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Strategies for improving the control of plant and fruit diseases affecting strawberry fields in Queensland and Florida

Christopher Menzel, Apollo Gomez and Lindsay Smith (Department of Agriculture, Fisheries and Forestry), and Jim Mertely, Teresa Seijo and Natalia Peres (University of Florida)

Strawberry plants are grown during winter in south-east Queensland and in Florida. These two areas share similar climates, agronomic systems, cultivars and diseases, with fruit production often affected by rain and diseases. The fruit can be damaged directly by rain, with water soaking, surface etching and cracking. There can also be an effect on pollination, with distorted berries following short periods of wet weather. Cultivars vary in their sensitivity to direct rain damage, however nearly all are affected when the fruit are mature.

The main fruit diseases affecting strawberries in south-east Queensland and Florida are grey mould (*Botrytis cinerea*), powdery mildew (*Podosphaera aphanis*), stem-end rot (*Gnomoniopsis fructicola*) and black spot (*Colletotrichum acutatum*). Powdery mildew and stem-end rot affect both the leaves and the developing fruit. All these diseases are spread and/or promoted by direct rain contact or by high humidity. Losses due to rain damage and fruit diseases can be up to 80% during severe weather events. In Florida, the plants, flowers and the fruit can also be affected by frosts. Cold weather is less of a problem in southern Queensland.

Horticulture Innovation Australia

For more information:

Dr Christopher Menzel
Department of Agriculture, Fisheries and Forestry

PO Box 5083
SCMC, Nambour, Qld 4560

T 07 5453 5945

E chris.menzel@daff.qld.gov.au

Research is investigating the use of protected cropping and other strategies to reduce the impact of rain, frost and diseases on commercial strawberry production in these two subtropical growing areas. We report on the relative productivity of plants growing under tunnels and in outdoor plots, and on the effect of various chemicals used to control the main fruit and foliar diseases. The investigations were conducted in south-east Queensland and Florida.

Research overview

We have screened a range of chemicals for their effect in controlling grey mould and stem-end rot in strawberry plants in southern Queensland. Two earlier experiments were set up in 2012 and 2013 at Nambour. The standard programs based on thiram and captan with several registered systemic fungicides generally gave good control of these diseases. Some other systemic fungicides were equally as effective as the standard program. Other products, including plant defence promoters, plant extracts, fatty acids, salts, bacteria, and fungi were intermediate or gave poor control of the diseases.

Studies conducted on the Sunshine Coast over the past two years have shown that strawberry plants growing under tunnels had higher yields and returns than plants growing in open, outdoor plots. Marketable yields were up to 40% higher in the plants growing under protected cropping. These responses were reflected by higher losses due to rain damage and/or grey mould in the plants growing outdoors. It was concluded that it would take about three years to recover the costs of the tunnels under moderately dry conditions in southern Queensland.

In other research, experiments have been set up in Florida, to examine the effect of different chemicals for the control of powdery mildew, an important disease affecting strawberry plants growing under tunnels. This work is being conducted by Dr Natalia Peres and her colleagues at the University of Florida. In the first experiment, the percentage of fruit affected by the fungus ranged from 11 to 44% across the different chemical treatments. In the second experiment, the percentage of fruit affected by the fungus ranged from 5 to 34%. In this year, there was a strong relationship between yield and the incidence of the disease on the fruit. Yields ranged from 5.3 t per ha in the worst treatment to 8.1 t per ha in the best treatment.

Screening of chemicals for the control of plant and fruit diseases

Christopher Menzel, Apollo Gomez and Lindsay Smith

An experiment was set up to screen different chemicals for their effect on fruit diseases affecting strawberry fields on the Sunshine Coast. Both standard fungicides and soft chemicals were assessed. Some of the chemicals included in 2014 had not been evaluated previously in south-east Queensland.

Bare-rooted transplants of 'Festival' were planted in early April at Nambour. The strawberry plants were grown using standard agronomy for this area. There were thirteen treatments in the experiment, using both standard and soft chemicals, including a nil control (see Table 1). The first applications of chemicals were applied in late May, with the first fruit harvested in mid-June and the last fruit harvested in late September.

Thiram and captan are registered for use on strawberry plants in Australia, with some limitations on withholding periods. There are also registrations for iprodione (Rovral® and other products), fenhexamid (Teldor®), penthiopyrad (Fontelis®), and cyprodinil + fludioxonil (Switch®) for use on strawberry plants in Australia. None of the other chemicals used in this experiment are registered for their use on strawberry plants in Australia. The list of registered products and permits for strawberry production are available on the Australian Pesticide and Veterinary Medicine Authority (APVMA) website (http://www.apvma.gov.au). The risk of the grey mould and other fungi becoming resistant to the various chemicals evaluated is shown in Table 2.

Fruit were harvested every week for an assessment of yield (fresh weight), number of fruit per plant and defects, including the incidence of disease. Mature fruit were classified as those that were at least three-quartered coloured. A record was kept of the number of fruit that were affected by rain or disease, along with those that were small (less than 10 g fresh weight) or misshaped, or that have other defects. Fruit that were affected by rain and disease were rated as diseased. Fruit that were small and misshaped were rated as misshaped. The main diseases affecting the crop in southern Queensland are generally grey mould (*Botrytis cinerea*) and stem-end rot

(*Gnomoniopsis fructicola*), with usually a very low incidence of powdery mildew (*Podosphaera aphanis*), and black spot (*Colletotrichum acutatum*).

Data were collected on daily rainfall at the site during the experiment. The plants were watered with over-head irrigation for eight weeks from 11 July to 9 September when the weather was fairly dry to promote the development of fruit diseases. During this time, the total amount of water applied to the crop by the sprinklers was 392 mm or about 6.5 mm per day.

Total rainfall over the harvest period from mid-June to late September was 195 mm, with some weeks completely dry and other weeks having more than 50 mm (see Figure 1). The over-head irrigation used from early July provided about another 400 mm of water to the canopy.

The effect of the chemicals on the performance of the plants is discussed in relation to the effect on grey mould, stem-end rot, combined diseases and then on marketable yield.

Treatments using thiram and/or captan gave good control of grey mould compared with the incidence of the disease in the control plots (see Table 1). Overall, the two treatments that included the systemic fungicides during wet weather or when the plants received over-head irrigation were best. These treatments were thiram/captan with systemic fungicides, and *B. subtilis* with thiram/captan and systemic fungicides. The multi-site fungicide chlorothalonil was nearly as effective as the two treatments using systemic fungicides during wet weather. Guazatine, and the two bacteria alone were slightly less effective, and the plant extract alone not effective.

The effect of the treatments on the incidence of stem-end rot was less clear than the effect of the treatments on the incidence of grey mould (see Table 1). This was because stem-end rot was less of a problem during the production season in 2014. The incidence of stem-end rot was only about a third of that of grey mould. Thiram or captan applied weekly or alternately, or used with the systemic fungicides applied during wet weather gave a lower incidence of the disease than the controls. Chlorothalonil and guazatine were also in the effective group, with guazatine the best. The other treatments, including *B. subtilis* alone or used with thiram/captan, the plant extract alone or used with thiram/captan, and *B. amyloliquefaciens* alone or

with thiram/captan were similar to the control plots.

There was a range in the effect of the chemicals on the incidence of grey mould and stem-end rot when the incidences of the diseases were combined (see Table 1). Treatments with captan and/or thiram, along with chlorothalonil and guazatine were rated as effective. Within this group, the two treatments that included the systemic fungicides were best. The treatments with the bacteria applied alone were intermediate, whereas the treatment with the plant extract alone was ineffective.

Table 1. Effect of fungicides on the incidence of grey mould and stem-end rot, and marketable yield in 'Festival' strawberry plants grown at Nambour in 2014. Data are the means of four replicates per treatment, and have been back-transformed. In the treatment with thiram alternated with captan, thiram was sprayed nine times and captan eight times. In the standard treatment with systemic fungicides, thiram and captan were sprayed two times, iprodione three times, fenhexamid three times, cyprodinil + fludioxonil three times, and penthiopyrad four times. In the treatment with the Bacillus subtilis, *thiram was sprayed one time, captan two times, the systemic fungicides as in other treatment with the systemics, and the bacteria 16 times. In the treatment with the plant extract, thiram and captan were sprayed four times each and the plant extract nine times. In the treatment with* B. amyloliquefaciens, *thiram and captan were sprayed four times each and the bacteria nine times. Chlorothalonil and guazatine were sprayed 17 times. In the treatment with* B. subtilis *alone, the bacteria were applied 16 times. In the treatment with plant extract alone, the extract was applied 17 times. In the treatment with* B. amyloliquefaciens *alone, the bacteria were applied 17 times. Iprodione = Rovral®; fenhexamid = Teldor®; cyprodinil + fludioxonil = Switch®; penthiopyrad = Fontelis®; Chlorothalonil (Bravo®) and guazatine (Panoctine®) are not registered for commercial use in strawberries in Australia at this time. The plant extract is an experimental product of lupins.* B. subtilis *is an experimental product; and* B. amyloliquefaciens *= Loli-pepta®.*

Treatment	Grey mould (%)	Stem-end rot (%)	Grey mould & stem-end rot (%)	Yield (g per plant)
Control	19	6	25	871
Thiram weekly	5	2	6	1660
Captan weekly	6	2	9	1349
Thiram alt. with captan	6	2	8	1413
Thiram/captan initially, with systemic fungicides during wet weather	1	2	3	1585
Chlorothalonil	3	3	6	1514
Guazatine	7	1	8	955
Bacillus subtilis	9	5	14	1175
Bacillus subtilis with thiram/captan initially, and systemic fungicides during wet weather	1	3	5	1413
F9110-1 (plant extract)	16	6	23	912
F9110-1 (plant extract) alt. with thiram/captan	8	4	12	1202
Bacillus amyloliquefaciens	10	5	15	1072
Bacillus amyloliquefaciens alt. with thiram/captan	6	4	10	1175

Table 2. The classification of the fungicides used in the chemical screening experiment at Nambour in 2014. The different groups are based on their mode of action as suggested by the Fungicide Resistance Action Committee (FRAC). The numbers and letters are used to distinguish the fungicidal groups according to their cross resistance behavior. Pyrimethanil (Scala®) is in the same class of fungicides as cyprodinil.

Fungicide	Common name	FRAC code	Comments
Thiram	Thiram	Group M3 (multi-site)	Low risk of resistance developing in fungi
Captan	Captan	Group M4 (multi-site)	Low risk of resistance developing in fungi
Iprodione	Rovral	Group 2	Resistance common in the grey mould & some other fungi
Fenhexamide	Teldor	Group 17	Low to moderate risk of resistance developing in fungi
Cyprodinil	Switch	Group 9	Resistance known in grey mould
Fludioxonil	Switch	Group 12	Resistance found sporadically
Penthiopyrad	Fontelis	Group 7	Resistance found in several fungi
Chlorothalonil	Bravo	Group M5 (multi-site)	Low risk of resistance developing in fungi
Guazatine	Panoctine	Group M7 (multi-site)	Low risk of resistance developing in fungi
Bacillus subtilis		Group F6	Resistance by fungi unknown
Bacillus amyloliquefaciens		Group F6	Resistance by fungi unknown
Pyrimethanil	Scala	Group 9	Resistance known in grey mould

There was a strong relationship between marketable yield and the incidence of the two diseases in the plants (see Figure 2). Yields tended to decrease as the incidence of grey mould and stem-end rot increased. Overall, the treatments that included thiram and captan had high yields, the control low yields, and most of the other treatments intermediate yields (see Table 1). The plants sprayed with guazatine had low yields.

The plants treated with guazatine had lower yields than expected, with symptoms of phytotoxicity in the leaves, smaller plants, and smaller unmarketable fruit. The applications of chlorothalonil left a white residue on the leaves, although the plants had good yields and fruit production.

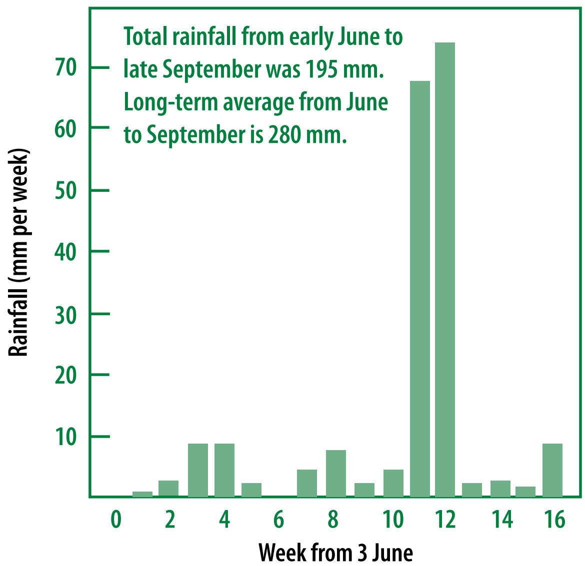

Figure 1. Rainfall during the fungicide screening experiment at Nambour in 2014.

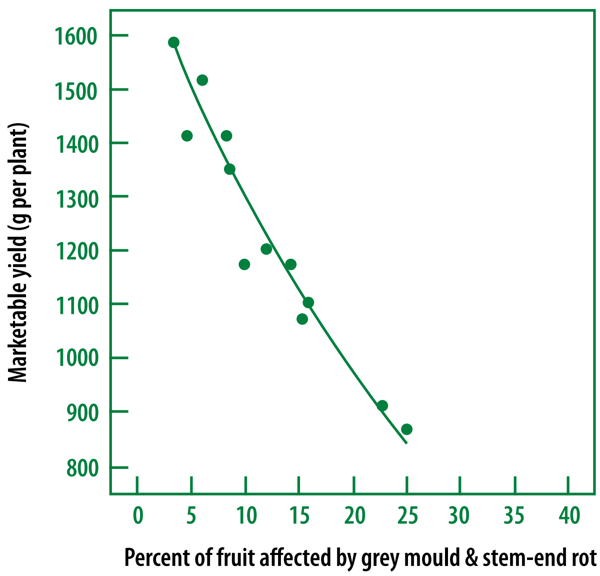

Figure 2. Relationship between marketable yield and the incidence of grey mould and stem-end rot in strawberry plants in the fungicide screening experiment at Nambour in 2014 (N = 12 treatments). Data are the means of four replicates per treatment and have been back-transformed. Yield decreased as the incidence of disease increased. The data for guazatine were excluded from the analysis because the chemical was phytotoxic.

These results suggest that the use of thiram and captan with the systemic fungicides during wet weather is likely to provide good control of grey mould and stem-end rot in strawberry fields in southern Queensland. The soft chemicals were rated as intermediate at best for their control of the two diseases. This response occurred in a relatively wet environment, with the plants given over-head irrigation for several weeks during the production season. It is possible that these soft chemicals may be more effective under less challenging conditions. These products could be used during drier weather to reduce the need for applications of the standard chemicals. The role of the other two multi-site acting fungicides is unclear. Chlorothalonil appeared to leave a white residue on the plants, while guazatine was phytotoxic. In 2013, we evaluated another multi-site acting fungicide, dithianon, and the results for that year showed that it was only partially effective against grey mould and stem-end rot.

We have assisted studies to help revise the labels for the use of thiram (supplied by Barmac/Amgrow in Australia) and captan (supplied by Crop Care in Australia) in strawberry crops in Australia. The APVMA has approved the submission to change the label for thiram to reduce the withholding period for this product from seven to two days. The previous label for the use of captan on strawberry plants only allowed a maximum of five applications per season and a one-day withholding period. The application to withdraw the limit was approved by APVMA in December 2014.

The revised labels for the use of thiram and captan in Australia should make it possible to develop a strategy for the strawberry industry based on fortnightly applications of these multi-site fungicides for part of the growing season. This would reduce the need for multiple applications of existing systemic fungicides that the grey mould and stem-end fungi are likely to become resistant to over the long term. An expansion on the number of applications of thiram and captan allowed in a season should increase the use of the multi-site fungicides in the future.

Evaluation of strawberry plants grown in tunnels under protected cropping

Christopher Menzel and Lindsay Smith

An experiment was set up to evaluate the performance of strawberry plants growing under protected cropping without the use of chemicals to control grey mould. Bare-rooted transplants of 'Festival' and a breeding line (Breeding Line 1) were planted in late March at Palmwoods. The strawberry plants were grown under plastic high tunnels or in open, outdoor plots, using commercial agronomy. The plastic structures used were standard Haygrove tunnels, which are utilized extensively in the United Kingdom, Australia and other places (www.haygrove.co.uk). These tunnels are about 8 m wide and 5 m high. Half the plants in each group received the normal sprays to control grey mould, while the other half of the plants received none of these sprays after the first harvest in mid-May. Both groups of plants received the normal sprays used to control pests, and other diseases, including powdery mildew.

Information was collected on the dry weight of the plants in July and September. The plants were harvested and divided into the leaves, crowns, roots, flowers and immature fruit. Fruit were harvested twice per week for an assessment of yield (fresh weight), number of fruit per plant and average fruit fresh weight. Mature fruit were classified as those that were at least three-quartered coloured. A record was kept of the number of fruit that were affected by rain and/or grey mould or both, along with those that were small (less than 12 g fresh weight) and/or misshaped or both, or that had other defects (mainly other diseases including powdery mildew, black spot, surface bronzing or bird damage). Fruit that were affected by rain and disease were rated as diseased. Fruit that were small and misshaped were rated as misshaped. There were four replicate plots for each treatment.

Two times over the growing season, eight sound mature fruit from the breeding line were collected from each plot for an assessment of post-harvest quality. The fruit from each plot were placed in 250-g punnets, and stored in the dark at 5°C for 5 days. They were stored at room temperature for a further day, and each fruit in the container scored for minor or major damage. The fruit for these two experiments were collected after both a wet and dry period.

Four times over the growing season, six sound mature fruit from the breeding line were collected from each plot for an assessment of total soluble solids content (brix°), and titratable acidity as citric acid. The fruit from each plot were placed in small freezer bags, and frozen until used for chemical analysis. The fruit for these four experiments were collected after both wet and dry periods.

Information was collected on daily minimum and maximum temperatures, and daily minimum and maximum relative humidities at the site during fruit development. There were four sensors in the outdoor plots and four sensors under the tunnels.

The plants growing outdoors were watered with over-head irrigation for ten weeks from 4 July to 9 September to promote the development of fruit diseases during dry weather. During this time, the total amount of water applied to the crop by the sprinklers was 480 mm or about 7 mm per day.

Total rainfall over the harvest period from mid-May to late September was 285 mm, with some weeks completely dry and other weeks receiving more than 50 mm (see Figure 3). The over-head irrigation used from early July provided about another 500 mm of water to the canopy.

Average daily minimum temperature was slightly higher under the tunnels (12.7°C) than outdoors (11.1°C). In contrast, average daily maximum temperatures were similar in the two growing environments (24.3°C versus 24.2°C). Average daily minimum relative humidity was higher under the tunnels (60%) than outdoors (50%). Average daily maximum relative humidity was lower under the tunnels (84%) than outdoors (99%), probably reflecting the use of the over-head irrigation from July to September in the outdoor growing areas.

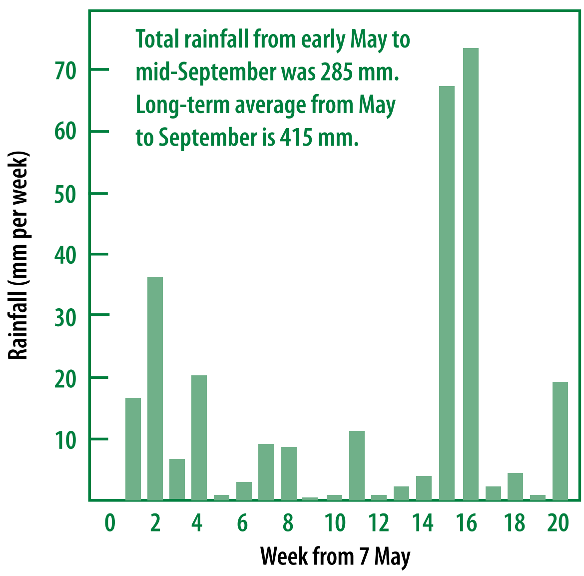

Figure 3. Rainfall during the protected cropping experiment at Palmwoods in 2014.

Plant dry matter production at Palmwoods was about 50% higher in 2014 than in 2013. This was possibly due to the higher radiation levels under dry

weather and clear skies. Growing system had no effect on average seasonal leaf, crown, root and potential yield as indicated by the weights of the flowers and immature fruit (see Table 3). This response was different to the results of the earlier experiments where the plants growing under the tunnels had smaller crowns and roots. Once again, this was probably due to the high average solar radiation levels in 2014.

The plants growing in the dry environment under the tunnels (without over-head irrigation) had higher marketable yields and returns than the plants growing in a wet environment outdoor (with over-head irrigation) (see Table 4). These responses were associated with higher losses for the plants growing outdoors than the plants growing under the tunnels (see Table 5). This was mainly due to higher losses due to rain damage and/or grey mould or both. Losses due to powdery mildew, and small and/or misshaped fruit or both were higher for the plants growing in the protected environment. Fruit under the tunnels were also smaller than fruit growing outdoors (see Table 4).

There was a strong interaction between growing system and the spray program on the incidence of grey mould in the plants. Spraying decreased the percentage of fruit affected by the disease when the plants were growing outdoors (15% of fruit affected versus 19%). However, there was no effect of spraying on the incidence of the disease when the plants were growing under the tunnels (2% of fruit affected in sprayed and non-sprayed plots).

Table 3. Effect of protected cropping on average seasonal plant dry weight in strawberry plants grown on the Sunshine Coast in 2014. The plants were grown in open, outdoor plots or under plastic tunnels. Half the plots were sprayed for the control of grey mould and the other plots not sprayed. The plants growing outdoors were watered with over-head irrigation from July to September to promote the development of fruit diseases during dry weather. Data are the means of 16 replicates per treatment, pooled over sprayed and unsprayed plots and over two cultivars/breeding lines.

Treatment	Leaves (g per plant)	Crowns (g per plant)	Roots (g per plant)	Flowers & immature fruit (g per plant)
Outdoor plot	24.8	9.4	3.8	15.9
Tunnel	26.8	9.6	4.0	15.4

Table 4. Effect of protected cropping on marketable yields, returns and average seasonal fruit fresh weight in strawberry plants grown on the Sunshine Coast in 2014. The plants were grown in open, outdoor plots or under plastic tunnels. Half the plots were sprayed for the control of grey mould and the other plots not sprayed. The plants growing outdoors were watered with over-head irrigation from July to September to promote the development of fruit diseases during dry weather. Data are the means of 16 replicates per treatment, pooled over sprayed and unsprayed plots and over two cultivars/breeding lines.

Treatment	Marketable yield (g per plant)	Gross return ($ per plant)	Average fruit fresh weight (g)
Outdoor plot	349	2.80	25.0
Tunnel	869	5.31	23.5

Table 5. Effect of protected cropping on the incidence of various fruit defects in strawberry plants grown on the Sunshine Coast in 2014. The plants were grown in open, outdoor plots or under plastic tunnels. Half the plots were sprayed for the control of grey mould and the other plots not sprayed. The plants growing outdoors were watered with over-head irrigation from July to September to promote the development of fruit diseases during dry weather. Other defects not presented include other diseases such as black spot, skin bronzing and bird damage. Data are the means of 16 replicates per treatment, pooled over sprayed and unsprayed plots and over two cultivars/breeding lines. Data have been back-transformed for presentation.

Treatment	Rain damage and/or grey mould (%)	Powdery mildew (%)	Small and/or misshaped (%)	All defects (%)
Outdoor plot	25	1	20	62
Tunnel	1	5	25	40

Growing system had no effect on the losses of fruit after harvest. Average losses of fruit over the two sampling times were 1.0 fruit out of eight in the plants growing under the tunnels and 1.1 fruit out of eight in the plants growing outdoors. There was no effect of growing system on fruit brix°. Average values were 7.5% in the plants growing under the tunnels and 7.8% in the plants growing outdoors. In contrast, fruit acidity was slightly higher in the plants growing under the tunnels (0.75%) than the plants growing outdoors (0.67%).

The results of this experiment confirm that strawberry plants growing in a dry environment under tunnels have higher yields and returns than plants growing in a wet environment outdoors. The plants growing outdoors were given additional over-head irrigation to duplicate a relatively wet season. The results for the sprayed and unsprayed plots suggest that strawberry plants growing under protected cropping probably do not need to be sprayed for the control of grey mould in southern Queensland. There was a higher incidence of powdery mildew in the plants growing under the tunnels than in the plants growing outdoors. Efforts need to be made to develop strawberry cultivars with better resistance to this disease.

The control of powdery mildew for strawberry crops growing under tunnels

Jim Mertely, Teresa Seijo and Natalia Peres

An experiment was conducted to investigate the effect of different chemicals for the control of powdery mildew (*Podosphaera aphanis*) affecting strawberry crops growing under plastic tunnels. This disease affects both the leaves and the fruit and can reduce marketable yields because of the damage to the surface of the fruit. Total fruit production can also be reduced because the fungus can affect the rate of photosynthesis in the leaves. The research was conducted by Dr Natalia Peres and her colleagues at the University of Florida. This area has a similar climate to south-east Queensland, with the berries grown during winter.

Bare-rooted, green-top 'Camarosa' transplants from Canada were planted on 22 October 2013 into plastic-mulched, raised beds in a plastic high tunnel in Florida. The beds were 71 cm wide on 1.2-m centers and had been fumigated with Telone C-35 at 281 kg per ha. Each bed contained two rows of plants 30 cm apart, with the plants along the rows planted 38 cm apart. Some plants were removed in late November to form 14-plant plots that were 2.9 m long, separated by 0.9 to 1.2 m of empty bed. The plants were irrigated by overhead sprinkler for the first ten days to facilitate establishment, and then irrigated and fertilized through the drip tape.

There were 15 different chemical treatments, including a water control (see Table 6). The treatments were arranged in randomized complete blocks, with four replicates on adjacent beds. The treatments were applied every seven to fourteen days over ten weeks from 6 December to 7 February, with a CO_2-backpack sprayer delivering 935 litres per ha at 60 psi through two T-Jet disc-core hollow-cone nozzles.

Colonization of the leaves by the powdery mildew fungus, *Podosphaera aphanis*, was evaluated by removing one leaflet from each of ten plants per plot on 30 January, and scoring ten microscopic fields per leaflet at a magnification of × 25 for the presence or absence of mycelium. The leaflets were taken from leaves previously tagged when the petioles were elongating on 19 December and were similar in age. The number of positive fields per leaflet was averaged for all ten leaflets per plot and expressed as a percentage of the fields colonized by the fungus.

Fruit were harvested twice per week over 16 harvests from 23 December to 13 February. The marketable fruit from each plant were counted and weighed. Fruit with visible signs of fungal growth on more than 25% of the achenes, and other unmarketable fruit were also counted. The incidence of the disease on the fruit was expressed as a percentage of all marketable and unmarketable fruit. Percentage data were transformed to the arcsin square roots before analysis. Back-transformed means are presented for the percentage of leaf area and the percentage of fruit infected with the fungus.

Due to the closed environment in the tunnels, powdery mildew was observed less than six weeks after planting. Young elongating leaves were tagged in mid-December and collected for observations in late December. An assessment of the coverage of the fungus on these leaves demonstrated the effectiveness of the different chemicals that were applied in the previous four weeks (see Table 6).

Table 6. Effect of different chemicals on the performance of strawberry plants grown under a plastic tunnel in Florida. The chemicals were applied in a series of 11-weekly applications made from 6 December 2013 to 14 February 2014. Data on fruit infections were based on the percentage of fruit with conspicuous powdery mildew growth on more than 25% of the achenes. Data on leaf infections were based on the percentage of powdery mildew coverage based on microscopic observations of leaves at a magnification of × 25. Wettable sulphur = Microthiol Disperse®; triflumizole = Procure®; quinoxyfen = Quintec®; myclobutanil = Rally®; cyflufenamid = Torino®; tetraconazole = Mettle®; azoxystrobin + propiconazole = Quilt Xcel®; azoxystrobin + difenconazole = Quadris Top®; potassium salts of fatty acids = M-Pede®; mono- and di-potassium salts of phosphorus acid + hydrogen peroxide = OxiPhos®; polypeptide beta-conglutin from lupin = Fracture®; chlorothalonil = Bravo®; pyraclostrobin + fluxapyroxad = Merivon®; and metrafenone = Vivando®. Data on the percentage of leaves and fruit affected by the fungus are back-transformed means. Data from J. Mertely, T. Seijo, and N.A. Peres from the University of Florida.

Treatment	Marketable yield (t per ha)	Percent of fruit affected by powdery mildew	Percent of positive fields for each leaflet with powdery mildew
Control	3.1	37	97
Pyraclostrobin + fluxapyroxad alt. with cyflufenamid	4.1	8	14
Quinoxyfen	3.7	9	29
Quinoxyfen alt. with cyflufenamid	5.0	9	18
Quinoxyfen alt. with myclobutanil	4.3	12	47
Tetraconazole alt. with cyflufenamid	4.9	9	48
Azoxystrobin + propiconazole	4.0	11	56
Azoxystrobin + difenconazole	3.6	18	57
Metrafenone	4.0	14	65
Triflumizole	4.4	18	74
Chlorothalonil	3.1	30	83
Potassium salts of fatty acids (x 1 conc.)	3.7	19	96
Potassium salts of fatty acids (x 2 conc.)	4.1	17	89
Wettable sulphur	4.4	20	91
Polypeptide beta-conglutin from lupin	3.8	25	94
Mono- and di-potassium salts of phosphorus acid + hydrogen peroxide	4.1	21	95

The most effective treatments for the reduction of leaf colonization were pyraclostrobin + fluxapyroxad (Merivon®) alternated with cyflufenamid (Torino®), and quinoxyfen (Quintec®) alternated with cyflufenamid. These treatments were applied over one cycle, with only two applications during the four weeks. These results suggest that all three products are effective against foliar colonization by the powdery mildew fungus. The two DMI fungicides, triflumizole (Procure®) and myclobutanil (Rally®) did not provide adequate control in the present experiment, although they have been effective in the past.

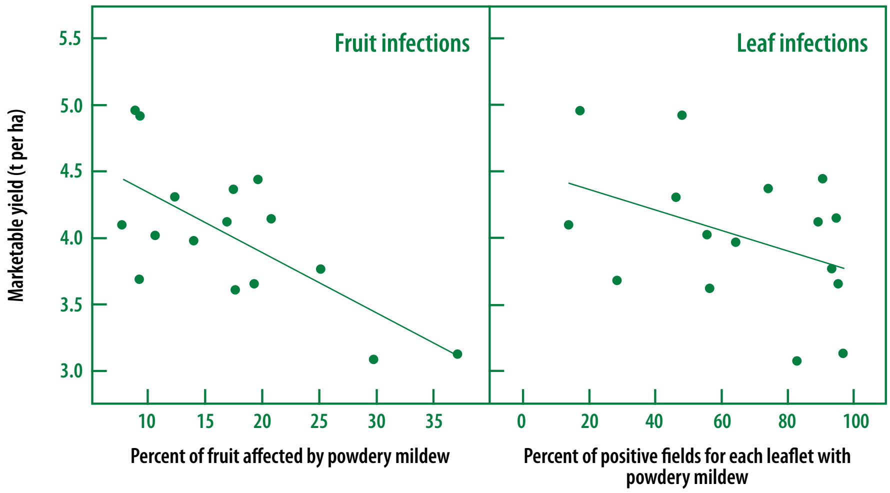

Figure 4. Relationship between marketable yield and the incidence of powdery mildew in 'Camarosa' strawberry plants in the fungicide screening experiment in Florida in 2013/14 (N = 15). Yield decreased as the incidence of disease on the fruit increased. There was a poor relationship with the incidence of the disease on the leaves. Data from J. Mertely, T. Seijo and N.A. Peres from the University of Florida.

Over the eight weeks when the fruit were harvested, many products including pyraclostrobin + fluxapyroxad, cyflufenamid, and quinoxyfen, azoxystrobin + propiconazole (Quilt Xcel®), and metrafenone (Vivando®) gave good control of mildew on the fruit (see Table 6). There were differences in marketable yield across the different treatments. However, these differences were not significant, reflecting the large variability in plots from the same treatments. Yield decreased as the incidence of disease on the fruit increased (see Figure 4). In contrast, there was a poor relationship with the incidence of the disease on the leaves. None of the chemicals were phytotoxic to the strawberry plants.

It can be concluded that fungicides vary in their control of powdery mildew affecting strawberry plants growing under tunnels. Further experiments are planned for the coming season in Florida. Recommendations will be made on the best strategies to control powdery mildew for strawberry plants growing under tunnels in Florida, and potential new chemicals to be evaluated in Australia.

Implications of the research and future activities

Three experiments were conducted to investigate different strategies used to control plant and fruit diseases affecting strawberry fields in Queensland and Florida. In the first experiment conducted in southern Queensland, different chemicals were evaluated for their effect in controlling grey mould and stem-end rot. In the second experiment initiated in the same area, plants of two cultivars were grown under plastic tunnels and their performance compared with that of plants grown in outdoor plots. A subset of plants was grown with and without the use of chemicals to control grey mould. In the final experiment set up in Florida, plants were grown under a plastic tunnel and sprayed with different chemicals to control powdery mildew.

The standard program based on captan and thiram, with iprodione, fenhexamid, cyprodinil + fludioxonil, or penthiopyrad gave good control of grey mould and stem-end rot in strawberry plants growing on the Sunshine Coast. This program was generally better than captan or thiram applied alone or together. Chlorothalonil and guazatine were rated as effective. The treatments with two different bacteria applied alone were intermediate, whereas the treatment with the plant extract alone was ineffective.

Plants growing in a dry environment under tunnels (without over-head irrigation) had higher yields and returns than plants growing in a wet environment in open, outdoor plots (with over-head irrigation). Gross returns were more than $2.00 per plant higher in the plants growing in a dry, protected environment.

The low incidence of grey mould in sprayed and unsprayed plots under the tunnels suggests that strawberry crops growing under plastic in southern Queensland probably do not need to be sprayed for this disease. There was a higher incidence of powdery mildew in the plants growing under the tunnels indicating that further efforts need to be made to develop cultivars that are more resistant to the disease.

Products including pyraclostrobin + fluxapyroxad, cyflufenamid, and quinoxyfen, azoxystrobin + propiconazole, and metrafenone gave good control of powdery mildew on the fruit in strawberry plants growing under tunnels in Florida. Yield decreased as the incidence of disease on the fruit increased. Further experiments are currently being conducted in Florida. Recommendations will be provided to industry on the best strategies to control this disease.

Researcher profiles

Christopher Menzel

Dr Menzel is a Principal Horticulturist for DAFF and has conducted research for the strawberry industry in Australia for the past ten years. Chris led recent research that examined transplant agronomy, and the control of crown rot and lethal yellows in strawberry fields. He is currently leader of research examining the potential of protected cropping of strawberry plants on the Sunshine Coast. Some of this research is being conducted in collaboration with colleagues from the University of Florida. Chris also leads the work being conducted with Apollo Gomez and Lindsay Smith to screen chemicals for the control of plant and fruit diseases in strawberry crops.

Apollo Gomez

Mr Gomez is a Research Scientist for DAFF and has been involved in research on diseases in strawberry plants for more than ten years. Apollo contributed to the recent work that developed strategies for the control of crown rot affecting strawberry fields in southern Queensland. His main interest at the moment is to develop better methods to control the major fruit diseases affecting the crop on the Sunshine Coast. Apollo also assists the strawberry industry to apply for permits and registrations for new chemicals. He has recently assisted efforts to change the labels for the use of thiram and captan in strawberry crops in Australia. Apollo is screening chemicals for the control of powdery mildew in strawberry nurseries in southern Queensland. He is also studying the biology of charcoal rot, an important crown and root rot disease affecting strawberry plants in many growing areas.

Lindsay Smith

Mr Smith is a Technical Assistant for DAFF and has been involved in many aspects of horticultural research for the past twenty years. He has provided support for projects on strawberry transplant agronomy, entomology and plant pathology. Lindsay is currently assisting the studies on protected cropping and fruit diseases in strawberry plants growing in south-east Queensland.

Natalia Peres

Dr Peres is an Associate Professor from the University of Florida in the United States. Natalia's main area of research is on fruit and plant diseases affecting strawberry crops. She has conducted research on the genetics and pathogenicity of different groups of the crown rot fungi. Dr Peres has also investigated different strategies for the control of grey mould, powdery mildew and black spot, important diseases affecting the crop in Florida and Australia. Natalia leads a team of plant pathology specialists at the University of Florida and has supervised several post-graduate students. Dr Peres has strong links with the research program at DAFF, and is currently assessing chemicals for the control of powdery mildew in strawberry plants growing under plastic tunnels.

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Not all the chemicals mentioned in this report are currently registered for use on strawberry nursery or fruit production fields. Please check current registrations for strawberries before using any of the chemicals. The product label is the official authority and should be used to verify all data relating to the use of a chemical.

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