Increasing the Production of Australian Wasabi

RIRDC Publication No. 09/007
Increasing the Production of Australian Wasabi

by Angela Sparrow

April 2009

RIRDC Publication No 09/007
RIRDC Project No PRJ-000738
Foreword

This project follows on from three consecutive research and development projects that have helped develop a wasabi industry in Australia. Initially intended as an export industry, wasabi products from early trials were highly acclaimed and domestic market demand quickly exceeded expectations. Consumer driven changes saw the development of production methodology for water-cultivated wasabi farms in 2003/04 but water shortages have made this difficult to sustain.

The aims of this current project were to develop the capacity of an Australian laboratory to produce commercial quantities of tissue-cultured wasabi planting stock to supplement imported stock; to improve product quality through disease management, adaptable cultivation methods and additional varieties; to build the networking capacity of the wasabi grower group and develop a strategic plan for the industry.

This report also details the development of the industry since 2005 and focuses on priority research areas identified at that time

The project has identified some key industry leaders and new business entities relating to wasabi production. While industry participants and stakeholders supported the ultimate development of a Wasabi Industry Strategic Plan, they felt that the industry was not yet sufficiently advanced to warrant this.

This project was funded from RIRDC Core Funds which are provided by the Australian Government. It was also funded by the Tasmanian State Government and individual companies representing the developing industry.

This report is an addition to RIRDC’s diverse range of over 1800 research publications and forms part of our New and Emerging Industries R&D program which aims to investigate and develop prospects for new industries in rural and regional Australia.

Most of our publications are available for viewing, downloading or purchasing online through our website www.rirdc.gov.au.

Peter O’Brien
Managing Director
Rural Industries Research and Development Corporation
Acknowledgments

The Principal Investigator for the project would like to thank Robert Buck and Ian and Diane Farquhar of Wasabi Growers of Tasmania P/L who provided field trial sites for both soil and water-cultivated wasabi systems. Additional acknowledgement is due to Ian and Diane Farquhar for their perseverance with wasabi production over the past 14 years, their consistent attendance at forums for research and development for the industry and their unwavering vision to see this new horticultural industry emerge.

The Principal Investigator would also like to thank Matthew and Jessica Marston for permitting field trials to be conducted on their property and for the enthusiasm with which field officers from TIAR were received. Their consistent attendance at industry workshops and willingness to maintain open communication channels among the wasabi grower group is greatly appreciated.

Thanks are also due to Robert and Zoe Suttie for providing access to their property for a further field trial.

The Principal Investigator would like to acknowledge the role of staff at Plant Sciences Division of Central Queensland University with micropropagation research, Jared Mendham (TIAR) for assistance in conducting the wasabi industry audit and industry snapshot and Terese Mackowski (TIAR) for her tireless administrative assistance throughout the project.
# Contents

Foreword ................................................................................................................................iii
Acknowledgments ................................................................................................................ .. iv
Abbreviations .................................................................................................................. ......vii
Executive Summary ............................................................................................................viii

1 Introduction ....................................................................................................................1

2 Objectives ..................................................................................................................... 2

3 Methodology ................................................................................................................... 4
  3.1 Tissue-culture propagation of wasabi in Australia .................................................. 4
  3.2 Quality improvements for wasabi ........................................................................... 4
    3.2.1 Testing new varieties ......................................................................................... 4
    3.2.2 Fungal protection strategies .............................................................................. 5
  3.3 Wasabi Grower Network ........................................................................................ 6

4 Detailed Results .............................................................................................................. 7
  4.1 Tissue-culture propagation of wasabi in Australia .................................................. 7
  4.2 Quality improvements for wasabi ........................................................................... 7
    4.2.1 Variety trials ...................................................................................................... 7
    4.2.2 Fungicide trials ................................................................................................ 12
  4.3 Wasabi Grower Network ...................................................................................... 14
  4.4 Industry Strategic Plan .......................................................................................... 18

5 Discussion of Results .................................................................................................... 19
  5.1 Tissue-culture propagation outcomes ................................................................. 19
  5.2 Field trial outcomes ............................................................................................. 19
    5.2.1 Varietal choices ............................................................................................... 19
    5.2.2 Fungicide trials ............................................................................................. 20
  5.3 Networking ........................................................................................................... 21
  5.4 Industry Strategic Plan .......................................................................................... 22

6 Implications ................................................................................................................... 23

7 Recommendations ........................................................................................................ 25

8 References ..................................................................................................................... 27

9 Appendices .................................................................................................................... 28
List of Tables

Table 1  Varietal lines used in field trials .................................................................5
Table 2  Quality parameters for mature wasabi stems ...............................................5
Table 3  Fungicide treatment summary ......................................................................6
Table 4  Harvest data from tasmanian wasabi farm ...................................................10
Table 5  Quality parameters for 10 wasabi varieties ..................................................11
Table 6  Calendar of events 2006/07 .......................................................................15

List of Figures

Figure 1  Tasmanian value-added wasabi products ....................................................1
Figure 2  On site data collection ................................................................................4
Figure 3  Fungicide trial plants half-way to maturity ...................................................6
Figure 4  Top performing varietal selections ...............................................................7
Figure 5  Wasabi variety trial pictured at 3 growth stages .........................................8
Figure 6  Growth rate of wasabi varieties grown in soil or water-culture .................9
Figure 7  The platypus ...............................................................................................9
Figure 8  Growth of component parts of wasabi .......................................................12
Figure 9  Growth of main stem of wasabi in Tasmania .............................................13
Figure 10 Incidence of black stem lesions in Tasmanian wasabi ..............................13
Figure 11 Effect of fungicide treatment on wasabi stems .......................................14
Figure 12 Field day images ......................................................................................17
Figure 13 Visit from Japanese wasabi agronomist ...................................................17
Figure 14 Wasabi component parts extend the range of pure wasabi products .......19
Figure 15 Stem blackening for wasabi varieties grown in either water or soil medium ....20
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPIW</td>
<td>Department of Primary Industries and Water (Tasmania)</td>
</tr>
<tr>
<td>TIAR</td>
<td>Tasmanian Institute of Agricultural Research</td>
</tr>
<tr>
<td>WGT</td>
<td>Wasabi Growers of Tasmania P/L</td>
</tr>
<tr>
<td>DED</td>
<td>Department of Economic Development (Tasmania)</td>
</tr>
<tr>
<td>MVEC</td>
<td>Meander Valley Enterprise Centre</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>TAFE</td>
<td>Tasmanian Institute of Technical and Further Education</td>
</tr>
<tr>
<td>MOU</td>
<td>Memorandum of Understanding</td>
</tr>
<tr>
<td>PhD</td>
<td>Doctorate of Philosophy</td>
</tr>
<tr>
<td>APVMA</td>
<td>Australian Pesticides and Veterinary Medicines Authority</td>
</tr>
</tbody>
</table>
Executive Summary

What this report is about

This report details the development of the Tasmanian wasabi industry since 2005 and focuses on priority research areas identified by the industry in April 2005. In the last 5 years, the immediate focus for Tasmanian growers has shifted from supplementing the Japanese market to replacement of imported wasabi products in Australia and the development of value-added wasabi products previously unknown to the Australian food industry. The report provides information on access to planting stock, crop protection strategies and grower communication networks.

Who this report is targeted at

The report targets current and potential growers of wasabi, researchers in Asian vegetables, plant propagation businesses and investors in specialty horticultural crops.

Background

Wasabi (Wasabia japonica Matsumara) is a perennial herb belonging to the Brassica family of plants, which includes broccoli, cabbage and mustards. The plant is a cool climate species native to Japan and is used to prepare a hot, pungent condiment served with traditional Japanese dishes such as sushi, sashimi and soba noodles. Ready-to-use wasabi pastes are also popular in the catering industry and dried powder made from stems and leaves is used to flavour foods ranging from rice crackers to ice cream. Wasabi is a high-value crop suited to small-scale production and was introduced to Tasmania in 1992 to assess its potential as a niche horticultural crop with the aim of supplementing supplies of fresh wasabi on the Japanese market.

Three prior RIRDC funded R&D projects have assisted the development of a wasabi industry in Tasmania and the first soil-cultivated crop was market-tested in 2000. These early research and development projects investigated production methods and varieties suited to Australian conditions and resulted in yields of 10 t/ha of soil-cultivated wasabi stem being produced in Tasmania in 2000. The product was highly acclaimed on the Australian market and sales of fresh stems ($110/kg) to restaurants in Sydney, Melbourne and Hobart have continued. Consumer driven changes initiated the development of production methodology for water-cultivated wasabi farms in Tasmania during 2003/04. Demand for wasabi products on the domestic market quickly exceeded expectations, but supply was limited by the small area under production.

New markets that use fresh leaves and a range of value-added products have been developed in Tasmania and have extended the options for the use of wasabi by Australian consumers. In December 2007 there were approximately 20 growers in Australia, the majority being located in Tasmania where climatic conditions favour the growth of high quality fresh wasabi products.

Expansion of the area under production has been constrained by lack of planting stock. Earlier research demonstrated that tissue-cultured planting stock provides the benefits of plant integrity and low disease status not available from seed lines. Dependence on imported stocks increases risk for new growers as quarantine requirements and minimum order size must be satisfied and imported plants are previously untested in Australian conditions. Seed and vegetative parts of several wasabi varieties that had been collected during the course of earlier R&D projects were used in variety trials conducted for this project.

Fungal diseases are the biggest threat to wasabi crop yields, so the demonstration of disease management practices that protect plants from fungal infection in field conditions and cause minimal environmental impact were included in this project.
Aims/Objectives

At the commencement of the project, three objectives were identified that would have a direct impact on primary producers of wasabi. A fourth objective was added in the closing stages of the project with the aim of taking the industry to a stage of development beyond that of a secondary interest. The major constraint to growth and development of the industry is the quantity of fresh product available, which is directly related to the area currently under production. The small size of existing plantings is largely due to lack of experience with techniques for growing wasabi, perceived risk involved in producing a crop for which the market is largely untested and the long lead time to obtain planting stock. The project aimed to address these issues by:

1. Assisting an Australian laboratory to produce commercial quantities of tissue-cultured wasabi planting stock
2. Improving product quality through disease management, water-culture and additional varieties
3. Building the networking capacity of the wasabi grower group
4. Assisting with the development of a Strategic Plan for the industry.

Beneficiaries of this research

The initial beneficiaries of this research will be primary producers as the work forms part of the foundation of primary production methodology for wasabi in Australia. A long-term benefit of the research will be economic growth, particularly for (but not exclusive to) Tasmania, as it will initiate the development of associated industries such as plant propagation facilities and manufacturing of processed food. Retailers of fine food products and consumers will ultimately benefit from the research, as growers are able to guarantee a sustainable supply to each of the market segments identified. Investors in niche horticultural production will benefit from the industry snapshot appended to this report.

Methods

Tissue-culture propagation of wasabi in Australia

The development of protocols for micro propagation (tissue-culture) of Australian wasabi selections was conducted as a collaborative project between Department of Primary Industries and Water, Tasmania and Central Queensland University (CQU) Plant Sciences Division. DPIW Tasmania provided mother plants for this research project and CQU research scientists documented methods for micro propagation of wasabi.

Product quality improvements

Field trials were conducted to test 10 varietal lines of wasabi. Plants were established in both soil and water-cultivated systems and plant performance tested by harvesting a sample of each variety at 3-monthly intervals over the 2-year growth cycle to assess plant performance. An evaluation of stem quality was conducted following the final harvest in October 2006.

Development of fungal protection strategies involved transferring information gained in earlier glasshouse trials to field conditions. For both water-cultivated and soil-cultivated wasabi this involved application of fungidal drenches to plantlets pre-planting and following up with protective fungicides during the summer infection period. Sample plants for each treatment were harvested at 3-monthly intervals over the 2-year growth cycle to assess disease status. These trials were undertaken in consultation with Wasabi Growers of Tasmania and were conducted on their commercial farm sites.

Wasabi Grower Network

A number of initiatives were undertaken by the Tasmanian Departments of Primary Industries & Water and Economic Development, as well as individual wasabi growers, to develop the networking capacity of the wasabi grower group for the purpose of confirming a niche rural industry in Tasmania. Workshops and public field days were conducted and a series of meetings were held to develop a suitable business model for the industry.
Industry Strategic Plan
An industry audit conducted in January 2008 was followed by workshops held in February 2008 and attended by industry participants. At the conclusion of the project the audit results and workshop outcomes were documented as a snapshot of the current status of the Tasmanian wasabi industry.

Key findings

Tissue-culture propagation outcomes
Further research is needed to bring the quality of wasabi plants micro propagated in Australia up to the standard of stocks imported from Japan. In particular, the refinement of sterilisation techniques is vital to ensuring the viability of micropropagated wasabi plants following their removal from the sterile propagation environment, as decontamination procedures remain unresolved.

Crop quality improvement
The choice of variety to be grown is determined by the type of product that is to be marketed. At present there are markets for fresh, dried and processed stems, fresh and dried leaves, and fresh leaf stalks. For the fresh stem market, size, colour, texture and flavour are important. These products can attract a premium price. For the fresh leaf market, leaves must meet strict size standards and have no imperfections. Such leaves are usually only produced in spring. For value-added products, such as processed wasabi stems, pickles, dressing and dried wasabi powder, the crop can be harvested at any time of the year and a small amount of imperfection is tolerated.

Treatment with Thiram® (Tetramethylthiuram disulfate) pre-planting appears to offer some protection from fungal infection for soil-grown wasabi. Even lower levels of infection were found when this treatment was followed up with fortnightly Kocide® (Copper Hydroxide) sprays during the summer months.

Networking
Whilst the majority of Tasmanian wasabi growers are fully employed in other disciplines, improving the wasabi grower’s network resulted in agreement among growers to coordinate their planting and harvesting schedules. As wasabi production in Australia is likely to continue to be a niche industry, there are significant benefits to increased collaboration among growers and this has been demonstrated by the communication network that exists as a consequence of this project.

Strategic Plan Development
In the final three months of this project the Tasmanian Institute of Agricultural Research conducted an industry audit and workshops to engage both growers and other supply chain members in the development of a strategic plan for the wasabi industry. The work was supported by Tasmanian Departments of Primary Industries & Water and Economic Development. However following the first of 2 proposed workshops, the grower group considered that they had not achieved the level of production necessary to effectively engage in consultation with other members of the supply chain and the discussion process was concluded.

Implications
Industry
The project outlines both the potential for success and a number of the shortfalls to be overcome for the establishment of a sustainable wasabi industry in Australia. Access to planting stock is a primary area for research and development. Until such time as adequate techniques for producing tissue-cultured planting stock have been achieved, growers and researchers should continue to import new varieties for testing in Australia while simultaneously fine-tuning techniques for vegetative propagation.

The majority of growers have focused production on soil-cultivated wasabi in preference to water-cultivated wasabi as it has fewer risks associated with production and allows for larger areas to be
established in a greater number of locations. An exciting alternative is hydroponic production of wasabi that commenced recently in Tasmania. However the superiority of this technique over soil-cultivation in terms of quality and economic viability has yet to be proven. The new variety ‘Green Thumb’ is recognised as a valuable asset to the Tasmanian wasabi gene pool and growers are encouraged to keep open the communication channels established with Japanese plant breeders to ensure that the most recently developed varieties continue to be accessible to Tasmanian producers.

Crop protection strategies have been improved as a result of this research and both growers and researchers should continue to test new protection strategies that have proven to be successful in related crops.

Communities
One unmeasured attribute of rural communities is the value that networking has in building a new industry. A field day held during the course of this project attracted over 60 attendants and resulted in more growers joining the industry, a greater range of value-added products being developed and further recognition by judges and connoisseurs of wasabi as a valuable addition to Tasmania’s range of fine foods. The project’s Principal Investigator notes: ‘I receive many calls and emails from people saying “I want wasabi, where can I get it?” That tells me that the demand is growing.’

Communities that are most likely to benefit from establishing wasabi farms and primary processing facilities for wasabi products are those in northern Tasmania, specifically the Meander and Fingal Valleys previously recognised for production of fat lambs and dairying. The Eastern Highlands of Tasmania have produced the best quality crops due to their cool summer temperatures and isolation from other Brassica vegetable crops.

Policy makers
It is the best interest of Tasmanian State Government Departments of Primary Industries and Economic Development and researchers at Tasmanian Institute of Agricultural Research to continue to invest in the future of this niche industry as one which explores new opportunities to generate wealth, and to build on Tasmania’s recognised success as a producer of fine foods which is largely attributable to its cool climate.

Recommendations
The following recommendations are targeted at research providers working in close association with government authorities and commercial producers of wasabi crops:

1 Ensure sustainable access to high quality planting stock
Continue to develop the relationship with the Japanese suppliers to maintain access to new varieties; refine techniques for vegetative propagation to produce commercial quantities of proven varieties.

2 Continue testing new varieties in both soil and hydroponic systems
These two systems are sufficiently different that future varietal testing should be conducted using both media to ensure that optimum flavour and colour parameters are obtained in either system.

3 Maintain communication among researchers of Asian vegetables
Communication among researchers of Asian vegetables plays a vital role in the development of niche Asian vegetable industries. RIRDC publication ‘Asian Foods newsletter’ and the annual meeting of researchers involved in RIRDC Asian foods projects are valuable communication tools for comparative analyses and help prevent the duplication of research.

4 Conduct on-farm efficacy trials for new crop protectants
Growers and researchers of Asian vegetables must continue to develop and improve new integrated pest management systems and the use of agricultural chemicals. Trials are best conducted on growers’ properties which provide environmental conditions suitable to this species and the opportunity to conduct collaborative research projects that involve wasabi industry representatives and research institutions.
5 Strengthen links in value-chain for the wasabi industry

While most Tasmanian wasabi growers are in the early stages of business development there remains some hesitation to attracting significant capital investment from an external source. Based on feedback from growers in February 2008, it was concluded that the process of developing a strategic plan for the wasabi industry should be repeated in three to five years time when production capacity had improved.
1 Introduction

Wasabi (*Wasabia japonica* Matsumara) is a perennial herb belonging to the Brassica family of plants, which includes broccoli, cabbage and mustards. The plant grows naturally in the shade of deciduous trees, alongside mountain streams in the highlands of Japan.

In 1992, wasabi was identified as a high-value crop suited to grow in Tasmania with the aim of supplementing the Japanese market. Early research and development projects resulted in yields of 10 t/ha of soil-cultivated wasabi stem being produced in Tasmania in 2000. The product was highly acclaimed on the Australian market and sales of fresh stems ($110/kg) to restaurants in Sydney, Melbourne and Hobart have continued. Demand continued to grow, but supply was limited by the small area under production. The immediate focus for Tasmanian growers has shifted from the Japanese market to replacement of imported wasabi products in Australia, Indonesia, and Malaysia.

![Figure 1](image1.png) **Tasmanian value-added wasabi products**

Wasabi paste is prepared by grating the fresh stem of the wasabi plant to form a hot, pungent condiment served with traditional Japanese dishes such as sushi, sashimi and soba noodles. Ready-to-use wasabi pastes are also popular in the catering industry and dried powder made from stems and leaves is used to flavour foods ranging from rice crackers to ice cream.

New markets that use fresh leaves and a range of value-added products have been developed in Tasmania and have extended the options for the use of wasabi by Australian consumers.

The involvement of new growers has been slowed by difficulties in accessing disease-free planting stock. Using mother plants selected from trials in Tasmania, several laboratories had attempted tissue-culture propagation of wasabi, but decontamination procedures proved difficult for this species. In 2003/04, the newly formed company ‘Wasabi Growers of Tasmania P/L’ imported 25,000 tissue-culture wasabi plants from Japanese stocks, but the logistics of transporting bare-rooted plants to Tasmania from international sources carries high risks.

In April 2005, a workshop attended by 20 current and potential growers was held and research and development priorities for the developing wasabi industry identified. These were to:

- diversify the range of varieties available
- access tissue-cultured stocks from Australian suppliers
- combat disease symptoms, and
- foster good communication networks with growers entering the industry.

A project was subsequently developed around these priorities, and this report details the results of that project.
2 Objectives

At the commencement of the project there were 3 main objectives, with a 4th objective being added in November 2007 and the project extended to March 2008. These objectives are outlined below:

1. **To assist an Australian laboratory to produce commercial quantities of tissue-cultured wasabi planting stock**

   It has been difficult for new growers interested in joining the industry to access disease-free planting stock. Using mother plants selected from trials in Tasmania, several laboratories have attempted tissue-culture propagation of wasabi, but decontamination procedures have proved difficult. In 2003/04, the newly formed company ‘Wasabi Growers of Tasmania P/L’ imported 25,000 tissue-culture wasabi plants from Japanese stocks, but the logistics of transporting bare-rooted plants to Tasmania from international sources carries high risks and an alternative source of planting stock produced in Australia was highly desirable.

2. **Improve product quality through disease management, water-culture and additional varieties**

   Product quality in Tasmanian crops had been compromised by the incidence of fungal disease symptoms causing black lesions in stem tissue. Traditionally, wasabi farms in Japan have used the fungicide Benlate® to control major fungal infections of wasabi. As this product is no longer registered for use in Australia, alternative control measures were necessary. Tasmanian research had previously identified strategies that may assist in the control of fungal infection and have minimal impact on the environment. These include the use of tissue-cultured planting stock (minimises risk of inherent infection common in seed stock) and application of a fungal drench prior to planting. These applications are particularly important for water-cultivated systems of wasabi production in which large volumes of water flow through gravel-based wasabi beds before returning to a natural stream. During this project protection strategies that had proved effective in pot trials were tested in field conditions.

   In addition, growers were keen to reduce the genetic vulnerability of the Tasmanian wasabi planting stock for future crops by expanding the number of varietal lines of wasabi available in Tasmania. To this end, 10 varietal lines were tested to assess their performance in Tasmanian field conditions. The variety trial was duplicated in both water and soil-cultivation systems.

3. **Build the networking capacity of the wasabi grower group**

   There is great value in providing the opportunity for growers to meet and discuss challenges such as supply of raw materials, modification of agronomic practices, inclement weather conditions and unexpected pests incursions. Mutual understanding and a willingness to share information are required to build a network of wasabi growers across southern Australia. This project has provided opportunities for growers to interact both socially and professionally on wasabi related issues. Wasabi growers recognise the benefits of working as a cohesive group to satisfy market demand by maintaining product quality and developing an integrated crop establishment and harvesting schedule.

4. **Develop a Strategic Plan for the industry**

   In November 2007 approval was granted by RIRDC to extend the project for the purpose of developing a strategic plan for wasabi industry. The Strategic Plan aimed to provide direction and focus for existing growers and prospective investors by conducting:
   - an internal analysis of the wasabi grower group (strengths and weaknesses, financial performance, people, operational limitations and current positioning in the market)
an external analysis of industry potential (competitors, market opportunities and threats, changing technology, regulatory and legislative concerns, market trends)

development of a purpose statement
goal setting
defining objectives to support the goals, and,
development of strategies to achieve the goals and a commitment to implementing the plan.

Whilst the Tasmanian grower group has established a good relationship with the Victorian growers, the Industry Strategic Plan focused on the Tasmanian industry where the majority of wasabi related businesses have been established and production potential is highest.
3. **Methodology**

3.1 **Tissue-culture propagation of wasabi in Australia**

The development of protocols for micropropagation (tissue-culture) of Australian wasabi selections was conducted as a collaborative project between DPIW Tasmania and Plant Sciences Division, Central Queensland University. DPIW Tasmania provided mother plants of 9 selected varietal lines from the collections housed at DPIW Mt Pleasant Laboratories in Launceston, Tasmania. The wasabi varietal collection began in 1999 and germplasm had been maintained by propagating vegetative splits at 2-year intervals. Details of the methods used by CQU research scientists for micropropagation of wasabi appear in Appendix 1.

3.2 **Quality improvements for wasabi**

The field trials for this project were conducted by DPIW in consultation with Wasabi Growers of Tasmania P/L and affiliated growers and were located at 4 sites in the central north of Tasmania.

3.2.1 **Testing new varieties**

Variatel lines of wasabi plants were sourced from wasabi stem and seed material that had been collected from Japan, USA and Victoria by DPIW and WGT over the previous 5 years. The plants were housed in glasshouse facilities at DPIW’s Mt Pleasant Laboratories and in 2005 were vegetatively propagated to produce 50 individuals of each of 8 varietal lines. Two newly bred varieties were added to the trial, and 50 individuals of each of these were imported from Japan specifically for the variety trial, bringing the total to 10 varietal lines tested (Table 1). In January 2006, following a 3-month hardening off period, plants were established in duplicate trials that used either a soil or water-cultivation system. The trial sites were located side by side at Mole Creek in Tasmania’s central north. Plant performance was tested by harvesting 3 plants of each variety at 3-monthly intervals to assess plant morphology (% component parts), biomass (kg/ha) and disease status (% tissue area displaying symptoms of infection).

![Figure 2 On-site data collection](image)
Table 1  Varietal lines used in field trials

<table>
<thead>
<tr>
<th>VARIETAL LINE No.</th>
<th>VARIETY NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Daruma W7*</td>
</tr>
<tr>
<td>2</td>
<td>Daruma FS 1*</td>
</tr>
<tr>
<td>3</td>
<td>Daruma FS2*</td>
</tr>
<tr>
<td>4</td>
<td>Green Thumb</td>
</tr>
<tr>
<td>5</td>
<td>Kyoto 980</td>
</tr>
<tr>
<td>6</td>
<td>Masamidori</td>
</tr>
<tr>
<td>7</td>
<td>Mazuma</td>
</tr>
<tr>
<td>8</td>
<td>Mazuma x Daruma</td>
</tr>
<tr>
<td>9</td>
<td>Midori</td>
</tr>
<tr>
<td>10</td>
<td>Top Taste</td>
</tr>
</tbody>
</table>

*Variatel lines 1-3 were selected on the basis of superior performance from original ‘Daruma’ seed stock.

Following the final harvest, a panel of 10 people conducted an independent taste assessment of the mature stems. A single stem sample of each of the 10 varieties grown in either soil or water was randomly placed around the tasting table and panellists scored each freshly grated stem on the basis of colour, appearance, heat, sweetness and texture (Table 2). After collation of the results, scores for each parameter were added together to give a final quality ranking for each of the 20 stems. The results of the variety trial are discussed in Section 4.2.1.

Table 2  Quality parameters for mature wasabi stems

<table>
<thead>
<tr>
<th>Score</th>
<th>Colour</th>
<th>Appearance</th>
<th>Heat</th>
<th>Sweetness</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Off</td>
<td>watery</td>
<td>nil</td>
<td>bitter</td>
<td>fibrous</td>
</tr>
<tr>
<td>1</td>
<td>dull/some black</td>
<td>grainy/fibrous</td>
<td>detectable</td>
<td>detectable</td>
<td>sandy</td>
</tr>
<tr>
<td>2</td>
<td>pale green</td>
<td>moldable</td>
<td>good</td>
<td>good</td>
<td>pasty</td>
</tr>
<tr>
<td>3</td>
<td>bright green</td>
<td>sticky</td>
<td>very hot</td>
<td>sweet</td>
<td>smooth</td>
</tr>
</tbody>
</table>

3.2.2  Fungal protection strategies

Information about fungal protection gained in glasshouse trials in 2003-05 was transferred to field conditions for this project. For water-cultivated wasabi, this was conducted on a commercial water-cultivated wasabi farm. Table 2 gives details of the treatments used. Three-month old plants raised in potting mix were soaked for 2 hours in a solution of 1g/L Thiram®. The seedling trays were then allowed to drain prior to planting in field conditions. Similarly, for treatments involving a pre-planting drench in Kocide®, plants in seedling trays were soaked in a solution of 2g/L KOCIDE® and allowed to drain before planting. For treatments 4 and 5 (see Table 3) the drench was followed up with application of a protective fungicide (2g/L KOCIDE®) during the summer infection periods in each year. Treatment conditions were replicated at 2 soil-cultivated wasabi farms in north central Tasmania. At each of the 3 sites, treatments were applied to each of 20 replicates. Three plants from each
treatment were harvested at 3-monthly intervals over the 14-month growing period to assess disease status (% area of stem tissue displaying symptoms of fungal infection). Figure 3 shows plants in the trial site that are half-way to maturity. The results of the fungicide trial are discussed in Section 4.2.2.

Table 3  Fungicide treatment summary

<table>
<thead>
<tr>
<th>TREATMENT No.</th>
<th>TREATMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Untreated</td>
</tr>
<tr>
<td>2</td>
<td>THIRAM® drench 7 days pre-planting</td>
</tr>
<tr>
<td>3</td>
<td>KOCIDE® drench pre-planting</td>
</tr>
<tr>
<td>4</td>
<td>THIRAM® drench pre-planting + foliar copper sprays at 14-day intervals Oct-Apr</td>
</tr>
<tr>
<td>5</td>
<td>KOCIDE® drench pre-planting + foliar copper sprays at 14-day intervals Oct-Apr</td>
</tr>
</tbody>
</table>

1 THIRAM® Active Constituent 800g/kg Thiram  
2 Active Constituent 400g/kg Copper present as Cupric Hydroxide

(a) Water-grown Mole Creek  (b) Soil-grown Westbury  (c) Soil-grown Mayberry

Figure 3  Fungicide trial plants at 3 sites - crop half–way to maturity

3.3  Wasabi Grower Network

During the course of this project, a number of initiatives were undertaken by the Tasmanian Departments of Primary Industries & Water and Economic Development, as well as individual wasabi growers, to develop the networking capacity of the wasabi grower group with a view to establishing a niche rural industry in Tasmania.

Initial meetings between Wasabi Growers of Tasmania P/L, Department of Economic Development and DPIWE had begun in November 2004 and continued throughout 2005. As the wasabi grower group began to expand in 2006, workshops and field days were included on the calendar and a series of meetings was held to develop a suitable business model for the industry. As the majority of Tasmanian wasabi growers are fully employed in other disciplines, some individuals were not able to attend all the meetings. However, the wasabi grower group generally showed consistent commitment throughout the course of the 2-year project. A calendar of events for the wasabi grower network is included in Section 4.3.
4. Detailed Results

4.1 Tissue-culture propagation of wasabi in Australia

Research for the establishment of in vitro techniques for propagating selected clones of wasabi (Wasabia japonica) was conducted by research scientists from Central Queensland University. The research report detailed in Appendix 1 includes the following: 1. Literature review; 2. Procurement of mother plants; 3. Disinfection; 4. Selection of suitable explants for multiplication; 5. Rapid multiplication in tissue culture; 6. Induction of roots from tissue-cultured plants; 7. Optimising nutrient concentrations to induce rooting in variety ‘Mazuma’; 8. Induction of somatic embryos in wasabi; 9. Recording response to light and temperature of hardened seedlings of wasabi.

The outcome of this collaborative research project was that in March 2007, a commercial shipment of 2,500 pieces of tissue-cultured wasabi sourced from Tasmanian mother stock was imported to Tasmania by a new wasabi production enterprise.

As a consequence of this project, CQU Plant Sciences Division enrolled a PhD candidate in March 2007, to investigate decontamination procedures and nutritional requirements of wasabi in vitro. The post-graduate student has kept the wasabi grower group up to date with quarterly reports on the progress of her research.

4.2 Quality improvements for wasabi

4.2.1 Variety trials

Varietal lines included 3 ‘Daruma’ selections from earlier Tasmanian grown wasabi field crops and 7 other varietal lines selected on the basis of recommendations from wasabi wholesalers in Japan, and growers in Japan, USA and Victoria, Australia.

Photographic images of top-performing varieties are shown in Figure 4 and images of the variety trial site over the 21-month trial period are shown in Figure 5.

Figure 4 Top performing varietal selections harvested 21 months after planting
Figure 5  Wasabi variety trial pictured at 3 growth stages
The performance of each variety is depicted in figure 6a-d and provides a useful assessment of yield of component parts of the wasabi plant.

The data indicates that soil-grown wasabi stems reach a mature weight of 50g after 12 months and then the size of the stems remain steady as the plant matures. However, water-grown wasabi grows more slowly to attain an average weight of 50g when the plant is fully mature 21-24 months.

The author notes that the rate of growth of water-grown wasabi early in the season may have been unduly influenced by an unexpected pest species i.e. the local platypus resident in the nearby stream. Until the animal was securely fenced out, it would frequently visit the trial site and uproot all of the plants looking for worms beneath the plants. The plants proceeded to grow normally once the site was made secure.

Whilst the data suggests that soil-grown wasabi may be ready for harvest after only 12 months due to the rapid growth of the primary stems, experience indicates that the flavour components of wasabi become more strongly developed as the plant matures. The author also
notes also that at this site, soil growing conditions were compromised by poor drainage and suggests that plant size reached a plateau at 12 months. If the site had been better drained, the plants probably would have continued to grow with main stems achieving average weights of 100g at 24 months. Table 5 shows an extract of harvest data collected in July 2007 from a different farm site with excellent drainage in north-west Tasmania (See Table 4).

Table 4  Harvest data from tasmanian wasabi farm

<table>
<thead>
<tr>
<th>QUADRAT SAMPLED</th>
<th>TOTAL PLANT WEIGHT (kg)</th>
<th>NUMBER OF PLANTS</th>
<th>STEMS LARGER THAN 60g (kg)</th>
<th>NUMBER OF STEMS LARGER THAN 60g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.900</td>
<td>5</td>
<td>0.909</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>3.600</td>
<td>6.5</td>
<td>1.025</td>
<td>9</td>
</tr>
<tr>
<td>Average/m²</td>
<td>4.250</td>
<td>5.75</td>
<td>0.967</td>
<td>9</td>
</tr>
</tbody>
</table>

It should be noted that in August 2007 ‘Wasabi Growers of Tasmania’ harvested fresh stems from a further site in the north-east highlands of Tasmania and reported double the yield for a production site of similar size to that assessed in Table 4, they attributed the greater yield mostly to lack of disease symptoms. The higher yielding location is characteristically cool with air and soil temperatures generally 5°C lower than at the site in the north-west of the state.

Yield alone is not a sufficient measure of the likely return from a wasabi crop. The taste of the mature stems varies considerably according to the variety and the growing medium as seen in Table 5. This table shows comparison of the quality parameters of each variety determined by a panel of taste testers at the conclusion of the variety trial when plants were 21 months old. Table 5 shows that the majority of varieties scored better when grown in water rather than soil medium.
Table 5  Quality parameters for 10 wasabi varieties

<table>
<thead>
<tr>
<th>VARIETY</th>
<th>GROWING MEDIUM</th>
<th>COLOUR</th>
<th>APPEARANCE</th>
<th>HEAT</th>
<th>SWEETNESS</th>
<th>TEXTURE</th>
<th>TOTAL/15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midori</td>
<td>Water</td>
<td>2.6</td>
<td>2.3</td>
<td>2.9</td>
<td>2.4</td>
<td>2.2</td>
<td>12.4</td>
</tr>
<tr>
<td>W 7</td>
<td>Water</td>
<td>2.6</td>
<td>2</td>
<td>2.4</td>
<td>1.7</td>
<td>2.3</td>
<td>11.0</td>
</tr>
<tr>
<td>Top Taste</td>
<td>Water</td>
<td>2.7</td>
<td>2.2</td>
<td>2.2</td>
<td>1.6</td>
<td>2.2</td>
<td>10.9</td>
</tr>
<tr>
<td>Mazuma x Daruma</td>
<td>Soil</td>
<td>2.6</td>
<td>2</td>
<td>1.9</td>
<td>1.9</td>
<td>2</td>
<td>10.4</td>
</tr>
<tr>
<td>Mazuma x Daruma</td>
<td>Water</td>
<td>2.3</td>
<td>1.8</td>
<td>2.9</td>
<td>1.9</td>
<td>1.4</td>
<td>10.3</td>
</tr>
<tr>
<td>Green Thumb</td>
<td>Water</td>
<td>2.5</td>
<td>2.4</td>
<td>1.6</td>
<td>1.4</td>
<td>2.2</td>
<td>10.1</td>
</tr>
<tr>
<td>Kyoto 980</td>
<td>Water</td>
<td>1.5</td>
<td>2.2</td>
<td>2.2</td>
<td>2</td>
<td>2</td>
<td>9.9</td>
</tr>
<tr>
<td>W 7</td>
<td>Soil</td>
<td>1.9</td>
<td>1.9</td>
<td>2.2</td>
<td>1.7</td>
<td>2</td>
<td>9.7</td>
</tr>
<tr>
<td>Mazuma</td>
<td>Water</td>
<td>1.3</td>
<td>2</td>
<td>2.5</td>
<td>1.3</td>
<td>2.3</td>
<td>9.4</td>
</tr>
<tr>
<td>FS 1</td>
<td>Water</td>
<td>2.3</td>
<td>1.3</td>
<td>1.7</td>
<td>1.9</td>
<td>1.6</td>
<td>8.8</td>
</tr>
<tr>
<td>FS 2</td>
<td>Water</td>
<td>2.5</td>
<td>1.1</td>
<td>1.6</td>
<td>1.6</td>
<td>1.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Kyoto 980</td>
<td>Soil</td>
<td>1.2</td>
<td>1.6</td>
<td>1.8</td>
<td>1.5</td>
<td>1.9</td>
<td>8.0</td>
</tr>
<tr>
<td>FS 1</td>
<td>Soil</td>
<td>1.4</td>
<td>1.8</td>
<td>1.6</td>
<td>1.3</td>
<td>1.3</td>
<td>7.4</td>
</tr>
<tr>
<td>Green Thumb</td>
<td>Soil</td>
<td>1.9</td>
<td>1.2</td>
<td>1.2</td>
<td>1.5</td>
<td>1.5</td>
<td>7.3</td>
</tr>
<tr>
<td>Masamidori</td>
<td>Water</td>
<td>1.4</td>
<td>1.2</td>
<td>1.9</td>
<td>1.1</td>
<td>1.5</td>
<td>7.1</td>
</tr>
<tr>
<td>Masamidori</td>
<td>Soil</td>
<td>1.4</td>
<td>1.5</td>
<td>1.3</td>
<td>0.7</td>
<td>1.4</td>
<td>6.3</td>
</tr>
<tr>
<td>FS 2</td>
<td>Soil</td>
<td>1.1</td>
<td>1.7</td>
<td>1.4</td>
<td>0.9</td>
<td>1.1</td>
<td>6.2</td>
</tr>
<tr>
<td>Midori</td>
<td>Soil</td>
<td>1.5</td>
<td>1.2</td>
<td>1.3</td>
<td>0.9</td>
<td>1.1</td>
<td>6.0</td>
</tr>
<tr>
<td>Mazuma</td>
<td>Soil</td>
<td>1.8</td>
<td>1.1</td>
<td>0.9</td>
<td>1</td>
<td>0.9</td>
<td>5.7</td>
</tr>
<tr>
<td>Top Taste</td>
<td>Soil</td>
<td>1.1</td>
<td>1.2</td>
<td>0.6</td>
<td>0.4</td>
<td>0.9</td>
<td>4.2</td>
</tr>
</tbody>
</table>

* Highest possible score = 15

In addition to the stem of wasabi plants, Tasmanian growers have identified markets for both leaf stalks (pickles) and the leaf blade (served fresh as a garnish) see Figure 14.
Data collected on the development of these plant components is shown in Figures 8 a-d.

![Figure 8 a](image_url) Leaf stalk weight of water-grown crops

![Figure 8 b](image_url) Leaf stalk weight of soil-grown crops

![Figure 8 c](image_url) Leaf blade weight of water-grown crops

![Figure 8 d](image_url) Leaf blade weight of soil-grown crops

**Figure 8**  Growth of component parts of wasabi

Of particular note from these figures is the excellent performance of variety ‘Green Thumb’. This variety is new to Tasmania, being introduced to commercial Tasmanian wasabi farms in August 2007. Once again, the data overall indicate a poorer performance from soil-grown wasabi than from water-grown plants.

4.2.2 Fungicide trials

Pot trials conducted from 2002-05 for the RIRDC project (DAT-39A Production and marketing of Tasmanian wasabi) identified *Rhizoctonia* and *Phoma* as the major causal organisms of black stem lesions in stems of mature wasabi plants. Those trials demonstrated that Thiram® and Kocide® were the most effective chemical protectants registered for use on *Brassicas* at that time. Using this information, the current project sought to repeat the treatments in field conditions to see if these chemicals afforded the same protection there. Results of the fungicide trial conducted at 3 sites in northern Tasmania have been presented in Figures 9 and 10. These figures show the yield of main stems and the incidence of black stem lesions for each treatment.
The data indicates that the yield of the whole wasabi plant, including the main stem, is largely unaffected by fungal infection. Once again, the data show that most growth occurs in the first 12 months of the growth cycle.

Figure 9 a-c  Growth of main stem of wasabi at 3 field sites in Northern Tasmania

Figure 10 a-c  Incidence of black stem lesions in wasabi at 3 field sites in northern Tasmania

Figure 10 indicates that at the 12 month growth stage, wasabi plants show the highest incidence of black lesions. For sites 1 and 2, these data were collected in July, when air and soil temperatures are low. For site 3, data was collected in October, following the flush of growth that is a characteristic response of wasabi to lengthening days.

The final harvest for this trial was made in October 2007 at the conclusion of the field trial component of the project. Figure 11 shows the effectiveness of treating wasabi plants with Thiram® pre-planting and following this with fortnightly applications of copper fungicide (Kocide®) during the summer infection period (October - March).
Figures 11 a & b: Site 1: Water-grown wasabi Mole Creek

Figures 11 c& d: Site 3: Soil-grown wasabi Mayberry

**Figure 11 a-d**  Effect of fungicide treatment on wasabi stems

Recommendations for crop protection strategies suited to Tasmanian wasabi farms has been summarised in a 2-page flyer for circulation to the public and is appended to this report as Appendix 2.

### 4.3 Wasabi Grower Network

During the course of this project, the number of sites growing wasabi in Tasmania has increased to a total of 10 localities in northern Tasmania, with one remaining at the south end of the central highlands. Four new wasabi related businesses have been registered in Tasmania as a result of the developing industry.

Wasabi Growers of Tasmania P/L (WGT) has been instrumental in developing a grower network by taking the role of importers of high quality planting stock, providing agronomic advice to growers and guaranteeing a market for fresh wasabi products. The rapport developed among the Tasmanian wasabi growers is based on a common goal - to see yet another niche industry of quality agricultural products develop in Tasmania.

Table 6 outlines the events held during the course of this project which have helped the wasabi grower network to evolve and new industry leaders emerge.
<table>
<thead>
<tr>
<th>DATE</th>
<th>FORMAT</th>
<th>OBJECTIVE</th>
<th>OUTCOME</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 January 2006</td>
<td>Meeting of DED, DPIW, independent growers (40% industry)</td>
<td>Define components of wasabi industry</td>
<td>Preparation of draft MOU by DED</td>
</tr>
<tr>
<td>11 May 2006</td>
<td>Meeting of DED, DPIW, growers (30% industry)</td>
<td>Sign MOU</td>
<td>Commitment to work together to progress industry</td>
</tr>
<tr>
<td>6 June 2006</td>
<td>Public field day at property of independent grower</td>
<td>Demonstrate field culture of soil grown wasabi</td>
<td>63 people in attendance; local newspaper coverage; confirm plans to double production area</td>
</tr>
<tr>
<td>14 August 2006</td>
<td>DED, DPIW, WGT growers (70% industry)</td>
<td>To assess growers interest in developing industry</td>
<td>WGT P/L to present their business plan</td>
</tr>
<tr>
<td>27 September</td>
<td>DPIW, TAFE, MOU signatories</td>
<td>To develop training module in small business planning for wasabi growers</td>
<td>Wasabi growers to participate in TAFE training workshops in 2007</td>
</tr>
<tr>
<td>16 October 2006</td>
<td>Meeting of, DPIW, MOU signatories, private business consultant (TAFE contact)</td>
<td>To engage a consultant to prepare an industry strategic plan and business plan</td>
<td>Consultant found to be unsuitable; TAFE training option abandoned</td>
</tr>
<tr>
<td>9-17 November 2006</td>
<td>Visit from Japanese wasabi consultant</td>
<td>To confirm growing methodology</td>
<td>Soil cultivation of wasabi to expand; water-cultivation in gravel beds abandoned; value-added products developed</td>
</tr>
<tr>
<td>15 March 2007</td>
<td>MVEC, DPIW, independent hazel nut and wasabi growers (90% wasabi industry)</td>
<td>Business Planning for 2 niche horticultural industries</td>
<td>Follow-up meeting to discuss business models</td>
</tr>
<tr>
<td>28 March 2007</td>
<td>DPIW, wasabi growers (90% industry), wasabi PhD candidate</td>
<td>Growers compare notes on crop development; meet PhD candidate</td>
<td>Growers exchange contact details and initiate newsletter</td>
</tr>
<tr>
<td>5 May 2007</td>
<td>MVEC, DPIW, wasabi growers (50% industry)</td>
<td>Discussion of business model options</td>
<td>Growers agree on preferred business model</td>
</tr>
<tr>
<td>Date</td>
<td>Location</td>
<td>Participants</td>
<td>Event Description</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------</td>
<td>----------------------</td>
<td>------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>9 June 2007</td>
<td>MVEC, DPIW, wasabi</td>
<td>50% industry</td>
<td>To discuss entry of other growers to existing company WGT</td>
</tr>
<tr>
<td></td>
<td>growers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 June 2007</td>
<td>‘Arandale wasabi’</td>
<td>host Australian</td>
<td>To demonstrate hydroponic production of wasabi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydroponics &amp; Greenhouse Industry field day</td>
<td></td>
</tr>
<tr>
<td>4 July 2007</td>
<td>MVEC, TIAR, wasabi</td>
<td>50% industry</td>
<td>To clarify role of potential new shareholders in WGT</td>
</tr>
<tr>
<td></td>
<td>growers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 September 2007</td>
<td>MVEC, TIAR, wasabi</td>
<td>30% industry</td>
<td>To identify future wasabi R&amp;D priorities for TIAR</td>
</tr>
<tr>
<td></td>
<td>growers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 October 2007</td>
<td>Wasabi Tasting: TIAR, current growers, intending growers and investors</td>
<td>10 participants-40% industry</td>
<td>To assess quality parameters of wasabi varieties</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 February 2008</td>
<td>Industry planning workshop (9 participants- 50% industry)</td>
<td></td>
<td>To outline procedure for developing industry strategic plan</td>
</tr>
</tbody>
</table>

Abbreviations:

- WGT: Wasabi Growers of Tasmania P/L
- DPIW: Department of Primary Industries and Water (Tasmania)
- TIAR: Tasmanian Institute of Agricultural Research
- DED: Department of Economic Development (Tasmania)
- MVEC: Meander Valley Enterprise Centre
- R&D: Research and Development
- TAFE: Tasmanian Institute of Technical and Further Education
- MOU: Memorandum of Understanding
- PhD: Doctorate of Philosophy
Figures 12 and 13 show photographic images of some of these gatherings.

Figure 12  Field day images June 2006

Figure 13  Visit from Japanese wasabi agronomist November 2006
4.4 Industry Strategic Plan

All industry participants contacted in December 2007 were supportive of the proposal to prepare a Strategic Plan for the wasabi industry. This support was confirmed by way of financial contribution to the process, participation in interviews for auditing purposes or and/or attendance at workshops.

Ten growers participated in the audit, and also a plant propagator and 5 major customers. A summary of the industry audit appears as Appendix 3. The first workshop held to develop the strategic plan included 4 representatives of the grower group, a plant propagation nursery owner, DED Project Officer Food, Manufacturing and ICT, the agricultural business consultant engaged for the purpose of facilitating the workshops, the PI for the project and Vegetable Marketing and Development Officer, TIAR.

Feedback from industry participants following the workshop resulted in the cancellation of the second half-day workshop which aimed to include other members of the value chain. Research and development personnel from Vegetable Centre TIAR subsequently documented a ‘snapshot’ of the wasabi industry which is appended at Appendix 4.
5. Discussion of Results

5.1 Tissue-culture propagation outcomes

During the course of RIRDC projects conducted from 1997-2005, germplasm of different wasabi varieties had been collected from the USA, Japan and wasabi growers at Thornton, in Victoria. In each case, the tissue was propagated under quarantine conditions and later moved to greenhouse facilities at DPIW Mount Pleasant Laboratories, Launceston. Attempts were made by several micropropagation laboratories in Tasmania to propagate wasabi using tissue-culture techniques, but with little lasting success. In May 2005, DPIW was approached by researchers at Plant Sciences Division, Central Queensland University, Rockhampton, for wasabi germplasm to conduct a research project aimed at establishing in vitro culture techniques for propagating selected clones of wasabi. In August 2005 a contract agreement was made between DPIW and Central Queensland University (CQU) for this purpose. In October of the same year, mature plants (3 years old) of 9 varietal lines were collected by the CQU research scientist and air freighted to Rockhampton for use as mother plants for micropropagation (tissue-culture) of wasabi.

In March 2007, 2200 tissue cultured plants were imported to Tasmania from CQU but 8 months later only 390 (18%) of these had survived. Much research is still needed to bring the quality of wasabi plants micropropagated in Australia up to the standard of stocks imported from Japan which normally have a 90% survival rate. In particular, the refinement of sterilisation techniques is vital to ensuring the viability of micropropagated wasabi plants following removal of the plants from culture tubes.

5.2 Field trial outcomes

5.2.1 Varietal choices

The choice of which variety should be grown relates to what type of wasabi product is to be marketed. At present there are markets for fresh, dried and processed stems, fresh and dried leaves, and fresh leaf stalks. For the fresh stem market, size, colour, texture and flavour are important - a premium price can be sought for these products. Similarly, fresh leaves must meet strict size standards and have no imperfections. Such leaves are very common in early spring when there is a fresh flush of growth, but almost impossible to find from late summer through the winter months.

In addition to the stem of wasabi plants, Tasmanian growers have identified markets for both leaf stalks (pickles) and the leaf blade (served fresh as a garnish) as shown in Figure 14.

Figure 14  Wasabi component parts extend the range of pure wasabi products
For value-added products, such as processed wasabi stems, pickles, dressing and dried wasabi powder, the crop can be harvested at any time of the year, as a small amount of imperfection can be tolerated. It is important to recognise that while a single crop can have its component parts directed to each of these market segments at harvest, it is unlikely that a crop that is repeatedly harvested for fresh leaves (leaf blade and/or leaf stalk) will yield stems of high quality due to infection sustained through wound sites made as a consequence of picking the leaves.

The data presented in this report indicates the variety ‘Green Thumb’ is best suited to a market requesting wasabi leaves (fresh or dried) and leaf stalks. The quality parameters of fresh stems of this variety also rated in the top 6 for the water-grown system. Variety ‘Midori’ outclassed the other varieties on fresh stem quality, and yield of leaf blade and stalk components was also high in water-grown systems. However, the data presented in Figure 15 shows that variety ‘Midori’ is highly susceptible to fungal infection causing stem blackened lesions thereby making it unsuitable for the fresh stem market. Variety ‘Midori’ and ‘Green Thumb’ both performed poorly in the soil-grown system but as has been noted previously (Section 3.2) it should be noted that growing conditions at this site were compromised due to poor drainage.

![Stem blackening (water-grown)](image1)

![Stem blackening (soil-grown)](image2)

*data collected in July 2007 when symptoms were most severe

**Figure 15** Incidence of main stem blackening for wasabi varieties grown in either water or soil medium.

### 5.2.2 Fungicide trials

The results shown in Figure 15 indicate that the largest zone of blackened lesions occurs in the stems of plants harvested in July, when air and soil temperatures are low and infection pressure should be minimal. It is possible that fungal infections that occurred in the summer months developed into stem lesions at this growth stage. It is interesting to note that there is an apparent recovery from the incidence of black lesions at the 15-month growth stage for sites 1 and 2. One explanation might be that the rapid growth rate associated with increased day-length at the onset of spring means the plants grow faster than the rate of spread of the infection. However, this is disputed by the fact that at site 3, which was planted 3 months later, plants still show a higher incidence of black lesions at the 12 month growth stage (October 2007).

Treatment with Thiram® pre-planting appears to offer some protection from fungal infection for soil-grown wasabi. When followed up with fortnightly Kocide® sprays during the summer months, wasabi grown at Sites 1 and 3 showed even lower incidence of infection. It is worth noting that the average temperature summer temperature at Site 2 is generally 5°C higher than at sites 1 and 3, so infection pressure is likely to be greater at this location. Kocide® applied pre-planting, or as a pre-planting treatment followed by further foliar applications during the summer, appears to offer less protection than the Thiram® treatments at all 3 sites. The results of the fungicide trials show that there was little disease protection for plants that were treated with a Kocide® dip pre-planting. This is an interesting observation in light of a report by
Savage in 2005, where a pre-treatment of wasabi plants with copper was common practice at a stream fed water-grown wasabi site on the West Coast of New Zealand.

At the commencement of this project, treatment of plants with Thiram® prior to planting was recommended as an effective control measure by incumbent DPIW plant pathologist. This recommendation is supported by work from South Africa (Praetorius 2004) in a paper entitled ‘The potential of plants with antifungal properties on future new crops’. The importance of providing conditions that promote the health of plants in their first few weeks of life was also emphasised in a paper presented at this conference by Louw, where he presented results demonstrating that early protection of seedlings from fungal infection was an effective means of ensuring the quality of plants at later stages of development.

The results of this trial indicate that pre-treating wasabi plants with Thiram® before planting has lasting effects on product quality.

5.3 Networking

In 1994, the Department of Primary Industries & Fisheries asked for expressions of interest from people involved in agricultural crop production to collaborate on a research project to investigate the potential for wasabi production in Tasmania. One of those primary producers has continued to be a reliable participant in three consecutive RIRDC funded projects and has maintained the objective of establishing a wasabi industry in Tasmania.

As wasabi is an unfamiliar crop in Australian cropping systems, primary producers have been cautious to invest in this niche industry. Meanwhile, Asian foods have gained popularity in the market place due to their characteristically low calorie/high flavour and nutritional status. Coincidentally, there have emerged a number of innovative growers, keen to investigate wasabi production as a unique cash crop. In most instances they have been hobby farmers or growers well-established in primary production with a view to investing in product diversity.

In May 2006, a memorandum of Understanding (MOU) was signed between two wasabi producing business entities and one independent collaborator within the wasabi grower group. Client Manager, Programs and Enterprise Improvement Division, Department of Economic Development (DED), and wasabi horticulturalist from Department of Primary Industries, Water and Environment (DPIWE) witnessed the occasion. The MOU was a formal acknowledgment of goodwill of the growers and their willingness to work cooperatively together to develop the wasabi industry.

In June 2006, a field day was held at a small production site in Westbury, 30 km west of Launceston, Tasmania. The central location of this site helped attract over 60 participants on a very cold mid-winter day. The event was well covered by local newspaper media from both north and north-west Tasmania and as a result within three months, two more growers had joined the industry.

In August 2006, a workshop was hosted by Department of Primary Industries & Water to discuss a suitable business model for the wasabi grower group. Ten wasabi growers and staff from DED and DPIW attended the meeting and a resolution was made by Wasabi Growers of Tasmania P/L to present a business plan to the larger grower group in December 2006. By September 2006, wasabi crops established at 10 locations in northern Tasmania totalled approximately 0.5ha.

In November 2006, Wasabi Growers of Tasmania P/L and Department of Primary Industries and Water hosted a Japanese agronomist who had 35 years experience in providing agronomic advice to the Japanese wasabi industry in Shimane Prefecture, Japan. The occasion was marked by a social gathering hosted by WGT and was followed up with visits to each of the production sites in northern Tasmania. Growers were provided with advice on production methods and recipes for value-added wasabi products. Members of the grower group exchanged farm visits and contact details to share ideas based on the experiences of individual growers.
Also in November 2006, members of the grower group recognised that assistance with small business management would be advantageous. Unfortunately, attempts to address specific training needs through Institute of TAFE Tasmania were thwarted because of a general breakdown in negotiations between representatives of the wasabi grower group and the proposed business consultant/trainer.

Commencing in March 2007, a series of workshops which engaged a business consultant were initiated by Wasabi Growers of Tasmania P/L and conducted by Meander Valley Enterprise Centre with support from DED. Attempts to establish a suitable business model for the grower group were not resolved during these workshops; however the growers did make plans to establish a harvesting schedule to maintain market supply of fresh wasabi products over the next three years. As a consequence of the workshops, the majority of growers were able to recognise their individual business strengths and the broad range of product options and market segments available. Consequently, the group agreed to adopt different business models according to their particular business interests.

In June 2007, a Tasmanian business trading as ‘Arandale Wasabi’ hosted a field day for delegates attending the Australian Hydroponic and Greenhouse Industry National conference. Approximately 75 people visited the wasabi site which demonstrated production of wasabi under a modern hydroponic system.

In October 2007, members of the wasabi grower group trading as ‘Tasmanian Wasabi Products’ were awarded two gold medals at the Hobart Fine Foods Show for their value-added wasabi products namely; ‘Wasabi dressing’ and ‘Wasabi pickles’. The top prize was awarded to Nichols Poultry for their wasabi mustard which included Tasmanian wasabi as a major ingredient.

In November 2007, several members of the grower group established a new company ‘Shima wasabi P/L’ that aims to produce and supply both fresh wasabi stems and leaves, and a range of value-added products containing pure Tasmanian wasabi.

5.4 Industry Strategic Plan

While research and development organisations involved with the relatively young wasabi industry recognise the benefits of developing a whole of industry strategic plan, such a plan cannot be developed in isolation from the primary producers. After consultation and deliberation on these matters, growers decided that the industry was not sufficiently developed to consider a strategic plan that included the input of considerable capital investment. Whilst such investment may be from an external source, growers felt that their small businesses were as yet very vulnerable and relinquishing some control to another party would compromise their own plans.
Implications

1. Australian laboratory to produce tissue-cultured wasabi planting stock

It is apparent from the collaborative research conducted with the University of Central Queensland that wasabi is a difficult species to propagate using tissue-culture techniques. This supports the findings of four other Tasmanian micropropagation laboratories that have been associated with RIRDC funded wasabi projects over the last 9 years. The problem is apparently two-fold: 1. The presence of endogenous bacteria in plant tissue necessitates the application of rigorous sterilisation techniques to ex-plants. 2. The high-water content of wasabi plant tissue makes it ‘soft’ and very vulnerable to damage by chemicals used in sterilisation, often leading to tissue death. Consequently, the starting tissue often either remains contaminated or does not survive the sterilisation process.

It may be that vegetative propagation of wasabi should be considered as an option to tissue culture. This technique is remarkably simple for wasabi, as any tissue carrying a bud can be use to generate a new plant. Unfortunately, any endogenous bacteria and internal fungal infections present are carried over to the vegetative splits, so that the new generation of plants is infected at the outset.

It may be prudent to take these splits in late-winter and to treat the fungal infections when the splits are quite small. The rapid onset of growth in early spring may then generate plants that are able to outgrow the endogenous infections and generate a commercially viable crop. This method of propagation has been in use in Japan for 450 years using seed as the primary planting stock with vegetative splits taken for 2 subsequent generations.

2. Product quality in response to disease management, water-culture and additional varieties

Two varieties of wasabi have been identified as producing fresh stems of high quality. Of these, ‘Green Thumb’ also showed high yielding characteristics. Future Tasmanian crops should focus on this variety which has been newly developed by Japanese wasabi plant breeders. Variety ‘Midori’, which achieved the highest score by the tasting panel (see Table 5) has provided the parent stock for the development of variety ‘Masamidori’, which is also a newly developed variety imported especially for this project. While the trial results for this variety were somewhat disappointing, the author notes that the site location for soil-grown treatments of this variety was very poor and there was considerable damage inflicted on the mature plants by scavenging rats in the week immediately prior to harvest. Historically, feral rats have shown to be very discerning when it comes to wasabi and only choose the ‘sweetest’ tasting varieties. ‘Masamidori’ is thereby worthy of further consideration.

During the course of this project it became apparent that a water-grown system, which combined the traditional Japanese method of diverting water from a local stream with modern agricultural technologies, was not suited to Tasmania. Despite choosing a site that provided access to cool abundant stream water, laser-leveling the site to optimise slope, accessing a range of gravel sources and installing sophisticated plumbing and irrigation equipment to deliver water to the gravel beds, there were insurmountable constraints put on the system by the prevailing site conditions. For example, whilst a constant source of water maintained at 11°C was available, microscopic silt particles carried in the stream water built up in the irrigation pipes and the gravel beds impeding the passage of water through the system. Subsequent unprecedented drought conditions meant that the supplementary water-pump used as stream water levels dropped was running for at least 6 months of the year. The final blow fraught on this system was the damage to fully mature plants caused by scavenging platypuses that had already interrupted the project’s field trials as described in Section 4.2. Consequently, in December 2007 ‘Wasabi Growers of Tasmania’ made the decision to pursue the soil-grown system of production in favour of the water-grown system.
Throughout the project, wasabi growers have reported frequently on the progress of their crops to the Principal Investigator for the project. From these reports, we can conclude that the highest yielding and superior quality plants are produced in locations that are characterised by cool temperatures. Average daily maxima in summer of 20°C air temperature and 11°C soil temperatures (Mathinna, north-east highlands, Tasmania) provide ideal conditions for wasabi for two reasons: 1. Fungal and bacterial organisms grow slowly at these temperatures, and 2: There are few other Brassica crops grown in this district. At Don, in north-west Tasmania, the average maximum summer air temperature is only 21°C and soil temperatures average 18°C, and whilst this makes it a prime vegetable growing area, wasabi stem quality is compromised by disease pressure due to surrounding Brassica crops.

In addition to choosing a cool microclimate and remote location, wasabi crops require constant vigilance with regard to disease control. In Tasmania, growers using a soil-based system have addressed this issue by constructing a series of small shade houses (30m x 6m) so any disease outbreak in one wasabi house can be confined by limiting access to that house, thereby reducing cross-contamination.

Whilst the results of the fungicide trial demonstrate that treatment of young plants with a Thiram™ dip prior to planting affords considerable protection from fungal infection, growers are advised to keep up to date with options for Integrated Pest Management of related plant species as well as new crop protectants and new varieties. One Tasmania grower is exploring the option of growing wasabi in a hydroponic system similar to those used for other greenhouse crops (capsicums, tomatoes, lettuce and herbs). Whilst the yield and quality parameters of wasabi produced in such a system are largely untested, this option does have major benefits in reducing the rate of infection impacting the crop from the surrounding environment (e.g. other Brassica crops and weeds). It is essential that such a closed system is established with uncontaminated planting stock (See Section 6.1).

3. Networking capacity of the wasabi grower group

At the commencement of this project the wasabi grower group consisted of ‘Wasabi Growers of Tasmania’, three associated growers supplying product to them and two independent growers. Since then, four additional wasabi growers have joined the group with some of the others developing a separate company. Although the majority of Tasmanian wasabi growers would be classed as ‘hobby farmers’, the group recognises the benefits of forming an association, and have initiated a regular newsletter for that purpose. A number of separate business entities have been established to target different market segments and complement one another by occupying various links in the value-supply chain. The process of negotiating a business model that is satisfactory to all parties in the wasabi grower group emphasised the need for a Business Plan specific to each entity, and the benefits to be gained by the development of a strategic plan for the industry.

4. Development of industry strategic plan

Support from the State Government departments of Primary Industries & Water, Economic Development and Tasmanian Institute of Agricultural Research was not sufficient motivation for development of an industry strategic plan at this stage. It may be more appropriate in 3 years time when the existing businesses have developed greater confidence in their own enterprise and have achieved a higher profile in the market place.
7. Recommendations

This project has been instrumental in assisting the development of the Tasmania wasabi industry. However, there remain a number of opportunities for collaborative research, and the following recommendations are made according to the priorities determined by researchers and industry representatives. Brian Chung (Manager, Product Development, Botanical Resources Australia) advises that it took 20 years of research and development to produce the first commercially viable pyrethrum crop in Australia (Brian Chung personal communication). At that rate, wasabi R&D has another 10 years to go!

**Recommendation 1  Ensure sustainable access to high quality planting stock**

In view of the difficulties with producing viable tissue-cultured planting stock in Australia, the author makes two recommendations:

1. Tasmanian wasabi growers continue to import stock from the Japanese supplier and to build the relationship so that new varieties are tested in both Australia and Japan.

2. Refine techniques for vegetative propagation to produce commercial quantities of ‘Green Thumb’ and ‘Midori’ planting stock. In particular, investigate options for sterilisation and fungal protection measures appropriate to splits taken from mature plants.

**Recommendation 2  Repeat the variety trial in both well-drained soil and hydroponic systems**

Unprecedented climatic conditions had a great bearing on the variety trial included in this project. The site was subjected to a 50-year flood in January of 2006, followed by two years of drought conditions such as never previously recorded in Tasmania. The author recommends that the top performing varieties ‘Green Thumb’ and ‘Midori’ be tested again at:

1. A site that provides good soil drainage and
2. In a modern hydroponic system. The objective being to determine whether the taste quality parameters attributable to the water-grown system are a function of restricted access to nutrients (can be closely monitored in a hydroponics system), or better aeration of the plants’ root system (achievable in both systems).

**Recommendation 3  Maintain communication among researchers of Asian vegetables**

Australian Pesticide and Veterinary Medicines Authority (APVMA) must issue minor use permits before crop protectant chemicals can be used on a species for which they are not currently registered. Like the majority of Asian vegetable species that have been introduced to Australian agricultural systems, wasabi is a brassica vegetable, so crop protection measures relevant to one species of Asian vegetable are often transferable to wasabi. Communication among researchers of Asian vegetables plays a vital role in the development of niche Asian vegetable industries. RIRDC publication ‘Asian Foods newsletter’ and the annual meeting of researchers involved in the RIRDC Asian Foods program are valuable communication tools that help prevent the duplication of research investigations and the wasabi grower association is encouraged to maintain communication with this research group.

**Recommendation 4  Conduct on-farm efficacy trials for new crop protectants**

Growers and researchers of Asian vegetables must remain vigilant to the development of new Integrated Pest Management systems and agricultural chemicals. In order to qualify for a minor use permit from APVMA, efficacy trials must be conducted for each vegetable species being produced. Because the microclimatic conditions required to grow wasabi are particularly specific, these trials are best conducted on growers’ properties rather than on University or State Government research farms which are often located where climatic conditions suit a range of vegetable species. In Tasmania, this approach provides an opportunity to develop collaborative research projects between the wasabi industry representatives and the Tasmanian Institute of Agricultural Research.
Recommendation 5  Develop a strategic plan for the wasabi industry

At the conclusion of this project, the wasabi grower group comprises 24 individuals growing wasabi at 11 sites, 10 of which are located in Tasmania and one in eastern Victoria. Within this group, there are four new wasabi-specific business entities in Tasmania, 3 of which were established during this project.

Whilst the development of an Industry Strategic Plan was considered by the grower group to be premature at this time, such a plan is considered an appropriate course of action for the future and should be reviewed in 2011.
8. References


Sparrow, A. ‘Production and Marketing of Tasmanian wasabi’ Rural Industries Research and Development Corporation publication no.06/085, 2006.

9. Appendices

Appendix 1  Micropropagation of Wasabi (*Wasabia japonica*)
Appendix 2  Summary Wasabi Industry Audit
Appendix 3  Wasabi Industry Snapshot
Appendix 4  ‘Wasabi News’ March 2008
Appendix 5  Publications
Micropropagation of Wasabi  
(*Wasabia japonica*)

This project officially commenced in August 2005. However the tissue culture tissue culture studies on wasabi had been initiated prior to its official commencement, and this included: feasibility of successful establishment of this temperate species in Rockhampton. Various experiments were carried out as part of this project and the results of these are summarised below.

1. Literature search

Literature review has been carried out and the information on propagation, growth and tissue culture of wasabi has been used in designing experiments and interpreting the data.

2. Procurement of mother plants

Mother plants of nine cultivars of wasabi (Mazuma, W7, FS1, FS2, Top Taste, Midori, 980, Elite, M x D) were provided by Mrs Angela sparrow. These plants were maintained in a growth cabinet at 10 °C (Figure 1), with a light intensity of 100-200 μmoles m⁻² s⁻¹ and used in tissue culture studies.

A three-day field trip to Launceston helped to procure mother plants for tissue culture and to discuss research needs with the farmers and scientists.
Parent plants were established in pot culture and were grown in a growth cabinet maintained at 10 °C, with a light intensity of 100-200 μ moles m⁻² s⁻¹.

3. Disinfection

The ex-plants (15-40 per cultivar) of these cultivars were disinfested using mercuric chloride and established in tissue culture using MS liquid media. The inoculated cultures were maintained in a tissue culture chamber (maintained at 22°C with a light intensity of 50-100 μmoles m⁻² s⁻¹), and the contaminated cultures were removed after 4-6 weeks. Some cultivars did not survive the disinfection procedure and some were infected after 4 weeks (eg 980, TT). These cultures were re-established from the mother plants that were maintained in the growth cabinet.

The disinfection of field-grown plants (kindly supplied by Mr Farquhar and Mrs Angela Sparrow) was found to be difficult, but the culture of those maintained in the glasshouse (Fig.1) proved easy.

The explants were grown initially in test tubes (Fig. 2) on MS liquid media (with BA and NAA) using paper boats.
Establishment of cultures from mother plants would take up to 6 months, due to sensitivity of explants to disinfestant (e.g., wasabi plants are very sensitive to sodium hypochlorite which is a very commonly used disinfestant) and slow growth in tissue culture (Figure 3).

At the start, disinfestation and establishment in tissue culture takes up to 6 months. Multiplication to large numbers (1000’s) requires a further 6 month period. Note in figure 3, FS1 has produced 2-3 shoots in about 5 weeks. For most cultivars, the plants can be sub-cultured within 4 weeks.
4. **Selection of suitable explants for multiplication**

Different explants were tested for their response to shoot production in tissue culture. Various parts of the plant (leaf, petiole, stem and axillary bud) were used to initiate shoots. Amongst these, stem segments containing axillary bud(s) were found to respond well and produce healthy shoots rapidly. All subsequent cultures were therefore produced using stem segments or axillary buds (Figure 4).

The plants should be subcultured once every 4-6 weeks; without which they will succumb to contamination or stop growing or deteriorate in culture.

![Figure 4](image1.png)

**Figure 4**  Shoot induction from stem (bottom left) and axillary buds (bottom right) was found the easiest.

5. **Rapid multiplication of wasabi in tissue culture**

Once the explants were found clean and growing well in tissue culture tubes, they were transferred to large tubs for rapid multiplication (Figure 5).

![Figure 5](image2.png)

**Figure 5**  Tubs with paper boats and liquid MS media and with plant growth regulators

The plants should be subcultured once every 4-6 weeks; without which they will succumb to contamination or stop growing or deteriorate in culture.
Stock cultures of all 9 cultivars are being maintained in tissue culture and these are being used for further multiplication, as and when the demand arises for these cultivars. A number of additional experiments/trials were carried out to optimise media composition, rooting and hardening.

5. Induction of roots from tissue cultured plants

We were fortunate to have sufficient tissue cultured plants from previous trials for carrying out acclimatisation and hardening experiments. Approximately 300 tissue cultured plants of Mazuma were transplanted into two types of potting media (Figure 6). Some of these plants were treated with rooting hormones and the others were not (Figure 7).

Figure 6  Homemade medium (top left hand corner) is inferior to commercial potting media.
Treatment with rooting hormone (IBA) helps with the survival and growth of tissue cultured plants.

This experiment revealed that a commercial potting mix was superior than the one prepared locally. Treating the explants with rooting hormone (IBA 0.1% or 0.4%) also improved their establishment and growth in the potting media (Figure 8).
Figure 8  Effect of using plant growth regulators on rooting of tissue cultured wasabi
6. **Optimising nutrient concentrations to induce rooting in Mazuma**

Mazuma plants that were raised via tissue culture were transferred on to stainless steel grids contained in rectangular plastic containers. These plants were grown in four media concentrations, viz 100%, 50%, 25% and 10% of full strength MS media. The shoot and root growth of Mazuma were assessed after 8 weeks. The best shoot and root growth occurred in 100% nutrient solution (Figures 9, 10). Thus, by altering the nutrient concentrations, the rate of growth can be regulated. This information was made use subsequently to adjust delivery times of tissue culture plants.

Figure 9 shows the effect of adding different hormones to the tissue culture medium. Plants labelled ‘A’ were raised in tissue culture media that contained BA and NAA. The tissue cultured shoots were then treated with 0.4% IBA before planting in the growth media. Plants labelled ‘B’ were raised in tissue culture media containing no growth hormones and the shoots derived from this process were treated with 0.4% IBA prior to transplanting. Note: the shoots that were raised on hormone-free tissue culture media (B) and then treated with IBA survived and grew better than those produced using hormones in the tissue culture media (A).

![Figure 9](image)  
**Figure 9**  Effect of nutrient concentration on shoot and root growth of Mazuma. Top: (l-r) 100% and 50%; bottom: 25% and 10% of full strength MS media.
7. Propagation of wasabi via Hydroponic culture

Young shoots were excised from the mother plants that were maintained in the growth chamber (Figure 1) and transferred into pots containing commercial potting mix. These pots were placed in the commercial hydroponic system (supplied by the Rockhampton Hydroponics Centre, Rockhampton). ‘Manutec’ nutrient solution was used and the hydroponic system was maintained in the growth cabinet at 10 °C (Figures 11 & 12).

![Image of wasabi cultivars in hydroponics](image)

**Figure 11** Cultivars of wasabi in hydroponics
All cultivars responded well to hydroponics and they produced healthy shoots in about 8 weeks after initiating in the hydroponics. Most cultivars survived and produced shoots, with F Elite being the most prolific cultivar.

8. Effect of temperature on multiplication rate of Mazuma in tissue culture

The tissue culture containers were placed in the tissue culture chamber that was maintained at 20-25 °C, and in the growth cabinet kept at 10 °C. The number and size of plants produced from these systems were compared after about 6 weeks.

The results showed that the plants that were maintained at 10 °C grew faster than those grown at 25 °C (Figure 13). Since the plants grown in both conditions were healthy, all further propagation work was carried out in the tissue culture chamber maintained at 22-25 °C, because the temperature of tissue culture chamber could not be changed as this chamber also housed other tropical species.
9. Induction of somatic embryos in wasabi

Somatic embryos are the tiny seedlings generated from non-reproductive parts (eg mitotic tissues) of the plant (usually from leaves and hypocotyls). Development of somatic embryos will assist in genetic engineering, cryopreservation and synthetic seed production. This technique can also be used for rapid multiplication of a selected cultivar.

The leaf explants of Mazuma were placed on solid MS media containing cytokinins. The leaves initially transformed into callus and then into somatic embryos (Figure 14). No regeneration of entire plants were carried out using somatic embryogenesis as it was much easier to produce new plants using stem sections than via somatic embryogenesis.
10. Response of hardened seedlings of wasabi to light and temperature

Mazuma plants that were produced from various tissue culture experiments were pooled and maintained in the growth cabinet. These seedlings (up to 300) were transplanted into pots (10 cm diameter) containing a commercial potting medum. These pots were initially maintained in the growth cabinet for about 6 weeks. They were removed from the growth cabinet, when the shoots grew to a height of 10 cm, and placed on benches in a potting shed. The potting shed had a solid roof, rolling doors and windows, so it only had access to diffused light.

The plants were maintained in the potting shed at various locations, so as to provide different intensities of diffused light, ranging from 5 μmoles/m² s to 25 μmoles m² s⁻¹. Initially, all plants survived well, but after 3 weeks, the plants that were kept at 5 μmoles m² s⁻¹ began to turn pale and died within 6 weeks, whereas those kept at 25 μmoles m² s⁻¹ grew normally.

The potting shed temperature is not controlled, so its temperature reflects diurnal variations. The potting shed temperature rose from around 10-25 °C during early winter to 15-30 °C during late winter. Because of this change, the plants that were maintained at 25 μmoles m² s⁻¹ also died when the temperature rose during late winter. This mortality was not due to lack of light but due to the heat shock.

Wasabi plants are highly tolerant of shade, but they rarely survive at critically low light levels. Likewise, they do not tolerate even short span of elevated temperatures (30-35°C) which is expected, as this is a temperate species.

Figure 15   Mazuma plants fail to survive at very low light intensity (<10 μ moles m² s⁻¹), and at high temperatures >25 °C for longer than 6 weeks
Conclusions

Suitable tissue culture techniques have been developed for propagation of nine cultivars of wasabi. The cultivars used in the study markedly differ in their responses to propagation. They also differ in their response to disinfestation, propagation, rooting and hardening procedures. Despite these variations, this project has identified techniques that will facilitate rapid multiplication of 5 of the 9 tested cultivars (F Elite, W7, FS1, Mazuma x Daruma and Mazuma).

Some cultivars grow very slowly in tissue culture (FS2) and the others are difficult to disinfest (Midori). These cultivars also differ in their tolerances to pests and diseases as well as light intensity and temperature in tissue culture. Amongst a number of features studied, these cultivars differ markedly in their growth rates. Thus, further cultivar-specific studies are warranted to optimise the best tissue culture conditions for rapid multiplication of the remaining 4 cultivars.

As a result of this research, the CQU can proudly claim that it can undertake mass propagation of wasabi and/or other crops (eg pineapple or ornamental plants) using the excellent facilities that are currently available at PSG.

Acknowledgments

I am grateful to Ms Alison Clarke, the green-thumb, for providing technical assistance and maintaining the tissue culture laboratory in a spotless condition. I thank Dr Poonam Bhatia for commencing tissue culture work with wasabi, Prof Bob Miles of ISRD, for part funding support, and Prof David Midmore, for the logistic support and inspiration. The funding assistance of the DPIWE and the generous support of Mrs Angela Sparrow for this project, are greatly acknowledged.
SUMMARY DOCUMENT

Australian & International production areas and marketing trends

Production
Produced and exported in Japan, Korea, Taiwan, North America, New Zealand and South Africa. Also produced in Germany and France, for their local markets. Recent trials in Victoria, appear to have had limited success.

Trends
Seems to be plenty of interest in the product at the moment, although the Australian market is very disjointed as customers are unfamiliar with supply options and the product itself. In other countries, there are companies investigating the medicinal and neutriceutical properties of wasabi, although larger companies are less interested as it is difficult to patent the IP.

Additional uses for wasabi
Very small quantities of wasabi products currently on the local market, as there hasn’t been enough regular supply to explore the size of the market. There is belief that a central processing area in Tasmania would have some merit.

Importing wasabi
Currently it seems that no fresh wasabi can be imported, although frozen wasabi may still be a potential import. Perceived threat is that of overseas companies importing product to compete in the market, rather than locals importing product to flatten out shortfalls in supply.

Tasmanian wasabi grower type and requirements

Outlets
Can sell as many stems as can be produced, however for the remaining 70% of the plant there is very little outlet. There has been some early testing of value-added products and direct sales to restaurateurs of additional plant components. As above, some sort of processing is needed to take full advantage of 100% of the plant.

Grower type and issues
No one grows wasabi as their principle interest, although some would like to. Not many people have harvested a fully commercial crop, and consequently there may be some discrepancy in the figures people believe they will get for their crop. Need greater area under production for the industry to reach critical mass.

Wish list
Sourcing well priced clean plants through a suitable local tissue culture laboratory is desirable. Growers also need to become more market focussed – catering to what the market wants, not what think they can produce.

Relationships and information
Relationships with customers are good when there is product to supply, but soon wanes when product is temporarily unavailable. Some sort of field day within the Tasmanian growers would help to grow the sense of industry and assist in developing stronger bonds.

Cost to produce and process

Costs
Variation in record keeping ranges from none at all through to estimates calculated per plant or by the square metre. There are no definite figures from which to make estimates, as very few growers have harvested an entire crop.

Outputs
Sales are mostly to local restaurants, provedores and premium Asian Seafood restaurants on the eastern seaboard, with only minor sales to producers of value-added products.

Competition

Within the Tasmanian Wasabi Industry
No real competition within the wasabi industry, but only basic information and relationship flow between the individual growers. Currently the primary producers are still very entrepreneurial and individual growers are pursuing their own ambitions.

Location
Location presents no freight problems, as it is necessary to freight fresh vegetable products from any of the suitable growing areas within Australia.

Overall competitiveness and value to grower
Most interviewees felt that the industry and their own individual operations would become cash positive in the near future, although that was not currently the case. The potential of a large company entering the market in Tasmania is a concern.
Tasmanian Wasabi Industry

2008 Industry Snapshot

20 February 2008
PURPOSE

The purpose of this document is to provide industry participants with a snapshot that reflects the current state of the Tasmanian wasabi industry and its surrounding elements.

PROCESS

This document has been prepared by Tasmanian Institute of Agricultural Research (TIAR) and the Department of Economic Development with the assistance of SCA Marketing (Tas) Pty Ltd as a result of:

- Access to an industry audit conducted in January – February 2008
- Facilitated discussions on 13 February 2008 at Department of Primary Industries & Water, Mt Pleasant Laboratories, Conference Room.

© Copyright February 2008: Copyright ownership for the text resides with Tasmanian Institute of Agricultural Research and as such may not be reproduced or transmitted in any form without the express written permission of the copyright owner. Tasmanian Institute of Agricultural Research does not accept any liability for damage caused by, or economic loss arising from, reliance on this information.
# EXECUTIVE SUMMARY

1.1 State of the Industry .......................... 4
1.2 Stage of Industry Evolution .................. 4
1.3 Conclusions & Implications .................. 4

# INDUSTRY REVIEW

2.1 Industry Value Chain .......................... 5
2.2 Industry Feedback ............................. 5
2.3 Outcomes ........................................ 6

# BUSINESS DRIVERS / SITUATIONAL ANALYSIS

3.1 External ......................................... 8
3.2 Industry ........................................ 9
3.3 Internal Capabilities ........................... 11
Executive Summary
1.1 State of the Industry
There is little competition within the Tasmanian growers group and, despite fragmentation of the industry, there is strong potential within its customer base to succeed. It currently is experiencing some issues regarding consistency of supply, however customers are looking for new products that are different to the norm to entice their end-consumers.

The industry has made some major gains in the past 5 years, with the identified weaknesses being far less significant than the achievements to date. The industry has positive business drivers, and barriers to entry and product differentiation offer the opportunity to occupy a unique product niche that is very difficult for other local and international industries, to replicate.

Unproven profitability, lack of specific markets and fragmentation of the industry are all potential constraints to the growth of the industry.

1.2 Stage of Industry Evolution
The industry is currently in the position where it can choose one of three options available:
- To continue as it currently is, with minimal outside investment and slow incremental growth of the industry.
- Undergo incremental growth from small investment and loans from financial institutions.
- Undergo substantial growth through large external financial investment in the mid term.

1.3 Conclusions & Implications
Following the initial planning stages, the majority of industry members who attended the workshop chose not to continue with the process to develop an Industry Plan due to divergent commercial issues and fragmentation of the group.

From this point in time, it will be up to individual businesses to create and develop growth strategies and the financial opportunities necessary to consolidate their position within the industry.
Section Two

Industry Review

2.1 Industry Value Chain
Developed to give an indication of the principle areas of value within the chain.

2.2 Industry Feedback
The industry audit conducted in Jan/Feb 2008 investigated several subjects pertinent to the Tasmanian wasabi industry.

From within the grower group, it appears that there is:

- little local competition as there is more than enough demand available for whatever product is produced
- very little threat of competition within the fresh and frozen product market, which is the growers’ main focus.

Like Tasmanian growers, most other countries involved in wasabi production typically cater for their own domestic markets.

Tasmanian growers generally grow wasabi as a secondary interest rather than as a primary source of income, and are either working full-time jobs or have a wasabi crop as a small component of a much larger farm.
Within the grower group there seems to be average to good information flow and relationships built, however as the current industry is still very entrepreneurial there is a reluctance to increase transparency and cohesion.

External to the grower group and further along the value chain, those interviewed were quite positive about the industry in Tasmania with generally good experiences reported.

There were two distinct groups identified:
- Most preferred their produce to be in the form of fresh stems and leaves, as those at the user-end of the chain generally made their own specialty products from the fresh produce and did not want to be restricted to existing value-added products.
- Alternatively, some were interested in value-added products and the potential they offer to target different market segments.

Most provedores were generally after small amounts of product, but were likely to make more consistent purchases if supply was more reliable. Generally the businesses interviewed used only one supplier, however some had been tried a new Tasmanian company in the weeks prior to the interview. One interviewee had used a Victorian company as its sole supplier. Generally there were few problems with industry contact and the industry looked to be emerging well. There were some queries about the size of the industry and a reticence to “step on toes” by ordering from different companies.

2.3 Industry Outcomes

2.3.1 Major Gains

The major gains achieved include:
- Understanding the range of plant genetics available and having access to part of that range for importation. There are no restrictions imposed by Plant Breeders Rights relevant to wasabi imported to Australia, freeing up the local industry to use splits and tissue-cultured plantlets for propagation purposes as it chooses.
- Better understanding of the environmental boundaries in Tasmania within which wasabi can be grown.
- Identification of product segments and procedures for product development required for wasabi products to enter the market both locally and nationally.
- Increased public and customer awareness that pure, high quality, Tasmanian produced wasabi products are currently available in Australia.
- Experience in growing wasabi - definition of problems and solutions relevant to growing wasabi in Tasmania’s environment.
- Extensive data sets and documented research reports stemming from government and industry programs, as well as the development of an international network of contacts.
2.3.2 Identified Weaknesses

The weaknesses identified include:

- No surety that the plant genetic material supplied by international organisations are best suited for growing conditions in Tasmania, but feeling that growers must take the plants recommended.
- Matching plant varieties to specific growing methods is difficult if not impossible – all growers in Tasmania usually use the same genetic material regardless of the different growing techniques employed.
- Little ability to make use of 100% of the plant, with the majority of growers using only 30% of the plant. This aspect of crop production needs further research and development in order to best utilise the extra 70% of the plant, a small portion of which is currently used in value-added products.
- Limited awareness of market size and demand profile, as there has never been sufficient Tasmanian product to test markets to their full extent. No awareness of whether there is a Tasmanian brand preference in the market.
SECTION THREE

Business Drivers / Situational Analysis

3.1 External

3.1.1 Political

Key political issues for the industry:

- Quarantine is a barrier for the Tasmanian industry in several ways:
  - It increases the cost of plant material entering Tasmania from well established, international tissue-culture labs, as well as increasing the length of time taken for delivery and the risks attached to importation.
  - Regulations do not permit importation of fresh product, and costs and regulations are likely to significantly decrease the potential to import frozen product. This protects the local industry from a foreign company importing to Australia and jeopardising the market.
  - By extension of the above, local companies are unable to import product to flatten out their supply cycle and cover periods when little or no local crop is available.
  - Public funding for research, development and commercialisation projects will be harder to obtain until crop potential has been demonstrated, or an industry plan developed. Achievement of either of these objectives will be difficult while the size of the industry is small and undergoing slow expansion.

3.1.2 Economic

Key economic issues for the industry:

- Underpricing of the entire supply chain may be an issue as it reduces the appeal of the industry to new entrants required for industry expansion.

- On the whole the economic outlook for the industry is positive.

3.1.3 Environmental

Key environmental issues for the industry:

- Management costs and regulatory costs - on the whole the environmental outlook for the industry is positive, with low foreseeable impact on these costs and little environmental impact on growing conditions.
3.1.4 Social
Key social issues for the industry are generally positive:
- The “slow food” movement in the food and beverage industries is increasing the appeal of higher priced condiments and increases the likelihood of wasabi products being used by a restaurant or home chef.
- The Australian market demonstrates an increasing willingness to try new and exciting flavours.
- The health benefits from wasabi are tangible and are backed up by research from Japan.
- Availability of labour may be a constraint. The current production method is highly labour intensive. Increasing the area under production to a size beyond that manageable by individual growers may have a negative impact on industry expansion.

3.1.5 Technologies
Key technology issues for the industry:
- The industry needs an injection of capital in order to facilitate research and development for growing and harvesting techniques that will exceed current capacities. With the increased efficiency this should bring, wasabi production will become more appealing throughout the value chain.

3.1.6 Summary
On the whole, the outlook created by identifying key drivers is positive, and indicate that there is a known pathway to pursue, demonstrated by crops of similar value and production intensity.

3.2 Industry
3.2.1 Concentration & Integration
Key issues around industry integration:
- There is considerable fragmentation within the industry caused by geographical isolation of farms, which hinders communication and the ability to share resources essential to wasabi production.
- The industry is also highly fragmented in terms of companies and individual entities in the developmental stage as entrepreneurial ventures with no real semblance of working together, except where bound by a company association.
- As a consequence of the preceding issues it will be very difficult for the industry to reach critical mass where the primary product is in high demand and new growers are attracted to the industry.
• Technological advances and R&D are areas in which the industry is doing well largely due to substantial investments from various government organisations. That support is coming to an end making the rate of subsequent advances difficult to maintain.

3.2.2 Barriers to Entry
Key barriers to entry for the industry:
• Knowledge is required that is specific to the sector, with only few individuals in possession of that knowledge.
• The ratio of risk to return on investment offered by the industry is quite high, making the industry relatively unappealing to bigger companies and risk-adverse investors.

3.2.3 Product Differentiation
Product differentiation opportunities for the industry:
• For fresh product, the wasabi industry in Tasmania is greatly differentiated as there is only one other producer in Australia and import of fresh product is currently prohibited. The product is quite differentiated from regular offerings in that it is a unique flavour sensation difficult to obtain from products currently available on the Australian market.
• Powdered wasabi, whilst currently only produced in small amounts for one customer, could be substituted for product from Japan. The only differentiation available in this circumstance is provenance.

3.2.4 Profitability
Key cost and margin challenges for the industry:
• The profitability of the industry is almost unknown in its current formation, with most growers going through the final cycles of research and development for production technology or having not yet sold a reasonable size crop. In the current climate, projections look good, however following commercialisation these projections may change.

3.2.5 Summary
Significant opportunities are available to the industry, and there is very low risk of aggressive competitive intrusion. There is high partnership potential through the body of existing knowledge, but this is at the risk of relinquishing some control.
3.3 Internal Capabilities

3.3.1 Financial
The key financial capabilities for the industry are:
- Weak, with high investment requirements and low return on investment until crops mature.

3.3.2 People
The key people / skills capabilities and issues facing the industry are:
- Strong, with diverse skills available among a small number of growers and advisors.
- Technically strong as well, with knowledge of improved growing methods gained from 10 years of trials.
- Many are part-time growers, which could affect the dedication to crop production and the required expansion in size of holdings.

3.3.3 IP / Systems / Processes
Key IP / systems / process capabilities and issues for the industry:
- There is a body of knowledge that is currently available to growers and potential investors, however there is no guarantee that it will be valued by current and incoming industry members.
- The required knowledge could “sieve out the tyre kickers” from those looking to enter the Tasmanian industry as there is a need for newcomers to learn correct procedures for successful crop production.

3.3.4 Markets & Customers
Key market and customer issues facing the industry:
- Skills are low, but gradually building.

3.3.5 Summary
Internal capabilities are growing, but the major constraint to industry growth is capital investment.
This issue of the ‘Wasabi News’ is dedicated to farm hygiene recommendations for wasabi production sites and has been prepared at the conclusion of field trials conducted by Tasmanian Institute of Agricultural Research which tested the effectiveness of fungicides registered for use on brassica vegetables in Tasmanian wasabi crops.

WHAT IS FARM HYGIENE?

"Farm Hygiene is the protection of the farming environment by preventing the introduction and/or spread of pests or diseases which may adversely affect production.”

Tasmania’s unique opportunity

Throughout Japan, disease organisms cause yield decline in wasabi crops. Traditional Japanese practices adopt methods that aim to reduce the impact of fungal and bacterial disease organisms. Producers in the United States and New Zealand indicate that wasabi diseases have already been introduced to their production systems.

Tasmania offers growers the opportunity to produce this highly valuable product in an environment devoid of traditional pests. Use of farm hygiene practices to minimize disease risk will provide a unique marketing advantage and should be given first priority in establishing and maintaining wasabi production systems.

The most detrimental organisms are fungi, such as Phoma wasabiae, Fusarium species, Pythium species, Erwinia aroideae and bacteria such as Corynebacterium species.

PREVENTION

- **Use disease-free planting material:**
  When establishing new production sites, use tissue-cultured material from an accredited laboratory to minimise the risk of disease transfer via planting stock.

- **Planting pre-treatment**
  Each new plant should be dipped in a solution of 1g/L Thiram® (Active Constituent 800g/kg Thiram) for 8 hours prior to planting in the field. This will provide long term protection.

- **Maintain good plant nutrition:**
  Avoid stress to plants. Healthy plants have greater disease resilience.

- **Be vigilant:**
  Check plants regularly for symptoms of disease. Plants displaying disease symptoms should be removed and destroyed immediately (deep burial or incineration).

- **Work from youngest to oldest:**
  Older plants carry greater disease risk, so commence with younger plants for all handling procedures.

- **Use Signs:**
  Place signs at entrances to your property or production site. Incorporate signage as reminders of the importance of hygiene in the workplace.
SITE HYGIENE

- **Access to the wasabi production site should be by appointment only:**
  Vehicles and pedestrians entering the production site should be free of contaminants. Where possible vehicles should be washed down at point of origin before proceeding to the wasabi farm.

**Footbaths or disposable overshoes used at each pedestrian access point:**

**Footbaths:** Pedestrians should remove free soil from footwear and then step into a shallow trough containing a foam rubber sponge soaked in disinfectant solution before proceeding onto the farm. Suitable disinfectants include:
- Dettol® solution (5%)
- Sodium hypochlorite (MILTON® full strength)
- Copper oxychloride (5g/L) - available at hardware outlets.

**Disposable overshoes:** These are fitted over footwear while visiting the farm and are removed at the farm gate when exiting the property. A seat should be provided for use while fitting the overshoes and a disposal unit provided for soiled overshoes.

WORK PRACTICE HYGIENE

- **Production sites should use dedicated tools:**
  Knives, secateurs and weeding implements should be kept clean. If a production area is divided into several blocks, dedicated equipment should be used at each block. Alternatively, commence working with younger plants first. Clean tools at end of the day by removing soil and plant material and disinfecting with Copper oxychloride solution (5 g/L).

- **Vegetative propagation:**
  Splits for vegetative propagation should be taken from wasabi plants in late winter. Each segment should be dipped in a solution of 1g/L Thiram® (Active Constituent 800g/kg Thiram) prior to planting in free-draining sand to stimulate root growth. A similar solution should be used to treat cutting tools between plants.

- **Crop maintenance:**
  Summer is the main infection period and application of 2g/L Kocide® fungicide (Active Constituent 400g/kg Copper present as Cupric Hydroxide) at 14-day intervals from October to April is recommended. Wasabi growers should keep up to date with current permits extended by Australian Pesticides and Veterinary Medicines Association for use of further chemicals on brassica vegetables as these may prove to be effective in protecting wasabi crops.
  Only chemicals that are currently registered for use on ‘all vegetables’ or ‘brassica vegetables’ are permitted for use on Tasmanian wasabi crops.

- **Harvesting leaves:**
  This is considered a high-risk operation with regard to disease transfer. It is recommended that farms specialising in the production of wasabi stems for the fresh market should only harvest leaf in conjunction with a sequential stem harvest in which the whole plant is removed. Alternatively a plot of wasabi that is isolated from the remainder of the crop should be dedicated to leaf production.

If you require further information about the items in this newsletter, contact Angela Sparrow at TIAR.

**Angela Sparrow**
Horticulturist (Wasabi)
Phone   (03) 6336 5349
Fax      (03) 6344 9814
E-mail   Angela.Sparrow@dpiw.tas.gov.au

**DISCLAIMER:** The Tasmanian Institute of Agricultural Research does not accept any liability for damage caused by, or economic loss arising from, reliance on this information.
Publications arising from project

Anon. ‘Wasabi crops will be a hot topic’ The Examiner newspaper, 25 May 2006.


Lewis, F. ‘Where there’s sushi, there’s wasabi’ Australian wasabi growers comment. The Age (Melbourne) magazine issue No.35 p.76, September 2007.


Sanders, P. ‘Wasabi adds bite to Tassie food exports’ The Examiner newspaper, 8 June 2006.

Sanders, P. ‘Plants the hottest topic at Westbury wasabi field day’ The Examiner newspaper, 8 June 2006.


Sparrow, A. ‘Wasabi varieties –compare the sensations.’ Tas Regions magazine, quarterly publication of Department Primary Industries and Water, December 2007.

Sparrow, A. ‘Wasabi crop on show at field day.’ Tas Regions magazine, quarterly publication of Department Primary Industries and Water, September 2006.

Sparrow, A. ‘Increasing the production of Australian wasabi’ Rural Industries Research and Development Corporation Project DAT- 43A presented to Asian Foods Meeting Paramatta, NSW March 2006.

Sparrow, A. ‘Increasing the production of Australian wasabi’ Rural Industries Research and Development Corporation Project DAT- 43A presented to Asian Foods Meeting Parramatta, NSW March 2006.


Increasing the Production of Australian Wasabi

This study develops the capacity of an Australian laboratory to produce commercial quantities of tissue-cultured wasabi planting stock to supplement imported stock, to improve product quality through disease management, adaptable cultivation methods and additional varieties. In addition, the project aimed to build the networking capacity of the wasabi grower group and develop a strategic plan for the industry.

The Rural Industries Research and Development Corporation (RIRDC) manages and funds priority research and translates results into practical outcomes for industry.

Our business is about developing a more profitable, dynamic and sustainable rural sector. Most of the information we produce can be downloaded for free or purchased from our website: www.rirdc.gov.au.

This publication can be viewed at our website—www.rirdc.gov.au. All RIRDC books can be purchased from:

www.rirdc.gov.au