The Protected Culture of Strawberry Plants Growing under Plastic Tunnels

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Contents

Summary

Strawberry growers in Australia produce about 72,000 tonnes of fruit worth $450 million each year. The main production centers are located in Queensland, Victoria and Western Australia, with production in Queensland worth $240 million. There are smaller industries in New South Wales, South Australia and Tasmania. Production on the Sunshine Coast in south-eastern Queensland in open field conditions is severely affected by rain most seasons. The fruit can also be lost to various diseases, including grey mould and stem-end rot.

We were interested in determining the productivity of plants growing under plastic high tunnels and protected from rainfall. Experiments were conducted over four years from 2012 to 2015 on the Sunshine Coast to compare the productivity of plants growing under tunnels with that of plants growing outdoors. Strawberries are also produced in Florida under similar growing conditions as in south-eastern Queensland, with production also affected by rain and diseases. Other experiments were conducted in Florida to assess the effect of different chemicals for the control of powdery mildew, an important disease affecting strawberry plants growing under protected cropping. Plants growing under tunnels often have a higher incidence of this disease compared with plants growing outdoors.

In the first two years' experiments at Palmwoods on the Sunshine Coast, with slightly lower than average rainfall, the marketable yields of the plants growing under the tunnels were 24 to 38% higher than the yields of the plants growing outdoors. The higher marketable yields under protected cropping were due to less rain damage and grey mould in the plants growing under the tunnels.

In the third year, supplementary over-head irrigation was given to the plants growing outdoors to give a water application about twice that of the long-term average for the season at Palmwoods. In the fourth year, no supplementary irrigation was given, and rainfall was about 80% of that of the long-term average for Palmwoods. In these last two experiments, half the plants in each group received the standard sprays to control grey mould, while the other half of the plants received none of these sprays. Both groups of plants received the standard sprays used to control pests, and other diseases, including powdery mildew. The relative marketable yields of the plants under the tunnels were more than 200% the yields of the plants outdoors in year three (over-head irrigation outdoors), but about a 25% lower in year four (no over-head irrigation outdoors). Average day temperatures under the tunnels were about 3^{o} to 4^{o}C warmer in August in 2015 than in 2014. There were no differences in the incidence of grey mould in sprayed and unsprayed plots under the tunnels. These results suggest that plants growing under tunnels may not need to be sprayed for this disease.

Overall, the four cultivar/breeding lines responded similarly to the growing environment and the spray programs. In 2012 and 2013, 'Festival' had a lower incidence of rain damage and/or grey mould than the other cultivar (Rubygem) and breeding lines, and 'Rubygem' had a higher incidence of small and/or misshaped fruit. In 2014 and 2015, 'Festival' generally had a lower incidence of rain damage and/or grey mould and powdery mildew than 'Breeding Line 1', and a higher incidence of small and/or misshaped fruit, especially when the plants were growing under the tunnels.

A model based on rainfall over the past 61 years at Palmwoods on the Sunshine Coast was used to estimate the time taken to recover the initial cost of the tunnels. The time taken to recover the cost of the tunnels varied from three to fifteen years, depending on the annual rainfall, relative production losses, and base productivity. The average pay-back period was five years, but can be reduced to three years with heavy rainfall. Other factors that might influence the economics of the tunnels include the life-span of the plastic and the rate of light transmission over time, and the susceptibility of individual tunnel structures to wind damage in different growing areas.

Strawberry plants growing in Queensland and Florida can be affected by powdery mildew. Plants growing under tunnels usually have a higher incidence of the disease than plants growing outdoors. In the disease experiments conducted in Florida, treatments that included pyraclostrobin + fluxapyroxad, or quinoxyfen applied alternately with cyflufenamid dramatically reduced the incidence of powdery mildew on the fruit. Overall, marketable yields tended to decrease as the incidence of the disease on the fruit increased. Metrafenone was also relatively effective. Quinoxyfen and cyflufenamid have recently been accepted for use in strawberry field nurseries in Australia. The use of these last two chemicals in nurseries would be expected to reduce levels of inoculum of powdery mildew in new transplants.

Information needs to be collected to determine whether the responses recorded from commercial growers are similar to those recorded from this project. Efforts should be made to develop strawberry cultivars that are less susceptible to powdery mildew for protected cropping. Data should be collected to determine whether fruit harvested from under tunnels have higher chemical residues than those harvested from outdoors, and whether this issue is likely to impact on food safety. Information should be collected on the effect of metrafenone on the control of powdery mildew in south-eastern Queensland.

Keywords

Grey mould; powdery mildew; stem-end rot; strawberry; *Botrytis cinerea*; *Gnomoniopsis fructicola*; *Podosphaera aphanis*; plastic high tunnels; protected cropping; yield; *Fragaria ×ananassa*.

Introduction

Strawberry growers in Australia produce about 72,000 tonnes of fruit worth $450 million each year. The main production centers are located in Queensland, Victoria and Western Australia, with production in Queensland worth $200 million. There are smaller industries in New South Wales, South Australia and Tasmania. Production in south-eastern Queensland in open field conditions is severely affected by rain most seasons. 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 (Herrington et al., 2009, 2011, 2013). Cultivars vary in their sensitivity to direct rain damage, however nearly all are affected when the fruit are mature.

Strawberry production in south-eastern Queensland is also affected by fruit disease which is promoted by direct rain contact or by high humidity (Menzel et al., 2014). These diseases are mainly 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. These diseases are mainly controlled by the application of fungicides. However, there are several problems with many of the products used by industry. Some of these chemicals are ineffective under wet weather, have limits to the number of applications allowed in a season, or may become ineffective in the long-term because of the development of fungicide resistance.

There have been several reports examining the productivity of strawberry plants growing under plastic tunnels in northern America. Experiments have been conducted in Canada (Burlakoti et al., 2013; Medina et al., 2011), California (Daugovish and Larson, 2009; Larson et al., 2009), Texas (Wallace and Webb, 2013), Kansas (Kadir et al., 2006), and Florida (Salamé-Donoso et al., 2010; Santos, 2013; Santos, et al., 2014). The plants growing under the tunnels had higher yields because of protection from frosts, rain, hail and cool/cold growing temperatures. The greatest differences in yield between the tunnel and outdoor plots are usually associated with severe weather events including frosts and prolonged cold weather (Kadir et al., 2006; Wallace and Webb, 2013). This usually occurs in marginal growing areas. The use of the plastic often extended the production season and reduced the incidence of fruit disease. In Mexico, the tunnels protected the crops growing at elevation from frosts and increased yields by 20 to 75% (Dávalos-González et al., 2014). In Turkey, the use of plastic extended the growing season and increased yields by 20% (Önal, 2000). In the Netherlands, protecting the crop from rain and fruit disease increased yields by 7% (Evenhuis and Wanten, 2006). There was a slightly different response reported in an experiment in Colombia (Grijalba et al., 2015). 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.

We were interested in studying the productivity of strawberry plants growing under tunnels in subtropical south-eastern Queensland (27^{o}S). In the first set of experiments conducted over two years, two cultivars and two breeding lines were grown under plastic high tunnels and their performance compared with that of plants grown in open, outdoor plots. In these experiments, rainfall during the fruit production period was slightly lower than the long-term average for Palmwoods. Palmwoods is one of the strawberry growing areas on the Sunshine Coast in south-eastern Queensland. In the second set of experiments conducted over two years, one cultivar (Festival) and one breeding line were grown under plastic high tunnels and their performance compared with that of plants grown outdoors. In the first year, supplementary over-head irrigation was given to the plants growing outdoors to provide a water quantity about twice that of the long term average rainfall for the season (see Methodology below). In the second year, no supplementary irrigation was given, and rainfall was about threequarters of the long-term average for the area. In these last two experiments, half the plants in each group received the standard sprays to control grey mould, while the other half of the plants received none of these sprays. Both groups of plants received the standard sprays used to control pests, and other diseases, including powdery mildew.

The main supplier of tunnels in Australia is Haygrove (www.haygrove.com.au). They sell a range of plastics and structures. The plastic is typically 150 to 200 µm thick and has a variable life span depending on the thickness of the film and growing conditions. Light transmission is up to 90% when the plastic is new. Transmission usually declines by a few percent each year, depending on environmental conditions. The life of the plastic varies with location and whether the plastic is stored over summer between strawberry crops on the Sunshine Coast. A typical lifespan for use just over winter would be at least six years on the Sunshine Coast. The susceptibility of the tunnels to strong winds depends on the type of structure, bracing and general engineering. Each location has a different set of circumstances.

In separate research, experiments were set-up over four years 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 disease affects strawberry plants in many growing areas, including Queensland and Florida. The incidence of powdery mildew is usually higher in plants growing under tunnels than in plants growing outdoors (Xiao et al., 2001), but is genotype specific. A high incidence of the disease has the potential to limit the profitability of growing strawberry plants under protected cropping.

To summarise, experiments were conducted in Queensland and in Florida to examine the productivity of strawberry plants growing under protected cropping. We were interested in determining whether the use of tunnels should be considered by commercial growers in the two producing areas.

Methodology

Four experiments were conducted over four years at Palmwoods on the Sunshine Coast, south-eastern Queensland to examine the productivity of strawberry plants growing under plastic high tunnels. In these experiments conducted in Queensland, plants were grown under tunnels and outdoors to examine the effect of rain on productivity in this environment. The plants were grown under plastic for the whole strawberry season. This was different to work conducted in California, where the plants were grown under the tunnels for just a few weeks.

Four experiments were also conducted in Florida to examine the effect of different chemicals on the incidence of powdery mildew in plants growing under a tunnel. Powdery mildew affects strawberry plants in both Queensland and Florida. In these experiments conducted in Florida, different chemical treatments were assessed to determine whether they could reduce the incidence of powdery mildew in strawberry plants growing under tunnels.

Protected cropping in south-eastern Queensland – rain damage and grey mould

Bare-rooted transplants (with leaves) of 'Festival', 'Rubygem', and two breeding lines noted as 'Breeding Line 1' and 'Breeding Line 2' were planted on 21 March 2012 and on 21 March 2013 at Palmwoods on the Sunshine Coast in south-eastern Queensland. The plants were grown on black polythene covered raised-soil beds either under plastic high tunnels or in open, outdoor plots. The plants were grown at 51,000 plants/ha.

The plastic structures used were standard Haygrove tunnels, which are utilized extensively in the United Kingdom, Australia and other places (Haygrove Ltd., Ledbury, UK). The polythene THP Visqueen luminance plastic was 200 µm thick, and has a lifespan of 3 to 6 years in some environments (BPI Visqueen Horticultural Products, Stevenston, UK). It has been shown to last at least six years at Palmwoods on the Sunshine Coast (Driscoll's Australia). The tunnels were 42 m long, 9 m wide and 4 m high. There can be problems with wind damage over this period, although no information is available on any losses in this area. Extreme winds occur infrequently and are usually associated with storms at this time. The risk of damage to the tunnels is dependent of their individual structure and the bracing and support used.

The plastic was placed over the tunnel frames in mid-May 2012 and left over summer in 2012/13. This meant that the plastic was placed over the frames for part of the year in 2012 and for the whole year in 2013. The sides of the tunnels were raised soon after planting each year to moderate temperatures close to the plants. There were two tunnels adjacent to each other and two outdoor plots adjacent to the tunnels. The 'whole-plots' (i.e. the tunnel and outdoor) were randomised in two replicates (as 'Outdoor1' 'Tunnel1', 'Tunnel2' 'Outdoor2'). Within each outdoor and tunnel there were two blocks (southern and northern ends) and within each block there were four randomised cultivars, with the cultivars being the same across the 2 whole-plots (outdoor and tunnel) within each replicate. The plants were grown in the two tunnels and the two outdoor plots (two growing environments or systems). In the tunnels, the southern end of each tunnel received no direct sunlight from outside, whereas in the northern end of each tunnel, the plots received some direct sunlight in the morning. There was about 3 m of row between the southern and northern blocks in the middle of each tunnel. There was a similar gap between the southern and northern blocks in the outdoor plots. This set-up gave four plots × 30 plants in each plot and 120 plants per treatment. An overview of the design for these two experiments is provided below. The plants in the two growing environments received similar spray applications for the control of pest and disease.

An overview of the design for the growing environment × cultivar experiment in 2012. A similar design was used in 2013.

	Outdoor 1		*Tunnel 1*		*Tunnel 2*		*Outdoor 2*	
	Row 1	*Row 2*	*Row 1*	*Row 2*	*Row 1*	*Row 2*	*Row 1*	*Row 2*
Southern section	Cultivar 1	Cultivar 2	Cultivar 4	Cultivar 1	Cultivar 1	Cultivar 3	Cultivar 4	Cultivar 3
	Cultivar 4	Cultivar 3	Cultivar 3	Cultivar 2	Cultivar 2	Cultivar 4	Cultivar 2	Cultivar 1
Northern section	Cultivar 2	Cultivar 4	Cultivar 1	Cultivar 3	Cultivar 3	Cultivar 1	Cultivar 1	Cultivar 2
	Cultivar 3	Cultivar 1	Cultivar 2	Cultivar 4	Cultivar 4	Cultivar 2	Cultivar 3	Cultivar 4

Bare-rooted transplants of 'Festival', and a breeding line noted as 'Breeding Line 1' (same line as in the earlier experiments) were planted on 24 March 2014 and on 19 March 2015 at Palmwoods. The plants were grown under plastic tunnels or outdoors. The plastic was placed over the tunnel frames in March 2014 and left over summer in 2014/15. This meant that the plastic was placed over the frames for part of the year in 2014 and for the whole year in 2015. In 2014, the plants growing outdoors were watered with over-head irrigation for ten weeks from early July to early 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/day (80 minutes of overhead irrigation over 24 h for the first two weeks and then 180 minutes over 24 h). No supplementary over-head irrigation was given to the plants growing outdoors in 2015. In each year, half the plants in each group received the standard sprays to control grey mould, while the other half of the plants received none of these sprays. Both groups of plants received the standard sprays used to control pests, and other diseases, including powdery mildew. All the cultivars received the same agronomy. The plants were grown in two tunnels and two outdoor plots (two growing environments or systems). The whole plots (tunnel and outdoor were the same as in previous years) and were replicated. The spray treatment (split-plots) was applied within the whole plots and the cultivar/breeding lines (subplots) were applied within the split-plots. An overview of the design for these two experiments is provided below. This set-up gave four plots × 30 or 40 plants in each plot and 120 or 160 plants per treatment.

An overview of the design for the growing environment × spray program × cultivar experiment in 2014. A similar design was used in 2015.

	Outdoor 1		*Tunnel 1*		*Tunnel 2*		*Outdoor 2*	
	Row 1	*Row 2*	*Row 1*	*Row 2*	*Row 1*	*Row 2*	*Row 1*	*Row 2*
Southern section	Control Cultivar 1	Spray Cultivar 2	Spray Cultivar 1	Control Cultivar 1	Control Cultivar 2	Spray Cultivar 1	Spray Cultivar 2	Control Cultivar 1
	Control Cultivar 2	Spray Cultivar 1	Spray Cultivar 2	Control Cultivar 2	Control Cultivar 1	Spray Cultivar 2	Spray Cultivar 1	Control Cultivar 2
Northern section	Spray Cultivar 2	Control Cultivar 1	Control Cultivar 2	Spray Cultivar 1	Spray Cultivar 2	Control Cultivar 1	Control Cultivar 2	Spray Cultivar 2
	Spray Cultivar 1	Control Cultivar 2	Control Cultivar 1	Spray Cultivar 2	Spray Cultivar 1	Control Cultivar 2	Control Cultivar 1	Spray Cultivar 1

The general lay-out of the experiments, planting system and plant agronomy is described in detail in Menzel et al. (2014).

Fruit were harvested once or twice per week for an assessment of marketable yield (fresh weight) and the total number of fruit/plant from mid-May to early October (2012) or to mid-September (2013) or to late September (2014 and 2015). Mature fruit were classified as those that were at least 75% coloured. A record was kept of the total number of fruit that were affected by rain or grey mould or both, or powdery mildew, along with those that were small (less than 12 g fresh weight) or misshaped or both, or that had other defects (mainly other disease, surface bronzing or bird damage). Fruit that were affected by rain and grey mould were rated as affected by grey mould. Fruit that were small and misshaped were rated as misshaped so that they could be grouped into one category.

Data on yield, returns per plant and on defects are presented as treatment means with standard errors (SEs).

A model based on rainfall over the past 61 years at Palmwoods on the Sunshine Coast was used to estimate the time taken to recover the initial cost of the tunnels in south-eastern Queensland based on the losses occurring in the present research. Average rainfall (over 61 years) from 1 May to 30 September in this area was 415 ± 29 mm, median rainfall was 375 mm, the lowest rainfall was 59 mm, and the highest rainfall was 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). The sensitivity of time taken to recover the cost of the tunnels was estimated using a range of levels of annual rainfall, relative production losses, and base productivity. The analysis took into account that about 15% of the growing area was lost due to the tunnel structures. The calculated yields per ha were reduced by this amount in the model. This model assumed marketable production changes occurred only on the farm with the tunnels not the effect of variations in market volume nor fruit quality on an industry wide basis (i.e. it assumes that market prices and volume are essentially stable).

Protected cropping in Florida – control of powdery mildew

Bare-rooted, transplants (with leaves) from Canada were planted in late October in 2011, 2012, 2013 ('Camarosa') and 2014 ('Winterstar') under a plastic high tunnel in Florida to examine the effect of fungicides on the control of powdery mildew. The tunnel was 92 m long, 8 m wide, and 5 m high. The planting systems and general plant agronomy have been described previously (Kennedy et al., 2013, 2014). Various chemical treatments (Tables 8 to 11), including a water control were applied. There were 17 treatments in 2011, 20 treatments in 2012, 15 treatments in 2013, and 15 treatments in 2014. Both standard and alternative (soft) chemicals were evaluated. The treatments were arranged in a randomized complete block design with four blocks on adjacent beds. The treatments were applied about every seven to fourteen days from early December to early February, with a CO_2-backpack sprayer delivering 935 litres/ha at 60 psi through two T-Jet disc-core hollow-cone nozzles.

Colonization of the leaves by the powdery mildew fungus, was evaluated by removing one leaflet from each of ten plants per plot in late 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 in mid-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 from late December to mid-February. The marketable fruit from each plant (no plant deaths) 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 data on disease incidence and marketable yield were analysed by one-way analysis of variance, with four blocks. The percentage data were transformed by 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.

Outputs

Industry Publications

Amiri, A. and N.A. Peres. 2013. Fungicide resistance monitoring of Botrytis. Berry/Vegetable Times (Florida) September, pp. 10–11.

Amiri, A. and N. Peres. 2014. Resistance of Botrytis to fungicides: what else do we know? Berry/Vegetable Times (Florida), September, pp. 4–5.

Menzel, C.M. 2012. The protected culture of strawberry plants growing under plastic tunnels. Horticulture Australia Limited Strawberry Industry Annual Report, p. 5.

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Menzel, C.M., A. Gomez, and L.A. Smith. 2012. Reducing the impact of plant and fruit diseases on strawberry production on the Sunshine Coast. Department of Agriculture, Fisheries and Forestry, 2 pp.

Menzel, C.M., A. Gomez, and L.A. Smith. 2013. Reducing the impact of plant and fruit diseases on strawberry production in southern Queensland. Department of Agriculture, Fisheries and Forestry, 2 pp.

Menzel, C.M., A. Gomez, and L. Smith. 2014. Improving the control of plant and fruit diseases in strawberry fields in southern Queensland. Simply Red (Queensland Strawberry Industry Promotions Council) 34:4–5.

Menzel, C.M., A. Gomez, and L.A. Smith. 2014. Improving the control of grey mould and stem-end rot in strawberry plants in southern Queensland. Simply Red (Queensland Strawberry Industry Promotions Council) 35:4–5.

Menzel, C.M., A. Gomez, and L.A. Smith. 2014. Better control of fruit diseases in strawberry fields in southern Queensland. Simply Red (Queensland Strawberry Industry Promotions Council) 36:8–9.

Menzel, C.M., A. Gomez, L.A. Smith, J. Mertely, T. Seijo, and N.A. Peres. 2013. Improving the management of plant and fruit diseases affecting strawberry production in Australia and Florida. Simply Red (Queensland Strawberry Industry Promotions Council) Special Issue No. 2, 20 pp.

Menzel, C.M., A. Gomez, L.A. Smith, and N.A. Peres. 2013. Reducing the impact of plant and fruit diseases on strawberry production. Simply Red (Queensland Strawberry Industry Promotions Council) Special Edition, 16 pp.

Menzel, C.M., J. Moisander, and L.A. Smith. 2012. The protected cropping of strawberry plants grown under plastic tunnels. Department of Agriculture, Fisheries and Forestry, 12 pp.

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Menzel, C.M. and L.A. Smith. 2015. Improving strawberry yields and fruit quality in southern Queensland using tunnels. Simply Red (Queensland Strawberry Industry Promotions Council) 38:4–6.

Menzel, C.M. and L.A. Smith. 2015. Performance of strawberry plants grown under plastic tunnels during a dry, cool, overcast season on the Sunshine Coast. Simply Red (Queensland Strawberry Industry Promotions Council) 39:12–14.

Field days and seminars

Queensland Strawberry Growers' Association Meetings. The QSGA holds four meetings a year at Glasshouse Mountains on the Sunshine Coast. Over the past four years, updates on progress in plant and fruit diseases have been provided to local producers. Printed reports were provided to the growers at many of these meetings.

Queensland Strawberry Growers' Field Day. A field day was hosted by QSGA for the industry on the Sunshine Coast at Wamuran in July 2013. About 150 commercial strawberry growers attended the day, which included displays from commercial operators such as machinery suppliers, chemical companies, fertilizer companies, and pest scouts, etc. Information on disease management and protected cropping was presented to industry.

Field days at trial site. Chris Menzel presented overviews of the research on the response of different cultivars growing under protected cropping at Palmwoods in Queensland in 2012, 2013 and 2014 and 2015.

Strawberries Australia Inc. Members of the project team provided a summary of the research to industry at a Strawberries Australia Inc. meeting held at Nambour in September 2012. Approximately 50 growers from around the country attended the field day. A flyer summarising the research was presented to the attendees.

Strawberry Growers' Meeting on the Granite Belt. Chris Menzel provided an overview of progress on protected cropping at a growers' meeting at Applethorpe in June 2015.

Scientific presentations

International Horticultural Congress. Chris Menzel presented a paper on protected cropping at this international meeting held in Brisbane in August 2014. The paper is due to be published in a volume of Acta Horticulturae.

Outcomes

Protected cropping in south-eastern Queensland – rain damage and grey mould

Strawberry plants were grown under tunnels and outdoors over four seasons from 2012 to 2015 with different growing conditions on the Sunshine Coast in south-eastern Queensland. In the third season, supplementary over-head irrigation was given to the plants growing outdoors to give a water application about twice that of the average for the area in a drier than average season. In the fourth year, no supplementary irrigation was given, and rainfall was lower than the long-term average for Palmwoods. It was also warmer during the day in August and September in 2015 than in 2014. In these last two experiments, 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 response of the plants to the growing system varied with the season and experimental set-up. In 2012 and 2013, the marketable yields of the plants growing under the tunnels were 24 to 38% higher than the yields of the plants growing outdoors. Over-head irrigation was not used in these experiments. In 2014, when overhead irrigation was applied to plants outdoors, the marketable yields of the plants under the tunnels were more than double those of plants outdoors. In contrast, in 2015, the yields of the plants under the tunnels were about a quarter less than the yields of plants outdoors. Overall yields were lower in 2015 than in 2014.

In general, the plants growing under the tunnels had fewer losses due to rain damage and/or grey mould than the plants growing outdoors, and had higher losses due to powdery mildew and small and/or misshaped fruit. In the first two experiments, 'Festival' had a lower incidence of rain damage and/or grey mould than the other cultivar and breeding lines, and 'Rubygem' had a higher incidence of small and/or misshaped fruit. In the last two experiments, 'Festival' generally had a lower incidence of rain damage and/or grey mould and powdery mildew than 'Breeding Line 1', and a higher incidence of small and/or misshaped fruit. These differences were more noticeable in the plants growing under the tunnels. 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-eastern Queensland may not need to be sprayed to control grey mould.

The current experiments suggest that it would take about five years to recover the cost of the tunnels in south-eastern Queensland under average conditions, and less than that under wetter conditions. These data relate to the productivity of plants growing in this project. It is not known if the response of plants growing in commercial fields would be the same as the response of plants growing in this study. These data also relate to the plastic not being replaced before six years. The life of the tunnels will vary with the type of plastic used, the growing environment and whether the plastic is stored over summer on the Sunshine Coast. Light transmission is about 90% when the plastic is new and decreases by a few percent each year. The tunnels are susceptible to damage by strong winds that can occasionally occur during storms in the area. The actual risks will depend on the type of tunnel, bracing, general engineering and the individual growing area.

Protected cropping in Florida – control of powdery mildew

Across all the various treatments 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 powdery mildew disease on the fruit. Metrafenone was also relatively effective. 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.

These chemicals (pyraclostrobin, quinoxyfen and cyflufenamid) have minor use permits for use on strawberry plants (runners only) in Australia at the time of the report publishing. None of the other chemicals used in this experiment are permitted or 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 (AVPMA) website (http://www.apvma.gov.au).

Evaluation and Discussion

Protected cropping in south-eastern Queensland – rain damage and grey mould

In the experiments conducted in south-eastern Queensland total rainfall was below 1 May to 30 September average (415 mm); total rainfall during the harvests from late May to early October 2012 was 357 mm, while total rainfall from mid-May to mid-September 2013 was 329 mm. In 2012 and 2013 there were only small differences in average mean daily temperatures and average mean daily relative humidities between the tunnel and open growing environments (Table 1).

Total rainfall during the harvests from mid-May to late September 2014 was 285 mm, while total rainfall from mid-May to late September 2015 was 233 mm. The over-head irrigation used outdoors from early July 2014 provided about another 500 mm of water to the canopy. In 2014, mean daily maximum and minimum temperatures were similar in the two growing environments (Table 2). Mean daily maximum relative humidities were higher outdoors than under the tunnels, reflecting the use of the over-head irrigation during the day. In contrast, mean daily minimum relative humidities were lower outdoors. In 2015, mean daily maximum and minimum temperatures were similar in the two growing environments (tunnels, and open plots without overhead irrigation) (Table 2). Mean daily maximum relative humidities were higher outdoors than under the tunnels, while mean daily minimum relative humidities were similar in the two growing environments. Maximum temperatures during August and September were 3^{o} to 4^{o}C higher in 2015 than in 2014 (data not presented). This was possibly one of the factors associated with the lower productivity in 2015.

Marketable yields were 38% higher in the plants growing under the tunnels than in the plants growing outdoors in 2012, and 24% higher in 2013 (Table 3). Returns reflected marketable yields. In 2012, returns were higher in the plants under the tunnels than in the plants outdoors. Returns were lower in 2013, with the tunnel plants once again more profitable than the outdoor plants (Table 3). The reason for the higher average productivity in 2012 than in 2013 is not known, with the two seasons having similar average temperature conditions.

In 2012 and 2013, there was no interaction between growing environment and cultivar/breeding line on marketable yields (Table 3). In 2012, average yields were higher in 'Festival', intermediate in 'Breeding Line 1' and 'Rubygem', and lower in 'Breeding Line 2'. In 2013, average yields were higher in 'Festival', 'Breeding Line 1' and 'Breeding Line 2', and lower in 'Rubygem'.

In 2014, the marketable yields of the plants growing in the dry environment under the tunnels were more than double the yields of the plants growing in the wet environment outdoors, with no effect of the spray program (in the tunnels or outdoors) (Table 4). Returns reflected marketable yields, with higher returns in the plants in the dry environment, and similar returns in the control and sprayed plots. In 2015, the plants growing under the tunnels had lower marketable yields than the plants growing outdoors, and the sprayed plants had higher marketable yields than the control plants (Table 4). Returns reflected marketable yields as in the previous year.

In 2014 and 2015, there was no interaction between growing environment and cultivar/breeding line or between spray program and cultivar/breeding line on marketable yield (Table 4). In 2014, yield was higher in 'Breeding Line 1' than in 'Festival'. In 2015, yield was similar in 'Breeding Line 1' and in 'Festival'.

In 2012 and 2013, average losses of production due to fruit defects were about 50% greater in the plants growing outdoors than in the plants growing under the tunnels (Table 5). About a quarter of the losses outdoors were due to rain damage and/or grey mould. Within this classification, most of the fruit were damaged by rain. The rest of the fruit were mainly culled because they were small and/or misshaped or both. Within this classification, most of the fruit were small. Differences in the incidence of mould between the two growing environments were small. The plants growing in the different environments had similar incidences of small and misshaped fruit (Table 5).

In 2014, average losses of production due to fruit defects were about 50% greater in the plants growing in the wet environment outdoors than in the plants growing in the dry environment under the tunnels (Table 6). On average, about half of the losses outdoors were due to rain damage and/or grey mould. Within this classification, most of the fruit were damaged by rain. Mould alone was less of an issue (Table 6). The rest of the fruit were mainly culled because they were small and/or misshaped. Within this classification, most of the fruit were small. The two growing environments had similar incidences of these issues (Table 6). The incidence of powdery mildew was very low outdoors, and higher under the tunnels.

In 2014, the average total incidence of fruit defects was similar in the control and sprayed plots, and with a similar incidence of grey mould in the control and in the sprayed plots (Table 6). There was a 4% difference between the incidence of the disease in control and sprayed plots outdoors, and no difference under the tunnels.

In 2014, 'Festival' had a higher incidence of small and/or misshaped fruit than the 'Breeding Line 1', especially under the tunnels (Table 6). In contrast, the 'Breeding Line 1' had a higher incidence of powdery mildew, especially under the tunnel.

In 2015, the total incidence of fruit defects was similar in the two growing environments (Table 6). They were higher in the unsprayed control than in the sprayed plots outdoors, but similar under the tunnels. The average incidences of rain damage and/or mould and mould alone were higher outdoors than under the tunnels (Table 6). 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 (Table 6). Within this classification, most of the fruit were small. The incidence of these issues was higher in the plants growing under the tunnels than in the plants growing outdoors. In contrast, spray program had no effect on the incidences of these defects. As in the previous year, the incidence of small and/or misshaped fruit was higher in 'Festival' than in the 'Breeding Line'.

In 2015, the average incidence of powdery mildew was higher in the plants growing under the tunnels than in the plants growing outdoors (Table 6). There was a large difference between the incidence of the disease in 'Festival' and the 'Breeding Line' under the tunnels, and no difference outdoors. There was a large difference between the incidence of grey mould in control and sprayed plots outdoors, and no difference under the tunnels (Table 6).

A model was developed to estimate the time taken to pay-back the initial cost of the tunnels in south-eastern Queensland ($115,000/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 (Table 7). The average pay-back period was five years, and three years with heavy rainfall.

Protected cropping in Florida – control of powdery mildew

There were four experiments conducted over four years in Florida to evaluate the effect of different chemicals for the control of powdery mildew in strawberry plants growing under tunnels. The effect of the chemicals was assessed by recording the incidence of the disease on the leaves and the fruit, and by recording marketable yield.

In 2011/12, all but five treatments reduced foliar colonization by the powdery mildew fungus compared with the water control (Table 8). Pyraclostrobin + fluxapyroxad and quinoxyfen alone or alternated with triflumizole, myclobutanil, or cyflufenamid were effective, with no more than 10% infection. More of the treatments reduced powdery mildew on the foliage than reduced the disease on the fruit. The incidence of the disease on the fruit ranged from 11 to 44% and mostly from 11 to 25%. The incidence of the disease on the leaves ranged from 2 to 98%, and mostly from 19 to 83%. Only two treatments reduced powdery mildew on both the foliage and the fruit: pyraclostrobin + fluxapyroxad, quinoxyfen alone. However, azoxystrobin + propiconazole, cyflufenamid alternated with triflumizole, and triflumizole alternated with NZBBA 1106 (*Bacillus subtilis* var. *amyloliquefaciens*) which have less than 30% leaf infections and less than 20% fruit infections may warrant further study. There were no significant ($P > 0.05$) differences in marketable yield amongst the different treatments (4.4 to 6.9 t/ha). It is also possible that some other factor influenced the growth and productivity of the plants.

In 2012/13, colonization of the fungus on the leaves exceeded 75% in the control and several ineffective treatments (Table 9). Foliar colonization was strongly suppressed (with no more than 15% infection) by pyraclostrobin + fluxapyroxad and quinoxyfen alone, and moderately suppressed by ten other treatments. With only three exceptions, most treatments reduced the incidence of the disease on the fruit when compared with the incidence of the disease in the control plots. Marketable yield was negatively correlated with the incidence of the disease on the fruit. High yield was expected to correlate with a low incidence of the disease on the fruit because conspicuously diseased, and so classified as unmarketable, fruit were culled and not included in the yield data. Yield was also related to the incidence of the disease on the leaves. Pyraclostrobin + fluxapyroxad produced the highest yield along with treatments containing quinoxyfen, triflumizole, and penthiopyrad. Interestingly, pyraclostrobin did not perform as well as pyraclostrobin + fluxapyroxad.

In 2013/14, the most effective treatments for the reduction of leaf colonization were pyraclostrobin + fluxapyroxad alternated with cyflufenamid, and quinoxyfen alternated with cyflufenamid (Table 10). These treatments were applied over one cycle, with only two applications during these four weeks. These results suggest that all four products are effective against foliar colonization by the powdery mildew fungus. The two DMI fungicides, triflumizole and myclobutanil did not provide adequate control in this experiment, although they have been effective in the past. Over the eight weeks when the fruit were harvested, many products including pyraclostrobin + fluxapyroxad, cyflufenamid, and quinoxyfen, azoxystrobin + propiconazole, and metrafenone gave good control of mildew on the fruit. There were differences in marketable yield across the different treatments. However, these differences were not significant ($P > 0.05$), reflecting the large variability in plots from the same treatments. It is possible that some other factor affected the performance of the plants. Yields were also lower that year because of the shorter harvest period. Yield decreased as the incidence of disease on the fruit increased. In contrast, there was a poor relationship of yield with the incidence of the disease on the leaves.

In 2014/15, colonization of the leaves by the fungus was influenced by treatments made during the first six weeks of spraying (Table 11). Foliar coverage by the powdery mildew fungus ranged from 7 to 86% across all the treatments and was 84% in the control plots. Most treatments reduced foliar coverage. The most dramatic reductions in foliar disease were made by treatments which included pyraclostrobin + fluxapyroxad, or quinoxyfen alternated with cyflufenamid. Treatments that included pyraclostrobin + fluxapyroxad, or quinoxyfen applied alternately with cyflufenamid dramatically reduced the incidence of the disease on the fruit. Overall, marketable yields tended to decrease as the incidence of the disease on the fruit increased. However, the data were highly variable with a treatment, resulting in non-significant ($P > 0.05$) differences in mean yields across the different treatments. There was no evidence of phytotoxicity in the experiment.

These chemicals (pyraclostrobin, quinoxyfen and cyflufenamid) have minor use permits for use on strawberry plants (runners only) in Australia at the time of the report publishing. None of the other chemicals used in this experiment are permitted or 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 (AVPMA) website (http://www.apvma.gov.au).

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Recommendations

1. Information should be collected in south-eastern Queensland to determine whether the responses recorded on commercial properties are similar to those recorded in this project

2. Efforts should be made to develop strawberry cultivars that are less susceptible to powdery mildew for protected cropping

3. Data should be collected to determine whether fruit harvested under tunnels have higher chemical residues than those harvested from outdoors, and whether this issue is likely to impact on food safety

4. Information should be collected on the effect of metrafenone on the control of powdery mildew in strawberry plants growing under tunnels in south-eastern Queensland

Scientific Refereed Publications

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Appendix

Table 1. Average mean daily environmental conditions in the study with strawberry plants growing at Palmwoods in south-eastern Queensland, in 2012 and 2013. Four cultivar/breeding lines were grown under plastic high tunnels or outdoors.

Growing environment	Mean daily max. temp. (°C)[z]	Mean daily min. temp. (°C)[z]	Mean daily max. relative humidity (%)[z]	Mean daily min. relative humidity (%)[z]
2012				
Outdoor	26.5 ± 0.2	10.5 ± 0.1	98 ± 1	42 ± 1
Tunnel	26.0 ± 0.2	11.9 ± 0.1	94 ± 1	44 ± 1
2013				
Outdoor	26.3 ± 0.1	11.7 ± 0.1	99 ± 1	46 ± 1
Tunnel	25.4 ± 0.1	13.1 ± 0.1	96 ± 1	49 ± 1

[z]Data are the means of four replicates per treatment. Data for 2012 are the averages from mid-May to mid-October, while the data for 2013 are the averages from May to mid-September. Max. = maximum; Min. = minimum.

Table 2. Average mean daily environmental conditions in the study with strawberry plants growing at Palmwoods in south-eastern Queensland, in 2014 and 2015. Two cultivar/breeding lines were grown with or without sprays for grey mould under plastic high tunnels or outdoors. In 2014, the plants growing outdoors were given supplementary overhead irrigation (wet environment), while the plants growing under the tunnels did not (dry environment). No supplementary irrigation was given in 2015.

Growing environment	Mean daily max. temp. (°C)[z]	Mean daily min. temp. (°C)[z]	Mean daily max. relative humidity (%)[z]	Mean daily min. relative humidity (%)[z]
2014				
Outdoor	24.2 ± 0.1	11.1 ± 0.1	99 ± 1	52 ± 1
Tunnel	24.3 ± 0.1	12.7 ± 0.1	84 ± 1	60 ± 1
2015				
Outdoor	26.7 ± 0.1	11.4 ± 0.1	98 ± 1	44 ± 1
Tunnel	26.6 ± 0.1	12.8 ± 0.1	93 ± 1	43 ± 1

[z]Data are the means of four replicates per treatment. Data are the averages from mid-May to late September. Max. = maximum; Min. = minimum.

Table 3. Effect of growing environment on the marketable yields and returns in strawberry plants growing at Palmwoods in south-eastern Queensland, in 2012 and 2013. The plants were grown under plastic high tunnels or outdoors.

Growing environment, spray program and cultivar/breeding line	Yield (g/plant)[z]	Returns ($/plant)[z]
2012		
Outdoor	720 ± 35	4.43 ± 0.22
Tunnel	991 ± 52	6.09 ± 0.32
Festival	1041 ± 78	6.35 ± 0.45
Breeding Line 1	868 ± 62	5.53 ± 0.38
Breeding Line 2	657 ± 35	3.97 ± 0.22
Rubygem	834 ±68	5.04 ± 0.43
Outdoor Festival	882 ± 58	5.42 ± 0.27
Outdoor Breeding Line 1	756 ± 39	4.85 ± 0.27
Outdoor Breeding Line 2	577 ± 17	3.46 ± 0.28
Outdoor Rubygem	800 ± 46	4.80 ± 0.27
Tunnel Festival	1246 ± 49	7.58 ± 0.27
Tunnel Breeding Line 1	979 ± 86	6.22 ± 0.53
Tunnel Breeding Line 2	738 ± 32	4.49 ± 0.16
Tunnel Rubygem	1001 ± 27	6.09 ± 0.12
2013		
Outdoor	479 ± 22	3.57 ± 0.15
Tunnel	594 ± 26	4.54 ± 0.16
Festival	599 ± 25	4.55 ± 0.18
Breeding Line 1	605 ± 38	4.46 ± 0.27
Breeding Line 2	542 ± 31	4.06 ± 0.26
Rubygem	416 ± 28	3.26 ± 0.21
Outdoor Festival	559 ± 10	4.15 ± 0.07
Outdoor Breeding Line 1	514 ± 28	3.83 ± 0.21
Outdoor Breeding Line 2	478 ± 50	3.48 ± 0.33
Outdoor Rubygem	411 ± 29	3.20 ± 0.22
Tunnel Festival	605 ± 50	4.73 ± 0.29
Tunnel Breeding Line 1	697 ± 11	5.10 ± 0.11
Tunnel Breeding Line 2	607 ± 26	4.64 ± 0.16
Tunnel Rubygem	466 ± 33	3.68 ± 0.18

[z]Data are the means of 16 replicates per treatment for the growing environment means, means of 8 replicates for the cultivar/breeding line means, and means of four replicates for the growing environment × cultivar/breeding line means.

Table 4. Effect of growing environment and spray program on marketable yield and returns in strawberry plants growing at Palmwoods in south-eastern Queensland, in 2014 and 2015. The plants were grown under plastic high tunnels or outdoors, and with or without sprays (control) for grey mould. In 2014, the plants growing outdoor were given supplementary overhead irrigation (wet environment), while the plants growing under the tunnels did not (dry environment). No supplementary irrigation was given in 2015.

Growing environment, spray program and cultivar/breeding line	Yield (g/plant)[z]	Returns ($/plant)[z]
2014		
Outdoor	349 ± 19	2.75 ± 0.11
Tunnel	869 ± 37	5.36 ± 0.21
Control	601 ± 75	3.97 ± 0.39
Sprayed	617 ± 71	4.14 ± 0.36
Festival	562 ± 76	3.75 ± 0.37
Breeding Line 1	656 ± 68	4.36 ± 0.37
Outdoor control	334 ± 25	2.65 ± 0.19
Outdoor sprayed	364 ± 29	2.85 ± 0.10
Tunnel control	869 ± 58	5.28 ± 0.36
Tunnel sprayed	869 ± 52	5.44 ± 0.26
Open Festival	291 ± 14	2.44 ± 0.13
Open Breeding Line 1	408 ± 19	3.06 ± 0.08
Tunnel Festival	833 ± 61	5.05 ± 0.29
Tunnel Breeding Line 1	905 ± 45	5.66 ± 0.30
2015		
Outdoor	466 ± 20	3.25 ± 0.13
Tunnel	359 ± 20	2.58 ± 0.12
Control	386 ± 20	2.77 ± 0.13
Sprayed	439 ± 26	3.06 ± 0.16
Festival	417 ± 30	3.00 ± 0.18
Breeding Line 1	408 ± 17	2.83 ± 0.12
Outdoor control	424 ± 22	3.02 ± 0.14
Outdoor sprayed	508 ± 29	3.48 ± 0.18
Tunnel control	348 ± 30	2.52 ± 0.19
Tunnel sprayed	371 ± 28	2.64 ± 0.17
Open Festival	497 ± 30	3.48 ± 0.16
Open Breeding Line 1	434 ± 26	3.02 ± 0.17
Tunnel Festival	336 ± 34	2.52 ± 0.22
Tunnel Breeding Line 1	383 ± 20	2.64 ± 0.14

[z]Data are the means of 16 replicates per treatment for the growing environment means, means of 8 replicates for the cultivar/breeding line means, and means of four replicates for the growing environment × cultivar/breeding line means.

Table 5. Effect of growing environment on the percentage of fruit with various defects in strawberry plants growing at Palmwoods in south-eastern Queensland, in 2012 and 2013. The plants were grown under plastic high tunnels or outdoors.

Growing environment, spray program and cultivar/breeding line	Fruit with rain damage and/or mould (%)[z]	Fruit classified as affected by mould (%)[z]	Fruit that were small and/or misshaped (%)[z]	Fruit that were classified as misshaped (%)[z]	Fruit with some defect (%)[z]
2012					
Outdoor	16.3 ± 1.0	2.8 ± 0.4	21.4 ± 1.5	5.4 ± 0.5	40.6 ± 1.7
Tunnel	5.6 ± 0.4	1.4 ± 0.2	20.6 ± 1.4	4.0 ± 0.3	27.3 ± 1.3
Festival	7.5 ± 1.7	1.9 ± 0.6	21.7 ± 0.8	4.2 ± 0.2	30.3 ± 2.3
Breeding Line 1	10.6 ± 2.0	2.8 ± 0.7	17.8 ± 0.5	6.4 ± 0.6	30.7 ± 2.5
Breeding Line 2	12.3 ± 2.3	1.1 ± 0.1	14.7 ± 0.8	2.5 ± 0.3	30.8 ± 2.9
Rubygem	13.1 ± 2.6	2.5 ± 0.5	29.0 ±0.5	5.8 ± 0.4	43.2 ± 3.0
Outdoor Festival	12.2 ± 0.8	3.3 ± 0.7	23.0 ± 1.6	4.3 ± 0.4	36.6 ± 1.9
Outdoor Breeding Line 1	15.4 ± 1.7	3.1 ± 1.4	18.2 ± 1.0	7.8 ± 0.5	36.9 ± 1.5
Outdoor Breeding Line 2	18.0 ± 1.3	1.2 ± 0.7	14.9 ± 3.4	2.9 ±0.9	38.0 ± 3.0
Outdoor Rubygem	16.4 ± 1.6	2.9 ± 0.6	27.7 ± 0.5	6.2 ± 0.6	45.5 ± 1.5
Tunnel Festival	3.5 ± 0.1	0.6 ± 0.1	21.8 ± 0.7	4.0 ± 0.2	25.8 ± 0.7
Tunnel Breeding Line 1	5.8 ± 0.4	2.5 ± 0.5	17.5 ± 0.5	5.0 ± 0.4	24.4 ± 0.7
Tunnel Breeding Line 2	6.6 ±0.5	1.0 ± 0.1	14.4 ± 1.3	2.0 ± 0.3	23.5 ± 1.2
Tunnel Rubygem	6.6 ± 0.2	1.5 ± 0.1	28.6 ± 0.8	4.9 ± 0.2	35.7 ± 0.7
2013					
Outdoor	15.9 ± 0.9	1.8 ± 0.4	30.4 ± 2.7	6.0 ± 0.6	47.1 ± 2.8
Tunnel	2.2 ± 0.3	0.8 ± 0.2	32.7 ± 3.5	3.2 ± 0.4	35.7 ± 3.5
Festival	5.8 ± 1.9	1.4 ± 0.7	34.1 ± 1.0	2.5 ± 0.5	40.7 ± 1.6
Breeding Line 1	8.9 ± 2.9	0.9 ± 0.3	17.5 ± 0.9	5.8 ± 1.0	27.0 ± 3.5
Breeding Line 2	10.6 ± 2.8	1.1 ± 0.3	24.2 ± 1.2	4.7 ± 0.6	36.1 ± 2.9
Rubygem	10.6 ± 3.0	1.9 ± 0.5	48.3 ±1.4	5.4 ±0.9	59.2 ± 1.9
Outdoor Festival	11.1 ± 0.9	2.5 ± 1.2	35.1 ± 0.7	3.3 ± 0.9	46.4 ± 1.6
Outdoor Breeding Line 1	16.4 ± 0.8	1.3 ± 0.4	18.5 ± 1.1	8.2 ± 0.5	35.8 ± 1.6
Outdoor Breeding Line 2	17.9 ± 0.8	1.0 ± 0.2	23.1 ± 5.2	5.4 ± 0.7	42.6 ± 5.6
Outdoor Rubygem	14.9 ± 1.4	2.0 ± 0.8	43.9 ± 0.5	5.9 ± 1.2	59.1 ± 1.7
Tunnel Festival	1.4 ± 0.2	0.3 ± 0.1	37.3 ± 1.8	1.5 ± 0.0.1	40.2 ± 1.8
Tunnel Breeding Line 1	1.4 ± 0.3	0.5 ± 0.2	16.4 ± 1.4	3.4 ± 0.7	18.3 ± 1.4
Tunnel Breeding Line 2	3.2 ± 0.7	1.2 ± 0.6	25.3 ± 1.8	4.0 ± 0.9	29.6 ± 1.5
Tunnel Rubygem	2.9 ± 0.3	1.2 ± 0.2	51.7 ± 0.9	3.8 ± 0.7	54.8 ± 1.0

[z]Data are the means of 16 replicates per treatment for the growing environment means, means of 8 replicates for the cultivar/breeding line means, and means of four replicates for the growing environment × cultivar/breeding line means.

Table 6. Effect of growing environment and spray program on the percentage of fruit with various defects in strawberry plants growing at Palmwoods in south-eastern Queensland, in 2014 and 2015. The plants were grown under plastic high tunnels or outdoors, and with or without sprays (control) for grey mould. In 2014, the plants growing outdoor were given supplementary overhead irrigation (wet environment), while the plants growing under the tunnels did not (dry environment). No supplementary irrigation was given in 2015.

Growing environment, spray program and cultivar/breeding line	Fruit with rain damage and/or mould (%)[z]	Fruit classified as affected by mould (%)[z]	Fruit that were small and/or misshaped (%)[z]	Fruit that were classified as misshaped (%)[z]	Fruit with powdery mildew (%)[z]	Fruit with some defect (%)[z]
2014						
Outdoor	32.2 ± 1.7	14.7 ± 1.1	24.9 ± 1.1	7.0 ± 0.7	0.5 ± 0.2	59.5 ± 1.1
Tunnel	0.6 ± 0.1	0.4 ± 0.1	29.5 ± 2.6	5.0 ± 0.3	10.1 ± 1.4	41.1 ± 1.5
Control	17.9 ± 4.6	8.7 ± 2.2	26.8 ± 2.3	5.9 ± 0.5	5.0 ± 1.5	51.0 ± 3.0
Sprayed	15.0 ± 3.8	6.5 ± 1.7	27.6 ± 1.9	6.2 ± 0.7	5.6 ± 1.7	49.7 ± 2.3
Festival	14.2 ± 3.6	7.0 ± 1.8	33.9 ± 1.6	4.6 ± 0.3	2.9 ± 0.6	52.3 ± 1.9
Breeding Line 1	18.6 ± 4.7	8.1 ± 2.2	20.5 ± 0.6	7.5 ± 0.6	7.7 ± 2.0	48.4 ± 3.3
Outdoor control	35.1 ± 2.5	16.8 ± 1.6	24.0 ± 1.7	6.3 ± 0.9	0.5 ± 0.2	61.4 ± 1.2
Outdoor sprayed	29.4 ± 1.9	12.7 ± 1.0	25.7 ± 1.6	7.8 ± 1.0	0.4 ± 0.2	57.6 ± 1.7
Tunnel control	0.6 ± 0.2	0.5 ± 0.1	29.6 ± 4.3	5.5± 0.3	9.5 ± 1.9	40.6 ± 2.6
Tunnel sprayed	0.5 ± 0.1	0.3 ± 0.1	29.4 ± 3.4	4.6 ± 0.5	10.7 ± 2.3	41.7 ± 1.6
Open Festival	28.0 ± 1.3	13.8 ± 0.2	28.6 ± 0.8	4.8 ± 0.4	0.7 ± 0.3	58.7 ± 1.4
Open Breeding Line 1	36.5 ± 2.4	15.7 ± 2.1	21.2 ± 0.9	9.3 ± 0.6	0.2 ± 0.1	60.4 ± 1.8
Tunnel Festival	0.4 ± 0.1	0.2 ± 0.1	39.2 ± 1.4	4.3 ± 0.4	5.1 ± 0.5	45.8 ± 1.1
Tunnel Breeding Line 1	0.7 ± 0.1	0.6 ± 0.1	19.9 ± 0.8	5.7 ± 0.3	15.2 ± 1.1	36.5 ± 1.4
2015						
Outdoor	20.6 ± 1.2	9.0 ± 0.9	25.4 ± 2.5	7.2 ± 0.6	0.4 ± 0.2	46.9 ± 2.4
Tunnel	0.5 ± 0.1	0.3 ± 0.1	33.8 ± 2.9	10.2 ± 0.7	10.4 ± 2.0	45.2 ± 2.5
Control	12.3 ± 3.2	6.1 ± 1.6	30.5 ± 3.2	9.3 ± 0.9	4.9 ± 1.7	48.5 ± 2.6
Sprayed	8.7 ± 2.1	3.2 ± 0.8	28.6 ± 2.6	8.1 ± 0.6	5.9 ± 2.1	43.6 ± 2.2
Festival	10.1 ± 2.6	4.6 ± 1.2	38.6 ± 2.2	9.5 ± 1.0	3.0 ± 0.9	52.0 ± 2.2
Breeding Line 1	10.9 ± 2.9	4.7 ± 1.4	20.6 ±1.2	7.9 ± 0.5	7.8 ± 2.4	40.0 ± 1.7
Outdoor control	24.4 ± 1.3	12.1 ± 0.7	25.4 ± 4.2	7.8 ± 1.1	0.6 ± 0.4	51.2 ± 3.0
Outdoor sprayed	16.7 ± 0.7	5.9 ± 0.6	25.3 ± 3.2	6.6 ± 0.6	0.1 ± 0.1	42.5 ± 3.4
Tunnel control	0.2 ± 0.1	0.1 ± 0.1	35.7 ± 4.4	10.9 ± 1.3	9.3 ± 2.7	45.8 ± 4.2
Tunnel sprayed	0.7 ± 0.1	0.4 ± 0.1	31.9 ± 4.0	9.5 ± 0.9	11.6 ± 3.1	44.6 ± 3.2
Open Festival	19.7 ± 1.4	8.8 ± 1.2	33.9 ± 2.4	7.4 ± 1.1	0.2 ± 0.1	54.0 ± 2.5
Open Breeding Line 1	21.4 ± 2.0	9.1 ± 1.5	16.9 ± 1.1	6.9 ± 0.6	0.6 ± 0.4	39.7 ± 2.2

Tunnel Festival	0.5 ± 0.2	0.3 ± 0.1	43.3 ± 2.9	11.5 ± 1.2	5.9 ± 1.2	50.1 ± 3.8
Tunnel Breeding Line 1	0.4 ± 0.1	0.3 ± 0.1	24.3 ± 1.3	8.8 ± 0.7	15.0 ± 3.1	40.3 ± 2.6

[z]Data are the means of 16 replicates per treatment for the growing environment means, means of 8 replicates for the cultivar/breeding line means, and means of four replicates for the growing environment × cultivar/breeding line means.

Table 7. Estimated pay-back period (years) to recover the initial cost of a plastic high tunnel for growing strawberry plants in south-eastern Queensland. The initial cost of the tunnel is $115,000/ha. Average yields are 500 g/plant and above average yields are 750 g/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/punnet. The additional costs of picking and packing the extra crop under the tunnels of $0.75/kg has been taken into account in the analysis. The analysis also assumes a loss of 15% of the planting area due to the structure of the tunnels. The weighted means were estimated using the pattern of rainfall over the past 61 years.

Scenario	Very dry	Dry	Average	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

Table 8. Effect of different chemicals on the incidence of powdery mildew in strawberry plants grown under a plastic tunnel in Florida in 2011/12. 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. Pyraclostrobin + fluxapyroxad = Merivon®; quinoxyfen = Quintec®; triflumizole = Procure®; myclobutanil = Rally®; cyflufenamid = Torino®; azoxystrobin + difenoconazole = Quadris Top®; azoxystrobin + propiconazole = Quilt Xcel®; penthiopyrad = Fontelis®; difenoconazole + propiconazole = Inspire Super®; *Bacillus subtilis* strain *QST-713* = Serenade Max®; potassium phosphate = K-Phite®; potassium silicate = Silmatrix®; experimental product *Bacillus subtilis* var. *amyloliquefaciens* = NZBBA 1106. Data on the percentage of leaves and fruit affected by the fungus are back-transformed means. In a column, means followed by no letter in common are significantly different ($P < 0.05$). Data from N.A. Peres from the University of Florida.

Treatment	Percent of microscope fields with powdery mildew from 100 field leaf samples	Percent of fruit affected by powdery mildew
Control	81 g	25 de
Pyraclostrobin + fluxapyroxad	2 a	11 a
Quinoxyfen	6 ab	15 ab
Triflumizole alt. with quinoxyfen	7 ab	17 a-d
Myclobutanil alt. with quinoxyfen	7 ab	18 a-d
Cyflufenamid alt. with quinoxyfen	10 abc	18 a-d
Azoxystrobin + difenoconazole	19 bcd	18 a-d
Cyflufenamid alt. with triflumizole	26 cde	16 abc
Azoxystrobin + propiconazole	27 de	16 abc
Penthiopyrad	33 de	21 bcd
Triflumizole alt. with *Bacillus subtilis* var. *amyloliquefaciens*	33 de	15 ab
Difenoconazole + propiconazole	50 ef	18 a-d
Tolfenpyrad	57 f	17 a-d
Bacillus subtilis + captan	80 g	32 e
Potassium phosphate + potassium silicate	80 g	16 abc
Triflumizole + *Bacillus subtilis* var. *amyloliquefaciens*	82 g	24 cde
Streptomyces violaceusniger	83 g	19 a-d
Bacillus subtilis + thiram	98 h	44 f

Table 9. 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 eight weekly applications made from 30 November 2012 to 18 January 2013. 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. Pyraclostrobin + fluxapyroxad = Merivon® =; quinoxyfen = Quintec®; flutriafol = Top Guard®; triflumizole = Procure®; myclobutanil = Rally®; cyflufenamid = Torino®; azoxystrobin + propiconazole = Quilt Xcel®; penthiopyrad = Fontelis®; acibenzolar S-methyl = the plant defence promoter Actigard®; pyraclostrobin = Cabrio®; potassium phosphite = K-Phite®; *Bacillus subtilis* strain *QST 713* = Optiva®; and experimental product *Bacillus subtilis* var. *amyloliquefaciens* = NZBBA. In a column, means followed by no letter in common are significantly different ($P < 0.05$). Data from N.A. Peres from the University of Florida.

Treatment	Marketable yield (t per ha)	Percent of microscope fields with powdery mildew from 100 field leaf samples	Percent of fruit affected by powdery mildew
Control	5.7 cde	91 ghi	32 i
Pyraclostrobin + fluxapyroxad	8.1 a	3 a	5 a
Quinoxyfen	7.1 ab	14 ab	14 b
Quinoxyfen alt. with myclobutanil	7.3 ab	20 bc	15 bce
Quinoxyfen alt. with cyflufenamid	6.9 abc	31 c	16 bcd
Flutriafol (× 1 conc.)	6.6 bcde	73 ef	16 bcd
Flutriafol (× 1.4 conc.)	6.6 bcde	78 efg	18 bcde
Flutriafol (× 2 conc.)	6.8 bcd	54 d	14 bc
Penthiopyrad	7.2 ab	55 d	16 bcd
Azoxystrobin + propiconazole	5.4 de	67 de	23 efg
Azoxystrobin + propiconazole with acibenzolar S-methyl	6.0 bcde	56 d	20 bcdef
Cyflufenamid	6.6 bcde	72 e	18 bcde
Triflumizole	7.1 ab	76 ef	20 bcdef
Triflumizole alt. with *B. subtilis* var. *amyloliquefaciens*	7.3 ab	75 ef	17 bcde
Pyraclostrobin	5.7 cde	78 efgh	20 cdef
Myclobutanil	5.7 cde	86 fghi	28 ghi
B. subtilis strain *QST 713* (× 1 conc.)	5.3 e	92 hi	34 i
B. subtilis strain *QST 713* (× 2 conc.)	6.2 bcde	93 i	26 fgh
Potassium phosphite (× 1 conc.)	6.0 bcde	95 i	21 def
Potassium phosphite (× 2 conc.)	5.5 cde	92 i	30 hi

Table 10. 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. Except for marketable yield which had no significant ($P > 0.05$) treatment effect, in a column, the means followed by no letter in common are significantly different ($P < 0.05$). Data from N.A. Peres from the University of Florida.

Treatment	Marketable yield (t per ha)	Percent of microscope fields with powdery mildew from 100 field leaf samples	Percent of fruit affected by powdery mildew
Control	3.1	97 g	37 i
Pyraclostrobin + fluxapyroxad alt. with cyflufenamid	4.1	14 a	8 a
Quinoxyfen	3.7	29 b	9 ab
Quinoxyfen alt. with cyflufenamid	5.0	18 ab	9 ab
Quinoxyfen alt. with myclobutanil	4.3	47 c	12 a-e
Tetraconazole alt. with cyflufenamid	4.9	48 c	9 ab
Azoxystrobin + propiconazole	4.0	56 cd	11 abcd
Azoxystrobin + difenconazole	3.6	57 cd	18 defg
Metrafenone	4.0	65 de	14 abcdef
Triflumizole	4.4	74 ef	18 cdefg
Chlorothalonil	3.1	83 fg	30 hi
Potassium salts of fatty acids (× 1 conc.)	3.7	96 g	19 efg
Potassium salts of fatty acids (× 2 conc.)	4.1	89 g	17 bcdef
Wettable sulphur	4.4	91 g	20 efg
Polypeptide beta-conglutin from lupin	3.8	94 g	25 gh
Mono- and di-potassium salts of phosphorus acid + hydrogen peroxide	4.1	95 g	21 fg

Table 11. 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 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 based on microscopic observations of 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. Except for marketable yield which had no significant ($P > 0.05$) treatment effect, in a column, the means followed by no letter in common are significantly different ($P < 0.05$). Data from N.A. Peres from the University of Florida.

Treatment	Marketable yield (t per ha)	Percent of microscope fields with powdery mildew from 100 field leaf samples	Percent of fruit affected by powdery mildew
Control	7.2	84 jk	42 k
Pyraclostrobin + fluxapyroxad	10.4	19 ab	9 a
Streptomyces lydicus & pyraclostrobin + fluxapyroxad (× 2 conc.) alt. with *Streptomyces lydicus*	9.6	7 a	12 abc
Streptomyces lydicus & pyraclostrobin + fluxapyroxad (× 1 conc.) alt. with *Streptomyces lydicus*	9.0	22 ab	13 abcd
Cyflufenamid	9.4	41 cd	20 bcdef
Quinoxyfen alt. with cyflufenamid	10.4	26 bc	11 ab
Tetraconazole	10.6	68 ghij	26 efghi
Tetraconazole alt. with cyflufenamid	7.6	45 cd	19 bcdef
Azoxystrobin + propiconazole alt. with cyflufenamid	8.1	60 e-h	30 ghij
Penthiopyrad	7.3	47 de	21 cdefg
Chitosan	7.8	46 de	27 efghi
Bacillus subtilis var. *amyloliquefaciens* strain *FZB 24*	8.4	76 hijk	31 ghij
Bacillus subtilis strain *QST 713* (liquid)	8.3	80 ijk	36 ijk
Bacillus subtilis strain *QST 713* (powder)	7.7	86 k	40 jk
Plant extract	7.7	58 efg	26 h