SIMPLY RED

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The performance of strawberry plants growing under plastic high tunnels in Queensland and Florida

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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. In these two growing areas, 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.

Fruit diseases also affect strawberry growing in south-east Queensland and in Florida. The most important fruit diseases affecting strawberries in these areas are grey mould, powdery mildew, stem-end rot and black spot. These diseases are caused by *Botrytis cinerea*, *Podosphaera aphanis*, *Gnomoniopsis*

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fructicola and *Colletotrichum acutatum*, respectively. 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. There are differences in the susceptibility of different cultivars to these diseases, although most cultivars are susceptible if conditions are ideal for the growth of the various fungi. Losses of fruit due to rain and disease on the Sunshine Coast can be up to 80% after prolonged wet periods, and probably are about 30% in an average wet year.

The main source of infection of the grey mould fungus for the fruit is from infected leaves. Conidia or spores are produced in large quantities on dead and dying foliage throughout the growing season. The conidia from infected leaves can be distributed through the air or with water. These then spread to the flowers, including the pistils, stamens and petals. Direct infection of fruit by conidia is not considered important, although the disease can be spread by fruit-to-fruit contact in severe epidemics. In an annual production system with several cycles of flowering and fruiting, conidia produced on diseased ripening fruit and small mummified fruit may contribute to inoculum building up during epidemics. Typically, there is an increase in the incidence of the disease as the duration of leaf wetness increases over the day. The optimum temperature for infection is about 20°C, with all the flowers infected if the leaves (and presumably the flowers) are wet for a full day. Infection of the flowers and the fruit is greatly reduced below 15°C and above 25°C.

Powdery mildew affects strawberry production in most growing areas, and is often more of an issue in plants growing under tunnels than in plants growing outdoors or in open-field situations. It is also more of an issue in certain cultivars than in others. Yields are often lower in severely affected plants due to infection of the flowers and developing fruit. Severe infections in the leaves can damage the leaves and reduce photosynthesis, and even cause the leaves to senesce prematurely. Control of the disease on both the fruit and leaves is usually required to achieve good fruit production. The leaf petioles, stolons, flower trusses, flowers and fruit can all be infected. Symptoms of the disease on the leaves are very distinctive. White patches of mycelia or fungal threads can cover the whole under surface of the leaves. The leaf edges eventually start to roll up, and red-purple blotches develop on the under surface of the leaves. Dark cleistothecia or spore-producing structures are often embedded in the fungal mycelia. The mycelial threads produce conidia as the primary inoculum for spreading an infection. Cleistothecia also produce conidia, but are mainly observed towards the end of the growing season or when infection is left uncontrolled.

The powdery mildew fungus can carry over from one season to the next on living infected leaves. Chains of dry, hyaline conidia are produced when weather conditions are suitable. Cleistothecia may also help the fungus survive between seasons in some circumstances. The development of the fungus is promoted by temperatures between 15° and 25°C and relative humidity above 75%. The conidia are spread by wind, with dispersal inhibited by rain and over-head irrigation. Low light levels also encourage the development of the disease. The disease can be introduced into commercial fruit farms with the new transplants. Effective chemical control requires targeting the newly developing leaves as the flushes emerge.

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 south-east Queensland and in Florida. We report on the relative productivity of plants growing under tunnels and in outdoor plots on the Sunshine Coast. We also report on the effect of different chemicals for the control of powdery mildew affecting strawberry plants growing under a plastic high tunnel in Florida.

Research overview

Studies conducted on the Sunshine Coast over the past three years have shown that strawberry plants growing under tunnels had higher yields and returns than plants growing outdoors. In the first two experiments, marketable yields were up to 40% higher in the plants growing under protected cropping in a slightly drier than average year. These responses were reflected by higher losses due to rain damage and grey mould in the plants growing outdoors. It was concluded from these experiments that it would take about three years to recover the costs of the tunnels under moderately dry conditions in southern Queensland.

A slightly different approach was adopted in 2014, when it was much drier than average at Palmwoods. Supplementary over-head irrigation was given to the plants growing outdoors to provide a water application about twice that of a normal season. In this experiment, 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. The yields of the plants in the dry environment under the tunnels were more than double the yields of the plants in the wet environment outdoors. There were higher losses due to grey mould in unsprayed than in sprayed plots outdoors, whereas there were no differences in the losses due to grey mould in unsprayed and sprayed plots under the tunnels. These results suggest that plants growing under plastic probably do not need to be sprayed for this disease.

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 year, the percentage of fruit affected by the fungus ranged from 11 to 44% across the different chemical treatments. In the second year, the percentage of fruit affected by the fungus ranged from 5 to 34%. In the third year, the percentage of fruit affected by the fungus ranged from 9 to 37%. In the last two years, there was a strong relationship between yield and the incidence of the disease on the fruit. In 2012/13, yields ranged from 5.3 t per ha in the worst treatment to 8.1 t per ha in the best treatment. In 2013/14, yields ranged from 3.1 t per ha in the worst treatment to 5.0 t per ha in the best treatment.

Evaluation of strawberry plants growing under plastic high tunnels in south-east Queensland

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 in 2015 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 late 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 June and August. 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, or powdery mildew, 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 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.

Table 1. Average mean daily environmental conditions in the study with strawberry plants growing on the Sunshine Coast in 2015. The plants were grown outdoors or under tunnels Data are the means of four replicates per treatment from mid-May to late September. Max. = maximum; min. = minimum.

Growing system	Mean daily max. temp. (°C)	Mean daily min. temp. (°C)	Mean daily max. relative humidity (%)	Mean daily min. relative humidity (%)
Outdoor	26.7	11.4	98	44
Tunnel	26.6	12.8	93	43

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.

Data on plant growth and yield are the means of four replicated blocks per treatment. The data on the percentage of fruit with different defects before harvest were transformed to arcsine square root prior to analysis. The data on the number of fruit with defects in storage out of a sample of eight were transformed to log10 (x + 1) prior to analysis. Treatment means were back-transformed for presentation.

Total rainfall over the harvest period from late May to late September was 233 mm, with some weeks completely dry and other weeks receiving more than 40 mm (see Figure 1). The rainfall was lower than the long-term average for this area of 280 mm. Average daily minimum temperature was slightly higher under the tunnels than outdoors (see Table 1). In contrast, average daily maximum temperatures were similar in the two growing environments. Average daily maximum relative humidity was slightly lower under the tunnels than outdoors, while average daily minimum relative humidity was similar in the two areas. Higher mean daily maximum relative humidities outdoors probably reflected dew next to the plants early in the morning.

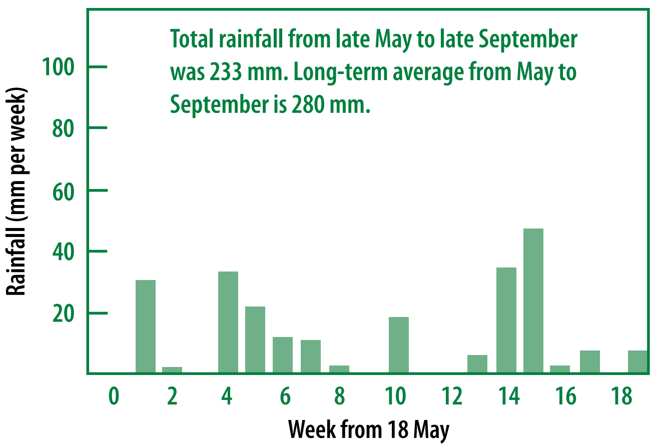

Figure 1. Rainfall during the protected cropping experiment on the Sunshine Coast in 2015.

The plants growing under the tunnels and outdoors had similar investments in leaf dry matter production (see Table 2). In contrast, crown and root dry matter production were higher in the plants growing under the tunnels than in the plants growing outdoors, while flower and immature fruit dry matter production was lower. Spraying had no effect on average seasonal dry matter production.

The plants growing under the tunnels had lower marketable yields and returns than the plants growing outdoors (see Table 3). These responses were associated with fewer flowers and immature fruit in the plants growing under the tunnels. The results in 2015 were different to those recorded in previous years where the yields of the plants growing under the tunnels were higher than the yields of the plants growing outdoors.

It was warmer during the day in 2015 than in 2014. For example, the average mean daily maximum temperature under the tunnels between May and September was 26.8°C in 2015 compared with 24.6°C in 2014. It was particularly warmer in August and September in 2015 than in 2014 (mean monthly maximum temperatures of 27.2°C versus 23.0°C, and 29.4°C versus 26.5°C). Night temperatures were similar in both years, with an average mean daily minimum temperature between May and September of 13.0°C in both years. Average daily solar radiation at the site between May and September was similar in 2014 and 2015 (14.4 and 14.2 MJ per m^2 per day). The plastic used in the tunnels was new in the first experiment, and one-year-old in the second experiment. New plastic transmits about 85% of sunlight, with light levels falling by about 5% per year thereafter.

Table 2. Effect of protected cropping on average seasonal plant dry weight in strawberry plants grown on the Sunshine Coast in 2015. The plants were grown outdoors or under tunnels. Half the plots were sprayed for the control of grey mould and the other plots not sprayed. Data are the means of 16 replicates per treatment pooled over sprayed and unsprayed plots and over two cultivar/breeding lines.

Treatment	Leaves (g per plant)	Crowns (g per plant)	Roots (g per plant)	Flowers & immature fruit (g per plant)
Outdoor	16.8	4.6	4.0	9.7
Tunnel	19.5	7.4	5.3	6.5
Control	17.2	5.9	4.6	7.6
Sprayed	19.1	6.1	4.7	8.6

In 2015, total losses of fruit were similar in the two growing areas (see Table 4). They were higher in the control than in the sprayed plots outdoors, but similar under the tunnels. Average losses due to rain damage and/or mould and due to mould alone were higher outdoors than under the tunnels. There were higher losses of fruit in these two categories in the control than in the sprayed plots outdoors, but no differences under the tunnels. As in the previous year, the main reason that the fruit were rejected was because they were small and/or misshaped (see Table 4). Within this classification, most of the fruit were small. Losses due to small and/or misshaped fruit were higher in the plants growing under the tunnels than the plants growing outdoors. The spray program had no effect on the incidences of these defects.

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 (7% of fruit affected versus 10%, back-transformed means). However, there was no effect of spraying on the incidence of the disease when the plants were growing under the tunnels (less than 1% of fruit affected in sprayed and non-sprayed plots, back-transformed means).

Table 3. Effect of protected cropping on marketable yields, returns and average seasonal fruit fresh weight in strawberry plants grown on the Sunshine Coast in 2015. The plants were grown outdoors or under tunnels. Half the plots were sprayed for the control of grey mould and the other plots not sprayed. Data are the means of 16 replicates per treatment pooled over sprayed and unsprayed plots and over two cultivar/breeding lines.

Treatment	Marketable yield (g per plant)	Gross return ($ per plant)	Average fruit fresh weight (g)
Outdoor	466	3.25	21.3
Tunnel	359	2.58	19.6
Control	389	2.77	20.3
Sprayed	439	3.06	20.6

The incidence of powdery mildew was higher in the plants growing under the tunnels than in the plants growing outdoors (see Table 4). There was a large difference between the incidence of the disease in 'Festival' and the breeding line under the tunnels (2% versus 10% of fruit affected, back-transformed means), and no difference outdoors (less than 1% of fruit affected, back-transformed means). Spraying had no effect on the incidence of the disease (see Table 4).

Table 4. Effect of protected cropping on the incidence of various fruit defects in strawberry plants grown on the Sunshine Coast in 2015. The plants were grown outdoors or under tunnels. Half the plots were sprayed for the control of grey mould and the other plots not sprayed. 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 cultivar/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	16	1	22	47
Tunnel	1	5	32	47
Control	6	1	28	50
Sprayed	4	2	26	44

Growing system and spray program had no effect on the losses of fruit after harvest. The average loss of fruit over the two sampling times was 0.7 fruit out of eight (back-transformed mean). Similarly, there was no effect of growing system or spray program on fruit brix°, with an average value of 9.3%. In contrast, fruit acidity was slightly higher in the plants growing under the tunnels (0.77%) than the plants growing outdoors (0.72%).

The results of this experiment are different to the three earlier experiments at Palmwoods. In 2012, 2013, and 2014, the plants growing under the tunnels had higher yields than the plants growing outdoors. In contrast, in 2015, the plants growing under the tunnels had lower yields than the plants growing outdoors. It was much hotter under the tunnels in 2015 than in 2014. It was possibly too warm for good flowering and fruit set under the tunnels in 2015. Overall yields were also lower in the outdoor plots in 2015 than in the other years. At Palmwoods, productivity under the tunnels was much lower in 2015 than in 2012, 2013 and 2014. Average yields were 359 g per plant compared with 991 g per plant, 594 g per plant, and 869 g per plant. These results demonstrate the importance of ventilation under the tunnels for successful production.

The results for the sprayed and unsprayed plots suggest that strawberry plants growing under protected culture 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.

Control of powdery mildew in strawberry plants growing under a plastic high tunnel in Florida

Jim Mertely, Teresa Seijo and Natalia Peres

An experiment was conducted to investigate the effect of different chemicals for the control of powdery mildew affecting strawberry crops growing under a plastic tunnel. 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 growing during winter. Due to the closed environment in the tunnels, powdery mildew is often observed less than six weeks after planting in this growing area.

Bare-rooted, green-top 'Sensation' transplants from Canada were planted on 8 October 2014 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 335 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 12-plant plots that were 2.5 m long, separated by 0.9 to 1.2 m of empty bed. The plants were irrigated by overhead sprinklers 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 5). 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 14 November to 16 January, 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 28 December, and scoring ten microscopic fields per leaflet at a magnification of × 25 for the presence or absence of mycelium. Fields that had more than half of the surface covered with mycelia were counted positive for the fungus. The leaflets were taken from leaves previously tagged when the petioles were elongating on 12 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 15 harvests from 1 December to 26 January. 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.

Powdery mildew quickly developed in the closed tunnel environment and was observed only four weeks after planting in Florida. Young leaves were tagged on 12 December and removed for microscopic observations on 28 December. Colonization of these leaves by the fungus was influenced directly or indirectly by treatments applied during the first six weeks of spraying (see Table 5). Foliar coverage of the disease ranged from 7 to 86% across all the treatments and was 84% in the control plots. Most treatments reduced foliar coverage, although tetraconazole (Mettle®) alone, and *Bacillus subtilis* (formulations of Serenade® and Taegro®) did not. Foliar coverage was moderately reduced by chitosan (Armour-Zen®) and the plant extract (Regalia®). The highest reductions in foliar disease were made by treatments which included pyraclostrobin + fluxapyroxad (Merivon®), or quinoxyfen (Quintec®) alternated with cyflufenamid (Torino®).

Fruit infections ranged from 9 to 40% across all the chemical treatments and was 42% in the control plots. Treatments that included pyraclostrobin + fluxapyroxad, or quinoxyfen applied alternately with cyflufenamid dramatically reduced the incidence of the disease on the fruit (see Table 5). Overall, marketable yields tended to decrease as the incidence of the disease on the fruit increased (see Figure 2). However, the data were highly variable within a treatment, resulting in non-significant differences in mean yields across the different treatments (see Table 5). There was a poorer relationship between yield and disease on the leaves. There was no evidence of phytotoxicity in the experiment.

Figure 2. Relationship between marketable yield and the incidence of powdery mildew in 'Sensation' strawberry plants in the fungicide screening experiment in Florida in 2014/15 (N = 15). Yield decreased as the incidence of disease on the fruit increased. There was a poorer 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.

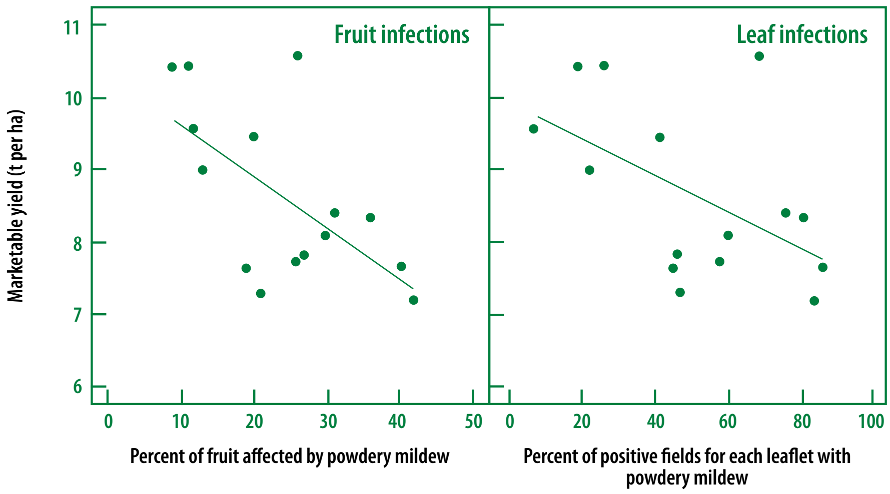

Table 5. Effect of different chemicals on the performance of 'Sensation' strawberry plants grown under a tunnel in Florida. The chemicals were applied in a series of ten-weekly applications made from 14 November 2014 to 16 January 2015. Data on fruit infections were based on the percentage of fruit with conspicuous powdery mildew growth on more than 25% of the achenes. Data on leaf infections were based on the percentage of powdery mildew coverage following microscopic observations of the leaves at a magnification of × 25. Streptomyces lydicus *= Actinovate®; pyraclostrobin + fluxapyroxad = Merivon®; cyflufenamid = Torino®; quinoxyfen = Quintec®; tetraconazole = Mettle®; penthiopyrad = Fontelis®; azoxystrobin + propiconazole = Quilt Xcel®;* Bacillus subtilis *var.* amyloliquefaciens *strain* FZB 24 *= Taegro®; chitosan = Armour-Zen®;* Bacillus subtilis *strain* QST 713 *= Serenade®. The plant extract is from giant knotweed,* Reynoutria sachalinensis *(Regalia®). 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	7.2	42	84
Pyraclostrobin + fluxapyroxad	10.4	9	19
Streptomyces lydicus & pyraclostrobin + fluxapyroxad (× 2 conc.) alt. with *Streptomyces lydicus*	9.6	12	7
Streptomyces lydicus & pyraclostrobin + fluxapyroxad (× 1 conc.) alt. with *Streptomyces lydicus*	9.0	13	22
Cyflufenamid	9.4	20	41
Quinoxyfen alt. with cyflufenamid	10.4	11	26
Tetraconazole	10.6	26	68
Tetraconazole alt. with cyflufenamid	7.6	19	45
Azoxystrobin + propiconazole alt. with cyflufenamid	8.1	30	60
Penthiopyrad	7.3	21	47
Chitosan	7.8	27	46
Bacillus subtilis var. *amyloliquefaciens* strain *FZB 24*	8.4	31	76
Bacillus subtilis strain *QST 713* (liquid)	8.3	36	80
Bacillus subtilis strain *QST 713* (powder)	7.7	40	86
Plant extract	7.7	26	58

Implications of the research

Two experiments were conducted in 2015 to investigate different strategies used to control plant and fruit diseases affecting strawberry fields in Queensland and Florida. In the first experiment initiated in southern Queensland, plants of two cultivar/breeding lines were grown under plastic high tunnels and their performance compared with that of plants grown outdoors. Subsets of plants were grown with and without the use of chemicals to control grey mould. In the second experiment set up in Florida, plants were grown under a tunnel and sprayed with different chemicals to control powdery mildew.

The response of the plants on the Sunshine Coast varied with the season and experimental set-up. In 2012 and 2013, the yields of the plants growing under the tunnels were 24 to 38% higher than the yields of the plants growing outdoors. In 2014, the yields of the plants under the tunnels were more than double those of plants outdoors. In that year, over-head irrigation was given to the plants growing outdoors to provide a water application about twice that of the average rainfall for the area. In contrast, in 2015, the yields of the plants under the tunnels were about a quarter less than the yields of plants outdoors and no over-head irrigation was provided to supplement the below average rainfall. Overall yields were lower in 2015 than in 2014. These responses were associated with higher day temperatures during most of the growing season in 2015. These results demonstrate the importance of ventilation under the tunnels in a warming climate.

In 2015, the plants growing under the tunnels generally had fewer losses due to rain damage and grey mould than the plants growing outdoors, and had higher losses due to powdery mildew and small and misshaped fruit. 'Festival' had more small and/or misshaped fruit and the breeding line more fruit affected by powdery mildew. Only cultivars with some resistance to powdery mildew should be grown under protected cropping. Spraying reduced the incidence of grey mould outdoors. In contrast, the incidence of the disease was very low under the tunnels and not affected by spraying. These results suggest that strawberry crops growing under protected cropping in south-east Queensland probably do not need to be sprayed for grey mould.

A model was developed to estimate the time taken to pay-back the initial cost of the tunnels on the Sunshine Coast of $115,000 per ha. The time taken to recover the cost of the tunnels varied from three to ten years, depending on the annual rainfall, relative production losses, and base productivity (see Table 6). The average pay-back period was five years, and only two or three years with heavy rainfall. Average rainfall from May to September in this area over 61 years is 415 ± 29 mm (mean ± standard error or SE), median rainfall is 375 mm, the lowest rainfall is 59 mm, and the highest rainfall is 1178 mm. Eight out of 61 years have been very dry (< 200 mm), nine years dry (200 – 300 mm), 21 years average (300 – 400 mm), nine years wet (400 -500 mm), and 14 years very wet (> 500 mm).

Table 6. Estimated pay-back period (years) to recover the initial cost of a plastic high tunnel for growing strawberry plants in south-east Queensland. The initial cost of the tunnel is $115,000 per ha. Average yields are 500 g per plant and above average yields are 750 g per plant. Moderate losses for very dry, dry, average, wet, and very wet years are 10, 15, 25, 30 and 35%, respectively. Severe losses for very dry, dry, average, wet, and very wet years are 15, 20, 30, 35 and 40%, respectively. Losses are more severe when the rainfall is distributed evenly over the growing season. Eight out of 61 years have been very dry (< 200 mm), nine years dry (200 – 300 mm), 21 years average (300 – 400 mm), nine years wet (400 – 500 mm), and 14 years very wet (> 500 mm). The price for fruit is $1.50 per punnet. The additional costs of picking and packing the extra crop under the tunnels of $0.75 per kg has been taken into account in the analysis. The weighted means were estimated using the pattern of rainfall over the past 61 years.

Scenario	Very dry	Dry	Average season	Wet	Very wet	Weighted mean
Average yields & moderate losses	15	10	6	5	4	7
Above average yields & moderate losses	10	7	4	3	3	5
Average yields & severe losses	10	8	5	4	4	6
Above average yields & severe losses	7	5	3	3	3	4

There have been several reports examining the productivity of strawberry plants growing under plastic tunnels in northern America. Experiments have been conducted in Canada, California, Texas, Kansas, and Florida. The average yields of the plants growing under the tunnels were 1.8 times higher than the average yields of the plants growing outdoors. The increase in productivity of the plants growing under protected cropping ranged from 43 to 750% (7.5 times higher). The plants growing under the tunnels had higher yields because of protection from frosts, rain, hail and cool growing temperatures. The use of the plastic often extended the production season and reduced the incidence of fruit disease.

In Mexico, tunnels protected the crops growing at elevation from frosts and increased yields by 20 to 75%. In Turkey, the use of plastic extended the growing season and increased yields by 20%. In the Netherlands, protecting the crop from rain and fruit disease increased yields by 7%. There was a slightly different response reported in a recent experiment in Colombia. It was noted that yields of 'Albion' were higher under tunnels than outdoors, while yields of 'Monterey' were similar in the two growing environments. It was suggested that the 'Monterey' plants growing under the tunnels were affected by calcium deficiency due to their strong growth.

Across all the various chemicals applied to the strawberry plants growing under the tunnels in Florida, treatments that included pyraclostrobin + fluxapyroxad, or quinoxyfen applied alternately with cyflufenamid dramatically reduced the incidence of the disease on the fruit. Quinoxyfen and cyflufenamid have recently been accepted for use in strawberry nurseries in Australia. The use of these chemicals in the nurseries would be expected to reduce levels of inoculum of powdery mildew in the new transplants.

Further experiments should be conducted in south-east Queensland to assess the economics of growing strawberry plants under plastic high tunnels. Information should be collected on the use of ventilation to prevent excessive temperatures under the plastic structures. Information should be collected on the effect of different planting systems to improve the profitability of protected cropping in south-east Queensland. Efforts should be made to develop strawberry cultivars that are less susceptible to powdery mildew when the plants are grown under protected cropping.

Researcher profiles

Christopher Menzel

Dr Menzel is a Principal Horticulturist for DAF and has conducted research for the strawberry industry in Australia for the past ten years. He has more than 30 years of experience in tropical horticulture. Chris is an Associate of the *Journal of Horticultural Science & Biotechnology* and *Scientia Horticulturae*. Dr Menzel led research that examined transplant agronomy, and the control of crown rot and lethal yellows in strawberry fields. He led research examining the potential of protected cropping of strawberry plants on the Sunshine Coast. Some of this research was conducted in collaboration with colleagues from the University of Florida. Chris also led the work conducted with Apollo Gomez and Lindsay Smith to screen chemicals for the control of plant and fruit diseases in strawberry crops. This work supported changes for the use of captan and thiram in commercial strawberry fields in Australia.

Lindsay Smith

Mr Smith is a Technical Assistant for DAF 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 has assisted 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. She has developed programs to assist commercial growers to decide when to apply fungicides to their crops. Natalia leads a team of plant pathology specialists at the University of Florida and has supervised several post-graduate students. She has been a major contributor to activities of the American Phytopathology Society (APS). Dr Peres has strong links with the research program at DAF, and has been assessing chemicals for the control of powdery mildew in strawberry plants growing under a plastic tunnel.

Teresa Seijo

Mrs Seijo is a Senior Biological Scientist at UF Gulf Coast Research and Education Center. She has assisted in many research projects on the diseases of strawberries and ornamentals for the past twenty years. Teresa has evaluated the effect of various products for the control of powdery mildew in Florida.

Jim Mertely

Mr Mertely is a Research Co-ordinator at the UF Gulf Coast Research and Education Center. He oversees the diagnostic clinic and fungicide experimental program for the plant pathology group. Jim has assisted the team evaluating products for the control of powdery mildew in Florida.

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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.