Horticulture Innovation Australia

Final Report

Integrated approach for control of foliar diseases in strawberry runner nurseries and management of chemical resistance

The Department of Agriculture and Fisheries (DAF)
Apollo Gomez

Project Number: BS13004

BS13004

This project has been funded by Horticulture Innovation Australia Limited using funds from the Australian Government and the following sources:

The Department of Agriculture and Fisheries (DAF)
Sweets Strawberry Runners
Red Jewel Nursery
Toolangi Certified Strawberry Runner Growers Co-operative

ISBN 978 0 7341 3967 2

Published and distributed by:
Horticulture Innovation Australia Limited
Level 8, 1 Chifley Square
Sydney NSW 2000
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Contents

Summary

Powdery mildew and leaf blotch are important diseases that affect strawberries in Australia. Both diseases can reduce transplant quality in the strawberry nursery sector, and decrease yield in the fruit sector. Disease control in the strawberry nursery and fruit sectors relies on the use of the fungicides myclobutanil and trifloxystrobin. Due to the way these fungicides act against the pathogen, their repeated use in the nurseries and fruit farms increases the risk of the fungus becoming resistant to the chemicals. Resistance is when a pathogen is no longer controlled by a fungicide when used as directed.

To address the risk of resistance, a series of field experiments were conducted in strawberry nurseries in Queensland and Victoria over three seasons to assess the efficacy of several fungicides, including biorationals, with different modes of action against the diseases. Biorational is a term given to products that are relatively non-toxic to humans and have a low impact on the environment, and include oils, soaps, microbials, minerals and botanicals.

Results showed that a number of fungicides, including biorationals, were effective against powdery mildew and leaf blotch. Three fungicidal actives, bupirimate, cyflufenamid and quinoxyfen, were granted minor-use permits for specific use against powdery mildew in strawberry runner production. Data from the trials supported two of the minor-use permits (bupirimate and cyflufenamid). Quinoxyfen was granted a minor-use permit not long after the commencement of the project after discussions between the industry and chemical company. The study supported quinoxyfen being effective against powdery mildew in strawberry runners.

Best practice chemical control of powdery mildew in nursery runner crops, is to avoid use of myclobutanil and trifloxystrobin (only apply early in the season if required), and rotate the recently permitted fungicides, quinoxyfen, bupirimate and cyflufenamid through the season. Nursery growers in Queensland and Victoria have now implemented this strategy. This will minimise the risk of the pathogen developing resistance to myclobutanil and trifloxystrobin in the fruit farms.

At the time of writing this final report, there are currently no permitted or registered fungicides for control of leaf blotch/stem-end rot in strawberry. However, results from trials showed that fluazinam, prochloraz and azoxystrobin+difenoconazole reduced the disease in strawberry nursery crops. Based on results from field trials, an application has been made for a minor-use permit for fluazinam against leaf blotch in the strawberry nursery sector only.

Access to a wide range of fungicides with different modes of action is important for managing fungicide resistance across the whole industry. Co-ordinated use of different fungicides between nursery and fruit production farms will assist in reducing the risk of fungicide resistance developing in pathogen populations. In the long term, it is anticipated that this practice will extend the effective life of current and new fungicides, and reduce the economic impact of diseases in the strawberry nursery and fruit sectors.

The coordination of fungicide use across both sectors can help guide future chemical use and registration of new products. This concept may also be applied to other horticultural industries with more than one generation of production/propagation (e.g. potato) to better manage the risk of chemical resistance.

Keywords

Fragaria x ananassa; Powdery mildew; leaf blotch; *Podosphaera aphanis*, *Gnomoniopsis fructicola*; fungicides; biorationals; disease incidence; mode of action

Introduction

The Australian strawberry industry is valued in excess of $420M per annum (Australian Horticulture Statistics Handbook Fruit 2014-15). Strawberry fruit is grown in all Australian states, with main production centres in Queensland, Victoria and Western Australia. Strawberry transplants (runners) are grown in nurseries located in Queensland and Victoria. Powdery mildew (caused by *Podosphaera aphanis*) and leaf blotch (caused by *Gnomoniopsis fructicola*) are important foliar diseases of strawberry runner crops in Australia. Both diseases also occur in fruit production regions, reducing fruit quality and marketable yield. Fruit diseases commonly cause losses of up to ten percent or more per annum (Menzel et al. 2012).

Management of powdery mildew and leaf blotch in strawberry nurseries and fruit farms is based mainly on the use of protectant and systemic fungicides. Prior to the commencement of this project runner and fruit growers mostly relied on the registered fungicides myclobutanil and trifloxystrobin for control of powdery mildew. Studies on *G. fructicola* by Menzel et al. (HIA Limited project BS11000) showed current fungicides used in strawberry fruit production for control of *Botrytis cinerea* can reduce the incidence of stem-end rot disease. Also, studies by Mattner et al, (HIA Limited Project BS07014) showed that the current fungicide registered for control of *Colletotrichum* spp. (prochloraz) could also reduce leaf blotch in strawberry nurseries. However, there is currently no registered control for *G. fructicola* in strawberry runner or fruit production in Australia.

Prior to the commencement of this project, industry did not have sufficient access to fungicides for effective control of powdery mildew. Growers in the strawberry nursery and fruit sectors were using the same fungicides, and were limited in the number of sprays they could apply per season due to the single-site or specific mode of action of the fungicide against the target pathogen. Although systemic fungicides are generally more effective than protectant fungicides, the over-reliance or repeated use in successive strawberry nursery and fruit production sectors risks the build-up of chemical resistance in the powdery mildew fungus. Fungicide resistance is when the effectiveness of a fungicide is reduced or no longer achieved when used as directed (CropLife Australia 2015). The industry as a whole was placing tremendous pressure on these chemicals to control powdery mildew.

Strawberry runners infected with or carrying *P. aphanis* may serve as a source of primary inoculum for powdery mildew on fruit farms (Peres and Mertely 2013). Studies by Mattner et al. (HIA Limited project BS07014) showed that *G. fructicola* can be present in symptomless petioles of strawberry runners. Infected runners from nurseries can spread *G. fructicola* to fruit production farms (Hutton 2009). Both pathogens were also listed as high priority in the recent 2016 Strawberries Strategic Agrichemical Review Process (HIA Limited project MT10029). For these reasons, the addition of effective disease management options in runner nurseries is essential to minimise disease problems in the nurseries and fruit farms. Furthermore, the development of a coordinated use strategy of fungicides with different modes of action between nursery and fruit production sectors is important to reduce the risk of resistance developing in the pathogens; and thereby extend the useful life of current registered fungicides. The coordination of fungicide use across strawberry nursery and fruit sectors may help guide future chemical use and registration of new products to manage chemical resistance in pathogens.

In this project, several fungicides and biorationals with different modes of action were assessed for their efficacy, including different spray programs of the most promising treatments, against *P. aphanis* and *G. fructicola* in strawberry runner nurseries over three years. Biorational is a term given to products that are relatively non-toxic to humans and have low impact on the environment (Grubinger 2016). This includes oils, soaps, microbial, minerals and botanicals/plant extracts. We also report on the efficacy of fungicides against *G. fructicola* in a study using symptomless strawberry petioles.

Methodology

Trial sites and cultivars

Field trials were conducted at strawberry runner nurseries in Queensland and Victoria over three years. Plants were grown to coincide with the runner growing seasons in 2013-14 (Year 1), 2014-15 (Year 2) and 2015-16 (Year 3). In Year 1 of the project, trials were held at two nurseries in Queensland and at three sites in Victoria. In Years 2 and 3, trials were held at the same locations in Queensland, and at two of the same locations in Victoria.

The strawberry cultivar 'Rubygem' was planted at both Queensland sites in Years 1 and 2. In Year 3, 'Rubygem' was planted at one Queensland site, and the cultivar 'Festival' at the other. In Victoria, the strawberry cultivar 'Monterey' was planted at two sites and 'Albion' on the third site in Year 1. In Year 2 in Victoria, 'Monterey' and 'Albion' were used, while in Year 3, 'Monterey' and 'Festival' were used. 'Rubygem' and 'Albion' were chosen due to anecdotal reports that the cultivar is susceptible to powdery mildew. Similarly, 'Monterey' was used due to anecdotal reports that it is susceptible to leaf blotch. In Year 3, 'Festival' was planted at one Queensland and one Victorian nursery to compare the efficacy of treatments using a standard cultivar grown at different locations. The strawberry runners were grown outdoors under standard horticultural agronomy for strawberry runner production and without additional application of fungicides.

Treatments

In Year 1 of the project, we compared the previous standard program for control of powdery mildew in strawberry nursery crops (rotation of sulphur, myclobutanil and trifloxystrobin), with eleven treatments including a protectant sulphur treatment and an untreated control (Table 1). We also assessed the treatments for control of leaf blotch compared with the untreated control (Table 2).

In Year 2, we compared the previous standard program for control of powdery mildew (as described above) with eight spray programs based on the use of the most promising treatments from Year 1 (quinoxyfen, bupirimate and cyflufenamid) (Table 3). A protectant sulphur treatment and an untreated control were also included in the trials. For leaf blotch, the most promising fungicides in Year 1 (azoxystrobin+difenoconazole, prochloraz and chlorothalonil) were further evaluated by reducing the applications from weekly (as in Year 1) to fortnightly, compared with an untreated control (Table 4). Chemical treatments for leaf blotch also included assessing the two components in azoxystrobin + difenoconazole separately. In Year 2, the trials also evaluated four biorational fungicides: potassium bicarbonate+potassium silicate, *Bacillus amyloliquefaciens*, a plant extract from sweet lupin (*Lupinus albus*), and a biorational experimental product.

In Year 3, we compared standard nursery fungicide programs for powdery mildew and leaf blotch with six alternative spray programs based on the most effective treatments in Years 1 and 2 (Tables 5 & 6). The first nursery standard (Standard program #1) is based on Queensland runner growers' rotation of sulphur, myclobutanil, trifloxystrobin, prochloraz and cyprodinil+fludioxonil. Prochloraz and cyprodinil+fludioxonil are registered for control of *Colletotrichum* spp., not for leaf blotch. The second standard program (Standard program #2) is based on Victorian runner growers' rotation of sulphur, myclobutanil, trifloxystrobin, prochloraz and azoxystrobin+difenoconazole (Victoria's state guidelines allow for this product to be used off-label). In Year 3, the project also evaluated three individual fungicides and three biorationals (Tables 5 & 6).

Experimental plots

Ten mother plants were planted in plots of 5 meter length in the nursery. One meter guard plots were placed between plots. In consultation with a biometrician, the plots were arranged in a randomised block design with four replicates of each treatment. Treatments were applied weekly using a knapsack sprayer. The trials in the strawberry nurseries relied on natural infection of powdery mildew and leaf blotch. As the season progresses the area of the spray plots size increased due to the developing runners. Treatments were applied using the maximum rate as per label or as recommended by participating crop protection companies. Plants were sprayed to the point of run-off. The start and end dates of the trial coincided with the runner season, and were coordinated with the participating runner growers.

Data collection

Data on disease incidence (% of leaves affected by powdery mildew or leaf blotch) was collected on runner crops at the end of the trial period. Runners assessed were within the inner-most area of 5m x 1m of the plot. In Year 1, one hundred trifoliate leaves per plot were randomly assessed in Queensland, and fifty trifoliate leaves per plot were randomly assessed in Victoria. In Years 2 and 3, one hundred trifoliate leaves per plot were randomly assessed from all trial sites. Powdery mildew symptoms include; leaf curling, white powdery fungal growth on the underside of the leaf, and purple to reddish blotches on both sides of the leaf. Leaf blotch symptoms usually begin as circular reddish-purple spots and gradually develop into large necrotic areas. Small, black fruiting bodies may also appear. Data was also taken on incidence of diseased plants (% of diseased plants) and disease severity (disease rating and area of leaf affected by disease). However, results for these parameters showed similar patterns to disease incidence of leaves and are not included in this report.

Laboratory studies

In Year 1, twenty symptomless petioles were randomly collected from all plots at the end of the trial period in Queensland (Table 7). In Year 2, fifty symptomless petioles from all plots and sites treated with fungicides for control of leaf blotch and biorational products were randomly collected (Table 8). In Year 3, fifty symptomless petioles were randomly collected from all treatments and sites, except the Sulphur treatment. Sections of petiole samples were surface sterilised (1% sodium hypochlorite) and plated onto potato dextrose agar amended with streptomycin and incubated for ten days. The incidence of *G. fructicola* isolated from the petioles (%) was recorded.

Data analysis

Trial sites were analysed separately. Disease incidence at each site was analysed using an arcsin transformation. Treatment means were back-transformed for presentation. Laboratory data were analysed using standard analysis of variance (ANOVA).

Project steering committee

A project steering committee was established to oversee the work required to achieve project objectives. Four project steering group meetings were held during the project, at least once each year, to guide the research and enhance the communication of outputs/new knowledge to the industry representatives. The Project Steering Committee consisted of three runner growers, one Strawberries

Australia representative, and representatives from HIA Limited, VSICA and DAF.

The runner growers were:

- Ian Mungall - Red Jewel Nursery
- Wally Sweet - Sweets Strawberry Runners
- George Weda - Toolangi Certified Strawberry Runner Growers Cooperative (TCSRGC)

Other committee members were:

- Nathan Roy (Strawberries Australia)
- Jodie Pedrana (HIA Limited/minor-use coordinator)
- Ben Callaghan (HIA Limited)
- Bradley Mills (HIA Limited)
- Mirko Milinkovic (VSICA)
- Frank Greenhalgh (VSICA)
- Di Davies (TCSRGC)
- Scott Mattner (VSICA) co-chaired each meetings and provided comments and technical input
- Apollo Gomez (DAF) co-chaired each meetings and provided comments and technical input

International Strawberry Symposium

Travel to Quebec City, Canada was undertaken to attend and present results from this project at the 8th International Strawberry Symposium organised under the auspices of International Society for Horticultural Science. The project leader gave an oral presentation on the overview and some preliminary results of the project. A copy of the travel report published in the national industry newsletter, Simply Red, is included in the Output section of this report.

Outputs

1. Publications

Gomez A (2014) Integrated approach for controlling foliar diseases in strawberry runner nurseries and managing chemical resistance. Horticulture Australia Limited Strawberry Industry Annual Report, p. 3.

Gomez A (2017) International Strawberry Symposium – From a Plant Pathology Perspective. Simply Red (Strawberry Innovation) 45: 6-7

Gomez A & Mattner S (2014) Addressing fungicide resistance and providing better control of powdery mildew and leaf blotch. Simply Red (Queensland Strawberry Industry Promotions Council) 34:7

Gomez A & Mattner S (2014) Addressing fungicide resistance and providing better control of powdery mildew and leaf blotch – Project update. Simply Red (Queensland Strawberry Industry Promotions Council) 35:8-9

Gomez A & Mattner S (2015) Addressing fungicide resistance and providing better control of powdery mildew and leaf blotch – Project update. Simply Red (Queensland Strawberry Industry Promotions Council) 37:6-7

Gomez A & Mattner S (2015) Fungicide resistance: How to better control powdery mildew and leaf blotch. Runner Round (VSICA) November 2015, p 4-5

Gomez A, Mattner S, Oag D, Nimmo P, Milinkovic M & Horstra C (2015) Protecting fungicide chemistry used in Australian strawberry production for better control of powdery mildew and leaf blotch – Simply Red (Queensland Strawberry Industry Promotions Council) 40:6-8

Gomez AO & Mattner SW (2015) Control of foliar diseases in Australian Strawberry Runner Nurseries. Proceedings of 20th Australasian Plant Pathology Society Conference, Fremantle, 14-16th September 2015, p.134 (Abstract)

Gomez A, Mattner S, Oag D, Nimmo P & Milinkovic M (2016) Sustainable control of powdery mildew and leaf blotch by using different fungicides for runner and fruit production. Simply Red (Strawberry Innovation) 42:6-7

Gomez A, Mattner S, Oag D, Nimmo P & Milinkovic M (2017) Industry-wide fungicide coordination for control of powdery mildew and leaf blotch. Simply Red (Strawberry Innovation) 45: 1-2

Mattner S & Gomez A (2015) Fungicide resistance: How to better control powdery mildew and leaf blotch. Runner Round Newsletter (Victorian Strawberry Industry Certification Authority)

2. Seminars/presentations

Project presentations at industry meetings and conferences/symposiums:

- David Oag - Applethorpe, Queensland July 2014
- Apollo Gomez – Glasshouse Mountains, Queensland October 2014
- Scott Mattner – Toolangi, Victoria November 2014

- Apollo Gomez – Applethorpe, Queensland June 2015
- Apollo Gomez – 20th Australasian Plant Pathology Conference, Fremantle September 2015
- Apollo Gomez – Glasshouse Mountains, Queensland October 2015
- Scott Mattner – Toolangi, Victoria November 2015
- Apollo Gomez – 8th International Strawberry Symposium, Quebec City August 2016
- Apollo Gomez – Glasshouse Mountains October 2016
- Scott Mattner – Toolangi, Victoria November 2016
- Scott Mattner – Toolangi, Victoria December 2016
- Apollo Gomez – Caboolture, Queensland February 2017

3. Project steering committee meetings/workshops

Four project steering group meetings were held during the project, at least once each year, to guide the research and enhance the communication of outputs/new knowledge to the industry representatives (runner growers, Strawberries Australia representative and Hort Innovation).

- May 2014, Horticulture Australia Limited Boardroom, Brisbane, Queensland
- August 2014, DAF Maroochy Research Facility, Nambour, Queensland
- September 2015, DAF Maroochy Research Facility, Nambour, Queensland
- October 2016, Qantas Meeting Room, Melbourne Airport, Victoria

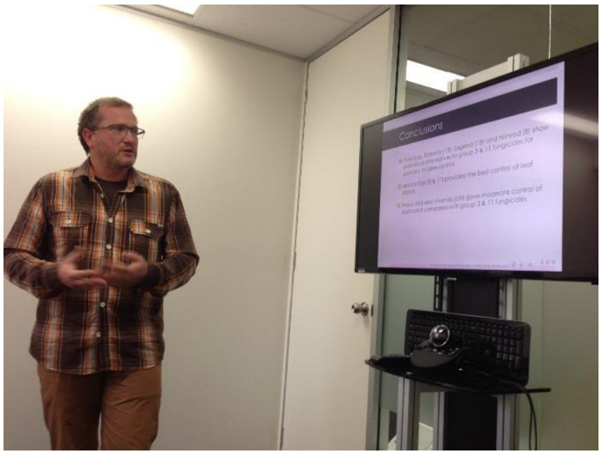

Fig 1. Project collaborator and co-chair Scott Mattner presenting an overview of the project during the May 2014 steering committee meeting

Fig 2. Ben Callaghan, from Horticulture Innovation Australia Limited, addressing the members of steering committee in September 2015

Fig 3. Discussions during the October 2016 project steering committee meeting

4. Minor-use Permits

Data from the trials supported the following/pending minor-use permit applications:

- PER80543 – Permit to allow **bupirimate** for control of powdery mildew in strawberry runner production
- PER 80670 – Permit to allow **cyflufenamid** for control of powdery mildew in strawberry runner production
- A minor-use permit application for fluazinam on behalf of the strawberry runner growers was submitted to the Australian Pesticides and Veterinary Medicines Authority (APVMA) in January 2017 using data from the trials. A decision is expected by September 2017.

5. Annual trial reports

Results on the effectiveness of treatments were shared to participating crop protection companies. Field trials reports were provided every year at the end of trial period.

Field trial reports were submitted to:

- 2014

Adama Australia

Agnova Technologies

BASF Australia

Bayer Crop Science

Dow AgroSciences Australia

DuPont Crop Protection Australia

Syngenta Australia

Fig 4. Scott Mattner with Lauren O'Connor, from Syngenta, inspecting field trials in Victoria

- 2015

Biofilm Crop Protection

FMC Australasia

Nufarm Australia

Organic Crop Protectants

Syngenta Australia

- 2016

Adama Australia

Agnova Technologies

Nufarm Australia

Organic Crop Protectants

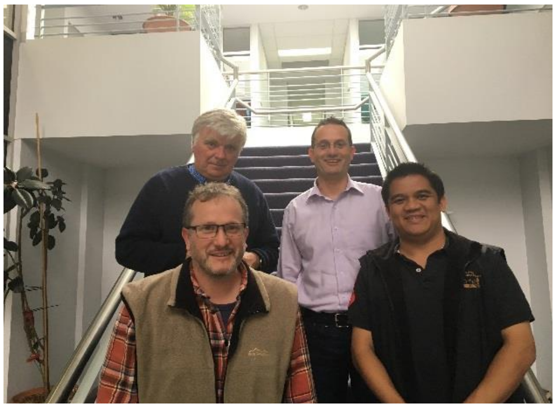

Fig 5. Scott Mattner (front, left) and Apollo Gomez (front, right) with Doug Wilson, Agnova Technical Consultant (back, left) and Anthony De Monte, Agnova Development Manager (back, right)

6. Report on the 8th International Strawberry Symposium

- Copy of Report submitted for publication in the national industry newsletter, Simply Red, March 2017

International Strawberry Symposium – from a Plant Pathology Perspective

Apollo Gomez, Department of Agriculture and Fisheries, Nambour

Just over six months ago, I attended the 8th International Strawberry Symposium in Quebec City, Canada. There were about 650 delegates and over 200 keynotes lectures, orals and posters presented at the meeting.

I presented a paper on our work addressing the risks of fungicide resistance in controlling diseases in strawberry nurseries. From the results of this work, Australian nurseries have access to new fungicides to control powdery mildew and are able to minimise the reliance on the fungicides fruit growers use in the field. This should help reduce the risk of fungicide resistance developing in the disease causing fungus. Pathologists and nursery growers at the symposium supported the idea of having separate fungicides in nurseries and fruit farms.

Fungicide resistance is not only an issue in Australia, resistance has also been reported in strawberry fields in North America. This is perhaps due to the fragmented system that occurs internationally, where a fruit grower in Canada, for example, can have transplants from the US, the Netherlands, or Spain etc., and have no knowledge of the fungicides that were applied in the nurseries of those countries. Our "closed" system in Australia allows us to co-ordinate the use of fungicides across the whole industry.

Pathologists and runner growers from North America were also envious of Australia's access to prochloraz fungicide, which is registered for use in our nurseries against *Colletotrichum* spp. They do not have access to this fungicide in North America.

Below are some of the other key topics from the symposium relevant to strawberry pathology:

- Additional silicon fertiliser appears to aid management of powdery mildew. Silicon must be absorbed through the roots, rather than the leaves for best results.
- Biological fungicides (e.g. laminarin and potassium bicarbonate) can be integrated in a chemical program to assist control of powdery mildew. However they do not give sufficient control under high disease pressure or when used without chemical application.
- Steam fumigation, as a non-chemical alternative, has been effective in some situations against weeds and soil borne pests, such as *Pythium* sp. and *Macrophomina phaseolina* (*M. phaseolina)*, and sometimes reduced yield losses of up to 20%.
- Breeding strawberry plants for resistance to diseases, especially soil-borne disease such as charcoal rot (causal agent *M. phaseolina*) is considered important by most international breeding programs.
- Overseas, some *M. phaseolina* isolates collected from different crops (e.g. melons, almond and protea) can infect strawberry plants, suggesting that other crops may be alternative hosts of the pathogen.
- Although fumigant alternatives to methyl bromide sometimes reduced the incidence of charcoal rot compared with the non-treated control, the results were not consistent. This was attributed

to the alternative fumigants not moving well in the soil profile, unlike methyl bromide which moves readily.

- Bumblebees have been used to help protect fruit against grey mould, by spreading spores and mycelium of *Glidocladium catenulatum* to the flowers of strawberry plants.
- New diseases of strawberry reported in Europe:
  - *Erwinia pyrifoliae*, a bacteria which causes intense blackening of immature fruits, calyxes and stems, and bacterial ooze on fruit surfaces. Found mainly in greenhouses.
  - *Pestalotiopsis* sp. a fungus recovered from wilting plants, along with *Phytophthora* sp. *Pestalotiopsis* sp. was artificially inoculated onto healthy strawberry plants with the pathogen confirmed as the causal agent.

Future considerations

A number of presentations on strawberry powdery mildew and charcoal rot demonstrates world-wide interest in these diseases. Breeding against pathogens, evaluating alternative controls, including non-chemical agents, cultural practices, and regular monitoring of pest and diseases are important for disease management.

Breeding for disease resistance is important for efficient disease management in the longer term. The Australian National Strawberry Breeding Program (Hort Innovation project BS12021) already evaluates lines from both temperate and sub-tropical production regions for resistance to the crown rot pathogens *Fusarium* sp., *Colletotrichum* sp. and *M. phaseolina*. There is also the potential to expand this to other diseases in the future.

On-going efficacy studies of alternative fungicides and biorational fungicides/products for management of plant and crown rot diseases would benefit the Australian strawberry industry. As new chemistries and products become available, identification of effective alternative options will help manage diseases in nurseries and fruit farms. Co-ordination of fungicide use across both sectors of production can help guide future chemical use and registration of new products.

Charcoal rot, caused by *M. phaseolina*, will continue to be a threat in Australia. In addition to breeding for resistance and looking for effective controls, investigation of alternative farm practices and alternative host sources would assist to better manage this disease.

Finally, it is important to have on-going monitoring of current diseases and for the presence of emerging diseases that may pose a threat to our industry. This includes testing for resistance of causal fungi to current fungicides.

Conclusion

The symposium provided an excellent opportunity to link with other strawberry researchers working on similar issues worldwide. New systems and tools have been identified with the potential to help address current issues and plan for future needs of the Australian industry, e.g. alternative approaches to chemical control against strawberry diseases. These have the potential to impact directly on the efficiencies and profitability of the national industry.

Acknowledgements

This project has been funded by Horticulture Innovation Australia Limited (BS13004) with co-investment from Red Jewel Nursery, Sweets Strawberry Runners and the Toolangi Certified Strawberry Runner Growers Co-operative and funds from the Australian Government as well as the Department of Agriculture and Fisheries.

If you would like more information, please contact Apollo Gomez at DAF Nambour on 07 5381 1300.

Fig 6. Apollo Gomez at the International Strawberry Symposium (left), and presenting a paper (right)

Fig 7. Strawberry nursery farm in Montreal

Fig 8. Strawberry fruit farm in Montreal

Outcomes

Results

Year 1 (2013-14)

At the end of the trial period, bupirimate, cyflufenamid, quinoxyfen, azoxystrobin+difenoconazole, proquinazid and the standard program were effective against powdery mildew compared with the untreated control (Table 1). Quinoxyfen and cyflufenamid were equally effective as the standard powdery mildew program across all trial sites. Metrafenone, prochloraz, chlorothalonil and spiroxamine were not effective or consistent against powdery mildew at all trial sites. Sulphur, which is used as a protectant, also did not consistently control powdery mildew.

Azoxystrobin+difenoconazole was the most effective treatment against leaf blotch at three trials sites in Victoria, followed by prochloraz and chlorothalonil (Table 2). Most of the other treatments either provided intermediate control or were ineffective against leaf blotch.

Table 1. Effect of different fungicides tested in Year 1 (2013-14) on the incidence of powdery mildew

Treatments	Powdery mildew incidence (%)			
	Qld 1	Qld 2	Vic 1	Vic 3
Untreated control	45 a	60 a	30 a	37 a
Sulphur	25 bcd	44 b	22 abc	36 a
PM Standard Program	11 ef	19 de	11 def	8 i
Quinoxyfen	19 bcdef	17 de	12 cdef	12 ghi
Proquinazid	23 bcde	18 de	8 ef	14 fgh
Bupirimate	13 def	12 e	8 ef	19 efg
Cyflufenamid	10 f	16 e	6 f	9 hi
Metrafenone	29 abc	29 cd	17 bcde	33 ab
Prochloraz	30 abc	40 bc	21 abcd	27 bc
Azoxystrobin+difenoconazole	18 cdef	11 e	13 cdef	19 def
Chlorothalonil	19 bcdef	42 bc	28 ab	26 bcd
Spiroxamine	34 ab	48 ab	14 cdef	24 cde

(PM) in strawberry nurseries in Queensland (Qld) and Victoria (Vic)

Values followed by different letters in each column are significantly different, where $p < 0.05$. Note. Vic 2 had low disease incidence and was not included in the analysis.

The effect of the fungicides on powdery mildew across different environments and cultivars was highly consistent and enabled us to develop treatment programs to evaluate in Year 2. Effective products further evaluated in Year 2 included bupirimate, cyflufenamid, quinoxyfen, azoxystrobin+difenoconazole, prochloraz and chlorothalonil. Quinoxyfen and proquinazid belong to the same group of fungicides (Group 13). Although effective against powdery mildew, the project steering committee decided to cease evaluation of proquinazid due to quinoxyfen being granted a minor-use permit for strawberry runners in early in 2014. Signs of phytotoxicity on the underside of strawberry leaves were observed in some plots treated with chlorothalonil. However, this was only observed at one trial site in Queensland, and was not consistent on all plots treated with chlorothalonil. HIA Limited project BS11000 reported white residues on strawberry plants in plots sprayed with weekly applications of chlorothalonil. For Year

2, the project steering committee decided to evaluate reduced applications (from weekly in Year 1 to fortnightly in Year 2) of leaf blotch treatments, including chlorothalonil. Spiroxamine and metrafenone were not effective or consistent against both diseases and the project steering committee decided to cease evaluation of these chemistries.

Table 2. Effect of different fungicides tested in Year 1 (2013-14) on the incidence of leaf blotch in Victorian (Vic) strawberry nurseries

Treatments	Leaf blotch incidence (%)		
	Vic 1	Vic 2	Vic 3
Untreated control	31 a	7 ab	28 a
Sulphur	21 bc	4 bc	22 ab
PM Standard Program	14 d	4 bc	19 abc
Quinoxyfen	26 ab	4 bc	21 ab
Proquinazid	22 bc	5 bc	19 abc
Bupirimate	21 bc	5 bc	16 bc
Cyflufenamid	22 bc	13 a	16 bc
Metrafenone	16 cd	2 cd	13 bc
Prochloraz	8 e	0.1 de	11 c
Azoxystrobin+difenoconazole	0.6 f	0 e	3 d
Chlorothalonil	12 de	3 bcd	11 c
Spiroxamine	22 bc	5 bc	21 ab

Values followed by different letters in each column are significantly different, where $p < 0.05$. Note. Queensland trial sites had very low incidence and were not included in the analysis.

Year 2 (2014-15)

Powdery mildew incidence in Year 2 was high at three sites. At the end of the trial period, results from all trial sites generally showed that the alternative spray programs based on several combinations of the effective fungicides found in Year 1 provided equivalent or better for control of powdery mildew compared with the current standard program (Table 3). At Vic 1, however, alternative programs 1 and 5 had a higher incidence of powdery mildew than the standard program. Alternative program 6, which contains all three effective fungicides from Year 1 were equally as effective as the PM standard program at all trial sites. The biorationals investigated did not consistently control powdery mildew across all trial sites, or recorded high disease incidence when applied alone throughout the season.

Leaf blotch pressure was low at three out of the four trial sites. Where disease occurred (Vic 1), difenoconazole provided equivalent control of leaf blotch to azoxystrobin+difenoconazole (Table 4). Azoxystrobin, chlorothalonil and prochloraz were equally effective against leaf blotch, but did not control the disease to the same level as azoxystrobin+difenoconazole. Also, based on this trial, changing the frequency of application from weekly (Year 1) to fortnightly (Year 2) showed no evidence of reducing the effectiveness of the fungicides against leaf blotch.

There were no phytotoxicity effects observed when treatments in Year 2 were applied fortnightly on strawberry runners.

Table 3. Effect of different fungicide programs and biorationals tested in Year 2 (2014-15) on the incidence of powdery mildew (PM) in Queensland (Qld) and Victoria (Vic)

	Powdery Mildew incidence (%)			
Treatments	Qld 1	Qld 2	Vic 1	Vic 2
Untreated control	88 a	80 ab	65 a	24 a
Sulphur	72 cde	68 bc	54 abcd	20 a
PM Standard	58 ef	53 def	31 h	10 cde
Alt. program 1 - PM Standard# with quinoxyfen	63 def	49 ef	48 def	9 de
Alt. program 2 - PM Standard* with bupirimate and quinoxyfen	50 fg	53 def	36 gh	10 cde
Alt. program 3 - Sulphur, bupirimate and quinoxyfen rotated	36 g	42 f	35 gh	6 e
Alt. program 4 - Sulphur, cyflufenamid and quinoxyfen rotated	55 f	44 f	32h	4 e
Alt. program 5 - Sulphur, bupirimate and cyflufenamid rotated	55 f	44 f	43efg	5 e
Alt. program 6 - Sulphur, bupirimate, cyflufenamid and quinoxyfen rotated	50 fg	53 def	38 fgh	11 cde
Potassium bicarbonate+potassium silicate	85 ab	66 bcd	52 cde	25 a
Bacillus amyloliquefaciens	79 abc	69 bc	58 abcd	22 a
NUL3074	73 bcd	74 ab	60 abc	19 abc
Extract from sweet lupin	84 abc	84 a	64 ab	20 ab

Values followed by different letters in each column are significantly different, where $p < 0.05$. # - Alt. program 1 was based on current PM Standard, and with only one application of trifloxystrobin. * Alt. program 2 was based current PM standard, but only one application each of trifloxystrobin and myclobutanil.

Table 4. Effect of different fungicides and biorationals tested in Year 2 (2014-15) on the incidence of leaf blotch

Treatment	Vic 1
Untreated control	31 a
Prochloraz	10 cd
Azoxystrobin+difenoconazole	1 e
Azoxystrobin	8 cd
Difenoconazole	3 de
Chlorothalonil	10 cd
Potassium bicarbonate+potassium silicate	17 bc
Bacillus amyloliquefaciens	25 ab
NUL3074	31 a
Extract from sweet lupin	28 ab

Values followed by different letters in each column are significantly different, where $p < 0.05$. Note. Three other sites had very low incidence and were not included in the analysis.

Based on the results of the project, two of the effective fungicides found in Year 1, bupirimate and cyflufenamid, were granted minor-use permits in 2015. In addition to quinoxyfen, runner growers in Queensland and Victoria have three new permitted products for control of powdery mildew.

The steering committee group decided to conduct research in Year 3 to evaluate spray programs containing the most promising fungicides for control of both powdery mildew (bupirimate, cyflufenamid, and quinoxyfen) and leaf blotch (azoxystrobin+difenoconazole, difenoconazole, prochloraz and chlorothalonil). In addition, the committee supported research to evaluate other stand-alone fungicides and biorationals against the diseases.

Year 3 (2015-16)

The alternative programs (1-6) incorporated several combinations of the more effective treatments from Years 1 and 2 against both powdery mildew and leaf blotch. At the end of the trial period, alternative program 1-5 were generally as good as the two nominated standards for Queensland and Victoria, and/or reduced diseases to low levels (Tables 5 and 6).

Alternative program 6 substituted sulphur for potassium bicarbonate+potassium silicate. The treatment did not control powdery mildew as well as the two nominated standard treatments. For leaf blotch, the treatment was as efficacious as the Standard program #1, but not as effective as the Standard program #2. When used as stand-alone, potassium bicarbonate+potassium silicate was inconsistent across all sites against powdery mildew and leaf blotch.

Table 5. Effect of different fungicide programs and biorational fungicides tested in Year 3 (2015-16) on the incidence of powdery mildew (PM) in Queensland (Qld) and Victoria (Vic)

Treatment	Qld 1	Qld 2	Vic 1
Untreated control	26 a	36 a	8 a
Sulphur	15 b	28 ab	6 a
PM Standard program #1, prochloraz and cyprodinil+fludioxonil	0 h	10 fg	1 c
PM Standard program #2, prochloraz, azoxystrobin+difenoconazole	3 fgh	11 fg	1 c
Alt. program 1 – New PM* program, prochloraz and chlorothalonil	5 defg	8 g	1 c
Alt. program 2 – New PM* program, azoxystrobin+difenoconazole and chlorothalonil	1 h	11 efg	1 c
Alt. program 3 – New PM* program, difenoconazole and chlorothalonil	3 fgh	12 efg	1 c
Alt. program 4 – New PM* program, azoxystrobin+difenoconazole, prochloraz and chlorothalonil	3 efgh	9 fg	1 bc
Alt. program 5 – New PM* program, prochloraz, chlorothalonil and fluazinam	1 fgh	12 efg	2 bc
Alt. program 6 – New PM* program, potassium bicarbonate+potassium silicate prochloraz and chlorothalonil	10 bcde	21 bc	1 c
AGN-014	2 fgh	14 def	6 a
Fluazinam	2 fgh	17 cde	6 a
Dithianon	11 bcd	21 bc	7 a
NUL 3195	6 cdef	19 cd	5 ab
NUL 3132	12 bc	32 a	6 a
Potassium bicarbonate + potassium silicate	10 bcde	19 cd	5 ab

Values followed by different letters in each column are significantly different, where $p < 0.05$. Note. Vic 2 had very low incidence and were not included in the analysis. * - New PM program includes rotation of bupirimate, cyflufenamid and bupirimate only.

Experimental product AGN-014 and fluazinam were as effective against powdery mildew as the Standard programs in Queensland, but not in Victoria. Fluazinam also controlled leaf blotch compared with untreated plants, and was as effective as Standard program #1 when applied in a spray program 5 with other fungicides. In contrast, AGN-014 did not consistently control leaf blotch when applied on its own.

Dithianon was not as effective against powdery mildew as the standard treatments and only provided intermediate control compared with the untreated plants. It also did not consistently control leaf blotch.

The experimental biorational products, NUL3195 and NUL3132, were not effective or inconsistent against powdery mildew when sprayed alone throughout the season, but consistently controlled leaf blotch compared with untreated plants.

There were no phytotoxicity effects observed when treatments in Year 3 were applied on strawberry runners.

Table 6. Effect of different fungicide programs and biorational fungicides tested in Year 3 (2015-16) on the incidence of leaf blotch in Queensland (Qld) and Victoria (Vic).

Treatment	Qld 1	Qld 2	Vic 1	Vic 2
Untreated control	25 a	6 a	10 a	9 a
Sulphur	18 ab	5 ab	8 ab	9 ab
PM Standard program #1, prochloraz and cyprodinil+fludioxonil	6 def	1 efg	2 def	2 f
PM Standard program #2, prochloraz, azoxystrobin+difenoconazole	2 f	1 efg	0 g	0 h
Alt. program 1 – New PM program, prochloraz and chlorothalonil	6 def	1 efg	3 def	2 f
Alt. program 2 – New PM program, azoxystrobin+difenoconazole and chlorothalonil	6 def	2 cdef	1 ef	0 h
Alt. program 3 – New PM program, difenoconazole and chlorothalonil	8 cd	3 bcde	2 def	1 fg
Alt. program 4 – New PM program, azoxystrobin+difenoconazole, prochloraz and chlorothalonil	7 def	2 bcdef	1 fg	0 h
Alt. program 5 – New PM program, prochloraz, chlorothalonil and fluazinam	9 cd	1 fg	2 def	3 def
Alt. program 6 – New PM program, potassium bicarbonate+potassium silicate, prochloraz and chlorothalonil	8 cd	1 fg	2 def	2 ef
AGN-014	14 bc	2 bcdef	7 abc	4 cde
Fluazinam	3 ef	0 g	5 bcd	5 cd
Dithianon	13 bcd	4 abc	7 abc	6 bc
NUL 3195	10 cd	3 bcde	4 cd	5 cd
NUL 3132	14 bc	0 g	4 cde	3 cdef
Potassium bicarbonate + potassium silicate	12 bcd	3 abcd	3 def	2 ef

Values followed by different letters in each column are significantly different, where $p < 0.05$.

There is potential for chlorothalonil as a component of spray program to control leaf blotch in strawberry runner production. Its value is that it introduces a different chemical group for control of the disease. In 2015 however, chlorothalonil was nominated and is currently under review by the APVMA. The project steering committee agreed than an assessment regarding a potential permit for chlorothalonil will be made when more information on the review becomes available.

Potassium bicarbonate on its own is currently registered on strawberry against powdery mildew. Based on results from this project, the co-formulation of potassium bicarbonate+potassium silicate was not consistent across four trial sites for control against powdery mildew. During application, it was found that the product did not mix well with water as nozzles and filters sometimes became blocked. It is possible that this explains its inconsistent efficacy in the current studies.

Isolation of G. fructicola

In Year 1, the fungus that causes leaf blotch (*G. fructicola*), was only recovered from one site (Table 7). There were no significant differences in the isolation of *G. fructicola* from symptomless petioles. However, the fungus was not recovered at all from the samples treated with the chemicals (e.g. azoxystrobin+difenoconazole, prochloraz and chlorothalonil) that controlled leaf blotch in the field.

In Year 2, *G. fructicola* fungus was only isolated from symptomless petioles collected from trials in Victoria (Table 8). Results showed the plots sprayed with the effective treatments against leaf blotch in Year 1, azoxystrobin+difenoconazole, prochloraz and chlorothalonil, had very low to nil isolations *of G. fructicola* from symptomless petioles. Furthermore, the plots sprayed with azoxystrobin and difenoconazole also had no isolation of *G. fructicola* from symptomless petioles. *G. fructicola* was isolated from symptomless petioles treated with the biorational products, with the exception of the nil isolation from petioles treated with experimental product NUL3074 in Vic 2.

In Year 3, there was very low to nil *G. fructicola* isolated from all four trial sites (not presented).

Table 7. Effect of different fungicides on isolations of *G. fructicola* from symptomless petioles in Year 1

Treatment	*G. fructicola* (%) from Qld 2
Untreated Control	10.4
Sulphur	2.9
PM Standard Program	3.7
Quinoxyfen	9.1
Proquinazid	3.2
Bupirimate	1.0
Cyflufenamid	8.7
Metrafenone	2.6
Prochloraz	0
Azoxystrobin+difenoconazole	0
Chlorothalonil	0
Spiroxamine	6.7

Values followed by different letters in each column are significantly different, where $p < 0.05$. Other trial sites had very low recovery of *G. fructicola* and were not included in the analysis.

Table 8. Effect of different fungicides on isolations *G. fructicola* from symptomless petioles in Year 2

	G. fructicola (%)	
Treatments	Vic 1	Vic 2
Untreated Control	18.4 a	4.1 ab
Prochloraz	1.7 bc	0 c
Azoxystrobin+difenoconazole	0.1 c	0 c
Azoxystrobin	0 c	0 c
Difenoconazole	0 c	0 c
Chlorothalonil	0 c	0 c
Potassium bicarbonate+potassium silicate	10.9 ab	2.9 bc
B. amyloliquefaciens	15.6 a	4.9 ab
NUL3074	12.3 a	0 c
Extract from sweet lupin	23.9 a	7.8 a

Values followed by different letters in each column are significantly different, where $p < 0.05$.
Queensland trial sites had very low to nil recovery of *G. fructicola* and were not included in the analysis.

Outcomes

The key outcome resulting from this project is that the strawberry industry can now implement a coordinated strategy between nursery and fruit sectors to reduce the risk of fungicide resistance developing in major foliar pathogens. The strategy relies on the use of different fungicide chemistries in the nursery and fruit sectors for the control of powdery mildew and leaf blotch. The fungicide programs now used in the nursery sector against these diseases were first identified, and permits developed, from research in this project.

Three minor-use permits were recently granted by the APVMA specific to strawberry runner production:

- PER14577 – Permit to allow quinoxyfen for control of powdery mildew in runner production
- PER80670 – Permit to allow cyflufenamid for control of powdery mildew in runner production
- PER80543 – Permit to allow bupirimate for control of powdery mildew in runner production

Two of the minor-use permits, (PER80670 and PER80543), were supported by data from this project. Quinoxyfen was granted a minor-use permit not long after the commencement of the project after discussions between industry and the chemical company. Results from this study supported quinoxyfen being effective against powdery mildew in strawberry runners. A minor-use permit application is currently pending for fluazinam against leaf blotch for the strawberry nursery sector only. Results from this project were used to support the application. In the future, runner growers may also choose to pursue a minor-use permit for chlorothalonil using data from the current project, depending on the outcome of the APVMA review on chlorothalonil.

Evaluation and Discussion

Discussion

A series of experiments were conducted over three years to investigate the efficacy of fungicides to control powdery mildew and leaf blotch in strawberry nurseries in Australia. The study found several fungicides with different modes of action that were effective against the diseases. This is significant as both nursery and fruit sectors of the strawberry industry were previously reliant on fungicides containing myclobutanil and trifloxystrobin against powdery mildew. Bupirimate, cyflufenamid and quinoxyfen are now permitted for use against powdery mildew specifically for strawberry runner production in Australia.

Research in the literature also supports the efficacy of recently permitted fungicides against strawberry powdery mildew. A study in Taiwan demonstrated bupirimate was effective in the control of powdery mildew in the nursery, and that use of bupirimate during harvest was not recommended (Leu et al. 1990). In Florida, quinoxyfen was effective in reducing foliar colonization of powdery mildew in strawberry (Peres 2013). Cyflufenamid has been shown to be effective on powdery mildew control in strawberry (Haramoto et al. 2006) and is recommended for control in Florida (Peres and Mertley 2013). These three fungicides are suitable for use in strawberry runner nurseries because their modes of action are different to fungicides that are used in the fruit sector i.e. myclobutanil, trifloxystrobin and penthiopyrad.

Results from this project showed that several treatments significantly reduced leaf blotch compared with the untreated control in the field and in the laboratory isolations from symptomless petioles. Our results concur with previous research that showed prochloraz and azoxystrobin+difenoconazole (HIA Limited project BS07014) were effective against leaf blotch. Prochloraz is registered for use in the strawberry nursery sector for control of disease caused by *Colletotrichum* spp.

The study found that the biorational fungicides investigated in this project were either not effective, or did not consistently control powdery mildew and leaf blotch when applied alone throughout the season. Nevertheless potassium bicarbonate+potassium silicate, and test products NUL3195 and NUL3132 reduced symptoms of leaf blotch in the field compared with the untreated control in Year 3. Spray programs containing combinations of different biorational products with traditional fungicides may be effective against these strawberry diseases and this requires further research.

Effective management practices for foliar diseases in the nursery that integrate chemical and non-chemical control is important to minimise infection in runners and may reduce fungicide use in fruit farms (Poling 2008; Garcia-Mendez et al. 2008). For example, the current project evaluated fungicide treatments based on the use of calendar spray applications. Predictive models now exist for growers in other horticultural industries to time fungicide applications for key foliar diseases, such as powdery mildew, based on environmental conditions and the risk of infection. Further research would be needed to develop similar models for use in strawberry nurseries, but may allow growers to apply fungicides more strategically and less frequently without reducing efficacy. In addition, the use of different fungicides in fruit farms and nurseries is expected to reduce the likelihood of fungicide resistance developing in pathogens (Strand 2008).

Evaluation

At the beginning of this project, it was anticipated that nursery growers would only commence use of the different fungicides identified though the current research, two years after its completion. However, nursery growers in both Queensland and Victoria have already fully adopted the new fungicides identified in this project and incorporated them in their fungicide programs (i.e. as soon as they became permitted and available). Three factors were critical in this accelerated adoption:

(1) Planning, close collaboration and communication of results from this project with chemical companies and HIA Limited's minor-use coordinator. This allowed rapid development and approval of minor-use permits for key fungicides specifically for use in the strawberry nursery industry.
(2) Close involvement of nursery growers in the steering group committee and the planning of research trials in this project. This ensured that research in this project was commercially viable and relevant, and that results were regularly communicated to and scrutinised by growers.
(3) Conducting and coordinating identical research trials across Australia on nursery growers' farms. This allowed growers to visualise the effects of treatments at their own farms, and compare their efficacy with identical treatments applied in other regions of Australia. It increased the confidence of growers in the robustness of treatments across different seasons, environments, disease pressures, and cultivars.

The anticipated impacts from the outcome of this project are: (1) the risk of the development of fungicide resistance in pathogen populations causing powdery mildew and leaf blotch in the strawberry industry is reduced, (2) the longevity of the effectiveness of currently registered fungicides in the strawberry industry is increased, and (3) the long-term incidence and severity of powdery mildew and stem-end rot in the strawberry fruit industry is reduced. It is difficult to quantitatively evaluate the benefits of these impacts, because the nursery sector has fully adopted the treatment programs from this project. Therefore, there is no longer any comparison available with previous industry practices. However, the usefulness of the outcomes from this project can be qualitatively evaluated by the fact that several chemical companies have now adopted the concept of coordinating registration and permits for their own chemistries between nursery and fruit production sectors of the strawberry industry. Also, overseas researchers and nursery and fruit growers endorsed the concept of coordinating the use of fungicides across the nursery and fruit sectors in feedback provided at the International Strawberry Symposium. One researcher lamented that this approach would be difficult to implement in some regions of the world because nursery and fruit sectors can occur in different states or countries (e.g. the nursery industry in Canada supplies runners to the fruit sector in south-east USA), and that this may present regulatory obstacles to the coordinated use of fungicides between the sectors.

The potential loss of the myclobutanil and trifloxystrobin across runner and fruit production sectors of the industry could equate to significant fruit losses in the magnitude of millions of dollars if these registered fungicides develop resistance in Australia. Due to the limited numbers of available control for strawberry foliar diseases in both sectors, subsequent devastating losses will continue to occur until an effective control is again found.

With new and effective controls identified, an important next step in the evaluation of this project is to measure the impact that fungicide programs now used in the nursery sector have on disease incidence and severity in the fruit production sector. At the beginning of this project, it was anticipated that the coordinated use of fungicides in the nursery and fruit production sectors would decrease disease in the fruit production sector by 5%, worth $12 million p.a. In preliminary work in this project we observed that runners treated with specific fungicides in the nursery had lower incidence of stem-end rot in the fruit production sector, but further research is required to confirm and quantify this.

The importance of this project to the nursery industry is reflected by the fact it was the first-time runner growers have come together as a national group to fund coordinated research for the benefit of the whole strawberry industry. The outcome in the current project may form a model on managing the risk of fungicide resistance in other horticultural industries that utilise vegetatively propagated transplants, produced over multiple generations (e.g. potato, raspberry). In addition, this model may also guide future registrations for fungicide use, not just in strawberry, but for other crops as well. Considering this, it may be warranted for HIA Limited to fund future research in this area under its Pool 2 stream of investment. The benefit of this is that it would allow co-investment from partners, such as the strawberry nursery sector, for future research in this area.

Recommendations

- Best-practice control of powdery mildew in strawberry nursery crops using chemicals is to rotate application of fungicides and biorationals. Myclobutanil and trifloxystrobin are recommended to be used early in the season, only if required (up to 1 application each). Then growers should rotate recently permitted fungicides, quinoxyfen (up to 4 applications per season), bupirimate (up to 4 applications) and cyflufenamid (up to 2 applications) through the season. Sulphur and potassium bicarbonate should be applied during the season at times when disease pressure is low, or between fungicide applications. This integrated approach to control of powdery mildew will minimise the risk of *P. aphanis* developing resistance to myclobutanil, trifloxystrobin and other fungicides in the strawberry industry.

- Best-practice control of powdery mildew in strawberry fruit crops using chemicals is to rotate the use of myclobutanil, trifloxystrobin and penthiopyrad. Potassium bicarbonate can also be used on strawberry fruit crops when disease pressure is low, when non-chemical control is required, or integrated with a fungicide program.

- It is recommended that industry support further studies of promising products identified in this project, such as the experimental product AGN-014 and potassium bicarbonate+potassium silicate for powdery mildew; and prochloraz, difenoconazole, azoxystrobin+difenoconazole and experimental biorational products NUL3195 and NUL 3132 for leaf blotch, and new options for control of powdery mildew and leaf blotch that may be suitable for use in strawberry nurseries.

- It is recommended that industry investigate fungicides with different modes of action, including biorationals, against powdery mildew for use in strawberry fruit crops. With harvest season extending up to more than nine months in some areas and increasing number of growers adopting protective cropping structures (which favours powdery mildew development), an additional product would be useful to rotate with currently registered fungicides myclobutanil, trifloxystrobin and penthiopyrad.

- Future chemical permits and registrations across the whole strawberry industry should be guided by the model developed in this project, where different actives are used in different sectors of the industry (i.e. nurseries and fruit production farms). It is anticipated that this coordinated strategy will reduce the risk of chemical resistance developing in pest populations.

- Further research is recommended to evaluate and quantify carry-on effects of the new spray regime in the nurseries to subsequent fruit production to further evaluate the benefits of this project to industry.

- This project has demonstrated that great benefits for the whole of the strawberry industry can be achieved through research and development applied at a regional level (i.e. Stanthorpe, Qld and Toolangi, Vic). This project was funded through voluntary contributions from industry matched by government money. The new funding structure of HIA Limited may present a challenge in the future because there is no longer a clear pathway to support industry-specific research through matched voluntary contributions, especially at a regional level. The future funding of research projects that are regionally significant, but have wider impacts, requires further consideration by the strawberry industry and HIA Limited.

Scientific Refereed Publications

Gomez A. O., Mattner S.W., Oag D., Nimmo P, Milinkovic M., 2016. Protecting fungicide chemistry used in Australian strawberry production for better control of powdery mildew and leaf blotch. In: *Acta Horticulturae* (in-press). International Society for Horticultural Science, Belgium

Intellectual Property/Commercialisation

No commercial IP generated

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Acknowledgements

This report is dedicated to the memory of the life of David Cosson, who was a highly respected nurseryman in the strawberry industry. David was heavily involved in the establishment and maintenance of the field trials at Toolangi, Victoria during this project. His passing is an irreplaceable loss to the industry.

The authors would like to thank and acknowledge the support and assistance given by: runner growers Ian Mungall, Wally Sweet, Len and the late David Cosson, Bernie Priestley and George Weda; Peter Nimmo, Allan McWaters, Mirko Milinkovic, Oscar Villalta, Corina Horstra, Larissa Coridas, Cora Zon, and Sarah Payne for assistance in field trials; Elizabeth Singh and Sonia Sledger for lab support; Bob Mayer for analysis of data; Chris Menzel and Mark Herrington for article and paper reviews; DAF project support staff Rod Edmonds, Remila Naidu and Sonia Silcock; and Jen Rowling (Strawberry IDO) for facilitating presentations to industry.

Appendices

Appendix 1.

Chemical/Active Ingredient	FRAC Code*	Trade Name	Concentration of Active Ingredient	Rates Used	Source
Sulphur	M2	Microthiol	800 g/kg	300 g/100 L	Nufarm
Chlorothalonil	M5	Bravo	720 g/L	2000 L/ha	Syngenta
Dithianon	M9	Dragon	700 g/kg	50 g/100 L	Crop Care
Azoxystrobin	11	Amistar	250 g/L	800 ml/ha	Syngenta
Azoxystrobin+difenoconazole	11 + 3	Amistar Top	200 g/L + 125 g/L	1000 ml/ha	Syngenta
Bupirimate	8	Nimrod	250 g/L	1500 ml/ha	Adama
Cyflufenamid	U6	Flute	50 g/L	350 ml/ha	Agnova
Cyprodinil+fludioxonil	12 + 9	Switch	375 g/kg + 250 g/kg	80 g/100 L	Syngenta
Difenoconazole	3	Score	250 g/L	500 ml/ha	Syngenta
Fluazinam	29	Gem	500 g/L	100 ml/100 L	Adama
Metrafenone	U8	Vivando	500 g/L	300 ml/ha	BASF
Myclobutanil	3	Systhane	400 g/kg	120 g/ha	Dow
Prochloraz	3	Octave	462 g/kg	100 g/100 L	FMC
Proquinazid	13	Talendo	200 g/L	250 ml/ha	DuPont
Pyriofenone	U8	AGN-014	300 g/L	500 ml/ha	Agnova
Quinoxyfen	13	Legend	250 g/L	60 ml/100 L	Dow
Spiroxamine	5	Prosper	500 g/L	60 ml/100 L	Bayer
Trifloxystrobin	11	Flint	500 g/L	300 g/ha	Bayer
Bacillus amyloliquefaciens	44	Loli-pepta	1 x 10^8 cfu/ml	5%	BioFilm
Extract from sweet lupin	NC	F-99011-1	263 g/L	3 L/ha	FMC
Potassium bicarbonate+potassium silicate	NC	Eco-carb II	-	600 g/100 L	Organic Crop Protectants
Experimental product	NC	NUL3074	-	3 L/ha	Nufarm
Experimental product	NC	NUL3195	-	900 ml/ha	Nufarm
Experimental product	NC	NUL3132	-	3500 ml/ha	Nufarm

Table 9: List of fungicides used during the project

*NC – Not classified