Kumar and Hayward 2005).

Other aspects of the environment	**Impact score**: G – major significance at the national level The host range of biovar 4 of *R. solanacearum* includes important crops such as tomato, potato, capsicum, eggplant, peanut and tobacco (Pegg and Moffett 1971). If these are affected by *R. solanacearum* imported on ginger from Fiji, many industries would be devastated.
Indirect	
Eradication, control etc.	**Impact score**: E – major significance at the district level *R. solanacearum* biovar4 was eradicated from the previous ginger-production area. However, this required moving the industry north.
Domestic trade	**Impact score**: F – major significance at the regional level If *R. solanacearum* biovar 4 causes the same devastation as seen in the mid 1960s, there would be severe shortages of ginger for sale on the domestic market. In addition, there would be shortages of produce from several vegetable and other industries.
International trade	**Impact score**: B – minor significance at the local level Australia's export trade in ginger is small. *R. solanacearum* is unlikely to have a major effect on international trade.
Environmental and non-commercial	**Impact score**: F – major significance at the regional level The full host range among native plant species is unknown. There are many native plants in forests adjacent to the ginger-growing area. The Australian Plant Pest Database shows that the host range of *R. solanacearum* includes native plants such as *Alpinia* sp., *Acacia mountfordiae*, *Archontophoenix alexandre*, *Heliconia* sp., *Strelitzia reginae*, *Eucalyptus urophylla* and *E. pellita.*

4.7.6 Unrestricted risk estimate

The unrestricted risk for *Ralstonia solanacearum* is: **HIGH**.

The unrestricted risk estimate for *Ralstonia solanacearum* of 'high' exceeds Australia's ALOP. Therefore, specific risk management measures are required for this pest.

4.8 Soft rot

Pythium vexans and *P. graminicola*

Pythium soft rot is currently regarded as the most serious pathogen affecting ginger in Fiji. Rhizome rot is likely to occur on crops in most years in Fiji, and it often limits the amount of planting material available for the next ginger crop. Immature ginger can suffer heavy losses when conditions are unusually wet for a month or two before harvest (Stirling *et al*. 2009).

P. myriotylum causes soft rot in both Australia and Fiji, but two additional species — *P. graminicola* and *P.vexans* — cause soft rot on ginger in Fiji (Fiji Ministry of Primary Industries) but they have not been found to cause rot on ginger in Australia.

4.8.1 Probability of entry

Probability of importation

The likelihood that these *Pythium* species will arrive in Australia with the importation of fresh ginger from Fiji is: **HIGH.**

- Infection by *Pythium* spp. is through buds, roots, developing rhizomes and the collar region of stems during warm, wet weather. Symptoms appear initially as water-soaked patches that enlarge and form a watery mass of rotting tissue. Rotting then attracts opportunistic bacteria, fungi and insects.
- *P. vexans* and *P. graminicola* have been isolated from diseased rhizomes in Fiji (Lomavatu *et al*. 2009; Smith *et al*. 2012).
- Small amounts of visible diseased tissue may be cut off a rhizome but infection still remains within the rhizome tissue.
- Imported rhizomes pose a risk as an infected source of plant material (Smith *et al*. 2012) and also through infested soil adhering to the rhizome and trapped in cavities and crevices between rhizome sections.
- *Pythium* is spread via infested rhizomes (Trujillo 1964) and as oospores surviving in debris in the soil (Fiji Ministry of Primary Industries; Dohroo 2005).
- Infections start from contaminated planting material, from populations of the fungus living saprophytically in the soil or on trash of previous ginger crops, or as dormant oospores. These fungi have wide host ranges and can survive on other host plants (Jackson 1995).
- The best method of managing the disease is by the use of disease-free rhizomes for planting (Dohroo 2005).
- Oospores in the rhizome or soil can remain viable for years, even after long fallows (Dohroo 2005). They have thick walls that enable them to survive adverse environmental conditions and between ginger crops (Fiji Ministry of Primary Industries).
- Pythium soft rot is widespread and occurs in all of the major ginger-growing areas in Fiji (Stirling *et al*. 2009; Smith *et al*. 2012).

- The soft rot caused by *Pythium* does not produce offensive odours, which are characteristic of bacterial rots (Trujillo 1964), and so many infected rhizomes are likely to go undetected.
- There are three major reasons why *Pythium* will always be a threat to ginger production in the hot and wet Fijian environment: pathogenicity tests show that the pathogen is capable of destroying ginger rhizomes in 1–2 weeks under ideal moisture and temperature conditions; the fact that heavy losses occur on steep, relatively well-drained slopes and in soils that dry out following 2–3 days of sunshine suggests that the disease is not necessarily exacerbated by poor drainage and may occur when soils are continually saturated from constant rain; chemical and some cultural methods of control are likely to be too expensive or impractical for Fijian growers with small holdings (Smith *et al*. 2012). Because these fungi are so difficult to control in Fiji, it will be extremely difficult to source *Pythium*-free rhizomes for export to Australia.
- The genus *Pythium* contains more than 100 species of animal and plant pathogens, mycoparasites and saprophytes and it is very difficult to determine *Pythium* species accurately on morphology alone. Kageyama *et al.* (2005) assessed 62 isolates of *P. graminicola* and related species, which are commonly misidentified, and pointed to the difficulty of relying solely on morphological characteristics for identification. They divided those isolates into seven DNA groups based on RLFP analysis. These DNA groups agreed with morphological differentiation so reliable identification of these species can now be accomplished by combining traditional morphological methods with DNA analysis. This illustrates the difficulty of reliably determining the presence of and identifying *Pythium* species in rhizomes before export from Fiji.
- Latent infections of rhizomes by *Pythium* spp. would not be picked up by pre-export inspection (Verhoeff 1974).

Probability of distribution

The likelihood that these *Pythium* species will be distributed within Australia in a viable state, as a result of the processing, sale or disposal of fresh ginger from Fiji, is: **HIGH**.

- Imported ginger will be distributed to many localities within Australia by wholesale and retail trade, and by individual consumers (Draft IRA p. 43).
- Individual consumers could carry small quantities of ginger rhizomes to urban, rural and natural localities. Small amounts of ginger waste could be discarded in these localities (Draft IRA p. 44).
- Some ginger rhizomes may be distributed to areas where host plants are grown (Draft IRA p. 44).
- Small amounts of ginger waste will be discarded into domestic compost (Draft IRA p. 44).
- Imported ginger will be used by ginger growers as planting material (see Section 2.2.2 of this response). This would introduce *Pythium* spp. into soil on commercial farms.
- Ginger is a host of *P. vexans* and *P. graminicola* (Fiji Ministry of Primary Industries).
- *P. vexans* and *P. graminicola* have wide host ranges (Kageyama *et al.* 2005).
- Hosts of *P. graminicola* include many grasses and cereals, capsicum, cotton, lupins, peas, sugarcane, faba bean and pineapple (USDA–ARS database).

- Hosts of *P. vexans* include onion, apple, orange, passionfruit, papaya, wheat, lucerne, *Pinus radiata*, nursery plants and the Australian natives *Callistemon pinifolius*, *Casuarina* sp., *Hakea purpurea* and *Leptospermum flavescens* (USDA–ARS database). Several of these native plants are known to be growing in the same regions as the main ginger-growing area (Bostock and Holland 2010).

Probability of entry (importation × distribution)

The likelihood that these *Pythium* species will enter Australia and be transferred in a viable state to a susceptible host, as a result of trade in fresh ginger from Fiji, is: **HIGH**.

4.8.2 Probability of establishment

The likelihood that these *Pythium* species will establish within Australia, based on a comparison of factors in the source and destination areas considered pertinent to their survival and reproduction, is: **HIGH**.

- Climatic conditions in parts of Australia match those in the ginger production areas in Fiji (Draft IRA p. 34).
- Infection occurs when motile zoospores, attracted to chemicals produced in the root rhizosphere, invade the root (Jackson 1995).
- Outbreaks of rhizome soft rot depend on the presence of a susceptible host, abundant soil moisture and high soil temperatures (Jackson 1995).
- Climatic conditions in some parts of Australia match those of the source areas in Fiji.
- All *Pythium* isolates obtained from ginger in Fiji and Australia grow well at high temperatures. They continue to grow slowly at 41 °C (Stirling *et al*. 2009).
- Dohroo (2005) noted that *P. vexans* has a lower temperature requirement than *P. myriotylum*, with a maximum tolerance limit of 34 °C. Therefore, *P. vexans* is likely to be even better adapted to the climatic conditions in the major ginger-growing region of Southeast Queensland than is *P. myriotylum*.
- Disease epidemics are triggered by wet weather events when soils remain saturated for lengthy periods during summer and early autumn (Stirling *et al*. 2009; Smith *et al*. 2012). These are similar to the conditions found in Southeast Queensland.

4.8.3 Probability of spread

The likelihood that these *Pythium* species will spread within Australia, based on a comparison of those factors in the source and destination areas considered pertinent to the expansion of the geographic distribution of the pests, is: **HIGH**.

- The primary source of soft rot is the oospore, but *Pythium* also produces zoospores with flagella that enable motility in water. Zoospores are very quickly spread in very wet soil and in surface water and are responsible for serious disease epidemics in Fiji (Fiji Ministry of Primary Industries).
- Infection occurs when motile zoospores, attracted to chemicals produced in the root rhizosphere, invade the root (Jackson 1995).
- Dohroo (2005) has recorded two ways in which *Pythium* is carried over and perpetuated: through diseased rhizomes and through oospores surviving in debris in the soil. Oospores in

the rhizome or soil can remain viable for years, and can therefore be spread long distances on footwear and machinery.

Probability of entry, establishment and spread

The overall likelihood that these *Pythium* species will be imported as a result of trade in fresh ginger from Fiji, be distributed in a viable state to a susceptible host, establish and spread within Australia, is: **HIGH**.

4.8.4 Probability of entry, establishment and spread

The likelihood that these *Pythium* species will enter Australia as a result of trade in fresh ginger from Fiji, be distributed in a viable state to a susceptible host, establish and spread within Australia, is: **HIGH**.

4.8.5 Consequences

Assessment of the consequences (direct and indirect) of these *Pythium* species for Australia is: **MODERATE**.

Criterion	Estimate and rationale
Direct	
Plant life or health	**Impact score**: E – major significance at the district level In newly planted crops, planting material usually rots a few weeks after planting. In young plants, growth is very poor, plants become yellow and wilted and eventually die. In mature plants, infection takes place through roots or via the collar region, with symptoms of leaf yellowing and collapse of affected shoots (Fiji Ministry of Primary Industries). Older leaves dry first, followed by younger leaves (Trujillo 1963; Fiji Ministry of Primary Industries). Rhizomes develop water-soaked lesions near the base of affected shoots and, under suitable environmental conditions, the rhizome then rots rapidly and is eventually destroyed (Jackson 1995; Fiji Ministry of Primary Industries). Losses due to *Pythium* soft rot occur regularly in Fiji. In 1997–98, rhizome rot destroyed 30–100% of mature ginger crops at four field sites in Fiji (Fullerton and Harris 1998), with similar losses to seed ginger in 2007–08 (Stirling *et al*. 2009). In India, *Pythium* is considered to be the most destructive disease of ginger, with losses of 80–90% in wet years. In South Korea, the incidence of soft rot is 50% (Jackson 1995). Chemical control options have so far proven to be largely ineffective in Fiji (Smith *et al*. 2012).
Other aspects of the environment	**Impact score**: D – significant at the district level Hosts of *P. graminicola* include many grasses and cereals, capsicum, cotton, lupins, peas, sugarcane and faba bean. Hosts of *P. vexans* include onion, apple, orange, passionfruit, papaya, wheat, lucerne, pineapple, *Pinus radiata* and nursery plants (USDA–ARS database). Therefore, it is likely that, if *Pythium* species with greater pathogenicity are imported from Fiji, they would reach and affect other important crops. Many native plants grow in forests adjacent to the ginger-growing region in Southeast Queensland. Known native hosts of *P. vexans* include *Callistemon pinifolius*, *Casuarina* sp., *Hakea purpurea* and *Leptospermum flavescens* (USDA–ARS database). Some of these native plants are known to be growing in the same regions as the main ginger-growing area (Bostock and Holland 2010). These and many other native plant hosts are likely to be affected by *P. vexans* in nearby ginger

	crops and there is a significant risk that it could spread to native host plants.
Indirect	
Eradication, control etc.	**Impact score**: B – minor significance at the local level Chemical control is not very effective (Smith *et al*. 2012). Ginger rhizomes may be affected by *P. vexans* and *P. graminicola*, reducing the availability of disease-free rhizomes for planting material.
Domestic trade	**Impact score**: C – minor significance at the district level Some ginger rhizomes are likely to be affected by *P. vexans* and *P. graminicola* and be unsalable on the domestic market, reducing the amount of ginger available.
International trade	**Impact score**: B – minor significance at the local level Australia's export trade in ginger is small. *Pythium* is unlikely to have a major effect on international trade.
Environmental and non-commercial	**Impact score**: D – significant at the district level This is unknown but there are many native plants in forests adjacent to the ginger-growing region, and *P. vexans* is a known host of several native plants. If pathogenic *Pythium* species reach host plants in native forests, there are likely to be both direct effects on host plants and indirect effects on their ecosystems, including both plants and animals.

4.8.6 Unrestricted risk estimate

The unrestricted risk for these *Pythium* species is: **MODERATE**.

The unrestricted risk estimate for these *Pythium* species of 'moderate' exceeds Australia's ALOP. Therefore, specific risk management measures are required for this pest.

4.9 Rhizome rot

Fusarium oxysporum f.sp. *zingiberi*

After *Pythium*, *Fusarium oxysporum* f.sp. *zingiberi* (*Foz*) is the Australian ginger industry's major disease concern. The symptoms of *Foz* infection were first recorded on ginger in Queensland in 1930 and the organism was identified in 1942 (Pegg *et al*. 1974). Affected plants become stunted and yellow, lower leaves wilt and shoots dry off completely. Severely affected rhizomes may be dry and show internal rot (Pegg *et al*. 1974; Trujillo 1963).

Although fungicides such as benomyl (Benlate) are used against *Foz* in Australian ginger crops, control of *Foz* relies mainly on the use of uninfested (clean) planting material (Stirling *et al.* 2012). This requires careful inspection to ensure that rhizomes are free of *Foz.* However, latent infections can harbour the pathogen without causing symptoms, so it would not be visible to the naked eye on inspection (Verhoeff 1974; Ishikawa 2004).

Some Fijian growers treat planting material with hot water at 51 °C for 10 minutes to control root-knot nematodes; however, a study by Domingues (2006) showed that eradication of *Foz* from rhizomes requires 45 °C for 2 hours or 55 °C for 20 minutes.

4.9.1 Probability of entry

Probability of importation

The likelihood that *Fusarium oxysporum* f.sp. *zingiberi* will arrive in Australia with the importation of fresh ginger from Fiji is: **HIGH**.

- *Foz* can persist in soil for many years. Infection occurs via cracks in rhizomes caused by injury, nematodes, insects or waterlogging (Pegg *et al*. 1974; Trujillo 1963).
- Latent infections of rhizomes by *Foz* would not be picked up by pre-export inspection Verhoeff 1974; Ishikawa 2004).
- Small amounts of visible diseased tissue may be cut off a rhizome but infection still remains within the rhizome tissue.
- Hot-water treatment at 51 °C for 10 minutes would not eliminate *Foz* from rhizomes (Domingues 2006).

Probability of distribution

The likelihood that *Fusarium oxysporum* f.sp. *zingiberi* will be distributed within Australia in a viable state to a susceptible part of a host, as a result of the processing, sale or disposal of fresh ginger from Fiji, is: **HIGH**.

- Imported ginger will be distributed to many localities within Australia by wholesale and retail trade, and by individual consumers (Draft IRA p. 43).
- Individual consumers could carry small quantities of ginger rhizomes to urban, rural and natural localities. Small amounts of ginger waste could be discarded in these localities (Draft IRA p. 44).

- Some ginger rhizomes may be distributed to areas where host plants are grown (Draft IRA p. 44).
- Small amounts of ginger waste will be discarded into domestic compost (Draft IRA p. 44).
- Imported ginger will be used by ginger growers as planting material (see Section 2.2.2 of this response). This would introduce *Foz* into soil on commercial farms.

Probability of entry (importation × distribution)

The likelihood that *Fusarium oxysporum* f.sp. *zingiberi* will enter Australia and be transferred in a viable state to a susceptible host, as a result of trade in fresh ginger from Fiji, is: **HIGH**.

4.9.2 Probability of establishment

The likelihood that *Fusarium oxysporum* f.sp. *zingiberi* will establish within Australia, based on a comparison of factors in the source and destination areas considered pertinent to their survival and reproduction, is: **HIGH**.

- Climatic conditions in parts of Australia match those in the ginger production areas in Fiji (Draft IRA p. 34).
- Ginger is a host of *Foz*. When rhizomes infested with *Foz* are planted, the fungus will become established in the soil.
- *Foz* has no known sexual stage, but produces three types of asexual spores: microconidia, macroconidia and chlamydospores. It is most commonly recovered from the soil as chlamydospores.
- Foz infects a healthy plant by means of mycelia or by germinating spores penetrating the plant's root tips, root wounds or lateral roots. The mycelium advances intracellularly through the root cortex and into the xylem.
- Most *F. oxysporum* can survive as saprophytes, which feed on dead and decaying organic matter.
- *Foz* spreads in two main ways. It can spread short distances by water splash and by movement of planting equipment. It can spread long distances in infected rhizomes.

4.9.3 Probability of spread

The likelihood that *Fusarium oxysporum* f.sp. *zingiberi* will spread within Australia, based on a comparison of those factors in the source and destination areas considered pertinent to the expansion of the geographic distribution of the pest, is: **MODERATE**.

- Although *Foz* causes disease only on ginger, it can persist on roots of symptomless non-host plants (Burgess *et al.* 2008).
- Good crop hygiene is important to prevent soil from diseased areas being introduced into disease-free areas on shoes and digging implements (Burgess *et al.* 2008).
- Water from irrigation or run-off from rainfall flowing over the ground can spread *F. oxysporum*, especially downhill (Ploetz *et al.* 1999).

4.9.4 Probability of entry, establishment and spread

The likelihood that *Fusarium oxysporum* f.sp. *zingiberi* will be imported as a result of trade in fresh ginger from Fiji, be distributed in a viable state to a susceptible host, establish and spread within Australia, is: **MODERATE**.

4.9.5 Consequences

Assessment of the potential consequences (direct and indirect) of *Fusarium oxysporum* f.sp. *zingiberi* for Australia is: **MODERATE**.

Criterion	Estimate and rationale
Direct	
Plant life or health	**Impact score**: E – major significance at the district level *Foz* is probably the most serious problem of ginger in Hawaii (Trujillo 1964) and it can cause up to 100% crop loss (Dohroo and Sharma 1992).
Other aspects of the environment	**Impact score**: A – indiscernible at the local level *Foz* is likely to be host specific so it is unlikely that it would affect other crops.
Indirect	
Eradication, control etc.	**Impact score**: B – minor significance at the local level *Foz* cannot be eradicated and fungicidal treatment of planting material protects rhizomes only up to early harvest. Ginger rhizomes may be affected, thus reducing the availability of disease-free rhizomes for planting material.
Domestic trade	**Impact score**: C – minor significance at the district level Some ginger rhizomes are likely to be affected by *Foz* and be unsalable on the domestic market, reducing the amount of ginger available for sale.
International trade	**Impact score**: B – minor significance at the local level Australia's export trade in ginger is small. *Foz* is unlikely to have a major effect on international trade.
Environmental and non-commercial	**Impact score**: A – indiscernible at the local level *Foz* is likely to be host specific so it is unlikely that it would affect native plant species.

4.9.6 Unrestricted risk estimate

The unrestricted risk for *Fusarium oxysporum* f.sp. *zingiberi* is: **MODERATE**.

The unrestricted risk estimate for *Fusarium oxysporum* f.sp. *zingiberi* of 'moderate' exceeds Australia's ALOP. Therefore, specific risk management measures are required for this pest.

Appendix 1

An experiment to examine the effect of packhouse washing of ginger rhizomes on soil retention and consequences of soil-borne pathogens being moved on fresh ginger for export

Mike Smith, Department of Agriculture, Fisheries & Forestry, Maroochy Research Station, Nambour QLD 4560

Aim: To investigate whether soil is retained on ginger destined for household consumption following washing and packing into cartons or containers in a commercial operation

Method: 'Queensland' ginger rhizomes were harvested on 9 May 2012 from beds that had not been top-dressed with sawdust mulch, and placed in bins (ca. 500 kg capacity). A bin was emptied into a wire tray, suspended over a frame (0.6 m high); rhizomes were spread evenly (2–3 hands deep) and washed with a high-pressure hose at 18 psi for 15 min (see Figure 1.1). The ginger was hosed thoroughly from above, below and from the sides. This same procedure was used commercially prior to the packhouse upgrading its washing facilities, and it was very similar to the operations shown in Fiji in Figure 3.4 of the Draft IRA.

Twenty hands of ginger were randomly selected and inspected for soil that may have been retained in the many cavities and creases formed by the complex morphology of the ginger rhizome. Soil was removed with a spatula and placed in a Petri dish for weighing. A separate dish was used for each hand that contained traces of soil.

The soil samples were then sent to the Nematology Diagnostic Laboratory of Agri-Science Queensland, DAFF, at Dutton Park. The soil was placed in Whitehead trays for 3 days to extract all nematodes, i.e. plant-parasitic and free-living nematodes.

Results: Of the 20 washed hands sampled, soil was found on 17 of them (85%). In three of these 17 hands, there was sufficient overlap of hands that, in a commercial operation, the hands would have been separated and the rhizomes re-washed. In other words, they represented two hands that were joined and overlapping; however, these constituted the greatest risk, with 9.01 g, 18.75 g and 45.41 g of soil being collected (*Note:* Data for those three hands were not used in the following calculations).

Of the remaining 14 samples, an average of 0.88 g (standard deviation = 1.28) of soil was collected from an average weight of rhizome of 275 g. The range of weights of fresh soil collected from the rhizomes was 0.05–4.51 g (see Figure 1.2).

Table A.1 shows the number of nematodes extracted from these soil samples. Nematode counts revealed that soil samples over 5 g contained hundreds of nematodes; 1–5 g contained between 2 and 50 nematodes; and soil less than 1 g contained between 0 and 17 nematodes. Of those soils less than 1 g, 82% contained at least one nematode.

Discussion: Using the data collected from this experiment it is possible to extrapolate the figures and estimate how much soil (potentially carrying serious pathogens of ginger) may be found in average consignments of ginger destined for the fresh market.

For instance, a 10 kg carton may be expected to contain 32 g of soil. Even if only 70% of the rhizomes contain traces of soil, this still means 22.4 g of soil will be found on rhizomes in a 10 kg carton. Take this further and 2.24 kg of soil could be found in a 1-tonne air-freight consignment and 22.4 kg in a 10-tonne sea-freight consignment.

Table A.1 Numbers of nematodes extracted from soil adhering to ginger rhizomes after thorough washing

Sample ID	Soil weight (g)	Free-living nematodes	Root-knot nematodes (*Meloidogyne* sp.)	Total nematodes
1	2.2	11	35	46
2	6.9	713	20	733
3	16.3	146	0	146
4	<1.0	6	0	6
5	<1.0	0	0	0
6	<1.0	1	0	1
7	<1.0	5	0	5
8	<1.0	6	0	6
9	3.2	8	41	49
10	<1.0	17	0	17
11	<1.0	2	0	2
12	<1.0	0	0	0
13	<1.0	1	0	1
14	<1.0	1	0	1
15	<1.0	1	0	1
16	45.0	84	10	94
17	<1.0	2	0	2

Conclusion: Due to the morphology of the ginger rhizome it is not possible to remove all traces of soil from ginger destined for the fresh market in a commercial operation. Therefore, soil, and soilborne pathogens, can be moved on rhizomes for the fresh market and these, in turn, can eventually be planted in home gardens or on commercial ginger farms.

Acknowledgements: I thank the Templeton family for allowing me to conduct this study at their farm and packhouse at Eumundi.

Appendix 2

SUN PRODUCE PTY LTD
PO BOX 133
BRISBANE MARKETS QLD 4106

REHB
CASH

REHBEIN FAMILY CO PTY LTD Invoice

30 ANTHONYS REST
BUNDABERG 4670

384314

REHB TAX INVOICE ABN : 980 ·· ····· 08 Oct 10

4346	GINGER	434	10.00	4340.00
**	**			

4340.00

Appendix 3

Risks from imported fresh ginger to ginger relatives in the Australian native environment

Jonathan Lidbetter, Research Horticulturist, NSW Department of Primary Industries, Central Coast Primary Industries Centre, Ourimbah NSW

Scientific classification of edible ginger

Species: *Zingiber officinale* Roscoe; ginger; native to South-East Asia

Genus: *Zingiber*; 141 species worldwide

Family: Zingiberaceae; 1548 species in 50 genera worldwide; pan-tropical distribution concentrated in South-East Asia

Order: Zingiberales; 8 families

Clade: Commelinids

Clade: Monocotyledons

Flora related to edible ginger

Although not a major component of the Australian flora and with relatively few species native or naturalised in Australia, much of the Zingiberales that is in Australia is concentrated in Queensland, with 32 of the 40 Australian species and 18 of the recognised genera, as shown in Table A.2. Furthermore, the family includes a number of horticultural genera used as commercial food and spice crops, such as banana (*Musa*), ginger (*Zingiber*), turmeric (*Curcuma*), cardamom (*Elettaria* and *Amomum*) and galangal (*Alpinia* and *Kaempferia*). Other genera regularly occurring in gardens in warmer climes include *Strelitzia*, *Canna*, *Maranta* and *Heliconia* (see Figure A.1).

Table A.2 Species counts in families of the Zingiberales and closely related genera

Family	World Species (Genera)	Australia Species (Genera)	Queensland Species (Genera)	New South Wales Species (Genera)
Musaceae	74 (2)	5 (1)	4 (1)	0 (0)
Heliconiaceae	207 (1)	2 (1)	1 (1)	0 (0)
Strelitziaceae	7(3)	1(1)	1 (1)	0 (0)
Lowiaceae	16 (1)	0 (0)	0 (0)	0 (0)
Cannaceae	12(1)	3 (1)	3 (1)	2 (1)
Marantaceae	539 (31)	5 (3)	2 (2)	0 (0)
Zingiberaceae	1548 (50)	21 (10)	18 (10)	3 (2)
Costaceae	137 (7)	3 (2)	3 (2)	0 (0)
Tribe totals	**2540 (96)**	**40 (19)**	**32(18)**	**5 (3)**
Other closely related families				
Haemodoraceae	101 (14)	95 (8)	5 (1)	5 (2)
Commelinaceae	723 (41)	52 (12)	38 (11)	17 (8)

Relatively closely related to the Zingiberales are the families Commelinaceae and Haemodoraceae, which also belong to the broader botanical clade Commenelids. The Commelinaceae is a cosmopolitan family that includes the common coastal weed *Tradescantia fluminernsis* (wandering jew). In contrast, the family Haemodoraceae is a primarily Australian family that is predominantly native to Western Australia but is also well represented right through the northern parts of Australia.

Figure A.1 Examples of ginger relatives that are commonly grown in home gardens: (a) *Maranta*, (b) *Heliconia* and (c) *Dichorisandra thyrsiflora* (blue ginger)

Disease susceptibility of related flora

Many but not all diseases have relatively narrow to moderate host ranges within related species or genera. However, flora that have not co-evolved with a disease are often at greater risk of susceptibility to that disease. Furthermore, several of the diseases and pests present in Fiji have wide host ranges and are known to cause significant economic damage to a range of crops across a range of genera.

Case study of myrtle rust incursion into Australia

A great example of the susceptibility of native plant species to introduced pathogens is the guava rust/myrtle rust *Puccinia psidii* complex (including *Uredo rangelii*). This disease was originally described in 1884 and is native to South and Central America. To date, only 25 host species have been recorded native to that region. The introduction of exotic plant species to South America saw this host list expand, particularly into the genus *Eucalyptus*. Host testing conducted in Brazil with a focus on Australian species saw the host list expand to over 125 species by 2010, with 85 of these being Australian natives (Carnegie and Lidbetter 2012).

The arrival of a suspected single strain of this disease into Australia has seen the disease affect over 250 species in 50 genera in Australia alone, and the recognised host list for the disease complex has expanded to a host range of more than 60 genera and 325 host species within two years of its first report in Australia. The disease is now established from the Daintree Rainforest north of Cairns right down the eastern seaboard to southern coastal NSW, as well as being widespread in Victoria. A number of plant species, although relatively common prior to the arrival of this disease, are under serious threat. Despite being a disease capable of being spread aerially, much of its movement has been associated with human activity (Carnegie and Cooper 2011).

Risk to non-related flora

Some of the pests and disease identified in the Draft IRA, particularly *Verticillium albo-atrum* and *Ralstonia solanacearum* are significant diseases that can affect a wide range of hosts with potential impacts on a range of horticultural crops and an unknown potential on a huge range of native species. A single Australian record identifies the native cycad *Lepidozamia peroffskyana* as a host of *Verticillium albo-atrum.* Similarly *Archontophoenix alexandrae* (Alexander palm) is reported as a host of *Ralstonia solanacearum*. Neither of these plant species belongs to the family Zingiberaceae nor even the larger clade recognised as the commenelids.

Undetermined at this stage but indicated by a number of horticultural crops is the risk posed directly to the genus *Solanum* (potato, eggplant and pepino) within the family Solanaceae (tomato, capsicum, eggplant, nightshade and tobacco) and then to the flora in general due to the wide distribution of this genus (see Figure A.2) as a horticultural crop, garden plant, native flora and weed.

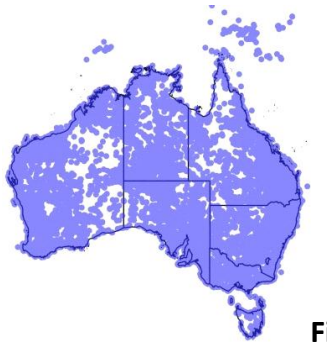


Figure A.2 Distribution of members of the genus *Solanum*

Establishment of ginger from imported fresh product

The likelihood of establishment of ginger plants from imported rhizomes is very high. This is particularly the case in urban areas of Sydney, Brisbane and even frost-free areas of Melbourne where ginger is currently cultivated. Further, it could also be the case for commercial growers of ginger who are looking to rapidly expand production.

Evidence from commercial waste dumps shows the ability of discarded material to establish uncared for, allowing for the persistence of infection (see Figure A.3).

The current public focus on exotic cuisine and home cultivation of herbs and spices, as evident from the success of cooking shows and websites advocating cultivation means, suggests that an undiscerning public is likely to plant any material, whether infected or not.

An on-line search for ‘growing ginger in NSW’ revealed numerous websites catering locally for those intending to grow ginger in NSW. These are either guides for ‘how to’ or answers to questions about how to grow ginger.

The general consensus is that it can be grown relatively easily, with the recommended approach being to go to the greengrocer for material, and none of the sites mention any need to evaluate rhizomes for signs of disease or pest problems.

The following is a small sample of websites and relevant quotes.

- ‘As well as growing the shop-bought ginger, you can do the same with shop-bought turmeric and galangal, too, if your climate is warm enough. All these plants thrive in warm climates, but can still do OK in temperate zones.
  I’m in Sydney and ginger and turmeric grow very readily here.’

  http://www.burkesbackyard.com.au/forum/2/54/Growing-fruit-and-vegetables/topic/11

- ‘About a year ago I decided to become self sufficient in this wonderful spice so I bought $25 worth of ginger from the local fruit shop. That gave me enough to put in 18 plants. I couldn’t live without turmeric so I planted it too. Cardamom is hard to kill, so in that went, together with some galangal.’

  http://www.abc.net.au/gardening/stories/s1755985.htm

Figure A.3 Germination of ginger rhizomes discarded as waste

- ‘You can buy ginger root from the shop and use it to grow more ginger. The new plants come from the very tip of the ginger roots.’

  http://forums.permaculture.org.au/showthread.php?1584-Help-with-Growing-Ginger

- ‘When I started growing ginger root I expected it to be difficult. It’s not.’

  http://www.tropicalpermaculture.com/growing-ginger.html

- ‘Hedychium would be the genus with the largest number of cold-hardy species. There are even enthusiasts in England who grow some outdoors.

- Alpinia also has species that grow vigorously in Sydney, including most of the Australian native spp. But I doubt that the spectacular A. purpurea will do well here, though it may just survive in warmer spots.

- I have found that Globba winitii overwinters surprisingly well in Sydney and comes back vigorously every year. This was widely sold as an indoor plant a few years ago.
- And Curcuma spp. are also worth trying. Turmeric, C. longa, puts out lots of foliage but never seems to flower (does it in the tropics even?). C. australasica from N. Qld is reported to flower here. I would love to get hold of C. alismatifolia from the hills of N Thailand.'

http://www.au.gardenweb.com/forums/load/oztrop/msg0723072125021.html

- 'Growing your own ginger generally involves searching out sprouting sections of fresh root ginger from the local green grocer and planting them in a well drained, nutrient enriched soil.'

http://www.annettemcfarlane.com/Ginger_Festival_2006.htm

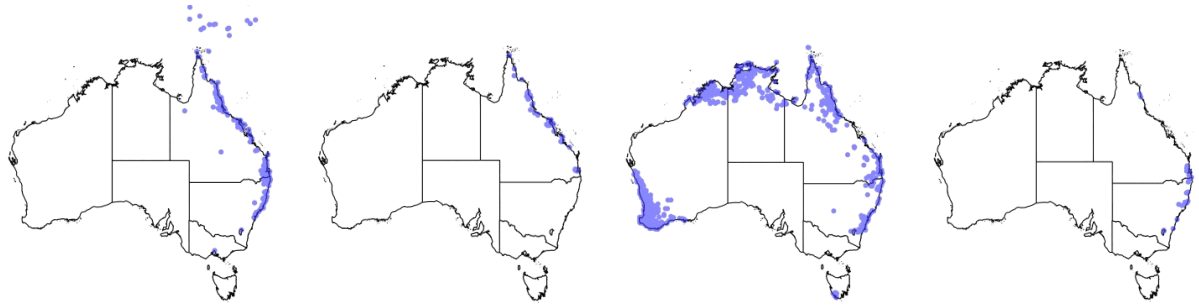
- 'OK, I'm a bit of a raver when I get going, and one thing that's guaranteed to get me going every time is ginger. You see it's so incredibly easy to grow and I've been on a bit of a mission to get ginger lovers everywhere to start growing it. In fact I'm so committed to this cause, that I've made videos about how to do it …'

http://www.gardendrum.com/stories/homegrown-ginger-and-post-rain-action

Risk of infection development in home-grown product

Infection of ginger in the public arena, although perhaps detected in severe cases, will rarely be reported, and the risk of spread to vulnerable plants in cultivation is high. If removed by the homeowner, at best it is likely to end up in domestic waste, but more likely it will end up in green waste or be discarded into waste piles in the home garden without treatment. With large parts of urban areas in all major capital cities having a close interface with bushland or often located above adjoining bushland stream catchments, the risk of spread into native bushland is high, as any infection would not be detected by a relevant authority until well established in that bushland.

Figure A.4 shows the distribution of some native relatives of edible ginger and their close proximity to the ginger-growing region and the urban areas where ginger is most likely to be grown in home gardens.



Alpinia sp. *Archontophoenix alexandrae* *Haemodorum* sp. *Lepidozamia peroffskyana*

Figure A.4 Distribution of some native plants that are known hosts of pests and diseases of edible ginger (from Australia's Virtual Herbarium, http://avh.ala.org.au)

Broadscale infection of commercial plantings is likely to be identified relatively quickly; nonetheless, once established, a soilborne disease becomes very difficult if not impossible to eradicate. The proximity of plantings to natural vegetation and watercourses, in conjunction with

the high rainfall and steep slopes (see Figure A.5) often present in ginger-growing areas, means that the risk of disease spreading to native vegetation is high.

Figure A.5 Ginger crops grown on steep slopes in Southeast Queensland with runoff into native rainforest and watercourses

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Appendix 4

An experiment to examine the pathogenicity of an Australian isolate of *Radopholus similis* on ginger

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Aim: To investigate the pathogenicity of the Australian isolate of the burrowing nematode on ginger and compare our results with similar pathogenicity studies conducted with a Fijian isolate

Method: Forty 2 L planter bags were filled with autoclaved potting mix and planted with a *Radopholus*-free 'seed piece' of 'Queensland' ginger. Pots were then transferred to a glasshouse and 12 weeks later half the pots were inoculated with 2000 *R. similis*. The nematode was obtained from a banana farm at Pimpama, Queensland and had been multiplied in the laboratory on sterile carrot tissue. Sixteen weeks after pots were inoculated, the number of yellowing or dead shoots in each pot was recorded, above-ground biomass in ten inoculated and ten control pots was measured and symptoms on seed pieces, newly developing rhizomes and roots were assessed. Nematodes were extracted by slicing the seed piece and rhizome finely and placing in a misting chamber for 7 days. Roots were chopped finely and placed in the misting chamber for the same length of time. Nematodes were recovered on a 38 µm sieve. To check that the nematodes were extracted successfully using the misting chamber, a subsample of rhizomes were macerated in a blender and sieved using a 38 µm sieve. Sixteen extra nematodes were extracted from the rhizome, so the misting method was considered successful at extracting the nematodes from the plant tissue.

Results: Both inoculated and non-inoculated plants grew normally and after 16 weeks they had several healthy green shoots up to 90 cm long. No yellowing or necrosis of shoots was noted. Yellowing and necrosis were not associated with damage caused by *R. similis*. Plant biomass was not significantly different between the control and inoculated plants (Table A.3).

Observations on tissue collected from affected plants showed that *R. similis* was causing minor damage to the base of the shoot, and in rhizome tissue at the point where shoots emerged from the rhizome. The nematode was also recovered from the occasional sunken lesion and blackened tissue on the rhizome surface, from discoloured tissue that extended 1–3 mm into the rhizome, and from seed pieces. However in no case was the nematode population in a seed piece or rhizome higher than 22 or 105 *R. similis*/100 g, respectively. In fact the total burrowing nematode population recovered was, on average, lower than that introduced during inoculation of pots (1423 vs. 2000). Estimates of the number of *R. similis* recovered after 16 weeks indicated that some nematode multiplication had occurred in roots, seed pieces and rhizomes (Table A.4). Results are not significantly different ($p = 0.05$).

Table A.3 Effect of *Radopholus similis* on ginger 16 weeks after plants growing in potting mix were either inoculated with 2000 nematodes or left uninoculated

Treatment	Fresh wt. shoots (g)	Fresh wt. seed piece (g)	Fresh wt. rhizome (g)
Control	130.5	30.4	202.1
R. similis	114.0	34.9	220.0

Table A.4 Numbers of *Radopholus similis* recovered 16 weeks after ginger plants were inoculated with 2000 nematodes or left uninoculated

	No. *R. similis*		
	per 100 g seed	per 100 g rhizome	per 100 g seed + rhizome + roots
Control	0	0	0
Inoculated	11	19	428

Discussion: The Australian isolate of *Radopholus similis* is capable of invading and feeding on ginger roots and rhizome, but it is not an aggressive pathogen and caused little to no damage to the ginger plant. In contrast, Turaganivalu *et al.* (2009) found that a Fijian isolate was capable of killing plants and destroying rhizomes under very similar conditions to those reported here. In the Australian pathogenicity experiment, of 2000 nematodes added to the pot, and average of 1423 *Radopholus similis* were recovered after 20 weeks. In the Fijian experiment, of 1500 nematodes added to the pot, an average of 15,638 were recovered indicating clearly that the Fijian *Radopholus similis* isolate can quickly and aggressively colonise and multiply on ginger rhizomes.

There is a growing body of evidence in the literature (Sarah 1993; Hahn *et al.* 1996; Quiros and Araya 2008) that describes large variability between geographically isolated populations of *R. similis* in both their ability to reproduce and their ability to cause damage. Clear differences in reproductive potential and the degree of host response have been demonstrated. The results from this study with the Australian isolate provide compelling evidence that it is a different strain of *Radopholus similis* to the more pathogenic strain found on ginger in Fiji. Furthermore Smith *et al*. (2007) did not find *R. similis* in banana roots or soil in Fiji, despite extensive sampling of banana plants growing adjacent to severely infected ginger crops. This raises questions about the host preference of *R. similis* in these situations and the potential risk of introducing a pest that is adapted to, and has a preference for, feeding on ginger roots and rhizomes.

Conclusion: Importing an isolate of *R. similis* from Fiji that has a different host range or greater pathogenicity than already present in Australia would present significant risks to the ginger and other industries.

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Appendix 5

In-vitro comparison of a Fijian and an Australian isolate of *Pythium vexans* on ginger

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Aim: To compare the growth of a Fijian and an Australian isolate of *Pythium vexans* on ginger pieces

Method:

Two isolates of *Pythium vexans* were compared. Isolate BRIP 43503 was collected from durian in Tully, Queensland, and isolate Fiji 11 was collected from Navua in Fiji. Cultures were grown on cornmeal agar at 25 °C.

Ginger rhizomes were cleaned by removing soil and washing in water. They were then air dried. Rhizomes were cut into 1 x 1 x 5.5 cm pieces and the outer layer peeled. The pieces were dipped in 70% ethanol and flamed to surface sterilise them.

Each rhizome piece was placed into a falcon tube. A 1 cm^2 piece of agar containing the *Pythium* isolate was placed on top of one end of each ginger piece. Then, 1.5 mL of sterile distilled water was added to each tube. Uninoculated ginger pieces were included as a control and treatments were replicated three times.

Tubes were incubated at 25 °C. Two or three days after inoculation, rhizome pieces were cut into 1 cm lengths and placed on cornmeal agar at 25 °C for one day. Culture plates were examined for *P. vexans*. For each rhizome piece, the maximum distance that *P. vexans* had grown away from the inoculation point was recorded.

Results:

Table A.5 shows that the Queensland isolate grew significantly further along the ginger piece than did the Fijian isolate.

Table A.5 Distances that two isolates of *Pythium vexans* grew away from the point of inoculation along ginger pieces after two or three days

Replicate	Control	BRIP 43503	Fiji 11
Two days after inoculation			
1	0	3	0
2	0	3	0
3	0	1	0
			$t = -3.575$, $p = 0.02$
Three days after inoculation			
1	0	5	1
2	0	5	1
3	0	4	0
			$t = -8.59$, $p = 0.001$

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