Integrated management of foliar diseases in vegetable crops

Dr Chrys Akem
The Department of Agriculture, Fisheries and Forestry, QLD

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VG07127 (March 2011) Integrated Management of Foliar Diseases in Vegetable Crops

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Department of Employment, Economic Development and Innovation

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Purpose of the report:

This report details research undertaken by the Department of Employment, Economic Development and Innovation (Agri-Science Queensland) in collaboration with the Department of Primary Industries (VIC), The South Australian Research and Development Institute (SA) and Peracto Pty Ltd (TAS). The overall aim of the project was to develop integrated pest management strategies based largely on the use of fungicide alternatives to manage the following key foliar diseases of vegetable crops: powdery mildew on pumpkins and zucchinis; downy mildew on lettuce, cucumbers and squash; anthracnose on cucumbers; and white blister on broccoli, cauliflower and Chinese cabbages. The expected outcomes were more sustainable options for managing these foliar diseases of vegetable crops instead of relying solely on the use of fungicides that often result in crop failure from resistance development by the target pathogens and residue issues at the market places.

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Media summaries

Downy mildew, powdery mildew, and anthracnose management on cucurbits

Production of cucurbits in Australia is affected by three fungal foliar diseases: powdery mildew, downy mildew, and anthracnose (caused by *Podosphaera xanthii, Pseudoperonospora cubensis*, and *Colletotrichum orbiculare*, respectively). These fungal diseases are particularly important in Queensland, where production value of cucurbits is 50% of the total value of cucurbit production in the country. A single disease control practice, such as fungicide sprays, cannot effectively manage foliar diseases in the long term. A more lasting efficacy of a disease management program should integrate several available practices, with each practice contributing to an overall acceptable level of disease control. Research in this project explored the use of cultivars with genetic resistance to the diseases and spray products alternative to fungicides, with the overall aim of using a reduced number of sprays with conventional systemic and contact fungicides. Field trials were conducted in Ayr, Bowen, and Gatton in Queensland to screen zucchini, squash, cucumber, and pumpkin cultivars for low reaction to the diseases and to evaluate the efficacy of alternative spray products on disease control. Commercial cultivars with moderate resistance to the diseases were identified as well as potential alternative spray products with acceptable efficacy. In field-grown zucchini, selected alternative products evaluated as part of spray programs and in combination with the use of cultivars with moderate resistance to the diseases performed equally to a conventional fungicide spray program. The information obtained with this research work can be used to develop integrated disease management programs. These programs should aim to keep pesticide inputs to a minimum, in order to avoid the application of unnecessary pesticides on non-targetted living species and the environment and to reduce potential pesticide residues in produce. These programs will also mitigate the development of resistance to fungicides by pathogen strains and therefore prolong the effective life of systemic fungicides.

Downy mildew and anthracnose management on lettuce

Downy mildew caused by *Bremia lactucae*, and anthracnose caused by *Microdochium panattonianum,* are two main fungal diseases of lettuce, often resulting in significant losses in cool and wet conditions. Growth room and field trials were undertaken to evaluate the relative susceptibility of commonly used lettuce cultivars to both diseases, and to evaluate the level of control provided by the application of new fungicides and environment friendly fungicide alternatives. While no anthracnose developed in the field trials, the growth room evaluations showed that none of the alternative products were effective at reducing disease and only Cabrio and Kocide® provided adequate control. These trials revealed that a number of alternative fungicides have the potential to be integrated into downy mildew control programs. In both growth room and field trials, FoliCal 19 Plus™ (Omnia, Australia) and Rezist® (Stoller Enterprises, Texas, USA) reduced the incidence and severity of downy mildew. Both products provided good control when compared to liquid copper protectant fungicides Kocide® and Tribase Blue®, and the phosphorus acid systemic fungicides AgriFos® and Phostrol®. While some other products suppressed the disease compared to no treatment, the level of disease was not economically acceptable.

White blister rust management on brassicas

White blister rust caused by *Albugo candida*, is a major threat to production of *Brassica* vegetables (e.g. broccoli, pak choi, cabbages, Brussels sprouts, cauliflower, and cabbage) in Victoria and Tasmania. The disease is commonly controlled with conventional fungicides. Commercial cultivars with some disease resistance have been developed and used as a disease control measure in these crops. Some of these cultivars became susceptible to pathogen populations. New fungicides as well as products alternative to fungicides need be evaluated in order to mitigate resistance development by pathogen populations to the few available systemic fungicides. The research carried out in Victoria and Tasmania aimed to identify alternatives to conventional fungicides and potential new fungicides to control white blister rust in *Brassica* crops.

In Victoria, a grower survey identified that agronomic qualities, not the resistance to white blister rust, were the main criteria for cultivar selection in both *B. oleracea* and *B. rapa*. In trials with seedlings, resistance to white blister rust was identified in cultivars *B. rapa* pak choi; *B. oleracea* Brussels sprouts, cauliflower, and cabbage. Two broccoli cultivars were identified as resistant to local populations of white blister rust in the field. From four alternative products evaluated, plant resistance activator, Bion50®WG and biological agent, *B. subtilis* were as effective as the systemic fungicide Amistar® on broccoli seedlings. Bion50®WG was as effective as Amistar® on Chinese cabbage and pak choi seedlings but it was phytotoxic. Neither of these treatments controlled the disease on Chinese cabbage and broccoli in field trials.

The research work carried out in Tasmania aimed to screen and identify alternative products to fungicides and new fungicides that may be used by growers for white blister control in broccoli crops. The industry standards, Amistar and Ridomil Gold Plus were effective in controlling white blister. Bion, a plant resistance activator, when applied with Amistar as a spray mixture, enhanced disease control as well as provided relatively long protection to leaves and heads from infections compared to Amistar alone. Polyram, a broad spectrum non-systemic fungicide, gave good control when applied in combination with Amistar. Aero, based on metiram plus pyraclostrobin, showed good activity for white blister control, but being to azoxystrobin and therefore, is not a suitable alternative to Amistar. NUL 1955 could be a suitable alternative to Ridomil Gold Plus and Amistar. Another new fungicide, NUL 2111 also showed activity in controlling white blister. Previcur had little or no effect in controlling white blister. Other non-fungicide and non-residual soft products such as Micro Plus (based on *Streptomyces lydicus*) and Bozul (food grade anti-fungal product based on sulphur dioxide and benzoic acid) had no effect for white blister control. Under frequent cold and frosty weather conditions, phytotoxicity due to Ridomil Gold Plus spray applications were noted. Overall, potential products that could be included in disease management products were identified. Some of these products require further evaluation and development so they can be used commercially.

Technical summaries

Downy mildew, powdery mildew, and anthracnose management on cucurbits

Powdery mildew (*Podosphaera xanthii*), downy mildew (*Pseudoperonospora cubensis*) and anthracnose (*Colletotrichum orbiculare*) are important foliar diseases that affect the production of cucurbits in Queensland. Research in this project explored the use of cultivars with genetic resistance to the diseases and spray products alternative to fungicides, in order to minimise the number of sprays of conventional systemic and contact fungicides. Twenty four (24) field trials were conducted in different locations (13 trials in Ayr, 3 in Bowen and 8 in Gatton) to screen zucchini, squash, cucumber, and pumpkin cultivars for low reaction to the diseases and to evaluate the efficacy of alternative spray products on disease control.

In 10 field trials conducted in Ayr and Bowen, moderate resistance to one or more foliar diseases were measured among several cultivars evaluated in zucchini (14 cultivars), cucumber (7), squash (4), and pumpkin (9). Notably, lower relative severities of powdery mildew were measured in zucchinis Paydirt, Crowbar, Caroline, Nitro, Amanda, Calida, while lower relative severities of downy mildew were measured in Zest, Nitro, and Golden Rod. Lower severities of powdery mildew were measured in squash cultivars Naches and Cochise and in pumpkins Kens Special and Dynamite. In cucumbers, lower relative severities of downy mildew and anthracnose were measured in Aladdin and Camelot. A table with relative resistance to the diseases was prepared combining results from different trials.

The effectiveness of 14 alternative fungicides was evaluated in 4 field trials conducted in Ayr and Bowen. Products tested included: micronized sulphur (Microthiol Disperss®); copper octanoate (Tricop®); potassium bicarbonate (Ecocarb®); phosphorus acid (Agri-Fos 600®); hydrogen dioxide (Peratec®); soluble silicon (Enhance KCS® and Stand SKH®); neem oil (Trilogy®); canola oil (Synertrol Horti oil®); tea tree oil (Timorex Gold®); acibenzolar-s-methyl (Bion® or Actigard®); chitosan (Aminogro®); milk, and propylene glycol alginate (Cal Agri 50NF®). Downy and powdery mildews were the main diseases found on both crops and anthracnose was also present on cucumbers. Tricop, Microthiol, Bion and Agri-Fos 600 provided acceptable downy mildew control; however, Microthiol and Bion caused phytotoxicity in cucumbers. Tricop, Microthiol, Stand SHK, milk, Timorex, Synertrol Horti Oil, Agri-Fos 600, Ecocarb and Aminogro provided acceptable control of powdery mildew. A table with the relative efficacy of the tested spray products on the foliar diseases was prepared combining results from different trials.

In 2 field trials conducted in Gatton, 12 zucchini and 12 pumpkin cultivars were screened for their reaction to foliar diseases. Cultivars with moderate resistance to the diseases were identified. The zucchini cultivars Amanda, Calida, Crowbar and Paydirt had similar levels of powdery mildew infection during the spring and autumn seasons; whereas Congo, Regal Black and JTZ905 had higher disease severity levels during the autumn trial. Yields were not superior in some of the cultivars with lower disease severity levels. The Jap type pumpkins appeared to be the most tolerant to the mildews, in particular powdery mildew, followed closely by the Jaradale types. The butternuts were the most susceptible for contracting mildew infection. In the 4 field trials in Gatton, the effectiveness of 9 alternative products was evaluated for control of powdery and downy mildews in zucchini and pumpkin. Bion showed promising but variable results in zucchini and pumpkins. Because of the cost and risks of phytotoxicity with this product, additional work should evaluate spray rates and number of sprays in cucurbits grown under different environmental conditions. Micronized sulphur (Microthiol) and phosphorous acid (Agri-Fos 600) were very good alternatives for powdery and downy mildew control respectively.

In North and South Queensland, most of the alternative products to fungicides were tested using weekly applications of the same active ingredient in order to assess their relative efficacy for controlling the different foliar diseases. However, it is not expected that these products would be used alone but in combination with other alternative products and with conventional systemic and contact fungicides kept to a minimum number of sprays.

In two field trials conducted in Ayr, foliar diseases were evaluated on zucchini cultivars with different reaction to foliar diseases and using several spray programs that included alternative products to fungicides. When cultivars with moderate resistance were used in spray programs with selected alternatives to fungicides (e.g. Bion®, Tricop®, Agri-Fos 600®, and Microthiol®), or when alternatives to fungicides were used with only one application of a conventional systemic fungicide, diseases were managed to acceptable low severity levels that led to similar fruit yields as in plants treated with three conventional systemic fungicides. Some spray programs with alternatives to fungicides had costs that were comparable to costs of a program that includes mostly conventional fungicides.

The information obtained in this research work can be used to develop integrated disease management programs. These programs should aim to keep pesticide input to a minimum, in order to avoid the application of unnecessary pesticides on non-targeted living species and the environment and to reduce pesticide residues in produce. These programs will also mitigate resistance development to fungicides by pathogen strains and therefore prolong the effective life of systemic fungicides.

Downy mildew and anthracnose management on lettuce

Growth room trials were undertaken to evaluate the relative susceptibility of 21 lettuce varieties to downy mildew (caused by *Bremia lactucae*) and anthracnose (caused by *Microdochium panattonianum).* Six growth room trials and two field trials were undertaken to evaluate the control achieved of both diseases with a range of fungicides and alternative products. The key findings of this research were:

- Only four of the varieties (cvs. Fortune, Sureshot, Winter Select and Constanza) were susceptible to downy mildew race AUS5.
- All varieties tested were susceptible to anthracnose, however three varieties (Tekero, Fortune and Bernadinas) had a lower incidence of infection with 50%, 76% and 78% of plants infected respectively compared to 100% in all other varieties.
- While all varieties were susceptible to anthracnose, there was variability in the severity of infection, with cv. Explore the most severely infected.
- In both growth room and field trials, alternative fungicides FoliCal 19 Plus™ and Rezist® reduced the incidence and severity of downy mildew.
- Cabrio® and Kocide® were the most effective products against the incidence of anthracnose in the growth room trials, and FoliCal 19 Plus™ reduced the severity of infection.

Alternative fungicides provide variable disease control and may be more effective when incorporated into a tailored spray program to reduce the reliance on systemic fungicides.

White blister management on brassicas

White blister rust of *Brassica* vegetables (caused by *Albugo candida*) is commonly controlled with conventional fungicides. Ten years after the disease outbreak on broccoli and cauliflowers in 2001, a number of commercial cultivars with some disease resistance were developed and introduced as a disease control measure in these crops. A few of these cultivars are currently cultivated but some were withdrawn once they became susceptible to pathogen populations, which are continuously adapting.

The project component in Victoria aimed to identify alternatives to conventional fungicides to control white blister rust in *Brassica oleracea* and *Brassica rapa* vegetable crops. This research project evaluated: 1) commercial cultivars of *B. oleracea* and *B. rapa* for resistance to white blister rust, and 2) alternatives to fungicides for control of white blister rust in these crops. The findings of this project are:

- A grower survey identified that agronomic qualities, not the resistance to white blister rust, were the main criteria for cultivar selection in both *B. oleracea* and *B. rapa*.
- Resistance to white blister rust was identified in seedlings of *B. rapa* pak choi 'Seven Gates'; *B. oleracea* Brussels sprouts 'Abacus'and 'Romulus, cauliflower 'Avalanche', and cabbage 'NIZ17-1091'. Brocccoli 'Tyson' and 'Booster' were resistant to local populations of *Albugo candida* in the field at the time of the trial.
- Out of four alternative treatments evaluated, plant resistance activator, Bion50®WG and biological agent, *B. subtilis* were as effective as the systemic fungicide Amistar® on broccoli seedlings. Bion50®WG was as effective as Amistar® on Chinese cabbage and pak choi seedlings but it was phytotoxic. Neither of these treatments controlled the disease on Chinese cabbage and broccoli in field trials.

In Tasmania, three trials were conducted at Harford, Forthside and Leith (north-west Tasmania), in 2009 and 2010. The research aimed to screen and identify alternative products that may be used by growers for white blister control. All products were applied in three sprays with 300 L/ha water volume, at the onset of white blister disease in broccoli crops, just before or at initial button crop stage.

- The industry standards, Amistar and Ridomil Gold Plus were effective in controlling white blister. Amistar at 0.4 L/ha was shown to be slightly more effective than Ridomil Gold Plus at 2.0 kg/ha. This could be due to a slight loss in efficacy by metalaxyl-M in Ridomil Gold Plus, because it was initially the sole fungicide used for white blister control in Tasmania. Even though, Ridomil is recommended for use in only up to two applications per crop, the use of multiple plantings adjacent to one another means that the pathogen was exposed to the fungicide for a much longer period of time in the consecutive crops. Amistar, is also prone to fungicide resistance if growers become more reliant on its use for white blister control.
- Bion, a plant resistance activator, when applied with Amistar, as a spray mixture enhanced disease control as well as provide relatively long protection to leaves and heads from infections compared to Amistar alone. Unfortunately, while it is an interesting product, the use of Bion by growers remains severely restricted because of a lack of interest in developing the product for commercial use.
- Polyram at 2.5 kg/ha, applied on its own was less effective in controlling white blister than Amistar or Ridomil. However, Polyram, applied in combination with Amistar, was shown to enhance white blister control. Polyram is a broad spectrum non-systemic fungicide, which is registered for use as a crop protectant for downy mildew (*Peronospora parasitica*) and ring spot (*Mycosphaerella brassicicola*) control in brassica crops. This makes it a convenient product for tank mix with Amistar for white blister control as well. When applied early, before or at the onset of disease, Polyram + Amistar showed good acitivity in controlling the three most common foliar diseases in the broccoli crop. This tank mixture is now used as a preferred industry standard by some growers in Tasmania for white blister control in place of Amistar only. The use of Amistar with a general crop protectant may make it less prone to fungicide resistance.
- Aero, based on metiram plus pyraclostrobin, showed good activity for white blister control. Pyraclostrobin is a strobilurin fungicide, similar to azoxystrobin and therefore, is not a suitable alternative to Amistar.
- NUL 1955 at 0.5 L/ha was bioequivalent to Ridomil Gold Plus at 2.0 kg/ha for controlling white blister. Hence, NUL 1955 could be a suitable alternative to Ridomil Gold Plus and

Amistar.

- Another new fungicide, NUL 2111 also showed activity in controlling white blister. Further studies, however are needed to establish suitable application rates.
- Previcur had little or no effect in controlling white blister.
- Other non-fungicide and non-residual soft products such as Micro Plus (based on *Streptomyces lydicus*) and Bozul (food grade anti-fungal product based on sulphur dioxide and benzoic acid) had no effect for white blister control.
- Under frequent cold and frosty weather conditions, phytotoxicity due to Ridomil Gold Plus spray applications were noted. Therefore, avoid using Ridomil Gold Plus under such conditions in late autumn and winter.

 

Use of Fungicide Alternatives to Control Foliar Diseases of Cucurbits

North Queensland research component

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Use of Fungicide Alternatives to Control Foliar Diseases of Cucurbits

Cucurbit production in Australia and in Queensland

Australia's cucurbit production had a value of $325.7 millions in 2008 and half of this value was from cucurbits grown in Queensland (Table 1). Zucchini and squash, pumpkin, and cucumber production values from Queensland were 76%, 43% and 37% of the total production values of these commodities in Australia, respectively (Table 1). In 2008, the zucchini and squash industry was worth $49.3 million to the Australian economy (Table 1). The total volume of cucurbits produced in Australia was 336,853 tonnes, with 47% of this volume produced in Queensland, the biggest producer (Table 2). Over 8,489 hectares were planted with cucurbits in Queensland in 2008, and this area represented 54% of the area planted with cucurbits in Australia (Table 3), 26% of the area planted with vegetables in Queensland, and 8% of the area planted with vegetables in Australia. Seventy three percent (73%) of the country's area planted with zucchini and squash was located in Queensland (Table 3). Cucurbits in Australia are produced largely for the domestic market although opportunities for overseas export have shown potential. Cucumbers are exported to New Zealand, Hong Kong, Singapore and Papua New Guinea, while pumpkins are regularly exported to Japan.

Table 1. Total value of cucurbit crops grown in Australia and the share from Queensland's production in 2009 (calculated from ABS Survey 2009)

Cucurbit crops grown in Qld	**Australia** Gross Value	**Queensland** Gross Value	
	($)	($)	(%)
Cucumbers	28,167,927	10,837,654	38.5
Honeydew melons	9,445,785	3,282,329	34.7
Pumpkins	63,871,711	27,732,577	43.4
Rockmelons and cantaloupes	65,031,650	30,464,274	46.8
Watermelons	94,024,718	41,723,710	44.4
Zucchinis, marrows and squashes	65,162,874	49,356,503	75.7
Total	325,704,665	163,397,047	50.2

Table 2. Total volume of cucurbit crops grown in Australia and the share from Queensland's production in 2009 (calculated from ABS Survey 2009)

Cucurbit crops grown in Qld	**Australia** Volume	**Queensland** Volume	
	(t)	(t)	(%)
Cucumbers	11,943	5,397	45.2
Honeydew melons	8,861	3,309	37.3
Pumpkins	100,711	42,614	42.3
Rockmelons and cantaloupes	60,339	29,906	49.6
Watermelons	131,035	60,088	45.9
Zucchinis, marrows and squashes	23,964	17,651	73.7
Total	336,853	158,965	47.2

Table 3. Total area of cucurbit crops grown in Australia and the share from Queensland's production in 2009 (calculated from ABS Survey 2009)

Cucurbit crops grown in Qld	**Australia** Area	**Queensland** Area	
	(ha)	(ha)	(%)
Cucumbers	455	219	48.
Honeydew melons	472	206	43.
Pumpkins	5,615	2,904	51.
Rockmelons and cantaloupes	2,868	1,237	43.
Watermelons	4,158	2,300	55.
Zucchinis, marrows and squashes	2,219	1,623	73.
Total	15,787	8,489	53.

Foliar diseases in cucurbits

The most common foliar diseases in cucurbits grown in North Queensland are powdery mildew, caused by *Podosphaera xanthii* (formerly *Sphaerotheca fuliginea*), downy mildew, caused by *Pseudoperonospora cubensis*, and anthracnose, caused by *Colletotrichum orbiculare*. The three diseases are serious diseases in the Cucurbitaceae family and they are caused by fungi that are obligate parasites, which mean that they require live host tissue in order to survive and reproduce. North Queensland has optimal conditions for these diseases to occur on crops every year, as the three pathogens must overwinter in an area that does not experience a hard frost and where wild or cultivated cucurbits are present.

These diseases are significant in cucurbit crops because they can lead to defoliation and decrease in fruit yield. In Queensland, powdery mildew causes more damage to those cucurbit crops with longer production cycles, such as pumpkins, melons, and watermelons. Downy mildew causes damage to cucurbit crop species with longer production cycles, as well as crops with shorter production cycles like zucchini, squash and cucumber (all with approximately 8 weeks from planting to finish). Anthracnose causes damage to cucumber, melons and watermelons, and in some instances to squash and pumpkins.

The environmental conditions that are required for the development of the three foliar diseases are different, although it is possible to find powdery mildew and downy mildew (and also anthracnose in some cucurbit species) on a plant at the same time. For infection (spore germination) to occur, powdery mildew does not require free water on leaves but still requires a level of air relative humidity close to 50%. High humidity also increases the rate at which the fungus grows after infection occurs. Spores will germinate above 10 ºC with an optimum of around 27 ºC and an upper limit of 32 ºC. Dry weather benefits disease development and spread. By contrast, downy mildew and anthracnose require free water on leaves for spore germination, which can happen at cooler temperatures than in powdery mildew.

In North Queensland, warm temperatures year round allow for the survival of the pathogen inoculums of the three diseases. The inoculums are present on farms every year at the beginning of the cropping season. Plantings of cucurbits in the Burdekin delta region can begin as early as the end of February and can continue until late August. These first crops are established on the ground (by direct seeding or transplanting) as soon as the summer rainfall period ends. The majority of crops are grown on raised beds with polyethylene mulch and drip irrigation. Some zucchini crops are grown on permanent bed systems, which are not cultivated every year, and which have plant residues (e.g. sorghum) as organic mulch on top of the planting beds.

To meet with market demand in southern metropolitan areas of Australia, cucurbits are grown following sequential plantings (e.g. biweekly in zucchini or squash) and with crops overlapped in time and in the same farm. There is close proximity between crops and, in many cases, growing crops are located near older or abandoned disease infected crops. Double cropping in the same soil in the same year is not a common practice. As the production season progresses, the amount of pathogen inoculum increases because there are more crops planted and there are more favourable environmental conditions for the diseases to develop and spread. This is the reason why serious disease problems on crops usually become evident during mid to late winter production season. Planting of new crops generally ends late in August because of factors such as higher temperatures and early rainfall in November, as well as increased problems from fungal and virus diseases and insect pests. Production in North Queensland also decreases in late spring and early summer because of the increase in supply from southern areas of Queensland.

Current foliar disease management practices and their implications

Currently, the three foliar diseases are managed mainly with sprays of conventional fungicides. These fungicides can be grouped into two main groups (contact and systemic), depending on the mode of action on the fungal pathogen. Spray programs that rely only on the use of systemic fungicides (which have a specific mode of action with single-site of activity) lead to the development of resistant fungal strains in a short period of time. With sequential plantings throughout the season, new crops grow adjacent to old ones, often previously infected, and have been sprayed several times. This production scheme significantly favours the development of pathogen strains resistant to systemic fungicides. Within a few years, the systemic fungicides can become ineffective against the pathogen. Development of resistance by the pathogen is less common when using contact fungicides, which have various modes of actions with multi-site of activities. An overuse of contact fungicides can also lead to high accumulation of undesirable chemicals (e.g. S and Cu) on fruit and in the environment. Overall, the sequence and type of active ingredients used to manage foliar diseases is very diverse across cucurbit farms.

Practices to reduce pesticide use and mitigate resistance development to systemic fungicides

A single crop growing practice (e.g. use of a disease resistant cultivar or a fungicide) cannot effectively manage foliar diseases in the long term. A more lasting efficacy of a disease management program should integrate several available practices, where each practice contributes to an overall acceptable level of disease control. The integration of different practices should aim for keeping pesticide inputs to a minimum, in order to avoid pesticide residues in produce and unnecessary pesticides directed to non target living species and the environment. The cost of the disease management program should also be economically feasible for the grower.

Two disease management practices that complement each other and that at the same time reduce the dependency on fungicides are growing cultivars with moderate resistance to the diseases and using alternative spray products. These spray products directly affect the fungus through contact activity, but some will also enter the plant organs and have systemic activity; others may benefit the plant’s health system so the plant is less likely to become infected and/or damaged. In general, these products have lower toxicity than conventional fungicides. The risk of development of pathogen strains resistant to these products is lower than with systemic fungicides. Most commercial cultivars are bred overseas and are listed as being resistant or tolerant to one or more diseases. They still need to be evaluated among different cultivars in field trials in the regions where they are commercially grown.

Objective of the project

The general objective of this project was to identify and evaluate management practices for foliar diseases (powdery mildew, downy mildew and anthracnose) which can contribute to acceptable levels of disease control in cucurbits (zucchini, squash, cucumber, and pumpkins).

The research in this project focused on two practices as fungicide alternatives: a) the use of cultivars with improved genetic resistance to the disease and b) the use of effective spray products alternative to conventional fungicides to reduce the amount of conventional fungicides used.

The integration of these practices into a disease management program is an alternative to the sole use of conventional fungicides. Reducing the use of conventional fungicides should minimise adverse effects of pesticides on human health and on the environment and also prolong the effective life of systemic fungicides (i.e. mitigate fungicide resistance development by the pathogen).

There are many cucurbits species, cultivars, and spray products. Every year, new cultivars and spray products are commercially available. A scenario for a crop and disease is characterised by the level of disease pressure; reaction of the cultivar to the disease; fungicide active ingredients available for use and their effectiveness in controlling the pathogen; spray sequence of active ingredients; spray rates; and spray equipment, to refer to a few variables. It is impossible to evaluate all disease management scenarios. We selected scenarios in order to investigate and demonstrate that integrated programs can be very effective in managing foliar diseases. In the three-year project, research activities were organised as follows:

Year 2008

- Cucurbit cultivars from seed companies and alternative products from chemical companies identified and selected.
- Field trials conducted to evaluate the reactions of cucurbit cultivars to foliar diseases carried out in locations in Ayr and Bowen.
- Dissemination of results through seminars with growers and other industry representatives.

Year 2009

- Field trials conducted in Ayr and Bowen to evaluate the reactions of disease susceptible cucurbit cultivars to foliar diseases when treated with spray products alternative to conventional fungicides.
- Dissemination of results through seminars with growers and other industry representatives.

Year 2010

- Field trials conducted in Ayr to evaluate the use of cultivars with disease resistance in combination with fungicide alternatives and minimal use of systemic fungicide sprays.
- Dissemination of results through seminars with growers and other industry representatives.

Powdery mildew in zucchini, squash, pumpkins, and cucumbers

The foliar disease is caused by the plant pathogenic fungus *Podosphaera xanthii* (formerly *Sphaerotheca fuliginea*). Small, circular, white, powdery patches occur on leaves, petioles and stems (Figures 1 and 2). The powdery growth usually develops first on crown leaves, on shaded lower leaves, and on leaf undersurfaces. The disease withdraws nutrients from the plant, reduces light interception by leaves and leads to leaf necrosis. The disease does not cause direct damage to fruits but can lead to production of smaller and fewer fruit. The yield reductions can be in the range of 0 to 70% compared to disease-free plants. In infected plants, the great variability in yield reduction is attributed to numerous factors, such as plant genetic resistance to the disease, plant's ability to produce fruit when the disease is present (e.g. in disease tolerant cultivars), crop's developmental stage at the time of infestation, disease inoculum abundance, length of the period with optimal environmental conditions for infection and disease development, length of the cropping period of the cucurbit species, and plant stress due to climate or crop managing practices.

Current disease management programs for powdery mildew consist of repeated and frequent sprays (every week or fortnight) with systemic and contact fungicides, starting before or after disease symptoms are detected on plants. Because of the longer withholding period of systemic fungicides, in short-crops such as zucchini, these can only be sprayed during early vegetative growth. Harvest of first fruits usually commences four weeks after transplanting seedlings (close to a week later with direct seeding) and with fruit picking every day or every other day. There are few conventional chemical options to control the disease during the harvesting period.

Systemic fungicides can control the fungal colonies that develop on both sides of the leaves, and on stems and petioles. Contact fungicides will only act on the fungus located on the sprayed area, thus they are effective in controlling the disease mainly on the top leaf surface. Systemic fungicides are known by the industry as the best control option available and they are commonly recommended to and used by growers. Some growers will only use systemic fungicides and they may or may not alternate sprays using active ingredients of different chemical groups in the spray schedule. Other growers alternate sprays of contact fungicides (protectants) and systemic fungicides, or they tank-mix both fungicide types.

Fungicide resistance development by pathogen populations

Powdery mildew is a frequent problem in cucurbits in the dry tropics of north Queensland. One activity that has been continued in North Queensland throughout this project is the monitoring of fungicide resistance in cucurbit powdery mildew populations. Growers rely on regular use of fungicide sprays to manage the disease. Sometimes even repeated sprays only offer limited control leading in some cases to crop failure. When this happens, it becomes important to monitor if pathogen strains are becoming resistant to specific fungicides in use. Loss of sensitivity by *P. xanthii* to Spinflo®, Nimrod®, Amistar®, and Bayfidan® was monitored in pathogen populations across several cucurbit crops in the Burdekin Delta region of north Queensland using a field bioassay. This consisted of spraying seedlings with each of the 4 fungicides and exposing them for a few hours to natural infection in target fields before observing for disease development under controlled conditions. Unsprayed seedlings served as controls. Loss of sensitivity was determined by comparing disease severity levels in the treated seedlings with the untreated controls. The 2008/2009 crop monitoring results suggested that resistance to the fungicides in use was likely with variable levels among different cucurbit species. This was confirmed during the following season. In general, resistance was more prevalent in late season crops than in early crops mainly because of the heavy build up of inoculum as seen in the untreated controls. In some fields, resistance could be detected even when the grower had not used any fungicides indicating extensive movement of spores across fields in the same region. This suggests that only an area-wide program for managing fungicide resistance could be effective. Seasonal monitoring for resistance is useful in making adjustments to cropping practices that rely on integrated approaches to delay resistance development.

Figure 1. Powdery mildew in pumpkin leaves.

Figure 2. Powdery mildew in zucchini stem and petioles.

Downy mildew in zucchini, squash, pumpkins, and cucumbers

The foliar disease is caused by the plant pathogenic fungus *Pseudoperonospora cubensis*. Only leaves are affected. Spots on leaves first appear pale green and then become yellow (Figures 3, 4 and 5). Finally the tissue becomes necrotic. Spots can be angular, delineated by leaf veins, but several spots occur together in a coalesced group. On the underside of the leaf spots typically appear water-soaked at first. In contrast with powdery mildew, spores of the downy mildew fungus are darker (purplish gray) and develop only on the underside of leaves. Spores are not always present and symptoms can vary greatly, thus diagnosis can be challenging.

Spores are easily dispersed by wind from one leaf spot to another leaf in one crop or to another crop planted nearby. Spore movement occurs primarily during late morning to midday. After a spore lands on a leaf and when the leaf is wet, the spore germinates and penetrates the leaf tissue. When night-time temperatures are between 13 and 24 ºC and relative humidity is above 90%, conditions are ideal for infection. Within approximately a week, new lesions are produced as a result of infection. Thus, new sites with more spores are produced. As this cycle continues, an epidemic occurs and control becomes increasingly difficult. Infection can also occur under cooler environments than those required for powdery mildew. Extensive defoliation can occur when conditions are favourable. Downy mildew can reduce yield, fruit quality, and harvesting time.

Recommendations for integrated management of downy mildew in cucurbits include planting resistant varieties, monitoring disease occurrence and weather forecasts, inspecting crops for symptoms weekly, and applying broad-spectrum protective fungicides before detection and systemic narrow-spectrum fungicides when downy mildew occurs early in the crop production. Overhead irrigation should be avoided.


Figure 3. Downy mildew in zucchini leaves.

Figure 4. Downy mildew in cucumber leaves.

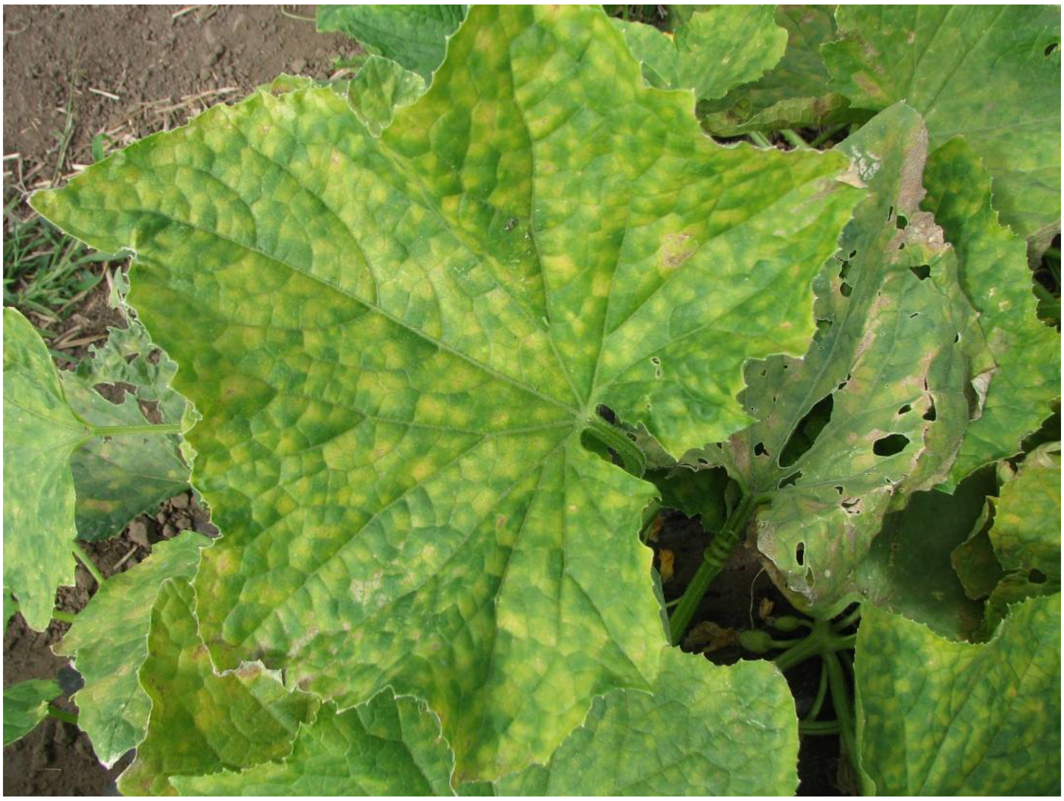

Figure 5. Downy mildew in cucumber leaves.

Anthracnose in cucumber

The foliar disease is caused by the plant pathogenic fungus *Colletotrichum orbiculare*. The fungus can infect cucumber, squash, pumpkin, melon and watermelon. Symptoms of anthracnose in cucumber may start with small round (2 mm diam.) pale yellow leaf spots. The round lesions will increase in diameter (up to 10 mm), as they turn from tan to dark brown (Figure 6). The lesions become dry and necrotic, often developing holes or cracks in the centre. The lesions may have polygonal shapes when leaf veins limit the edges of the leaf spots. As the disease progresses, the spots may coalesce leaving the whole leaf with necrosis. Lesions can also form on petioles, stems and fruit. The spore-bearing structures (acervuli) of the causal fungus are found in the necrotic lesions. They are tan or light orange in colour and contain numerous spores in a slimy matrix. A diagnostic feature of this disease is the presence of dark brown hairs, or setae, in the acervuli. The setae are visible with a hand lens or dissecting microscope.

The pathogen survives between crops in infected crop debris, in volunteer plants, or in weeds of the cucurbit family. It can be carried on seed harvested from infected fruit and spread by the feeding of cucumber beetles (*Diabrotica* spp.). Long periods of leaf wetness (e.g. rain, dew, and overhead irrigation), warm temperatures (23 to 26ºC) and high humidity favour disease infection and development. Spores are splashed from leaf to leaf, and plant to plant, during irrigation or rain events. Several disease cycles can occur in a single growing season, resulting in defoliation of severely infected plants.

In cucumber, yield reduction occurs from the defoliation of plants. Cucumbers are more affected than squash and pumpkins. The disease may cause damage to melons and watermelons. Management of anthracnose in cucurbits should involve both plant genetic resistance and chemical measures. There are cucumber cultivars listed as resistant to anthracnose but these need to be evaluated locally in field trials. Fungicides will not cure leaves with lesions.

Figure 6. Anthracnose in cucumber leaves.

Spray products alternative to fungicides

There are a number of spray products sometimes classified as “biological products” which include three broad groups: protectants (products that are organic or inorganic, and synthetic or natural), plant defence activators, and biological control agents. In general, these products have very low toxicity to humans and the environment. These biological products differ greatly in their mode of action. When used alone in a disease management program, the biological products repress fungal infections but are not as effective as systemic or contact fungicides. Many of these biological products could be very important components of disease management programs that aim to minimize pesticide use and prolong the life of effective systemic fungicides. For best results, biological products should be sprayed at specific times in the progression of the disease. They could also be alternated with sprays of systemic fungicides. Table 4 lists products that were reported to have an acceptable level of foliar disease suppression in cucurbits.

Table 4. Products identified as having a level of suppression on selected foliar diseases in cucurbits (PM: powdery mildew, DM: downy mildew, AT: anthracnose). Some of these products may not be registered or have permits for use in Australia. Updated information can be obtained by accessing the Australian Pesticides and Veterinary Medicines Authority (APVMA) website: www.apvma.gov.au

Type of alternative product	**Main active ingredient**	**Examples of trade names (Australia and overseas)**	**PM**	**DM**	**AT**
Inorganic products (Synthetic and/or natural)	**Formulations containing sulphur**				
	Micronized sulphur and other formulations of sulphur	Microthiol Disperss; Thiolux; MicroSulf	●		
	Formulations containing copper				
	Copper hidroxide	Kocide 2000	●	●	
	Copper octanoate (also known as “copper soap”)	Cueva; NEU 1140F; Tricop	●	●	●
	Basic copper sulphate		●	●	
	Formulations containing salts of monovalent cations				
	Potassium bicarbonate	Kaligreen; Armicarb 100; Ecocarb; MilStop; Remedy	●	●	●
	Potassium salts of fatty acids (safer soaps)	M-Pede	●		
	Mono- and di-potassium salts of phosphoric acid	Fosphite		●	●
	Phosphonic acid (Phosphorus Acid)	Foli-R-Fos; Agri-Fos		●	
	Mono-potassium phosphate	eKsPunge; Nutrol LC	●		
	Potassium phosphite	Helena Pro-phyt		●	
	Formulations containing oxidants				
	Hydrogen dioxide	OxiDate; Hdh peroxide; Peratex	●	●	●
	Formulations containing silica				
	Soluble silicon (percentages of potassium silicate)	Kasil 1; AgSil 21, 25; SilMatrix; Siliforce; Stand SKH; Enhance KCS	●		

Table 4 continued

Type of alternative product	Main active ingredient	Examples of trade names (Australia and overseas)	PM	DM	AT
Organic products (Synthetic and/or natural)	**Formulations containing oils**				
	Cinnamon oil	Cinnamite; Cinnacure; Valero	●		
	Cotton oil, Corn oil, Garlic extract, Potassium bicarb.	GC-3 oil	●		
	Cotton oil, Garlic extract, Clove oil	SaferGro Mildew Cure	●		
	Clove, Rosemary, Peppermint, & Soybean oils, Malic acid, sodium bicarb.	EF400	●	●	
	Canola oil	Synertrol Horti Oil	●	●	
	Jojoba (*Buxus chinensis*) oil	E-Rase	●		
	Mineral oil	JMS Stylet-Oil	●		
	Neem (*Azaridachta indica*) oil	Trilogy	●	●	●
	Soybean oil derivative	Bionatrol-M	●		
	Vegetable oil	Synertrol Oil	●	●	
	Ethoxylated Alcohol (Boric acid, orange oil, surfactants)	Prev-AM	●	●	
	Formulations containing plant defence activators				
	Acibenzolar-s-methyl	Actigard; Bion 50 WG	●	●	
	Chitosan (poly-D-glucosamine) [fish/sea shell protein + trace elements]	Aminogro	●	●	
	Chitosan (poly-D-glucosamine)	Elexa 4	●	●	
	DL-β-aminobutyric acid (BABA)		●	●	●
	Plant (Reynoutria sachalinensis) extract	Milsana	●		
	Harpin protein	Messenger	●	●	
	Formulations containing milk products				
	Cow milk powdered full-fat (5-10%)	Several brands for human consumption or calf diet supplement	●		
	Whey	Lacto-San	●		
Living organisms	**Formulations containing biological fungicides**				
Fungi	*Ampelomyces quisqualis* isolate M-10	AQ10	●		
	Sporothrix flocculosa (syn. *Pseudozyma flocculosa*)	Sporodex	●		
	Lecanicillium lecanii	Mycotal, Vertalec	●		
Bacteria	*Bacillus pumilus* strain 2808	Sonata	●	●	
	Bacillus subtilis strain QST 713	Serenade	●	●	●
	Pseudomonas fluorescens	Biomonas	●	●	
	Streptomyces lydicus	Micro108, Actinovate SP	●	●	

Other agronomic practices

Cultural practices for disease control can help reduce the amount of spores available for causing infection. Some of these practices such as removal and burning of infected plant debris and unmarketable fruit from the field may be impracticable. Ploughing debris down deeply into the soil may not be possible if using permanent bed systems with minimum tillage. With severe infections, crop rotation for at least two years with crop species that are not cucurbits has been suggested. Volunteer cucurbits should be controlled as they will aid pathogen survival. Overhead irrigation should be avoided (which is still used on some cucurbit crops in the Tablelands), as it promotes long periods of wetness on leaves and aids in the spread of the fungus from plant to plant.

List and brief descriptions of trials conducted in North Queensland

Tolerance to powdery and downy mildews in zucchini. Ten commercially available cultivars (Houdini; Paydirt; Caroline; Nitro; Amanda; Congo; Crowbar; Calida; Zest; and Golden Rod) and four experimental lines (CLX29881; 7708; HMX5702; and HMX5713) of zucchini were evaluated for reactions to commonly occurring foliar diseases in North Queensland. Three field trials were conducted in Ayr (early and mid season plantings) and Bowen (late season planting) in 2008. Crops were grown following conventional practices but were not sprayed with fungicides. Disease severities on plants were assessed and fruit yield was measured.

Tolerance to powdery and downy mildews in pumpkin. Six commercially available cultivars (Sampson; Early Jarragrey; Royal Grey; Kens Special; Dynamite; TNT) and three experimental lines (183-6; 188-6; Kens Special 864) of pumpkin were evaluated for reactions to commonly occurring foliar diseases in North Queensland. Three field trials were conducted in Ayr (early and mid season plantings) and Bowen (late season planting) in 2008. Crops were grown following conventional practices but were not sprayed with fungicides. Disease severities on plants were assessed and fruit yield was measured.

Tolerance to downy mildew, powdery mildew, and anthracnose in cucumber. Six commercially available cultivars (Camelot; Aladdin; Gremlin; Stonewall; Diamante; and Crystal Salad) and an experimental line (HMX4453) of cucumber were evaluated for reactions to commonly occurring foliar diseases in North Queensland. Two field trials were conducted in Ayr (early and mid season plantings) in 2008. Crops were grown following conventional practices but were not sprayed with fungicides. Disease severities on plants were assessed and fruit yield was measured.

Tolerance to downy mildew and powdery mildew in squash. Four commercially available cultivars (Sunburst; Delica; Naches; and Cochise) were evaluated for reactions to commonly occurring foliar diseases in North Queensland. Two field trials were conducted in Ayr (early and mid season plantings) in 2008. Crops were grown following conventional practices but were not sprayed with fungicides. Disease severities on plants were assessed and fruit yield was measured.

Efficacy of products alternative to fungicides in managing powdery and downy mildews in zucchini. Fourteen spray products [micronized sulphur (Microthiol Disperss®); copper octanoate (Tricop®); potassium bicarbonate (Ecocarb®); phosphorus acid (Agri-Fos 600®); hydrogen dioxide (Peratec®); soluble silicon (Enhance KCS® and Stand SKH®); neem oil (Trilogy®); canola oil (Synertrol Horti oil®); tea tree oil (Timorex Gold®); acibenzolar-s-methyl (Bion®); chitosan (Aminogro®); milk, and propylene glycol alginate (Cal Agri 50NF®)] that are alternative to conventional systemic and contact fungicides used for managing commonly occurring foliar diseases in cucurbits were evaluated on zucchini in North Queensland. Three field trials were conducted in Ayr (early and mid season plantings) and Bowen (late season planting) in 2009. A cultivar susceptible to downy mildew and powdery mildew (Congo) was used. Control plots were not sprayed, sprayed with water, or sprayed with conventional fungicides with systemic and contact actions. Disease severities on plants were assessed and fruit yield was measured.

Efficacy of products alternative to fungicides in managing anthracnose and downy mildews in cucumber. Spray products that are alternative to conventional systemic and contact fungicides used for managing foliar diseases on cucurbits were evaluated on cucumber in North Queensland. Two field trials were conducted in Ayr (mid and late season plantings) in 2009. Fourteen alternative products [micronized sulphur (Microthiol Disperss®); copper octanoate (Tricop®); potassium bicarbonate (Ecocarb®); phosphorus acid (Agri-Fos 600®); hydrogen dioxide (Peratec®); soluble silicon (Enhance KCS® and Stand SKH®); neem oil (Trilogy®); canola oil (Synertrol Horti oil®); tea tree oil (Timorex Gold®); acibenzolar-s-methyl (Bion®); chitosan (Aminogro®); milk, and propylene glycol alginate (Cal Agri 50NF®)] were tested on a cultivar susceptible to downy mildew and powdery mildew (Crystal Salad) and eight alternative products [micronized sulphur (Microthiol Disperss®); copper octanoate (Tricop®); hydrogen dioxide (Peratec®); neem oil (Trilogy®); canola oil (Synertrol Horti oil®); tea tree oil (Timorex Gold®); acibenzolar-s-methyl (Bion®); and milk] were tested on a cultivar susceptible to anthracnose (Gremlin). Control plots were either not sprayed, sprayed with water, or sprayed with conventional fungicides with systemic and contact actions. Disease severities on plants were assessed and fruit yield was measured.

Integrated management of powdery mildew and downy mildew in zucchini. Four spray programs and a non-sprayed control were evaluated on four zucchini cultivars (two previously rated as moderate resistant to powdery and downy mildews: Paydirt and Nitro, and two susceptible: Houdini and Calida) for efficacy to manage commonly occurring foliar diseases in North Queensland. Spray programs included one or more of the following fungicide alternatives: Agri-Fos 600®, Bion®, and Tricop®. A conventional fungicide program included Acrobat MZ®, Amistar®, Mancozeb®, Nimrod®, and Bravo®. Micronized sulphur (Microthiol Disperss®) was included in every spray program. Two field trials were conducted in Ayr (mid and late season plantings) in 2010. Disease severities on plants were assessed and fruit yield was measured.

Tolerance to foliar diseases in zucchini, squash, cucumber and pumpkin cultivars in North Queensland

Summary

A key component in integrated foliar disease management of cucurbits is the use of plant genetic resistance. Commercial cucurbit cultivars and new cultivar lines should be screened for resistance to foliar diseases in the regions where they are commercially grown in order to identify cultivars with acceptable low disease levels and high marketable yields. Six field trials were conducted in the dry tropics of north Queensland, to evaluate the reactions to powdery mildew (*Podosphaera xanthii*), downy mildew (*Pseudoperonospora cubensis*), and anthracnose (*Colletotrichum orbiculare*) in a range of cultivars and lines of zucchini (Houdini; CLX29881; 7708; Paydirt; Caroline; Nitro; Amanda; Congo; Crowbar; HMX5702; Calida; Zest; Golden Rod; HMX5713), squash (Sunburst; Delica; Naches; Cochise), cucumber (Camelot; Aladdin; Gremlin; Stonewall; HMX4453; Diamante; Crystal Salad), and pumpkin (Sampson; 183-6; 188-6; Early Jarragrey; Royal Grey; Kens Special 864; Kens Special; Dynamite; TNT). Crops were grown without fungicide sprays at two research locations, with plantings in June and July, in order to favour conditions for disease initiation and spread. Plants were assessed for disease severity throughout the cropping season and the areas under the disease progression curve were calculated for comparison among cultivars. Cultivars with acceptable low disease levels and adequate marketable yields were identified from the collection of each cucurbit species evaluated and can be used in integrated disease management programs.

The common objective of the trials conducted in 2008 was to evaluate the reaction to powdery mildew, downy mildew, and anthracnose in a range of cultivars of zucchini, squash, cucumber, and pumpkin cultivars grown across tropical locations in north Queensland, Australia (Table 5). Powdery mildew and downy mildew are foliar diseases of concern in all the selected cucurbits but anthracnose mainly affects cucumbers. Commercial available cultivars and breeding lines close to be released to the market were sourced from the main vegetable seed companies. The field trials were conducted at the DEEDI Ayr and Bowen Research Stations. Crops were not sprayed for disease control and pathogen infections occurred from natural inoculum present in the area. The Bowen Research Station was selected as one of the trial sites because this location commonly has environmental conditions with lower air humidity levels which favour powdery mildew development during the winter cropping season when compared to environmental conditions in Ayr. In Ayr, environmental conditions after April usually include days with morning dew, or an occasional rain, and gives optimum conditions (i.e. wet leaf surfaces during cool temperatures) for germination of downy mildew spores and disease development.

Table 5. Trials carried out in Ayr and Bowen to screen cultivars of selected cucurbits for their reaction to powdery mildew, downy mildew and anthracnose.

Cucurbit	Trial Location	Planting date	Number of cultivars evaluated	Main diseases present
Zucchini	Ayr	29 April	13	Downy Mildew
	Ayr	2 July	13	Downy Mildew
	Bowen	19 June	13	Powdery mildew Downy Mildew
Squash	Ayr	29 April	4	Downy Mildew Powdery mildew
	Ayr	15 June	4	Downy Mildew Powdery mildew
Cucumber	Ayr	29 April	7	Downy Mildew Anthracnose
	Ayr	2 July	7	Downy Mildew Anthracnose
Pumpkin	Ayr	29 April	9	Downy Mildew
	Ayr	2 July	9	Downy Mildew
	Bowen	19 June	9	Downy Mildew Powdery mildew

Tolerance to powdery mildew and downy mildew in zucchini

Introduction

The main objective of these studies was to evaluate the reaction to powdery mildew and downy mildew in a range of zucchini cultivars available and grown across tropical locations in north Queensland.

Materials and Methods

Fourteen cultivars (Table 6) were evaluated for resistance to natural infection by powdery mildew in Ayr and Bowen DEEDI Research Stations (Figure 7). In three field trials, plots with 10 plants per plot were arranged in randomized complete block designs with four replications. Seedlings with three unfolded leaves were transplanted, in Ayr on 29 April and 2 July 2008, and in Bowen on 19 June 2008, into drip-irrigated (2 L/m/h) raised beds covered with black polyethylene mulch. Bed rows were 1.52 m from each other and plants were 0.55 m apart within bed rows. Pre-plant fertilizer (N-P-K, 13-15-13 at 4 kg/100 m row) was applied in two bands of the planting beds. After flowering, fertilizers applied through drip irrigation included potassium nitrate (three applications at 0.6 kg/100 m of row) alternated weekly with calcium nitrate (two applications at 0.5 kg/100 m of row). Plots were irrigated as needed, with water delivered two to four times per week for irrigation periods that ranged from 2 to 4 h. No fungicides were applied. Weeds were managed with Roundup (7 mL/L), applied as a directed shielded spray in the area between plots during the early part of the season, and with manual cultivation in the later part of the season. Insecticide Confidor Guard, (14 mL/100 m of row) was drip-injected once after transplanting for controlling whitefly [*Bemisia* spp. (Hemiptera: Aleyrodidae)] and cotton aphid [*Aphis gossypii* Glover (Homoptera: Aphididae)]. In each plot, disease severity was assessed in five plants on the adaxial and abaxial leaf surfaces of two leaves in the upper plant canopy, and on two leaves in the lower plant canopy. In the trial planted in Ayr on 29 April, disease severity assessments were done on 11 June, 19 June and 30 June. In the trial planted in Ayr on 2 July, disease severity assessment for downy mildew was done on 28 August. In the trial planted in Bowen on 19 June, disease severity assessments for powdery mildew were done on 14 August, 27 August, and 11 September, and for downy mildew on 27 Aug. Each selected leaf was assigned a disease severity score based on the percentage of leaf surface covered with powdery mildew colonies and of downy mildew leaf spots (Table 7). In one trial, disease severity was also assessed on plant stems (visually determining the percentage of the stem length covered with powdery mildew colonies) (Figure 8). The disease intensity over time (area under the disease-progress curve or AUDPC) was calculated for periods that included three or more dates of disease severity assessment The formula used was $AUDPC = \Sigma([(x_i+x_{i-1})/2](t_i-t_{i-1}))$ where x_i was the rating at each evaluation time and (t_i-t_{i-1}) was the time between evaluations. Weight and number of harvested fruits picked every two days during a 4 to five week period were recorded in Ayr. Disease severity data were analysed with analysis of variance using GENSTAT software. Disease severity scores used in the field were converted into percentage values of leaf area covered with the disease and subsequently subject to arcsine transformation previous to statistical analyses. Back-transformed means are presented. Maximum and minimum day temperatures, air relative humidity (9 am), and rainfall at the DEEDI Research Stations in Ayr and Bowen from May are presented in Figure 9.

Table 6. Zucchini cultivars evaluated for reaction to foliar diseases in field trials in North Queensland.

Cultivar's name	Fruit colour	Seed Company
Amanda	green	Clause
Calida	green	Clause
CLX29881	green	Clause
HMX5702	green	Clause
HMX5713	green	Clause
Golden Rod	yellow	Clause
Zest	green	Lefroy Valley Seeds
7708	green	Lefroy Valley Seeds
Houdini	green	Syngenta
Paydirt	green	Syngenta
Crowbar	green	Syngenta
Caroline	green	South Pacific Seeds
582-6 (Nitro)	green	South Pacific Seeds
Congo	green	Seminis

Table 7. Disease severity scores used to assess disease severity on plant leaves in the field plots and their percentages of leaf area covered with powdery mildew or downy mildew symptoms. Cards with images of leaves at different disease severity levels were prepared and used to assess severity on field plots.

Disease severity scores	Percentage of leaf area with symptoms (%)
0	0
1	0.3 - 4.7
2	5 - 9.7
3	10 - 29.7
4	30 - 74.7 and some leaf necrosis
5	75 - 100 and extended leaf necrosis

Figure 7. Zucchini field trials in Ayr (left) and Bowen (right) where reactions of several cultivars to powdery mildew and downy mildew were evaluated.

Figure 8. Stems of zucchini plants affected by powdery mildew. Numbers indicate percentage of stem and petioles covered with the disease.

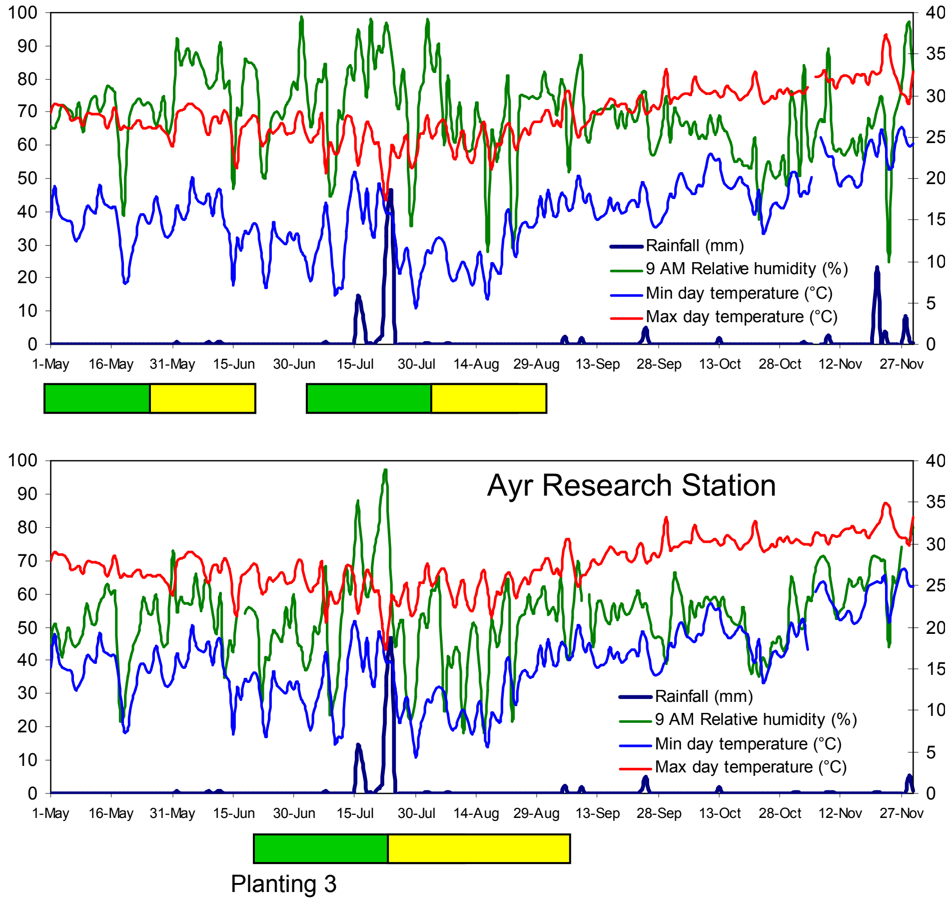

Figure 9. Maximum and minimum day temperatures, air relative humidity (9 am), and rainfall at the DEEDI Research Stations in Ayr and Bowen from May to end of November in 2008.

Results and Discussion

Planting 29 April 2008 in Ayr

Downy mildew was the main foliar disease during the first planting in Ayr. Powdery mildew was at very low levels at the time when the trial was terminated. There were differences in downy mildew severity (measured as AUDPC) among zucchini cultivars (Table 8). Cultivars such as Houdini, HMX570, 7708, Calida, and Congo (one of the standard cultivars in the region) were more affected by downy mildew than cultivars Nitro and Golden Rod. Cultivar Amanda, with intermediate levels of downy mildew severity between Houdini and Nitro had greater yield in total weight and number of fruits than Nitro (Table 9).

Table 8. Downy mildew severity and fruit yield in thirteen zucchini cultivars planted 29 April 2008 in Ayr, Queensland.

	Downy mildew severity[z]								
	Top-canopy leaves				Low-canopy leaves				Top-Low
	Percentage of area covered with lesions (%)[y]			AUDPC[w]	Percentage of area covered with lesions (%)			AUDPC	Mean AUDPC[x]
Cultivar	11-June	18-June	30-June	(%-days)	11-June	18-June	30-June	(%-days)	(%-days)
Houdini	12	65 a	100 a	1244 a	64 a	99 a	100 a	1736 a	1490 a
HMX570	7	48 ab	94 ab	1013 ab	38 bcd	98 a	100 ab	1617 abc	1315 ab
7708	10	43 abc	74 cd	883 bc	54 ab	94 ab	100 a	1631 ab	1257 abc
Calida	8	43 abc	66 cde	832 bcd	46 abc	84 abc	100 a	1544 abcd	1188 bc
Congo	7	41 abc	85 bc	905 bc	17 ef	84 abc	100 a	1441 bcde	1173 bc
Caroline	9	45 abc	65 cde	851 bcd	25 def	85 abc	94 abcd	1425 bcde	1138 bcd
Amanda	7	36 bc	70 cde	782 bcde	27 cde	75 bc	98 abc	1355 bcde	1068 bcd
Crowbar	6	33 bc	63 de	714 bcde	19 def	81 bc	97 abc	1358 bcde	1036 cd
Congo Net[v]	7	36 bc	61 de	734 bcde	19 def	68 cd	100 ab	1298 de	1016 cde
Paydirt	8	39 bc	58 de	751 bcde	20 def	79 bc	87 cd	1261 def	1006 cde
CLX29881	8	30 bcd	53 de	633 cde	19 ef	79 bc	94 abcd	1339 cde	986 cde
Zest	6	32 bcd	48 e	615 cde	18 ef	66 cd	80 d	1164 ef	889 de
582-6 (Nitro)	6	23 cd	50 e	565 de	34 bcde	62 cd	91 bcd	1202 ef	884 de
Golden Rod	4	12 d	62 de	517 e	9 f	44 d	92 bcd	983 f	750 e
P-value	0.078	0.022	<.001	0.002	<.001	0.002	<.001	<.001	<.001

[z] Analysis of variance (ANOVA) performed on data. Means followed by the same letter within a column are not significantly different from each other (Fisher's protected least significant difference, α = 0.05).

[y] Arc-sin transformation was used for percentage data prior to analysis. Back-transformed means are presented.

[w] Area under Disease Progress Curve (AUDPC) calculated for disease severity assessed 11 June, 18 June, and 30 June.

[x] Mean AUDPC calculated between top and low canopy AUDPC values.

[v] In this treatment, a floating polypropylene sheet covered Congo plants from transplanting (29 April 2008) until commence of blooming

Table 9. Fruit yield in thirteen zucchini cultivars planted 29 April 2008 in Ayr, Queensland.

	Fruit yield[z]		
Cultivar	(g/fruit)	(No.×1000/ha)[y]	(t/ha)[y]
Houdini	158	111.2 abcd	17.6 cdefg
HMX570	200	108.3 bcde	21.7 ab
7708	194	108.9 bcde	21.1 abc
Calida	167	90.9 f	15.2 g
Congo	174	108.9 bcde	19.0 bcdef
Caroline	187	103.5 cdef	19.4 bcde
Amanda	192	127.4 a	24.5 a
Crowbar	177	112.4 abc	19.9 bcd
Congo Net[x]	170	92.7 ef	15.8 efg
Paydirt	179	87.3 f	15.6 fg
CLX29881	160	101.1 cdef	16.2 defg
Zest	198	99.9 cdef	19.8 bcd
582-6 (Nitro)	183	95.1 def	17.4 cdefg
Golden Rod	141	125.0 ab	17.6 cdefg
P-value	*0.079*	*0.001*	*0.001*

[z] Analysis of variance (ANOVA) performed on data. Means followed by the same letter within a column are not significantly different from each other (Fisher's protected least significant difference, α = 0.05).

[y] Yield per ha calculated for a full area cropped (11,962 plants/ha) with no drive ways.

[x] In this treatment, a floating polypropylene sheet covered Congo plants from transplanting (29 April 2008) until commence of blooming

Planting 2 July 2008 in Ayr

Downy mildew was the most important foliar disease in the second planting of zucchini in Ayr. Disease severity was assessed on August 28. At this date, significant differences of disease severity were only on top canopy leaves (Table 10). Downy mildew severity was low in Golden Rod and high in Houdini. Golden Rod and HMX5713 which had low downy mildew severities also had lower total yields in weight than cultivars that had been more affected by the disease, such as Houdini (Table 10).

Table 10. Downy mildew severity and fruit yield in fourteen zucchini cultivars planted 2 July 2008 in Ayr, Queensland.

	Downy mildew severity[z] Percentage of area covered with lesions on 28-Aug. (%)[y]			Fruit yield [w]		
Cultivar	Upper-canopy leaves	Lower-canopy leaves	Average Upper-Lower leaves	(g/fruit)	(No.×1000/ha)	(t/ha)
Houdini	5.0 a	37.9	21.5	258 abc	74.2 abcd	19.2 abcd
CLX29881	2.9 ab	33.8	18.4	213 cde	89.7 ab	19.2 abcd
7708	2.3 abc	22.2	12.3	287 a	55.0 e	15.2 de
Paydirt	1.9 abcd	23.9	12.9	223 bcd	90.9 a	20.3 abcd
Caroline	1.7 abcde	29.9	15.8	271 a	78.4 abc	21.0 abc
582-6 (Nitro)	1.7 abcde	21.3	11.5	284 a	71.8 bcde	20.0 abcd
Amanda	1.5 bcde	38.0	19.8	264 ab	75.4 abc	20.0 abcd
Congo	1.4 bcde	22.5	12.0	269 ab	86.7 ab	22.9 ab
Crowbar	1.4 bcde	27.1	14.3	222 bcd	82.5 abc	18.5 bcd
HMX5702	1.2 bcde	27.8	14.5	286 a	82.5 abc	23.8 a
Calida	0.7 bcde	23.8	12.3	206 de	56.2 de	11.5 ef
Zest	0.5 cde	15.2	7.9	251 abcd	65.2 cde	16.2 cde
Golden Rod	0.2 de	18.9	9.6	158 f	73.6 abcd	11.7 ef
HMX5713	0.2 e	21.4	10.8	174 ef	56.8 de	9.8 f
P-value	*0.043*	*0.145*	*0.096*	*0.001*	*0.001*	*0.001*

[z] Analysis of variance (ANOVA) performed on data. Means followed by the same letter within a column are not significantly different from each other (Fisher's protected least significant difference, α = 0.05).
[y] Arc-sin transformation was used for percentage data prior to analysis. Back-transformed means are presented.
[w] Yield per ha calculated for a full area cropped (11,962 plants/ha) with no drive ways.

Planting 15 June 2008 in Bowen

Both downy mildew and powdery mildew were present on zucchini plants planted in Bowen. A greater development of powdery mildew on plants in Bowen in comparison to the plantings at Ayr was possibly due to the drier environment in Bowen. Powdery mildew severities measured over time (AUDPC) are presented in Table 11 and Figure 10 for upper and lower leaves of the plant canopy and for stems. Cultivars such as Calida, CLX29881, Nitro, and Zest had relatively low disease severities when compared to HMX5702, 7708, Golden Rod, Houdini, Crowbar and Congo (Table 11). Images of stems and petioles of zucchini cultivars at the time the crop was terminated are presented in Figure 11. There were clear differences among cultivars (Figure 12).

When plants were assessed for downy mildew in Bowen on 28 August, Zest and Calida were two cultivars that were less affected by this disease (Table 12). However, differences in downy mildew severity among cultivars were smaller in the planting at Bowen (and in the second planting at Ayr) than in the first planting at Ayr (Figure 13).

Table 11. Powdery mildew severity over time on leaves (low and top levels of the plant canopy) and stems in 13 zucchini cultivars planted 15 June 2008 in Bowen, Queensland. Fruits were removed from plants but yield was not recorded.

	Powdery mildew severity [z]			
	Low-canopy leaves	Top-canopy leaves	Mean Top-Low	Stem
	AUDPC[y] 14 Aug-11 Sept	AUDPC 14 Aug-11 Sept	AUDPC 14 Aug-11 Sept	AUDPC 14 Aug-11 Sept
Cultivar	(%-days)	(%-days)	(%-days)	(%-days)
HMX5702	1708 a	325 a	1017 a	1634 bc
7708	1391 a	206 b	798 a	1783 ab
GoldenRod	918 b	92 c	505 b	1987 a
Houdini	816 bc	142 bc	479 bc	1850 ab
Crowbar	768 bc	62 c	415 bc	646 e
Congo	837 bc	102 bc	470 bc	1787 ab
Caroline	647 bcd	136 bc	391 bcd	755 e
Paydirt	517 bcde	54 c	285 bcde	586 e
Amanda	418 cde	84 c	251 cde	1322 cd
Zest	291 de	43 c	167 de	1632 bc
582-6 (Nitro)	237 de	50 c	143 e	704 e
CLX29881	211 e	43 c	127 e	661 e
Calida	198 e	54 c	126 e	1193 d
P-value	*0.001*	*0.001*	*0.001*	*0.001*

[z] Analysis of variance (ANOVA) performed on data. Means followed by the same letter within a column are not significantly different from each other (Fisher's protected least significant difference, α = 0.05).
[y] Area under Disease Progress Curve (AUDPC) calculated for the period 14 August to 11 September.

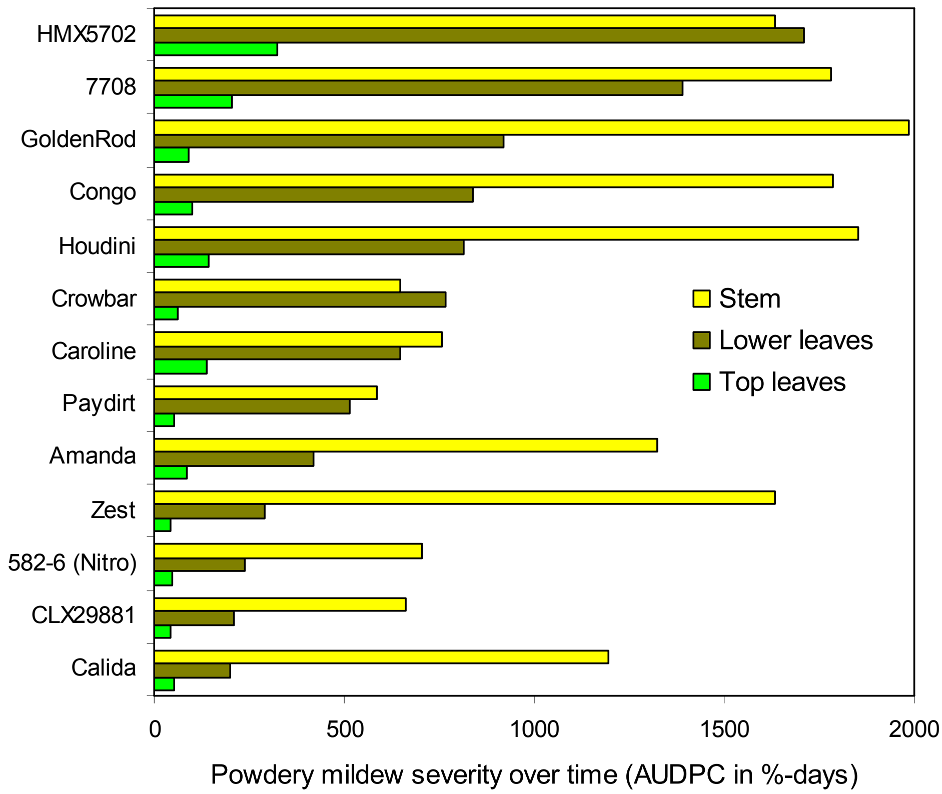

Figure 10. Powdery mildew severity over time (AUDPC from 14 Aug to 11 Sept) on 13 zucchini cultivars planted on 15 June 2008 in Bowen, Queensland.

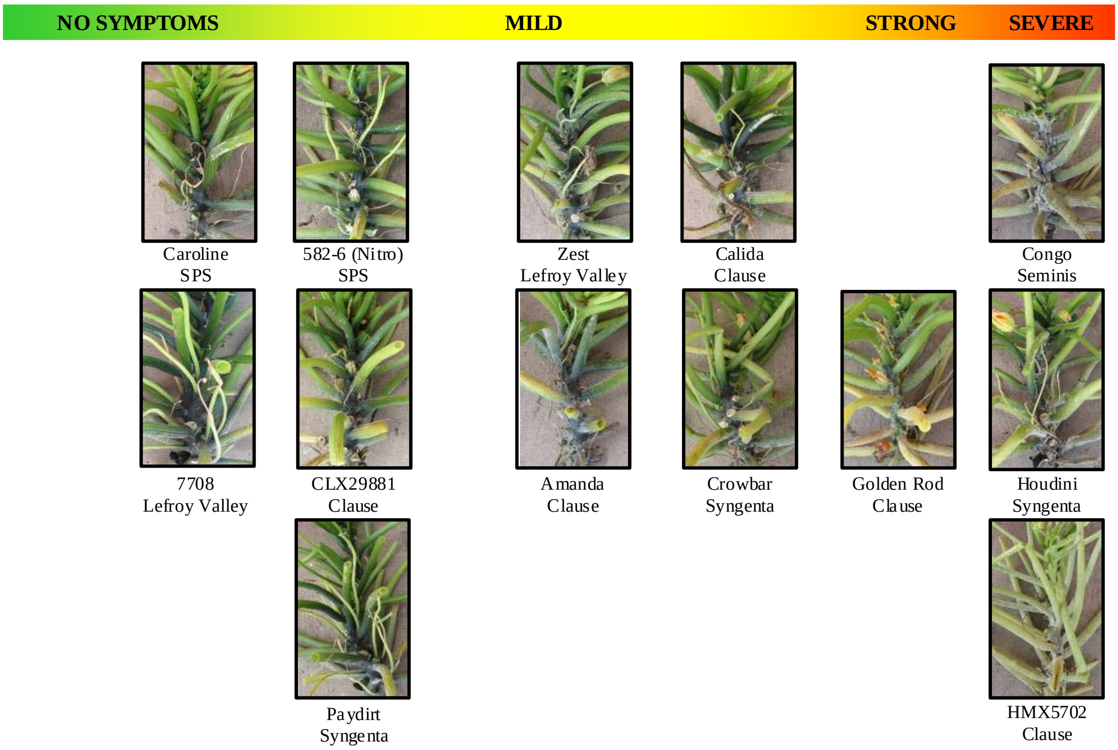

Figure 11. Powdery mildew on stems of zucchini cultivars grown without fungicides, 60 days after they were transplanted in Bowen in 2008. Grouping based on percentage of the stem and petioles covered with powdery mildew colonies.

Figure 12. Powdery mildew severity in two cultivars: Nitro (left) with very low disease severity and Houdini (right), where disease severity on leaves, stems and petioles was high.

Table 12. Downy mildew severity in twelve zucchini cultivars planted 15 June 2008 in Bowen, Queensland.

	Downy mildew severity [z]		
	Percentage of area covered with lesions on 27-Aug. (%)		
Cultivar	Upper-canopy leaves [y]	Lower-canopy leaves	Average Upper-Lower canopy
582-6 (Nitro)	25.7 a	54.0	46.7
Amanda	21.9 ab	51.9	43.4
7708	21.9 abc	53.7	41.6
Paydirt	21.4 abc	52.0	42.7
HMX5702	21.4 abc	50.7	41.6
Houdini	21.1 abc	52.4	44.6
Crowbar	21.0 abc	50.9	42.6
Golden Rod	20.8 abc	52.9	38.7
CLX29881	19.6 bcd	49.9	41.3
Caroline	18.6 bcd	52.6	39.1
Congo	18.1 bcd	56.9	38.1
Calida	16.0 cd	53.1	40.1
Zest	13.4 d	48.2	34.6
P-value	*0.031*	*0.733*	*0.374*

[z] Analysis of variance (ANOVA) performed on data. Means followed by the same letter within a column are not significantly different from each other (Fisher's protected least significant difference, α = 0.05). Arc-sin transformation was used for percentage data prior to analysis. Back-transformed means are presented.

[y] Upper canopy include leaves from node 16 to up to 21 and lower canopy include leaves from node 1 to 15.

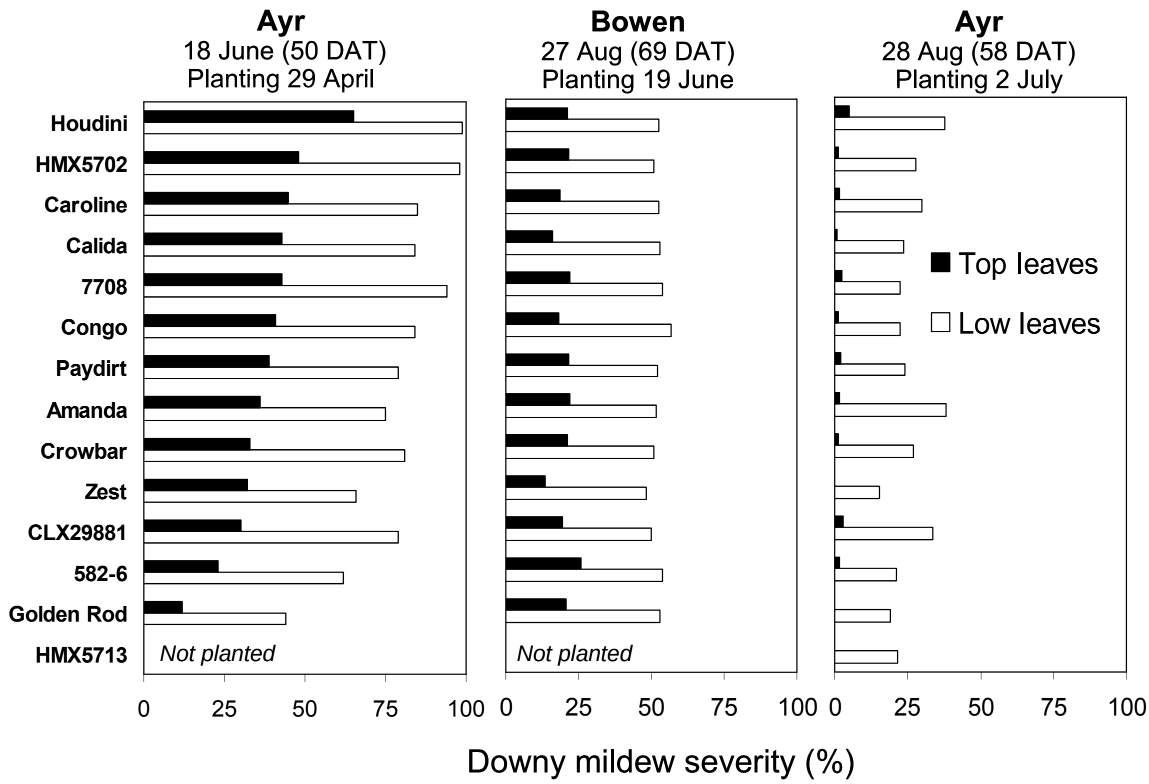

Figure 13. Downy mildew severity 14 zucchini cultivars at the end of their harvesting period in crops planted in Ayr and Bowen in 2008. DAT: days after transplanting. Disease severity measured as percentage of the leaf area with downy mildew symptoms.

Combined effects of downy mildew and powdery mildew in zucchini cultivars

Cultivars were plotted in Figure 14 according to their relative reaction to powdery mildew and downy mildew using data gathered in trials at Ayr and Bowen. When searching for cultivars with low reaction to foliar diseases, differences among cultivars were greater with powdery mildew than with downy mildew.

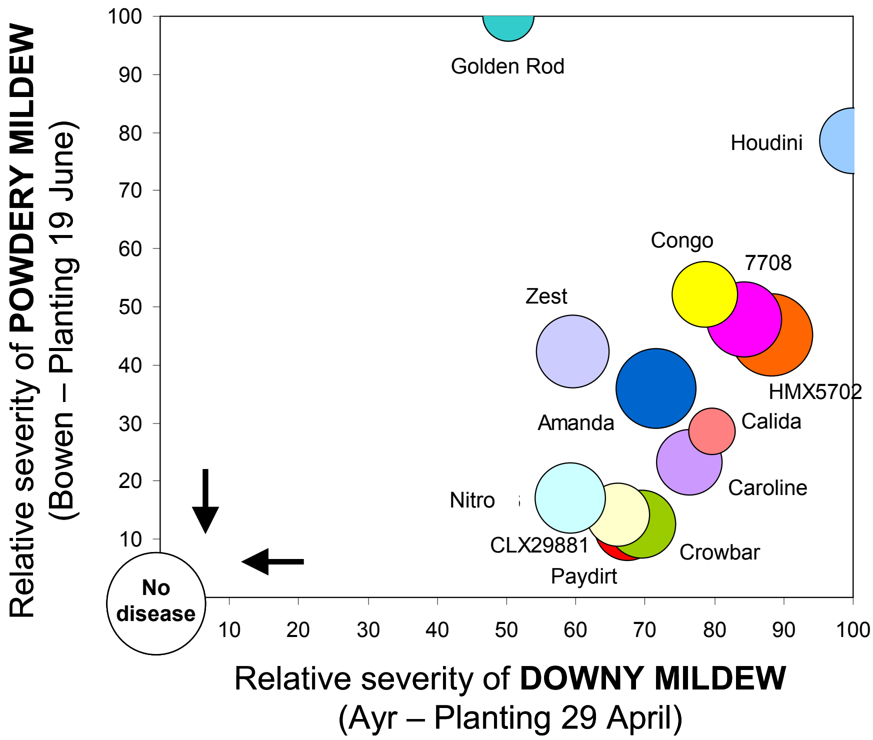

Figure 14. Reactions to powdery mildew and downy mildew in 13 zucchini cultivars combining results from two field trials conducted in 2008, one in Bowen where powdery mildew disease pressure was high, and the other one in Ayr, where downy mildew pressure was high. Relative values (in %) to cultivars with high sensitivity to the disease were plotted (cultivar Houdini was set to 100% for downy mildew and Golden Rod to 100% for powdery mildew). Diameter of the circles is proportional to total fruit yield.

Tolerance to downy mildew and anthracnose in cucumber

Introduction

The main objective of these studies was to evaluate the reaction to downy mildew and anthracnose in a range of cucumber cultivars available and grown across tropical locations in north Queensland. The main diseases were anthracnose and downy mildew. Reaction to powdery mildew was not evaluated because the disease was at very low severity levels in all trials. The disease was detected (also at low levels) on susceptible cultivar Crystal Salad at the time the trials were terminated.

Materials and Methods

Seven cultivars (Table 13) were evaluated for resistance to natural infection by downy mildew and anthracnose in Ayr. In two field trials, plots with 10 plants per plot were arranged in randomized complete block designs with four replications. Seedlings with three unfolded leaves were transplanted on 29 April and 2 July 2008, into drip-irrigated (2 L/m/h) raised beds covered with black polyethylene mulch. Bed rows were 1.52 m from each other and plants were 0.55 m apart within bed rows. Pre-plant fertilizer (N-P-K, 13-15-13 at 4 kg/100 m row) was applied in two bands of the planting beds. After flowering, fertilizers applied through drip irrigation included potassium nitrate (three applications at 0.6 kg/100 m of row) alternated weekly with calcium nitrate (two applications at 0.5 kg/100 m of row). Plots were irrigated as needed, with water delivered two to four times per week for irrigation periods that ranged from 2 to 4 h. No fungicides were applied. Weeds were managed with Roundup (7 mL/L), applied as a directed shielded spray in the area between plots during the early part of the season, and with manual cultivation in the later part of the season. Insecticide Confidor Guard, (14 mL/100 m of row) was drip-injected once after transplanting for controlling whitefly [*Bemisia* spp. (Hemiptera: Aleyrodidae)] and cotton aphid [*Aphis gossypii* Glover (Homoptera: Aphididae)]. In each plot, disease severity was assessed in five plants on the adaxial and abaxial leaf surfaces of two leaves in the upper plant canopy, and on two leaves in the lower plant canopy. In the trial planted in Ayr on 29 April, disease severity assessments were done on 6 June, 11 June and 17 June. In the trial planted in Ayr on 2 July, disease severity assessment for downy mildew was done on 1 September. Each selected leaf was assigned a disease severity score based on the percentage of leaf surface covered with powdery mildew colonies and of downy mildew leaf spots (Table 14). In one trial, disease severity was also assessed on plant stems (visually determining the percentage of the stem covered by the disease). The disease intensity over time (area under the disease-progress curve or AUDPC) was calculated for periods that included three or more dates of disease severity assessment. The formula used was $AUDPC = \Sigma([(x_i+x_{i-1})/2](t_i-t_{i-1}))$ where x_i was the rating at each evaluation time and (t_i-t_{i-1}) was the time between evaluations. Weight and number of harvested fruits picked every two days during a 4 to five week period were recorded in Ayr. Disease severity data were analysed with analysis of variance using GENSTAT software. Disease severity scores used in the field were converted into percentage values of leaf area covered with the disease and subsequently subject to arcsine transformation previous to statistical analyses. Back-transformed means are presented.

Table 13. Cucumber cultivars evaluated for reaction to foliar diseases in field trials in North Queensland.

Cultivar's name	Fruit colour / type	Seed Company
Camelot	Dark green / Slicing	Terranova
Aladdin	Green / Lebanese	South Pacific Seeds
Gremlin	Dark green / Slicing	South Pacific Seeds
Stonewall	Dark green / Slicing	Clause
HMX4453	Dark green / Slicing	Clause
Diamante	Dark green / Slicing	Clause
Crystal Salad	White-Cream / oval	South Pacific Seeds

Table 14. Disease severity scores used to assess disease severity on plant leaves in the field plots and their percentages of leaf area covered with downy mildew or anthracnose symptoms. Cards with images of leaves at different disease severity levels were prepared and used to assess severity on field plots.

Disease severity scores	Percentage of leaf area with symptoms (%)
0	0
1	0.3 - 4.7
2	5 - 9.7
3	10 - 29.7
4	30 - 74.7 and some leaf necrosis
5	75 - 100 and extended leaf necrosis

Results and Discussion

The cultivar used as control, Crystal Salad, was very susceptible to downy mildew and had the lowest fruit yield (Tables 15 and 16). Plants of this cultivar became infected soon after planting in both trials (Figure 15).

In the first trial, Camelot, Stonewall, Diamante, and Aladdin had low reactions to downy mildew but Aladdin, followed by Camelot also had low reactions to anthracnose (Table 15). High anthracnose severity levels were measured in HMX4453, Gremlin and Diamante. Total fruit yields were greater in Aladdin than Gremlin with intermediate yield values with the other cultivars (Table 15). In the second trial, Aladdin was the cultivar with the lowest reaction to anthracnose (Table 16). Yields were high in all cultivars but HMX4453 and Crystal Salad (Table 16). Images of canopies of the plants seventy days after planting are presented in Figure 16. Aladdin is a Lebanese fruit type for field production, so it is a different type and smaller size of fruit than the other slicing type cultivars.

Table 15. Downy mildew and anthracnose severities over time (6 June to 17 June) and fruit yield in seven cucumber cultivars planted in Ayr on 29 April 2008.

	Downy mildew [z]	Anthracnose	Fruit yield [w]		
Cultivar	AUDPC [y] (%-days)	AUDPC (%-days)	(t/ha)	(No. x 1000/ha)	(g/fruit)
Camelot	18 d	207 bcd	35.6 ab	197 b	181 a
Aladdin	47 cd	123 d	39.3 a	278 a	143 b
Gremlin	119 b	392 ab	32.4 b	188 b	175 a
Stonewall	30 d	371 abc	32.9 ab	190 b	173 a
HMX4453	99 bc	511 a	32.9 ab	184 b	178 a
Diamante	23 d	387 ab	34.1 ab	185 b	185 a
Crystal Salad	908 a	163 cd	11.6 c	96 c	121 c
P-value	*0.001*	*0.001*	*0.001*	*0.001*	*0.001*

[z] Analysis of variance (ANOVA) performed on data. Means followed by the same letter within a column are not significantly different from each other (Fisher's protected least significant difference, α = 0.05).
[y] Area under Disease Progress Curve (AUDPC) calculated for the period 6 June to 17 June.
[w] Yield per ha calculated for a full area cropped (11,962 plants/ha) with no drive ways.

Table 16. Severity of downy mildew and anthracnose on 1 September in seven cucumber cultivars planted in Ayr on 6 July 2008.

	Downy mildew severity (%) [z, y]	Anthracnose severity (%)	Fruit yield [w]		
Cultivar	1 Sept 08	1 Sept 08	(t/ha)	(No.×1000/ha)	(g/fruit)
Camelot	7.8 b	13.6 bc	34.0 a	153 a	224 a
Aladdin	8.5 b	2.4 d	30.2 a	169 a	179 b
Gremlin	6.9 b	10.4 c	27.6 ab	130 ab	212 a
Stonewall	8.8 b	16.7 abc	29.0 ab	135 a	216 a
HMX4453	6.8 b	19.2 ab	21.6 b	94 bc	230 a
Diamante	10.5 b	16.4 abc	29.8 a	139 a	213 a
Crystal Salad	30.9 a	23.9 a	5.9 c	56 c	106 c
P-value	*0.001*	*0.011*	*0.001*	*0.001*	*0.001*

[z] Analysis of variance (ANOVA) performed on data. Means followed by the same letter within a column are not significantly different from each other (Fisher's protected least significant difference, α = 0.05).
[y] Arc-sin transformation was used for percentage data prior to analysis. Back-transformed means are presented.
[w] Yield per ha calculated for a full area cropped (11,962 plants/ha) with no drive ways.

Figure 15. Cucumber cultivar Crystal Salad (right) presented high downy mildew severity compared to cultivar Camelot (right) when they were grown without fungicides in Ayr in 2008.

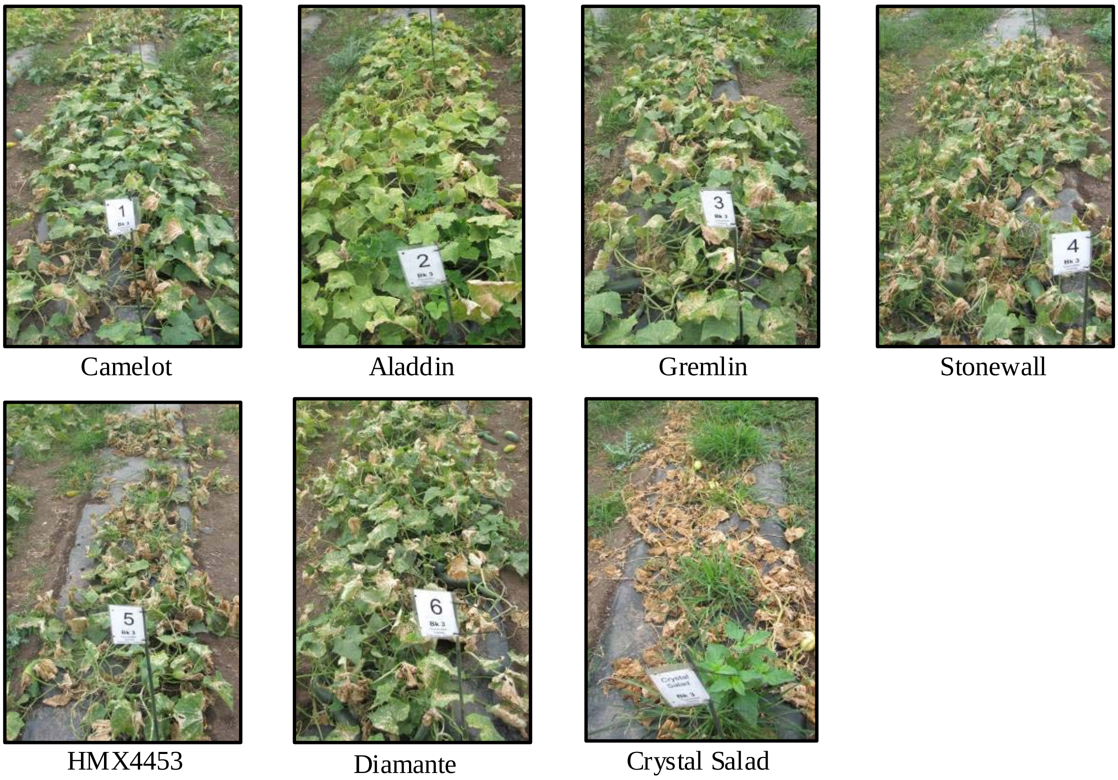

Figure 16. Canopies of cucumber cultivars grown without fungicides 70 days after they were transplanted in Ayr on 29 April 2008.

Combined effects of downy mildew and anthracnose in cucumber cultivars

Cultivars were plotted in Figure 17 according to their reactions to anthracnose and downy mildew using data (AUDPC) gathered in two trials at Ayr. When searching for cultivars with low reaction to foliar diseases, differences among cultivars were greater with anthracnose than with downy mildew.

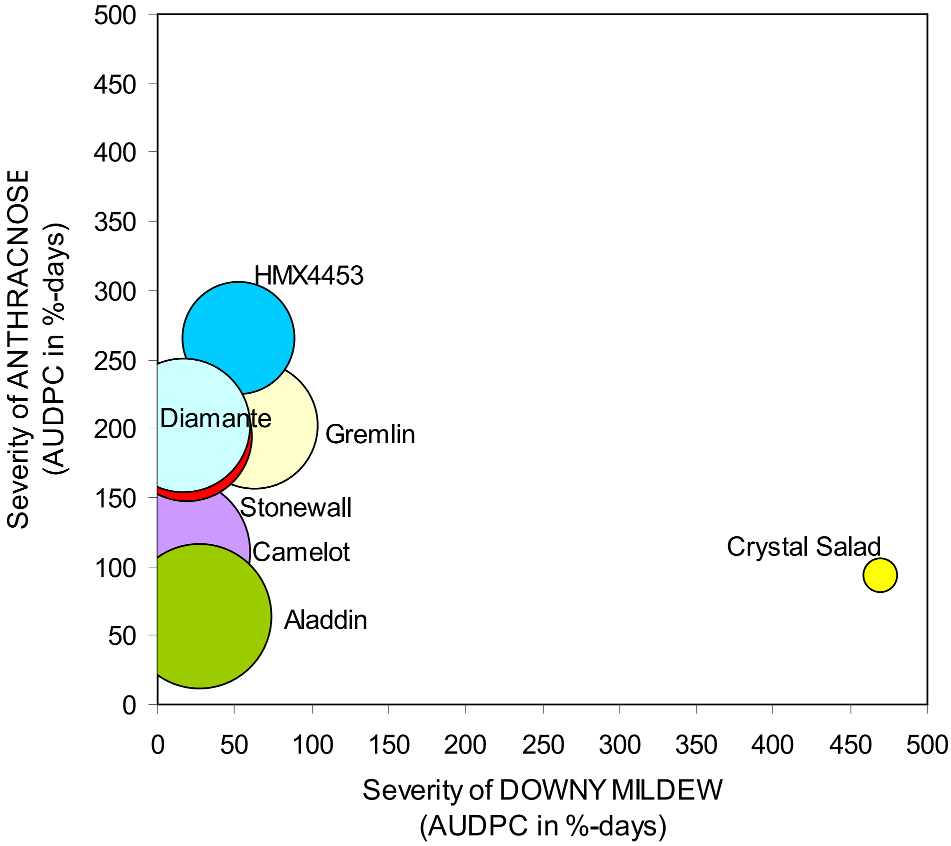

Figure 17. Reactions to anthracnose and downy mildew in 7 cucumber cultivars combining results from two field trials conducted in Ayr 2008, one planted on 29 April and the other planted on 6 July. Diameter of the circles is proportional to total fruit yield. Crystal Salad was severely affected by downy mildew early in the two crops, thus it was difficult to assess reactions to anthracnose.

Tolerance of foliar diseases in squash

Introduction

The main objective of these studies was to evaluate the reaction to powdery mildew and downy mildew in a range of squash cultivars available and grown across tropical locations in north Queensland.

Materials and Methods

Four squash cultivars of different fruit types (Table 17 and Figure 18) were evaluated for resistance to natural infection by powdery mildew and downy mildew in two trials at the DEEDI Ayr Research Station, in Ayr. In an alluvial soil, field plots with eight plants per plot were arranged in a randomized complete block design with four replications. Three week old seedlings with three unfolded leaves were transplanted on 29 April and on 15 June 2008 into drip-irrigated (2 L/m/h) raised beds covered with black polyethylene mulch. Bed rows were 1.52 m from each other and plants were 0.55 m apart within bed rows. Pre-plant fertilizer (N-P-K, 13-15-13 at 4 kg/100 m row) was applied in two bands of the planting beds. After flowering, fertilizers applied through drip irrigation included potassium nitrate (three applications at 0.6 kg/100 m of row) alternated weekly with calcium nitrate (two applications at 0.5 kg/100 m of row). Plots were irrigated as needed, with water delivered two to four times per week for irrigation periods that ranged from 2 to 4 h. No fungicides were applied. Weeds were managed with manual cultivation. Insecticide Confidor Guard, (14 mL/100 m of row) was drip-injected once after transplanting for controlling whitefly [*Bemisia* spp. (Hemiptera: Aleyrodidae)] and cotton aphid [*Aphis gossypii* Glover (Homoptera: Aphididae)]. In each plot, disease severity was assessed in eight plants on the adaxial and abaxial leaf surfaces of two leaves in the upper plant canopy, and on two leaves in the lower plant canopy, on 27 June, in the crop planted in April, and on 8 Sept, in the crop planted in June. Each selected leaf was assigned a disease severity score based on the percentage of leaf surface covered with powdery mildew colonies and of downy mildew leaf spots (Table 18). Weight and number of harvested fruits were recorded. Disease severity data were analysed with analysis of variance using GENSTAT software. Disease severity scores used in the field were converted into percentage values of leaf area covered with the disease and subsequently subject to arcsine transformation previous to statistical analyses. Back-transformed means are presented.

Table 17. Squash cultivars evaluated for reaction to foliar diseases in field trials in North Queensland.

Cultivar's name	Fruit colour / type	Seed Company
Sunburst	yellow / scallop or pattypan	Terranova
Delica	light to dark / green round	Terranova
Naches	light green / dumpling type	South Pacific Seeds
Cochise	light green / gem type	South Pacific Seeds

Figure 18. Fruit types of the squash cultivars evaluated in Ayr in 2008. Fruits of Delica could be harvested at different stages of maturity.

Table 18. Disease severity scores used to assess disease severity on plant leaves in the field plots and their percentages of leaf area covered with downy mildew or powdery mildew symptoms. Cards with images of leaves at different disease severity levels were prepared and used to assess severity on field plots.

Disease severity scores	Percentage of leaf area with symptoms (%)
0	0
1	0.3 - 4.7
2	5 - 9.7
3	10 - 29.7
4	30 - 74.7 and some leaf necrosis
5	75 - 100 and extended leaf necrosis

Results and Discussion

The severities of foliar diseases on squash plants at the end of the cropping period are presented in Table 19. Cultivars Cochise and Naches were less sensitive to powdery mildew than Delica and Sunburst. With downy mildew, the differences among cultivars for their reaction to the disease were smaller than with powdery mildew (Figure 19). Sunburst had slightly lower downy mildew severity than Naches.

Only Naches and Cochise had similar fruit types. Fruit yields are presented in Table 19. Plants of cultivar Delica grew much like a pumpkin plant and it would probably perform better using wider distances between plants or rows. Fruits of Delica could be harvested at different stages of maturity and were still tender when they reached a dark-green colour.

Table 19. Powdery mildew and downy mildew severities in four squash cultivars grown in Ayr in 2008.

Cultivar	Disease severity as percentage of leaf area covered with lesions (%)		Fruit yield		
	Powdery mildew	Downy mildew	t/ha	no.x1000/ha	g/fruit
Planting 29 April					
Sunburst	27.6 ab	46.9 b	17.4 a	160 a	108
Delica	43.4 a	39.1 b	na	na	na
Naches	6.8 c	72.2 a	14.8 ab	124 b	121
Cochise	16.2 bc	72.2 a	12.9 b	95 c	136
P-value	*0.007*	*0.001*	*0.014*	*0.003*	*0.05*
Planting 15 June					
Sunburst	52.1 a	32.6 b	15.7	117 a	132 b
Delica	53.7 a	45.6 a	10.0	28 c	342 b
Naches	6.8 b	40.6 a	15.0	95 ab	159 b
Cochise	6.7 b	32.2 b	13.2	86 b	155 a
P-value	*0.001*	*0.002*	*0.108*	*0.001*	*0.001*

Disease severity assessments were done on 27 June, in the crop planted in April, and on 8 Sept, in the crop planted in June.

Analysis of variance (ANOVA) performed on data. Means followed by the same letter within a column are not significantly different from each other (Fisher's protected least significant difference, α = 0.05).

Arc-sin transformation was used for percentage data prior to analysis. Back-transformed means are presented.

na: Fruit yield in Delica was not measured in the first planting.

Combined effects of downy mildew and powdery mildew in squash cultivars

Cultivars were plotted in Figure 19 according to their reactions to powdery mildew and downy mildew using data (%) gathered in two trials at Ayr.

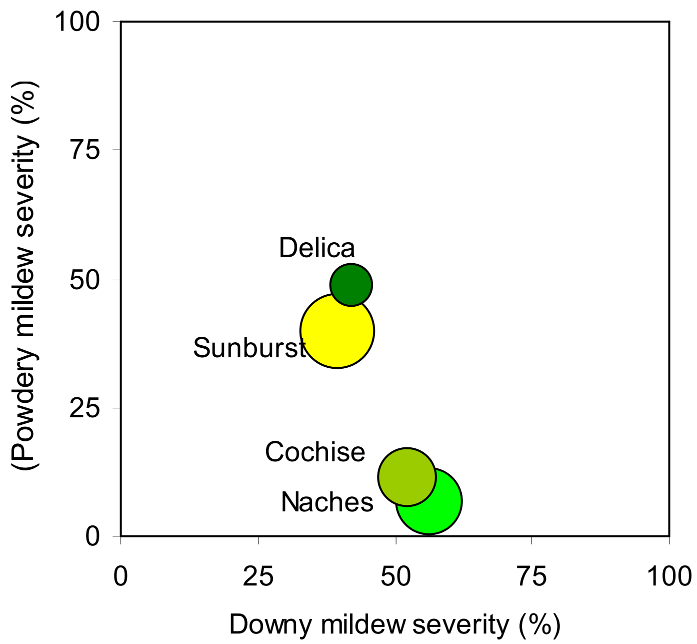

Figure 19. Reactions to powdery mildew and downy mildew in four squash cultivars combining results from two field trials conducted in Ayr in 2008. Disease severity is percentage of leaf area covered with disease symptoms. Diameter of the circles is proportional to total fruit yield.

Tolerance to foliar diseases in pumpkin

Introduction

The main objective of these studies was to evaluate the reaction to downy mildew and powdery mildew in a range of pumpkin cultivars available and grown across tropical locations in north Queensland.

Materials and Methods

Nine pumpkin cultivars of different fruit types (Table 20) were evaluated for resistance to natural infection by powdery mildew and downy mildew in three field trials conducted in Ayr and Bowen. Field plots with six plants per plot were arranged in a randomized complete block design with four replications. Three week old seedlings with three unfolded leaves were transplanted, on 29 April and 2 July in Ayr and 19 June in Bowen, into drip-irrigated (2 L/m/h) raised beds covered with black polyethylene mulch. Bed rows were 3.04 m from each other and plants were 1.0 m apart within bed rows. Pre-plant fertilizer (N-P-K, 13-15-13 at 4 kg/100 m row) was applied in two bands of the planting beds. After flowering, fertilizers applied through drip irrigation included potassium nitrate (three applications at 0.6 kg/100 m of row) alternated weekly with calcium nitrate (two applications at 0.5 kg/100 m of row), and one final application of potassium sulphate (0.2 kg/100 m of row). Plots were irrigated as needed, with water delivered two to three times per week for irrigation periods that ranged from 2 to 4 h. No fungicides were applied. Weeds were managed with Roundup (a.i. glyphosate; product dilution rate 7 mL/L), applied as a directed shielded spray in the area between plots during the early part of the season, and with manual cultivation in the later part of the season. Insecticide Confidor Guard, (a.i. imidacloprid; product application rate: 14 mL/100 m of row) was drip-injected once after transplanting for controlling whitefly [*Bemisia* spp. (Hemiptera: Aleyrodidae)] and cotton aphid [*Aphis gossypii* Glover (Homoptera: Aphididae)]. In each plot, disease severity was assessed on 8 leaves of four plants (Table 21). Two runner shoots were randomly selected in each plant and disease severity was assessed on the lower surfaces of the leaves located at leaf node number 8, counting from the youngest fully expanded leaf near the shoot tip. Each selected leaf was assigned a disease severity score based on the percentage of leaf surface covered with powdery mildew colonies and of downy mildew leaf spots. The disease intensity over time (area under the disease-progress curve or AUDPC) was calculated as AUDPC = $\Sigma([(x_i+x_{i-1})/2](t_i-t_{i-1}))$ where x_i was the rating at each evaluation time and (t_i-t_{i-1}) was the time between evaluations. Weight and number of harvested fruits were recorded. Fruit yield and disease severity data were analysed with analysis of variance using GENSTAT. Disease severity scores used in the field were converted into percentage values of leaf area covered with the disease and subsequently subject to arcsine transformation previous to statistical analyses. Back-transformed means are presented.

Results are presented for the planting in Bowen where both, downy mildew and powdery mildew, were present. Plantings in Ayr were mostly affected by downy mildew. In Bowen, disease severity was assessed on 20 Aug, 27 Aug and 11 Sep. Fruits were harvested on 14 Oct. Mean high and low temperatures (ºC) during the crop growing period in Bowen were 25.5/12.0 in June, 24.3/12.6 in July, 25.1/11.3 in Aug, 28.4/16.8 in Sep, and 30.3/19.9 in Oct, respectively. Rainfall (mm) was 0, 105, 0.4, 10.4, and 2.0 for the latter months, respectively.

Table 20. Pumpkin cultivars evaluated for reaction to foliar diseases in field trials in North Queensland.

Cultivar's name	**Fruit type**	**Seed Company**
Sampson	Grey	Terranova
183-6	Grey	South Pacific Seeds
188-6	Grey	South Pacific Seeds
Early Jarragrey	Grey	Clause
Royal Grey	Grey	Clause
Kens Special 864	Japanese	South Pacific Seeds
Kens Special	Japanese	South Pacific Seeds
Dynamite	Japanese	Clause
TNT	Butternut	Clause

Table 21. Disease severity scores used to assess disease severity on plant leaves in the field plots and their percentages of leaf area covered with downy mildew or powdery mildew symptoms. Cards with images of leaves at different disease severity levels were prepared and used to assess severity on field plots.

Disease severity scores	Percentage of leaf area with symptoms (%)
0	0
1	0.3 - 4.7
2	5 - 9.7
3	10 - 29.7
4	30 - 74.7 and some leaf necrosis
5	75 - 100 and extended leaf necrosis

Results and Discussion

Planting 15 June 2008 in Bowen

Powdery mildew was first observed on cotyledons and first leaves on 16 July. During Aug and Sep, disease severity was minimal on the upper leaf surface but increased on the lower leaf surfaces in all cultivars with the exception of the three Japanese fruit cultivars. On 20 Aug, the greatest disease severity values among all cultivars were in the grey fruit cultivars Royal Grey and 183-6 (28% on average). At 89 days after transplanting (11 Sep), the three Japanese fruit cultivars had values of AUPDC that were not significantly different among each other and that were the lowest AUDPC values among all the evaluated cultivars. Royal Grey and 183-6 had the highest disease severity based on AUDPC values among the nine cultivars tested. Based on AUDPC values, Royal Grey and 183-6 (average 1058 %-days) had twice the disease severity average of grey fruit cultivars Sampson, 188-6, and Early Jaragrey (average 510 %-days). Nevertheless, yields in weight and number of fruit of Royal Grey and 183-6 were comparable to grey fruit cultivars Sampson and 188-6. Early Jarragrey had disease severity based on AUDPC values that were comparable to those in Sampson and 188-6. However, Early Jarragrey had the lowest fruit yield in weight among the grey fruit cultivars. The heaviest fruits were those of the grey fruit cultivar 188-6 (6.2 kg) and the lightest were from the butternut cultivar TNT (1.3 kg). Among Japanese cultivars, fruit weights were not significantly different from each other (average 2.0 kg). Fruit quality (cosmetic appearance of fruit) was not affected by powdery mildew.

Cultivars were affected similarly by downy mildew severity over the time of disease assessment (Table 23). When disease was assessed on 11 September, the lowest disease severity was measured in the Japanese type Ken Special and the highest in the grey cultivar 188-6 (Table 23). Images of the fruit types in the cultivars evaluated are presented in Figure 20.

Table 22. Powdery mildew severity and fruit yield in nine pumpkin cultivars grown in Bowen, Qld. in 2008.

		Powdery mildew severity[z]						
		Percentage of area covered on lower leaf surface (%)[y]			AUDPC[w]	Fruit yield[z, x]		
Cultivar	Fruit type	20-Aug	27-Aug	11-Sept	(%-days)	(kg/fruit)	(No.×1000/ha)	(t/ha)
Sampson	Grey	8.3 bc	6.5bcd	48.2 ab	462 c	4.8 b	6.7 cd	32.3 ab
183-6	Grey	25.8 a	33.3 a	73.6 a	1009 a	4.8 b	7.4 bc	36.1 a
188-6	Grey	9.2 bc	10.8 bc	55.9 ab	570 bc	6.2 a	5.2 d	32.3 ab
Early Jarragrey[t]	Grey	9.2 bc	15.9 b	38.7 b	497 bc	3.8 c	6.2 cd	22.7 c
Royal Grey	Grey	29.7 a	42.2 a	71.7 a	1106 a	3.2 d	9.6 a	30.5 b
Kens Spec. 864	Jap	1.6 d	1.2 d	1.4 c	29 d	1.9 e	10.9 a	21.1 c
Kens Special	Jap	3.0 cd	1.1 d	2.0 c	38 d	2.0 e	9.9 a	20.3 c
Dynamite	Jap	4.6bcd	3.0 cd	4.1 c	80 d	2.1 e	9.4 ab	19.9 c
TNT	Butternut	10.4 b	16.3 b	70.3 a	743 b	1.3 f	9.1 ab	11.7 d
P-value		<.001	<.001	<.001	<.001	<.001	<.001	<.001

[z] Analysis of variance (ANOVA) performed on data. Means followed by the same letter within a column are not significantly different from each other (Fisher's protected least significant difference, α = 0.05).
[y] Arc-sin square root transformation was used for percentage data prior to analysis. Back-transformed means are presented.
[w] Area under disease progress curve (AUDPC) calculated for disease severity assessed 20 Aug, 27 Aug, and 11 Sep.
[x] Yield per ha calculated for a full area cropped (3,290 plants/ha) with no drive ways.

Table 23. Downy mildew severity and fruit yield in nine pumpkin cultivars grown in Bowen, Qld. in 2008.

		Downy mildew severity[z]			
		Percentage of area covered on lower leaf surface (%)[y]			AUDPC[w]
Cultivar	Fruit type	20-Aug	27-Aug	11-Sept	(%-days)
Sampson	Grey	16.1	10.8	33.5 ab	426
183-6	Grey	15.3	23.3	20.1 bcd	461
188-6	Grey	10.7	17.3	39.8 a	526
Early Jarragrey	Grey	31.3	20.0	30.3 abc	557
Royal Grey	Grey	31.3	10.9	28.2 abc	441
Kens Special 864	Japanese	13.3	6.3	22.8 bcd	287
Kens Special	Japanese	27.0	7.8	12.9 d	277
Dynamite	Japanese	19.1	10.3	18.6 cd	320
TNT[t]	Butternut	43.6	10.7	19.2 cd	414
P-value		*0.246*	*0.058*	*0.008*	*0.143*

[z] Analysis of variance (ANOVA) performed on data. Means followed by the same letter within a column are not significantly different from each other (Fisher's protected least significant difference, α = 0.05).
[y] Arc-sin square root transformation was used for percentage data prior to analysis. Back-transformed means are presented.
[w] Area under disease progress curve (AUDPC) calculated for disease severity assessed 20 Aug, 27 Aug, and 11 Sep.
[x] Yield per ha calculated for a full area cropped (3,290 plants/ha) with no drive ways.

Figure 20. Fruits in pumpkin cultivars that were evaluated for their reaction to powdery mildew and downy mildew in 2008.

Combined effects of downy mildew and powdery mildew in pumpkin cultivars

Cultivars were plotted in Figure 21 according to their reactions to powdery mildew and downy mildew using data (AUDPC) gathered in a trial at Bowen.

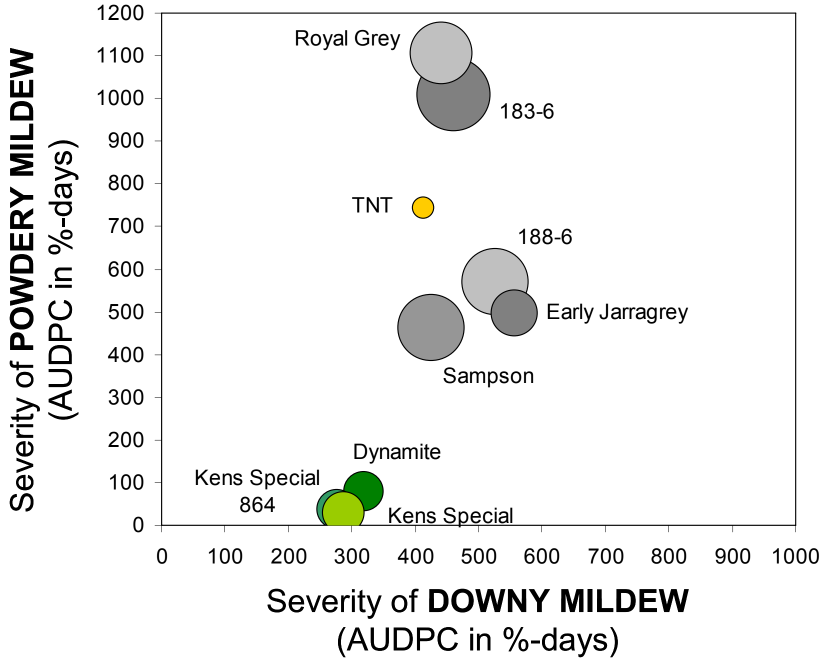

Figure 21. Severity of powdery mildew and downy mildew over time (AUDPC) in pumpkin cultivars grown in Bowen in 2008 (Planting 19 June). Diameter of the circles is proportional to the fruit yield in weight.

Relative reaction of cucurbit cultivars to foliar diseases in field trials conducted in North Qld. in 2008

The tested cucurbit cultivars were grouped as moderate resistant to the disease, sensitive to the disease, and highly sensitive to the disease, according to results from field trials (Table 24).

Table 24. Relative reaction of cucurbit cultivars to foliar diseases in field trials conducted in North Qld. in 2008

	Downy mildew	Powdery mildew	Anthracnose
Zucchini			
Amanda	●	●●	--
Calida	●	●●	--
CLX29881	●●	●●●	--
HMX5702	●	●	--
Golden Rod	●●	●	--
Zest	●●	●●	--
7708	●	●	--
Houdini	●	●	--
Paydirt	●	●●●	--
Crowbar	●	●●●	--
Caroline	●	●●●	--
582-6 (Nitro)	●●	●●●	--
Congo	●	●	--
Squash			
Sunburst	●●	●●	--
Delica	●●	●●	--
Naches	●●	●●●	--
Cochise	●●	●●●	--
Pumpkin			
Sampson	●	●●	--
183-6	●	●	--
188-6	●	●	--
Early Jarragrey	●	●	--
Royal Grey	●	●	--
Kens Special 864	●●	●●●	--
Kens Special	●●	●●●	--
Dynamite	●	●●●	--
TNT	●	●	--
Cucumber			
Camelot	●●●	--	●●●
Aladdin	●●●	--	●●●
Gremlin	●●	--	●
Stonewall	●●●	--	●
HMX4453	●●●	--	●
Diamante	●●	--	●
Crystal Salad	●	--	●

Within cucurbit species, the relative reaction of the cultivar to the disease was established using information from trials conducted in Ayr and Bowen in 2008. ●●● Moderate resistant to the disease; ●● Sensitive to the disease; ● Highly sensitive to the disease. -- Disease was either present at very low levels on plants or symptoms appeared at the time the crop was terminated.

Products alternative to fungicides for managing foliar diseases

Summary

Management of foliar diseases of cucurbits depends largely on the use of fungicide sprays. This could be costly and unsustainable when resistance from the target pathogens develops from excessive use. Reducing the number of seasonal systemic sprays to a minimum should delay the development of resistance from the different fungal strains and thereby prolong the effective life of the fungicides. This can be done with fungicide alternatives. The efficacies of 14 fungicide alternatives, sprayed weekly on field-grown zucchini and cucumber cultivars were evaluated for the control of powdery mildew (*Podosphaera xanthii*), downy mildew (*Pseudoperonospora cubensis*) and anthracnose (*Colletotrichum orbiculare*) in four field trials in northern Queensland. Control plots were either not sprayed, sprayed with water, or sprayed with conventional fungicides with systemic and contact actions. Tested products included: micronized sulphur (Microthiol Disperss®); copper octanoate (Tricop®); potassium bicarbonate (Ecocarb®); phosphorus acid (Agri-Fos 600®); hydrogen dioxide (Peratec®); soluble silicon (Enhance KCS® and Stand SKH®); neem oil (Trilogy®); canola oil (Synertrol Horti oil®); tea tree oil (Timorex Gold®); acibenzolar-s-methyl (Bion® or Actigard®); chitosan (Aminogro®); milk, and propylene glycol alginate (Cal Agri 50NF®). Downy and powdery mildews were the main diseases on both crops and anthracnose was also present on cucumbers. Tricop, Microthiol, Bion and Agri-Fos 600 provided acceptable downy mildew control; however Microthiol and Bion caused phytotoxicity in cucumbers. Tricop, Microthiol, Stand SHK, milk, Timorex, Synertrol Horti Oil, Agri-Fos 600, Ecocarb and Aminogro provided acceptable control of powdery mildew. Although some of these alternative products used alone in a //weekly spray program were not as effective as conventional fungicides for suppressing the target foliar diseases, they provided a degree of control that should make them good components in an integrated disease management program that includes a reduced number of systemic fungicide applications.

Four trials were carried out in Ayr and Bowen (Table 25) to evaluate the effectiveness of alternative products to conventional fungicides in zucchini and cucumber (Tables 26 and 27). These products were tested with weekly applications of the same active ingredient in order to assess their relative efficacy for controlling the different foliar diseases. However, it is not expected that these products would be used alone but in combination with other alternative products and with conventional systemic and contact fungicides kept to a minimum number of sprays. Control plots were either not sprayed, sprayed with water, or sprayed with conventional fungicides with systemic and contact actions (Table 28).

Table 25. Trials carried out in Ayr and Bowen to evaluate the effectiveness of selected spray products alternative to conventional fungicides in the management of powdery mildew, downy mildew and anthracnose.

Cucurbit	Trial Location	Planting date	Number of spray treatments
Zucchini	Ayr	4 June	14 + controls
	Bowen	6 July	14 + controls
Cucumber	Ayr	29 June	8 + controls
	Ayr	5 August	8 + controls

Control treatments were plants that were not sprayed, sprayed with water, and plants sprayed with a program that included conventional fungicides.

Table 26. Selected products alternative to conventional fungicides and spray rates used in zucchini and cucumber field trials in Ayr and Bowen in 2009.

Active Constituent	Formulation	Trade name of *tested* product	Manufacturer or distributor in AU	Rate per ha used (Volume 1000 L/ha 90-100 psi)	
Micronised sulfur	800 g/kg	Microthiol Disperss®	Nufarm	11.2	kg
Copper octanoate	18 g/L	Tricop®	Colin Campbell (Chemicals) Pty Ltd	10	L
Potassium bicarbonate		Ecocarb®	Organic Crop Protectants Pty Ltd	4	kg
Phosphorus acid	600 g/L	AgriFos-600®	Agrichem Mfg. Co.	3	L
Hydrogen peroxide + peroxyacetic acid	250g/L + 50g/L	Peratec®	Jaegar Australia Pty Ltd	10	L
NPK + S + Si + Ca	NPK 1.7-0-5 + 4.1% S + 11% Si + 7% Ca	Enhance KCS®	Agrichem Mfg. Co.	6	L
NPK + Si + humic acid	NPK 0-0-15 + 20% Silica + 1% humic acid	Stand SKH®	Agrichem Mfg. Co.	3	L
Neem oil		Trilogy®	Certis (USA)	10	L
Canola oil	850g/L	Synertrol-Horti-Oil	Organic Crop Protectants Pty Ltd	5	L
Green tee/tea tree (*Melaleuca alternifolia*) oil	23.8 % (w/w) oil	Timorex Gold®	Biomor Israel Ltd [distrib. by Colin Campbell (Chemicals) Pty Ltd]	8	L
Acibenzolar-s-methyl	500 g/L or g/kg	Bion® or Actigard®	Syngenta Crop Protection Pty Ltd	0.07	kg
Chitosan (trace elements + fish proteins)	30.7% (w/v) total solids	Aminogro®	Organic Crop Protectants Pty Ltd	10	L
Cow's milk	powder	Milk	food grade, commercial brands	15	kg
Propylene glycol alginate (hydrated)	28% (w/v)	Cal-Agri-50NF	Cal-Agri Products	4	L

Table 27. Effectiveness in reducing one or more foliar diseases in selected products alternative to conventional fungicides (information obtained from label or reports)

Active Constituent	Trade name of *tested* product	Claimed control of foliar disease in cucurbits		
		Powdery mildew	Downy mildew	Anthracnose
Micronised sulfur	*Microthiol Disperss*	●		
Copper octanoate	*Tricop*	●	●	●
Potassium bicarbonate	*Ecocarb*	●	●	●
Phosphorus acid	*AgriFos-600*		●	
Hydrogen dioxide	*Peratec*	●	●	●
Soluble silicon	*Enhance KCS*	●		
Soluble silicon	*Stand SKH*	●		
Neem oil	*Trilogy*	●	●	●
Canola oil	*Synertrol-Horti-Oil*	●	●	
Green tee oil	*Timorex Gold*	●	●	
Acibenzolar-s-methyl	*Bion*	●	●	
Chitosan	*Aminogro*	●	●	
Cow's milk (powder)	*Milk*	●		
Propylene glycol alginate	*Cal-Agri-50NF*	●		

Table 28. Main constituent ingredients and commercial products used in spray programs in 2010.

Week	Active ingredient	Formulation	Commercial product tested	Manufacturer or distributor in AU	Spray rate /ha
1 & 2	Dimethomorph + Mancozeb	500 g/L + 750 g/kg	Acrobat SC® + Mancozeb	BASF Australia Ltd Farmoz Pty Ltd	360 mL+ 1.6 kg
3	Mancozeb	750 g/kg	Mancozeb 750®	Farmoz Pty Ltd	1.6 kg
4	Bupirimate[y]	250 g/L	Nimrod®	Farmoz Pty Ltd	600 mL
5	Mancozeb	750 g/kg	Mancozeb 750®	Farmoz Pty Ltd	1.6 kg
6	Chlorotalonil	720 g/L	Bravo®	Syngenta Crop Protection Pty Ltd	2.5 L
5	Mancozeb	750 g/kg	Mancozeb 750®	Farmoz Pty Ltd	1.6 kg

In all trials, fungicides were applied using CO_2-pressurized sprayers with a 1-m boom that could attach 2 or 3 nozzles (Figure 22). During the crop season, the sprayer was calibrated to deliver different spray volumes (from 300 to 1000 L/ha) to achieve full leaf area coverage as plants grew in size. Spray pressures used were 620.5 (90 psi) and 689.5 kPa (100 psi) to ensure penetration of drops within the canopy and reaching the stem. Rates of active ingredients per hectare were kept constant during the season but width of spray band was increased as plant canopies became wider.

Figure 22. Trolley and backpack CO_2-pressurized sprayers used in 2009 (top left and right) and unit mounted on wheels (bottom left and right) used in 2010. The spray products were prepared in 1-L plastic bottles, which were attached to the header of sprayer before treating the 10-m^2 plots.

Efficacy of spray products alternatives to fungicides in zucchini

Introduction

The main objective of these studies was to evaluate the efficacy of spray products alternative to conventional fungicides on powdery mildew and downy mildew in a disease susceptible zucchini cultivar in north Queensland.

Materials and Methods

Fourteen foliar spray treatments were evaluated for their effectiveness in controlling powdery mildew and downy mildew in two eight-week-long zucchini crops of disease susceptible cultivar "Congo" planted in Ayr (4 June) and Bowen (6 July), in 2009. Plants of a disease sensitive cultivar "Congo" were sprayed weekly with the same alternative product during the entire crop period (Table 26). Control treatments were plots with plants that were not sprayed with fungicides, sprayed with water, or plants under a spray program that included conventional fungicides (Table 28). In an alluvial soil, experimental field plots with 10 plants per plot were arranged as a complete randomised design replicated in four blocks. In both planting dates, seedlings with three unfolded leaves were transplanted into drip-irrigated (2 L/m/h) raised beds covered with black polyethylene mulch. Bed rows were 1.52 m from each other and plants were 0.55 m apart within bed rows. Pre-plant fertilizer (N-P-K, 13-15-13 at 4 kg/100 m row) was applied in two bands of the planting beds. After flowering, fertilizers applied through drip irrigation included potassium nitrate (three applications at 0.6 kg/100 m of row) alternated weekly with calcium nitrate (two applications at 0.4 kg/100 m of row). Plots were irrigated as needed, with water delivered two to four times per week for irrigation periods that ranged from 2 to 4 h. Weeds were managed with Roundup (7 mL/L), applied as a directed shielded spray in the area between plots during the early part of the season, and with manual cultivation in the later part of the season. Insecticide Confidor Guard, (14 mL/100 m of row) was drip-injected once after transplanting for controlling whitefly [*Bemisia* spp. (Hemiptera: Aleyrodidae)] and cotton aphid [*Aphis gossypii* Glover (Homoptera: Aphididae)].

The spray rates were selected from product labels or were provided by the chemical companies (Table 26). The spray applications were done with a spray unit powered by pressurised CO_2. The spray boom could use one, two or three nozzles (low drift or cone). Nozzles were added as plants increased in size. The top and lateral nozzles in the spray boom directed the spray to the top and both lateral sides of the plant row, giving good spray coverage outside and inside the plant canopy. Spray calibrations were conducted to spray high volumes (up to 1000 L/ha) at high pressure (90 to 100 PSI [621 to 689 kPa]) on larger plants, in order to ensure that plant canopies were entirely wetted.

In each plot, disease severity was assessed in five plants on leaf surfaces of two leaves in the upper plant canopy, and on two leaves in the lower plant canopy. Each selected leaf was assigned a disease severity score based on the percentage of leaf surface covered with powdery mildew colonies and of downy mildew leaf spots (Table 29). The disease intensity over time (area under the disease-progress curve or AUDPC with %-days as units) was calculated as $AUDPC = \Sigma([(x_i+x_{i-1})/2](t_i-t_{i-1}))$ where x_i was the rating at each evaluation time and (t_i-t_{i-1}) was the time between evaluations. Fruits were harvested every two days and weight and number were recorded. Disease severity and fruit yield data were analysed with analysis of variance using GENSTAT software.

Table 29. Disease severity scores used to assess disease severity on plant leaves in the field plots and their percentages of leaf area covered with powdery mildew or downy mildew symptoms. Cards with images of leaves at different disease severity levels were prepared and used to assess severity on field plots.

Disease severity scores	Percentage of leaf area with symptoms (%)
0	0
1	0.3 - 4.7
2	5 - 9.7
3	10 - 29.7
4	30 - 74.7 and some leaf necrosis
5	75 - 100 and extended leaf necrosis

Results and Discussion

In the zucchini crop planted in Ayr in 4 June 2009, severity of powdery mildew in zucchini at the end of the crop was at low levels (<20%) in plants that had weekly sprays of either micronized sulphur (Microthiol) or Tricop (Figure 23). Milk and Stand SKH were also effective but led to severity levels between 30 and 40%. A group of products with similar efficacies (all leading to values close to 50% of disease severity) included the conventional fungicides, Enhance KCS, Cal Agri 50NF, Trilogy, and Bion. Higher disease severities (>50% but <70%) were measured in plants sprayed with either water, Timorex, Aminogro, Synertrol Horti oil, Ecocarb or Agri Fos 600. Unsprayed plants and plants sprayed with Peratec had powdery mildew severities greater than 70%.

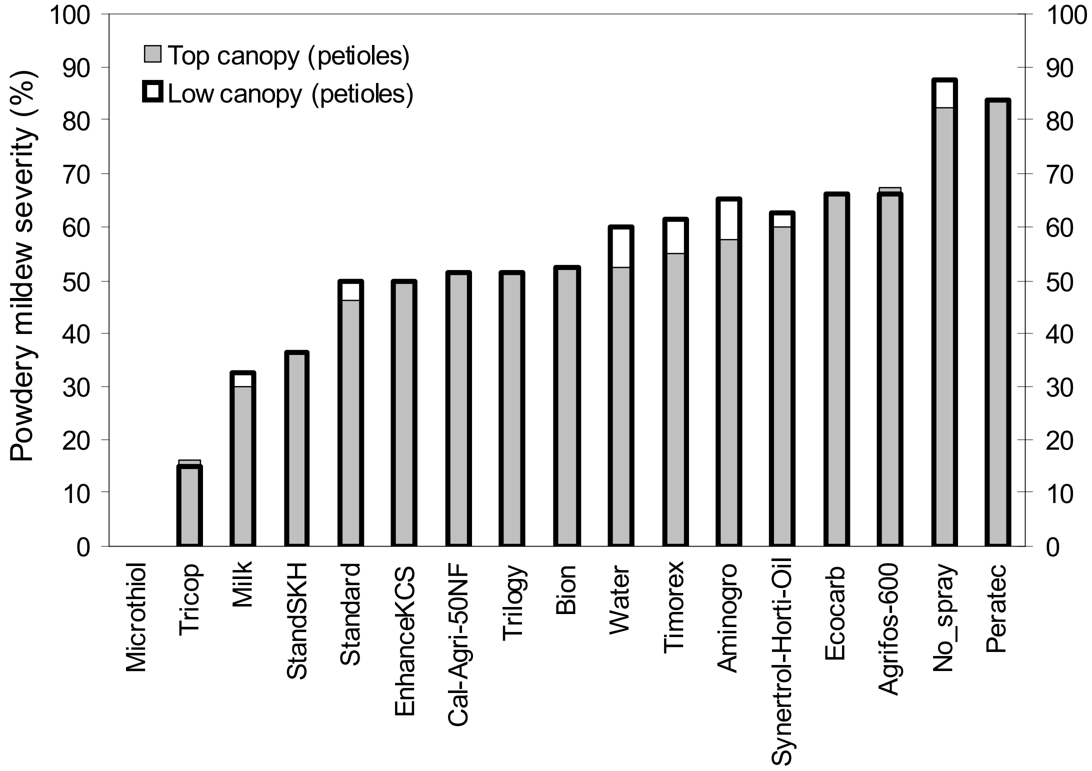

Figure 23. Efficacy of spray products on powdery mildew in "Congo" zucchini planted in Ayr in 4 June 2009. Single disease severity rating, top and low canopy leaves, at the end of the crop (12 Aug.).

Powdery mildew severity plotted in Figure 23 was also plotted with the downy mildew severity data and the total fruit yield (Figure 24). Products that had an effect in keeping downy mildew at levels lower than non sprayed plants were Bion, the conventional fungicides, Agri Fos 600, Microthiol, Tricop. The remaining products led to downy mildew severities that did not differ with severity in plants that were not sprayed. Tricop and Microthiol gave acceptable control of both diseases. Fruit yields were variable across treatments but slightly higher in plants treated with conventional fungicides or Microthiol.

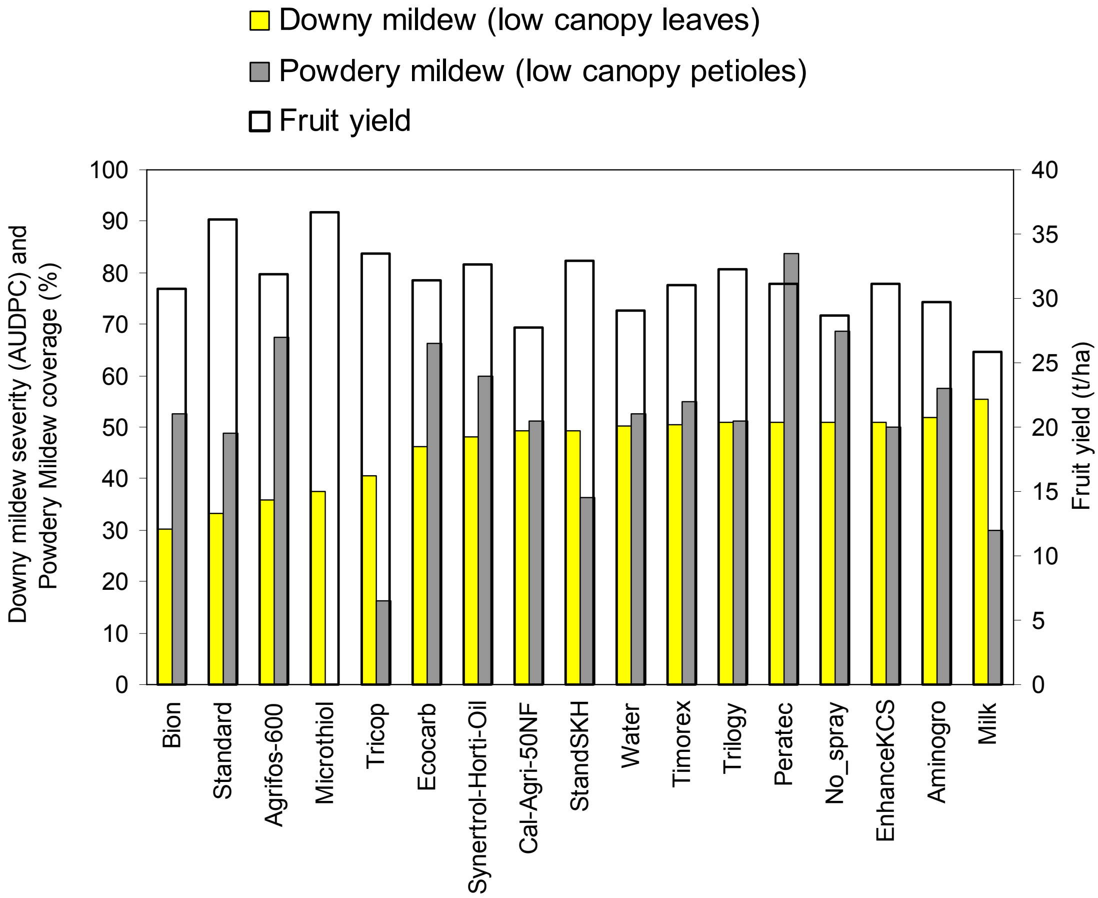

Figure 24. Efficacy of spray products on downy mildew and powdery mildew, and total fruit yield (16 harvests in a 5-week period) in "Congo" zucchini planted in Ayr in 4 June 2009.

Powdery mildew was the main disease in Bowen. The efficacies of alternative spray products were similar to those measured with the planting in Ayr. Microthiol was very effective controlling powdery mildew (Figure 25). Powdery mildew measured over time (AUDPC) was similar in plants treated with products such as Bion, Tricop, Trilogy, Milk, Timorex, Cal Agri 50NF, and Synertrol Horti-oil (Figure 25). In plants treated with Bion, we could not observe phytotoxicity (in the form of curled leaves or stunted plants) in zucchini. However, total fruit yields in plants treated with Bion were lower than in plants treated with conventional fungicides or in plants treated with sulphur (Figure 25).

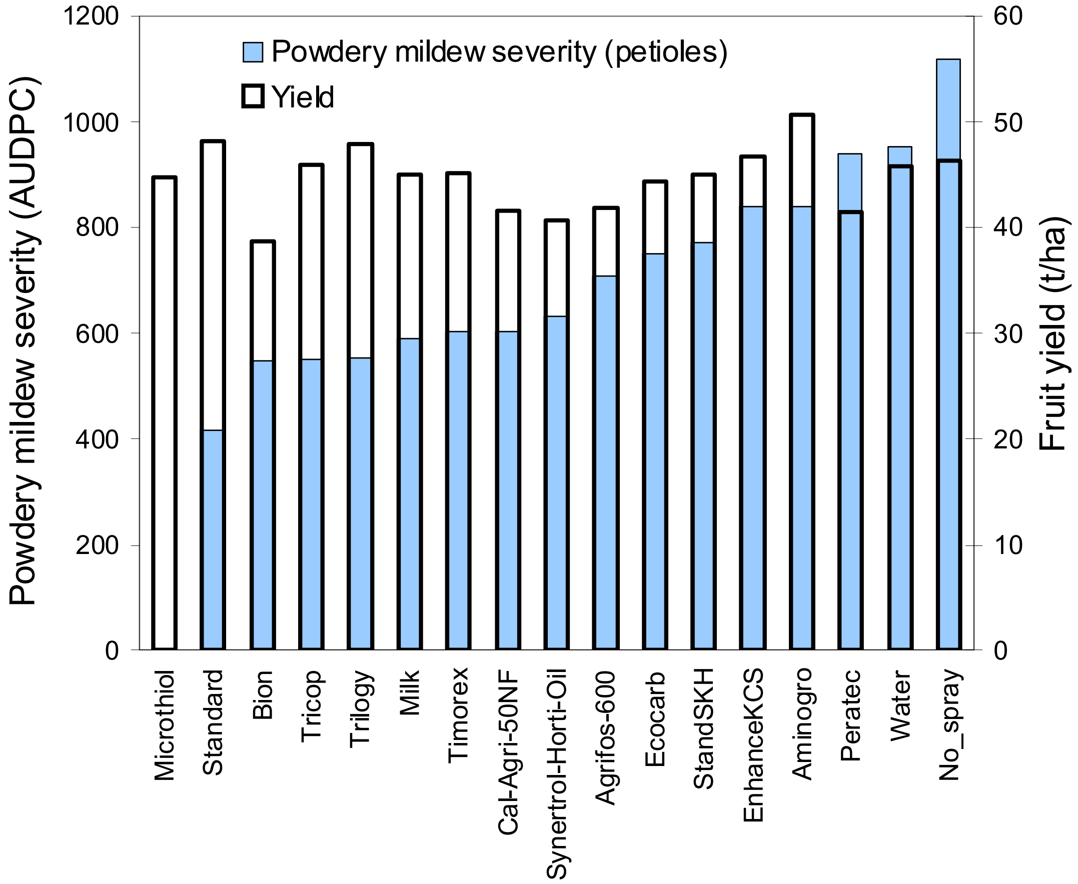

Figure 25. Efficacy of spray products on powdery mildew and total fruit yield (12 harvests in a 4-week period) in “Congo” zucchini planted in Bowen in 6 July 2009.

Efficacy of spray products alternatives to fungicides in cucumber

Introduction

The main objective of these studies was to evaluate the efficacy of spray products alternative to conventional fungicides on downy mildew and anthracnose in disease susceptible cucumber cultivars in north Queensland.

Materials and Methods

Two cucumber field trials were grown next to the trial with zucchinis in Ayr in 2009. Management practices were similar to those described for zucchini and disease assessment on leaves followed the same procedures described for cucumber cultivar trials grown in 2008. In the first trial Crystal Salad (a cultivar susceptible to downy mildew) was transplanted in June 29 and in the second trial, Gremlin, (a cultivar sensitive to anthracnose) was transplanted on 5 August.

Results and Discussion

In Crystal Salad, downy mildew was kept at low levels and yields were high in plants treated with conventional fungicides (Figure 26). Bion gave good control of the downy mildew but plants became stunted and did not produce fruits. Microthiol also reduced yield in cucumbers (Figures 26 and 27). Plants treated with Tricop had almost twice the downy mildew severity than plants sprayed with conventional fungicides; however total fruit yields were similar. Disease severity levels varied with other products and fruit yields were lower than in plants treated with conventional fungicides or Tricop (Figure 26).

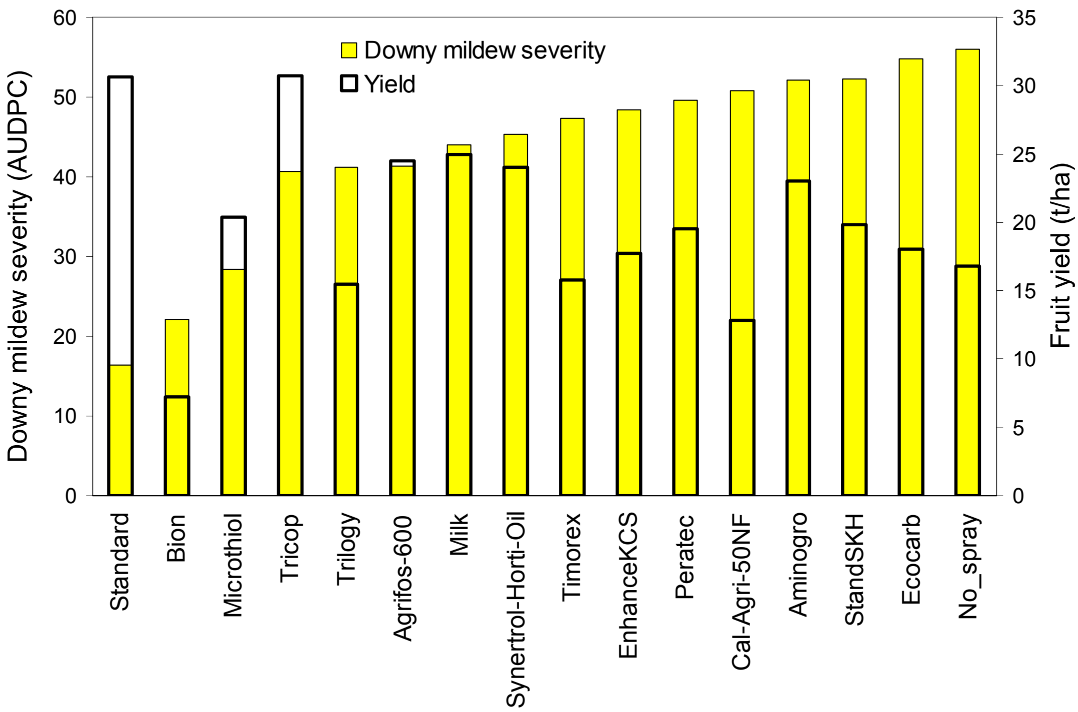

Figure 26. Efficacy of spray products on downy mildew over time and total fruit yield (9 harvests in a 4-week period) in "Crystal Salad" cucumber planted in Ayr in 29 June 2009.

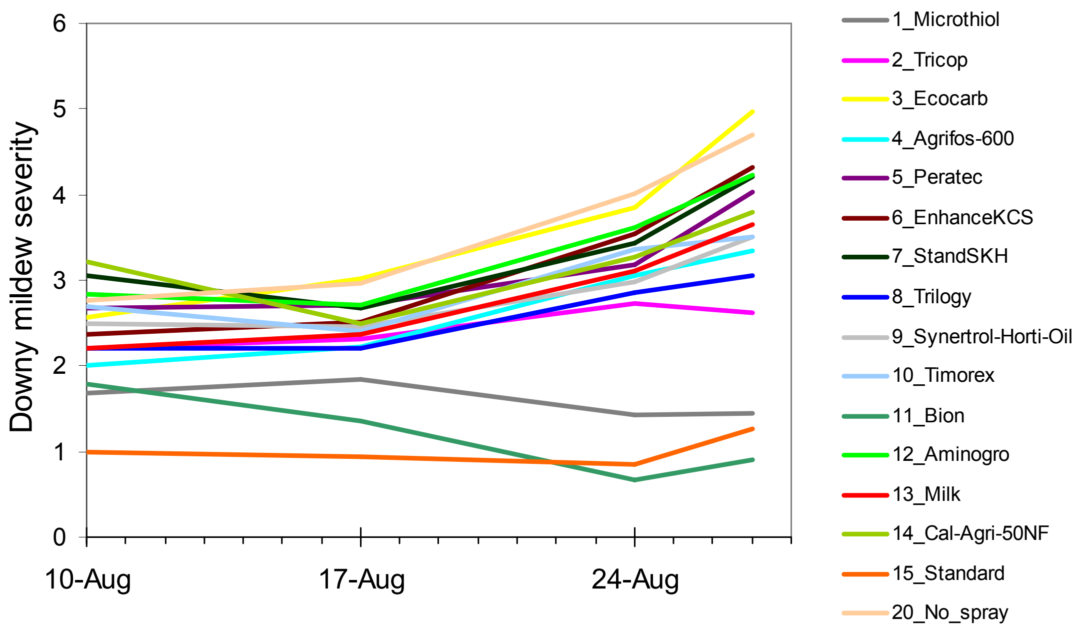

Figure 27. Downy mildew severity field scores in Crystal Salad cucumber grown in Ayr, Qld in 2009

With cultivar Gremlin, anthracnose severity was low in plants treated with conventional fungicides (Figures 28 and 29). Adequate control was also achieved with Tricop (Figures 28 and 29). Bion and Microthiol gave good control but negatively affected plant growth and fruit yields were low (Figure 28). Milk, Trilogy, Synertrol Horti-oil, Peratec and Timorex left plants with similar disease severity levels as plants that were not sprayed. Under the latter treatments, fruit yields were lower than in plants treated with conventional fungicides (Figure 28).

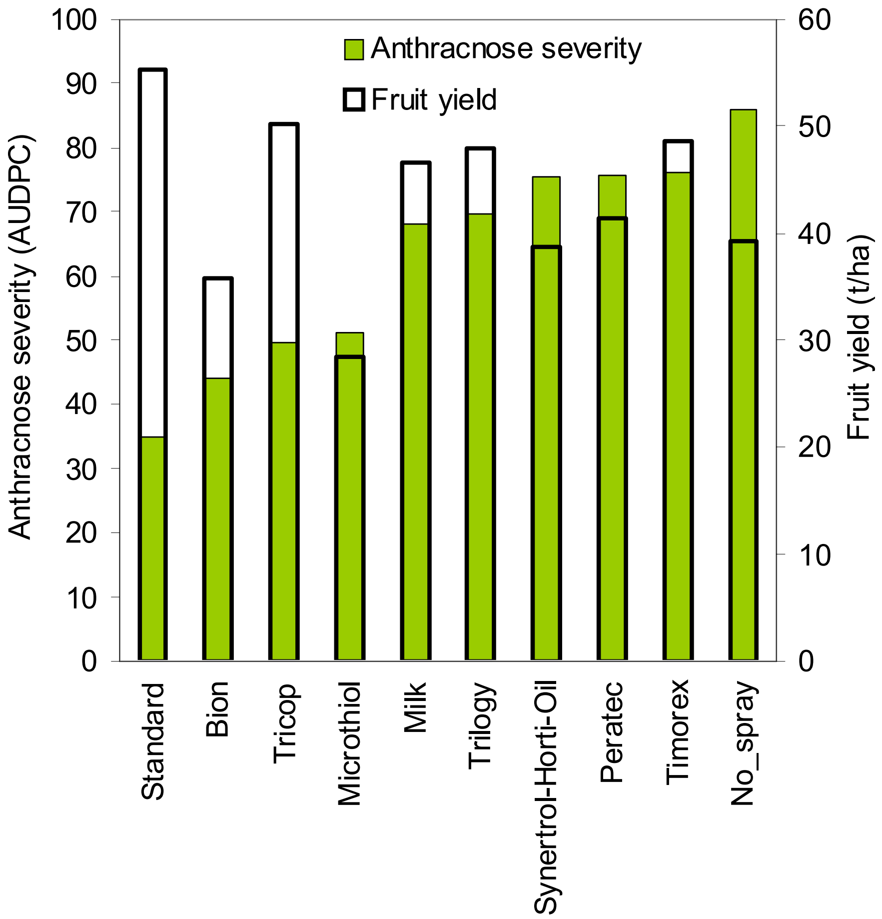

Figure 28. Efficacy of spray products on anthracnose and total fruit yield (12 harvests in a 5-week period) in "Gremlin" cucumber planted in Ayr in 5 August 2009.

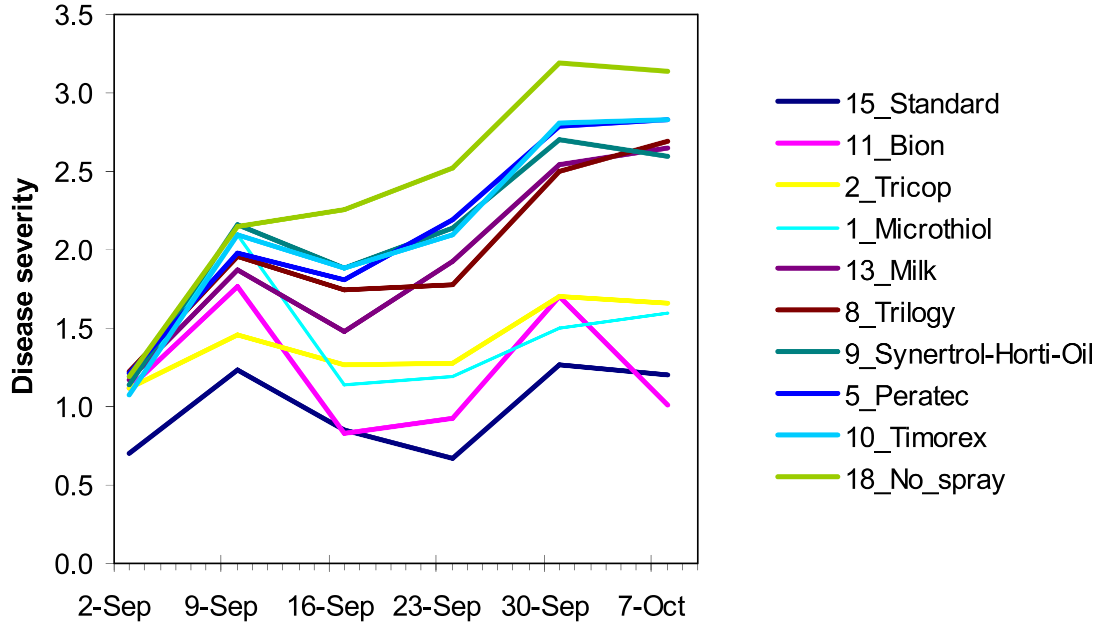

Figure 29. Anthracnose severity field scores in Gremlin cucumber grown in Ayr, Qld in 2009.

Relative effectiveness of spray products for controlling foliar diseases in cucumber and zucchini in North Qld. in 2009

The relative effectiveness of alternative spray products that could be used for managing foliar diseases in cucumber and zucchini are listed in Table 30. These products were evaluated at the spray rates indicated in Table 26 and in programs where the same active ingredient was sprayed at weekly intervals. Selected products are listed along with cultivars that showed moderate resistance to one or more foliar diseases in Table 31.

Table 30. Relative effectiveness of spray products for controlling foliar diseases in cucumber and zucchini in North Qld. in 2009

	Cucumber		**Zucchini**	
	Downy mildew	**Anthracnose**	**Downy mildew**	**Powdery mildew**
Bion	●●● Ph/Yr	●●● Ph/Yr	●●● Yr	●● Yr
Microthiol	●●● Yr	●●● Yr	●●●	●●●
Tricop	●●	●●●	●●	●●●
Trilogy	●●	●●	●	●●
Agrifos 600	●●	not tested	●●●	●●
milk	●●	●●	●	●●
Synertrol Horti Oil	●●	●	●	●●
Timorex	●	●	●	●●
Enhance KCS	●	not tested	●	●●
Stand SKH	●	not tested	●	●●
Peratec	●	●	●	●
CalAgri 50NF	●	not tested	●	●●
Ecocarb	●	not tested	●	●●

Relative disease suppression to conventional fungicides and no spray controls. Weekly sprays at runoff volumes. ●●● Good to medium; ●● Medium to low; ● Low to none; Ph: Phytotoxicity observed; Yr: possibly yield reduction with weekly applications of the spray product.

Table 31. Cultivars and products alternative to conventional fungicides that may be integrated in foliar disease management programs in cucumber and zucchini, based on results from trials conducted in 2008 and 2009.

	Cultivar *	Alternative fungicide **	Conventional fungicide ***
Zucchini			
Downy mildew	Golden Rod Zest 582-6 (Nitro) CLX29881 Paydirt Crowbar	Microthiol Disperss Tricop Trilogy Agri-Fos 600	Acrobat (+ MZ) Ridomil Gold, or other
Powdery mildew	Paydirt Crowbar 582-6 CLX29881 Caroline Amanda Calida	Tricop Trilogy Agri-Fos 600 milk Synertrol Horti Oil Timorex Enhance KCS Stand SKH Ecocarb	Amistar Nimrod Bafidan Bravo Morestan, or other
Cucumber			
Downy mildew	Aladin Camelot Stonewall Diamante HMX4453	Tricop Agri-Fos 600 Synertrol Horti Oil milk	Acrobat (+ MZ) Ridomil Gold, or other
Anthracnose	Aladin Camelot Stonewall	Tricop Trilogy milk	Amistar Nimrod, or other

Always check with APVMA (http://www.apvma.gov.au/) that products currently have a label or permit for their specific use.

*List based on trials carried in north Qld. in 2008. Not all current cultivar options are listed.

**List based on trials carried in north Qld in 2009. See table with relative ratings for effectiveness of spray products for controlling foliar diseases in cucumber and zucchini. Not all current options are listed.

***List based on available products. Aim is to use only one or two applications of a systemic fungicide in addition to the use of fungicide alternatives. Not all current options are listed.

Evaluation of crop genetic resistance and spray products alternative to fungicides for managing foliar diseases in zucchini

Summary

Powdery and downy mildew are foliar diseases that infect all cucurbit crop species grown in the Dry Tropics. During the March-to-November cucurbit cropping season, management practices such as sequential planting, proximity between crops at different growth stages, abandonment of infected crops, and overuse of systemic fungicides favour the survival and proliferation of pathogen strains resistant to fungicides because carryover inoculum becomes exposed to multiple sprays of the same active ingredient. By selecting cultivars with plant genetic resistance to powdery mildew (*Podosphaera xanthii*) and downy mildew (*Pseudoperonospora cubensis*), in combination with the use of alternative fungicide products and a minimum number of systemic fungicide sprays, it may be possible to improve disease control, extend the useful life of existing and new systemic fungicides, and reduce the use of pesticides. In two field trials, planted in Ayr in June and August 2010, four foliar spray programs and a non-sprayed control were evaluated in eight-week-long crops of four zucchini cultivars (two previously rated as moderate resistant to powdery and downy mildews: Paydirt and Nitro and two susceptible: Houdini and Calida). Weekly-spray programs included Agri-Fos 600® (AF), Bion® (BN), and Tricop® (TP), as fungicide alternatives. A conventional fungicide program included Acrobat®+Mancozeb (AMZ), Amistar® (AR), Mancozeb (MZ), Nimrod® (ND), and Bravo® (BV). Micronized sulphur (Microthiol Disperss®, MD) was included in every spray program. The evaluated scenarios were: a) BN-BN-BN-TP-MD-TP-MD-TP; b) AF-AF-AF-TP-MD-TP-MD-TP; c) AF-AF-AMZ-TP-MD-TP-MD-TP; d) AMZ-AR-MZ-ND-BV-MD-BV-MD; and e) no spray. In both plantings, when the use of cultivars with moderate resistance was integrated in spray programs that used alternatives to fungicides (scenarios “a”, “b”, and “c”), disease severity levels in plants were lower or equal than in plants sprayed only with conventional fungicides (“d”). Late rainfall favoured downy mildew pressure, which was 5.7 times greater in Aug-Sept than June-July. With the crop that grew in Aug-Sept, spray programs that included alternative products (“a”, “b”, and “c”) led to fruit yields 12% greater than with program “d” (conventional fungicides) and 43% greater than with plants that were not sprayed. Cultivars Nitro and Paydirt, performed with greater yields than Calida and Houdini. An area wide management plan for these diseases should integrate the use of crop genetic resistance to the disease, products alternative to conventional fungicides, effective conventional fungicides, and crop hygiene practices.

Introduction

Powdery mildew (*Podosphaera xanthii*) and downy mildew (*Pseudoperonospora cubensis*) limit the productivity of many cucurbit crops in the Dry Tropics of north Queensland. Management of these diseases is largely done with conventional fungicides but efficacy of disease control is variable. During the March-to-November cucurbit cropping season, crop practices such as sequential and overlapping plantings, proximity between crops at different growth stages, abandonment of infected crops, and overuse of systemic fungicides, favour the survival and proliferation of pathogen strains resistant to fungicides because carryover inoculum becomes exposed to multiple sprays of the same active ingredient. There is some early evidence on resistance developing by powdery mildew strains to commonly-used systemic fungicides in the Burdekin area. By selecting cultivars with plant genetic resistance to powdery mildew and downy mildew, in combination with the use of alternative fungicide products and a minimum number of systemic fungicide sprays, it may be possible to control the disease to acceptable levels, extend the useful life of existing and new systemic fungicides, and reduce the use of pesticides.

The number of possible spray programs that can be evaluated is large, as there are several alternative products, conventional fungicides, and many cucurbit species (at least 6 grown commercially) and cultivars. Promising cultivars with some acceptable resistance to the diseases and spray products alternative to conventional fungicides with some acceptable level of efficacy were listed in Tables 24 and 30. Agri-Fos 600® (phosphorous acid, which has systemic activity and targets downy mildew; has a label for use in cucurbits in Australia), Bion® (acibenzolar-s-methyl, a plant health activator with no registration/permit for use in cucurbits in Australia. In the USA, a dry formulation named Actigard 50WG® is labelled for use in cucurbits and other vegetables), and Tricop® (copper octanoate, which has contact activity and targets powdery and downy mildew; has a label for use in cucurbits in Australia) performed relatively well when evaluated on zucchini in the field trials conducted in 2009. A micronized formulation of sulphur (Microthiol Disperss®) also gave acceptable disease control against both foliar diseases in zucchini. These spray products were selected and their effectiveness of controlling powdery and downy mildew control was evaluated. The products were included in spray programs used on zucchini cultivars with different reaction to the disease. Disease severity in the plants under different spray programs were compared to scenarios where plants were either not sprayed or sprayed with conventional fungicides.

The aims of these trials were to evaluate the integration of genetic resistance with spray programs that include reduced amounts of conventional contact and systemic fungicides and determine if they can provide effective disease control with no reduction in marketable yields when compared to a selected conventional spray program.

Materials and Methods

Four foliar disease spray programs and a non-spray control were evaluated for severity of powdery mildew and downy mildew in two eight-week-long zucchini crops planted at the DEEDI Ayr Research Station in 2 June and 3 August 2010. The spray programs were evaluated on two moderately resistant zucchini cultivars, Paydirt and Nitro, and two susceptible cultivars, Houdini and Calida (Table 32). The weekly-spray programs included Agri-Fos 600® (AF), Bion® (BN), and Tricop® (TP), as fungicide alternatives and the conventional fungicides Acrobat® + Mancozeb (AMZ), Amistar® (AR), Mancozeb (MZ), Nimrod® (ND), and Bravo® (BV) (Table 33). Sulphur, as a micronized formulation (Microthiol Disperss®, MD), was included in every spray program. The orders in which products were sprayed within programs are presented in Table 34. Control treatments were plots with plants that were not sprayed with fungicides or alternative products ("e") and plots with plants sprayed with conventional fungicides ("d") (Table 34). The programs "a" to "c" mainly differed on the active ingredients that were used in the first three weeks after transplanting. Copper octanoate (Tricop®) and micronized sulphur (Microthiol Disperss®) have a withholding period for harvest (WHP) of one day and were selected as spray products for use during the fruit harvest period. Program "a" included Bion (the dry formulation was used, which is the same as Actigard 50WG in USA), which should be used early in the crop season but which may lead to phytotoxicity if used at spray rates higher than recommended or when it is used as the single product throughout the spray program period (see results for year 2009). Agri-Fos 600, has a systemic action and was used early in the season in programs "b" and "c". Program "c" had one spray of Acrobat which was the only conventional systemic fungicide in this spray program treatment and which was mixed with Mancozeb, a contact fungicide. Program "d" was composed of conventional fungicides, with three sprays of systemic fungicides (Acrobat, Amistar, and Nimrod), two commonly used contact fungicides (Mancozeb and Bravo), and micronized sulphur.

In an alluvial soil, experimental field plots with 10 plants per plot were arranged as a split-plot (spray program as main plot and cultivar as subplot) replicated in four blocks. In both planting dates, seedlings with three unfolded leaves were transplanted into drip-irrigated (2 L/m/h) raised beds covered with black polyethylene mulch. Bed rows were 1.52 m from each other and plants were 0.55 m apart within bed rows. Pre-plant fertilizer (N-P-K, 13-15-13 at 4 kg/100 m row) was applied in two bands of the planting beds. After flowering, fertilizers applied through drip irrigation included potassium nitrate (three applications at 0.6 kg/100 m of row) alternated weekly with calcium nitrate (two applications at 0.4 kg/100 m of row). Plots were irrigated as needed, with water delivered two to four times per week for irrigation periods that ranged from 2 to 4 h. Weeds were managed with Roundup (7 mL/L), applied as a directed shielded spray in the area between plots during the early part of the season, and with manual cultivation in the later part of the season. Insecticide Confidor Guard, (14 mL/100 m of row) was drip-injected once after transplanting for controlling whitefly [*Bemisia* spp. (Hemiptera: Aleyrodidae)] and cotton aphid [*Aphis gossypii* Glover (Homoptera: Aphididae)].

The spray rates were selected from product labels or were provided by the chemical companies (Table 35). These spray rates were the same as those used in the previous field trials conducted in 2009, where the evaluated programs were based on repeated weekly sprays of the same active ingredient. The spray applications were done with a spray unit powered by pressurised CO_2, which was mounted on wheels. The spray boom could use one, two or three nozzles (low drift or cone). Nozzles were added as plants increased in size. The top and lateral nozzles in the spray boom directed the spray to the top and both lateral sides of the plant row, giving good spray coverage outside and inside the plant canopy. Spray calibrations were conducted to spray high volumes (up to 1000 L/ha) at high pressure (90 to 100 PSI [621 to 689 kPa]) on larger plants, in order to ensure that plant canopies were entirely wetted.

In each plot, disease severity was assessed in five plants on leaf surfaces of two leaves in the upper plant canopy, and on two leaves in the lower plant canopy. With the crop planted 2 June, disease assessments were done on dates 7, 14, 21, and 27 July for powdery mildew (adaxial and abaxial leaf surfaces) and 13, 21 and 27 July for downy mildew (adaxial leaf surface). With the crop planted 3 August, disease assessments were done on dates 24 Aug, 1 Sept, 7 Sept, and 14 Sept for powdery mildew, and 25 Aug, 31 Aug, 6 Sept, 21 Sept, 24 Sept and 1 Oct for downy mildew. Each selected leaf was assigned a disease severity score based on the percentage of leaf surface covered with powdery mildew colonies and of downy mildew leaf spots (Table 36). The disease intensity over time [area under the disease-progress curve (AUDPC with %-days as units)] was calculated with the following formula: AUDPC = $\Sigma([(x_i+x_{i-1})/2](t_i-t_{i-1}))$, where x_i was the rating at each evaluation time and (t_i-t_{i-1}) was the time between evaluations. Fruits were harvested every two days and weight and number were recorded during 33 days (14 fruit picks between 29 June and 28 July) in the first planting and 29 days (14 fruit picks between 27 Aug and 29 Set) in the second planting.

Disease severity and fruit yield data were analysed with analysis of variance using GENSTAT software. Disease severity scores used in the field were converted into percentage values of leaf area covered with the disease and subsequently subject to arcsine transformation previous to statistical analyses. Back-transformed means are presented.

Climate data measured by the Bureau of Meteorology in Ayr and for the growing period of the two crops is presented in Figure 30. During the crop growing period, mean high and low temperatures (ºC) were 26.2/13.6 in June, 26.6/16.5 in July, 26.1/15.0 in Aug, 28.8/19.9 in Sep, respectively. Mean air relative humidity (9 am) for the latter months was 72, 75, 72, and 75% respectively. Total rainfall (mm) was 5, 1, 65, and 100 for the June, July, August, and September, respectively.

Table 32. Relative resistance to powdery and downy mildews in four zucchini cultivars.

	Relative resistance to the disease[z]	
Cultivar	Powdery mildew	Downy mildew
Houdini[y]	Low	Low
Calida[w]	Medium	Medium to Low
Nitro[x]	High	Medium
Paydirt[y]	High	Medium

[z] Based on disease severity data (AUDPC) in cultivars evaluated in field trials in Ayr and Bowen in 2008. Low or high relative resistance mean that there will be high or low disease severity when inoculum is present, environmental conditions for infection are favourable, and disease is not treated for control.
[y] Obtained from Syngenta Seeds.
[w] Obtained from Clause Seeds.
[x] Obtained from SPS Seeds.

Table 33. Main constituent ingredients and commercial products used in spray programs in 2010.

Active ingredient	Formulation	Commercial product tested	Acronym used	Manufacturer or distributor in AU
Phosphorus acid	600 g/L	Agri-Fos 600®	AF	Agrichem
Acibenzolar-s-methyl[z]	500 g/L (or 500 g/kg)	Bion® (or Actigard 50WG®)	BN	Syngenta Crop Protection Pty Ltd
Copper octanoate	18 g/L	Tricop®	TP	Colin Campbell (Chemicals) Pty Ltd
Dimethomorph + Mancozeb	500 g/L + 750 g/kg	Acrobat SC® + Mancozeb	AMZ	BASF Australia Ltd Farmoz Pty Ltd
Azoxystrobin	250 g/L	Amistar 250 SC®	AR	Syngenta Crop Protection Pty Ltd
Mancozeb	750 g/kg	Mancozeb 750®	MZ	Farmoz Pty Ltd
Bupirimate[y]	250 g/L	Nimrod®	ND	Farmoz Pty Ltd
Chlorotalonil	720 g/L	Bravo®	BV	Syngenta Crop Protection Pty Ltd
Micronized sulphur	800 g/kg	Microthiol Disperss®	MD	Nufarm

[z]No permit for use in vegetables in Australia. At present, Bion (Liquid formulation; 500 g/L acibenzolar-s-methyl) can only be used for seed treatment in cotton in Australia. In our trials we used a dry formulation: Actigard 50WG, labelled in the USA for use in cucurbits (spray rate 0.5 oz – 1 oz per acre with no more than 0.25 lb/acre-season, and with 0-day WHP) and, as Bion, manufactured by Syngenta Crop Protection Pty Ltd.
[y]Permit for use (registration for melons).

Table 34. Selected disease management programs for powdery and downy mildews used in two zucchini crops planted in Ayr. The disease management scenarios included the use of fungicide alternative products, conventional systemic and protectant fungicides, a combination of both, and no spray treatment for disease control.

Weeks from planting	1	2	3	4	5	6	7	8
Dates of sprays								
First crop planted 2 June 2010	10 June	17 June	24 June	1 July	7 July	14 July	21 July	28 July
Second crop planted 3 Aug 2010	13 Aug	19 Aug	26 Aug	2 Sep	9 Sep	16 Sep	23 Sep	--
Spray program[z]								
a) BN-BN-BN-TP-MD-TP-MD-TP	BN	BN	BN	TP	MD	TP	MD	TP
b) AF-AF-AF-TP-MD-TP-MD-TP	AF	AF	AF	TP	MD	TP	MD	TP
c) AF-AF-AMZ-TP-MD-TP-MD-TP	AF	AF	AMZ	TP	MD	TP	MD	TP
d) AMZ-AR-MZ-ND-BV-MD-BV-MD	AMZ	AR	MZ	ND	BV	MD	BV	MD
e) No spray	--	--	--	--	--	--	--	--

[z]BN: Bion (acibenzolar-s-methyl); TP: Tricop (copper octanoate); MD: Sulfur (micronized sulphur formulation); AF: Agri-Fos (potassium salts of phosphorous acid); AMZ: Acrobat (dimethomorph) + mancozeb; MZ: mancozeb; AR: Amistar (azoxystrobin); ND: Nimrod (bupirimate); BV: Bravo (chlorotalonil).

Table 35. Spray rates and amounts of products used in the selected spray programs.

Commercial product tested	Acronym used	Spray rate per ha[z]	Amount of product used per ha with banded sprays (50 to 100% of bed width)	Water volumes used per ha in each spray
Agri-Fos 600®	AF	900 mL	450; 450; 563 mL	300; 400; 800 L/ha
Bion® or Actigard®	BN	70 g	50; 60; 70 g	300; 400; 1000 L/ha
Tricop®	TP	10 L	7.9; 10; 10 L	all sprays 1000 L/ha
Acrobat SC® + Mancozeb	AMZ	360 mL+ 1.6 kg	180 mL + 0.8 kg; 225 mL + 1 kg	300 L/ha; 800 L/ha
Amistar 250 SC®	AR	288 mL	143.8 mL	400 L/ha
Mancozeb 750	MZ	1.6 kg	1 kg	800 L/ha
Nimrod®	ND	600 mL	474 mL	400 L/ha
Bravo®	BV	2.5 L	all sprays 2.5 L	all sprays 1000 L/ha
Microthiol Disperss®	MD	11.2 kg	all sprays 11.2 kg	all sprays 1000 L/ha

[z]Spray rate obtained from label or manufacturer was the same in every application but the volume of water (from 300 up to 1000 L/ha) and amount of fungicide used varied with the width of the sprayed band, which depended on canopy size (the stage of crop development). Sprays were applied with a CO_2 pressurised sprayer, operated at pressures of 90 to 100 PSI (621 to 689 kPa) using a combination of flat fan nozzle (Hardi MD 015, green) positioned above either two hollow cone nozzles (Albuz ATR80, purple) or two flat fan nozzle (Hardi MD 02, yellow), from both sides of the crop canopy. Polysorbate (Tween 20) was added as a surfactant at a rate of 0.2 mL/L (0.2% v/v) spray volume in all spray treatments.

Table 36. Disease severity scores used to assess disease severity on plant leaves in the field plots and their percentages of leaf area covered with powdery mildew or downy mildew symptoms. Cards with images of leaves at different disease severity levels were prepared and used to assess severity on field plots.

Disease severity scores	Percentage of leaf area with symptoms (%)
0	0
1	0.3 - 4.7
2	5 - 9.7
3	10 - 29.7
4	30 - 74.7 and some leaf necrosis
5	75 - 100 and extended leaf necrosis

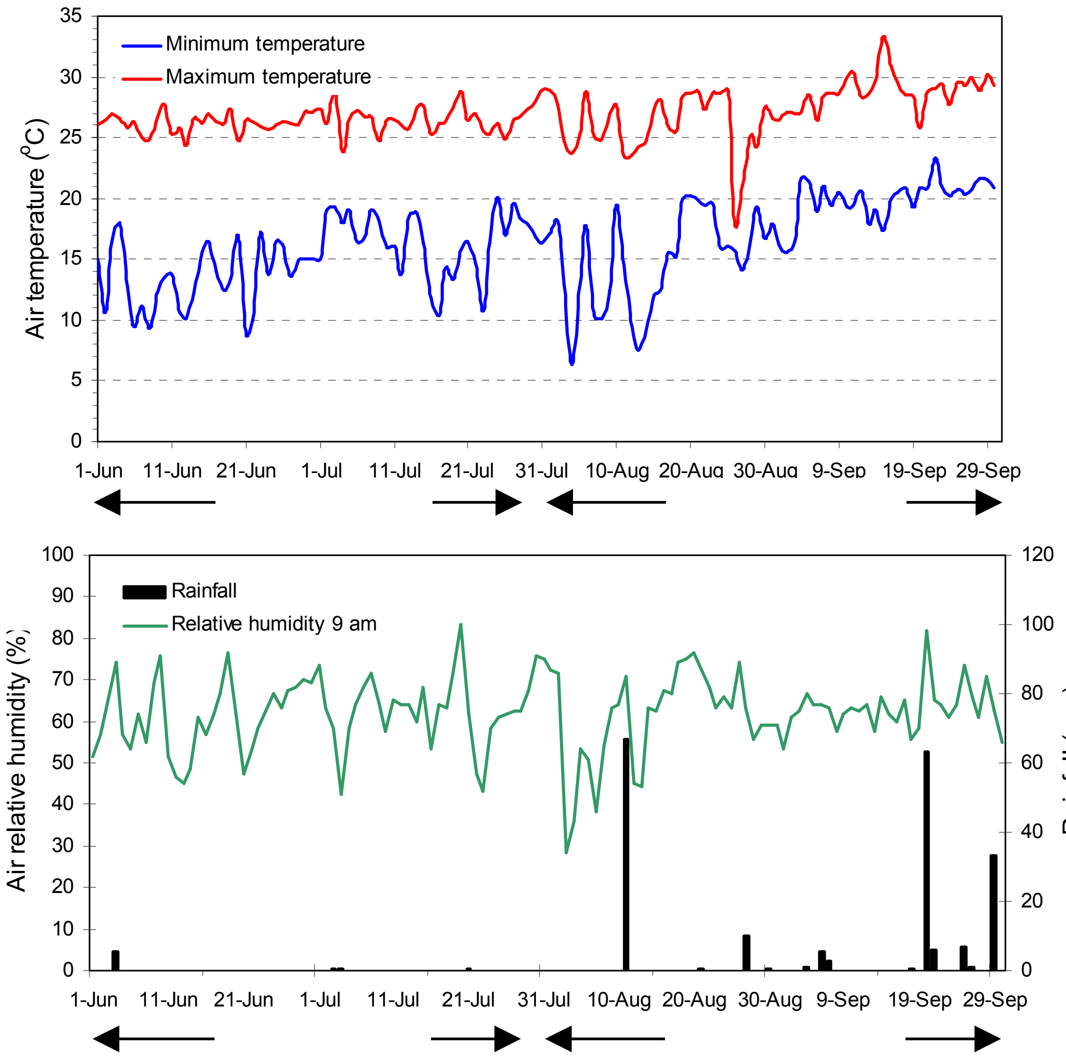

Figure 30. Maximum and minimum day air temperatures, air relative humidity at 9 am, and rainfall in Ayr in 2010 during the period when the two zucchini crops were grown.

Results

Total disease severities (downy mildew and powdery mildew) over time (AUDPC) were plotted together in Figure 31 (June planting) and Figure 32 (August planting) for all evaluated spray programs and zucchini cultivars. Figures 33 and 34 include bar graphs with means for disease severities and yield in each treatment combination. Mean values for disease severity and fruit yield in each spray-cultivar treatment are presented in Tables 37, 38, and 39 for the June planting and in Tables 40, 41, and 42 for the August planting. Means of main treatment effects (spray program and cultivar) and statistical significances in the analyses of data were included for reference in Tables 43 and 44 (June planting) and Tables 45 and 46 (August planting). Estimates for the prices of spray products and costs of the spray programs in the evaluated scenarios are given in Tables 47 and 48.

Downy mildew caused more foliar damage than powdery mildew in both zucchini trials, and leaf damage was more severe in the crop planted in August. In plants that were not sprayed with fungicides, downy mildew severity (averaged among the four cultivars) was 195 %-days in the June planting and 1115 %-days in the August planting. Increased downy mildew severity in the second planting was probably associated to frequent days with rains during the months of August and September (Figure 30) and to greater abundance of disease inoculum from the nearby crop planted in June. The severity of powdery mildew in plants that were not sprayed was greater in the crop planted in June (115 %-days) than in the crop planted in August (65 %-days). The environment during the period August-September was atypical for Ayr, as drier weather conditions are more common at that time of the year. Almost no rain in June-July may explain why powdery mildew led to greater disease severity in the earlier planting (Figure 30).

Zucchini trial planted in June

When cultivars were not sprayed for disease control, disease severity levels were higher in Houdini and Calida than in Nitro or Calida (Figure 31). Houdini was highly sensitive to both foliar diseases but Calida was more sensitive to downy mildew (Figure 31). These cultivar responses were in agreement with the results from disease reactions among different zucchini cultivars evaluated in Ayr and Bowen in 2008. Comparisons for all possible combinations of treatments are presented in Tables 37 and 38 because there were significant “Spray Program x Cultivar” interactions for total disease severity with both diseases.

Powdery mildew was kept at low severity levels in Houdini, a disease sensitive cultivar, when any of the spray programs were used (Table 37). There were no differences in disease control when comparing programs that used conventional fungicides with those that used alternative products (Table 37). In comparison to powdery mildew severity in unsprayed plants, spray programs did not improve disease control in Nitro, Paydirt, and Calida, cultivars known to have moderate resistance to powdery mildew (Table 37).

Downy mildew severity was high in Calida and Houdini when these cultivars were not sprayed (Figure 31). However, the severity of downy mildew was greatly reduced in cultivars with moderate resistance to this disease (Nitro and Paydirt). Programs “a”, “b”, and “c” gave disease control levels that were as good as or better than the program “d” which used conventional fungicides (Table 38).

Total fruit yield was not increased with any of the selected spray programs when compared to yields of plants that were not sprayed (Table 39). There were, however, differences in fruit yield among the four cultivars (Table 39). In the June planting, Calida and Houdini had greater total yields in weight, both averaging 10% greater yield than Nitro and 23% greater yield than Paydirt (Table 39). When zucchini cultivars were screened for disease resistance in 2008 we identified cultivars that were sensitive to the disease but that were high yielding (an example is the cultivar Congo which is still widely used and has been in the market for a long time; it can be classified as “tolerant” in relation to foliar diseases and yield response).

Zucchini trial planted in August

In the second planting, the effects of spray and cultivar treatments on disease control and fruit yield were different from those measured in the June planting (Figure 32). Downy mildew severity levels in non sprayed plants were 5.7 times higher than those measured in the first planting. In this second trial, Houdini still responded as a cultivar with higher severity to powdery mildew and downy mildew (Tables 40 and 41). Downy mildew severity in Houdini was not decreased by any of spray programs when compared to plants that were not sprayed (Table 41). Powdery mildew severity during August-September was low and, overall, it was not affected by spray programs (Table 40).

When the program “a”, which included Bion, was used on Calida, Nitro, and Paydirt, downy mildew severity were at lower or same levels than plants in program “d” (Table 41). Treatment “a” decreased downy mildew severity by 28% in Calida, and by 37% in Nitro in comparison to disease levels in plants that were not sprayed (Table 41). With Calida, Nitro, and Paydirt, programs “b” and “c” led to downy and powdery mildew disease severity levels that were as low as program “d” (Table 41).

With spray programs that included alternative products (“a”, “b”, and “c”), fruit yield increased in the order of 12% when compared to the program “d” (conventional fungicides) and by 43% when compared to plants that were not sprayed (Table 42). Cultivars Nitro and Paydirt, performed with greater yields than Calida and Houdini (Table 42).

Discussion

Disease pressure was low during the June-July growing period. It was particularly low for powdery mildew. In the first trial, it was possible to measure that in those cultivars with moderate resistance to downy and powdery mildew (e.g. Nitro and Paydirt), disease severity was low even when they were not sprayed with fungicides or alternative products. However, in cultivars with high sensitivity to both diseases (e.g. Houdini and Calida), severity was kept low only when plants were in spray programs that included either conventional fungicides or alternative products. Yields were not affected by spray programs but cultivars with higher sensitivity to the diseases had the highest yields.

Downy mildew pressure was high during the August-September growing period, when the second trial was conducted. Overall, in this trial it was possible to measure that in those cultivars with moderate resistance to downy and powdery mildew (i.e. Nitro and Paydirt), disease severity was lower when they were under spray programs that used either conventional fungicides or alternative products. However, in cultivars with high sensitivity to both diseases (particularly with Houdini), severity was high even when plants were under spray programs that used either conventional fungicides or alternative products. In general, total fruit yields were lower when plants were not under a spray program. Within spray programs, those that included alternative to conventional fungicides had higher yields than in the selected conventional program.

Costs of the spray programs were calculated for the scenarios in the August planting (high downy mildew disease pressure), using current prices of spray products (Tables 47 and 48). Because Bion is not sold directly to growers in Australia, its price was estimated from the price of Actigard in the US ($2/g). Although the program "a", which included Bion, was effective with cultivars that had some resistance to the diseases, its cost was 1.6 times higher than the cost of program "d" which included conventional fungicides. Lower rates of Bion or reduced spray operations should be evaluated to determine if the disease can be managed effectively at a lower cost. The least costly program was "b" followed by "c" and "d" (Table 48).

Both experiments gave indication that the use of effective products alternative to conventional fungicides (such as Bion, Agri-Fos, and Tricop), in combination with cultivars with moderate genetic resistance to the disease (Nitro and Paydirt) could keep disease severity at low acceptable levels and could lead to acceptable yields. Disease severity levels when using the combination of alternative fungicides and cultivars with moderate resistance to the disease were similar or lower than using a program with conventional fungicides. If these integrated practices are economically feasible for growers, the number of sprays with conventional systemic fungicides could be reduced. This would help mitigate the development of resistance to systemic fungicides by pathogen strains. Other alternative products not evaluated in these two trials and that gave acceptable disease control in 2008 field trials could be included in spray programs. The programs could be used with cultivars that have moderate resistance to both foliar diseases. The cultivars should be selected taking in consideration other plant attributes that are important to the grower (e.g. upright plant architecture, virus resistance or tolerance, and silvering caused by whiteflies). New programs should first be evaluated for efficacy of disease control, yield, and cost in small cropping areas. An area wide management plan for these diseases should integrate the use of crop genetic resistance to the disease, products alternative to conventional fungicides, effective conventional fungicides, and crop hygiene practices.

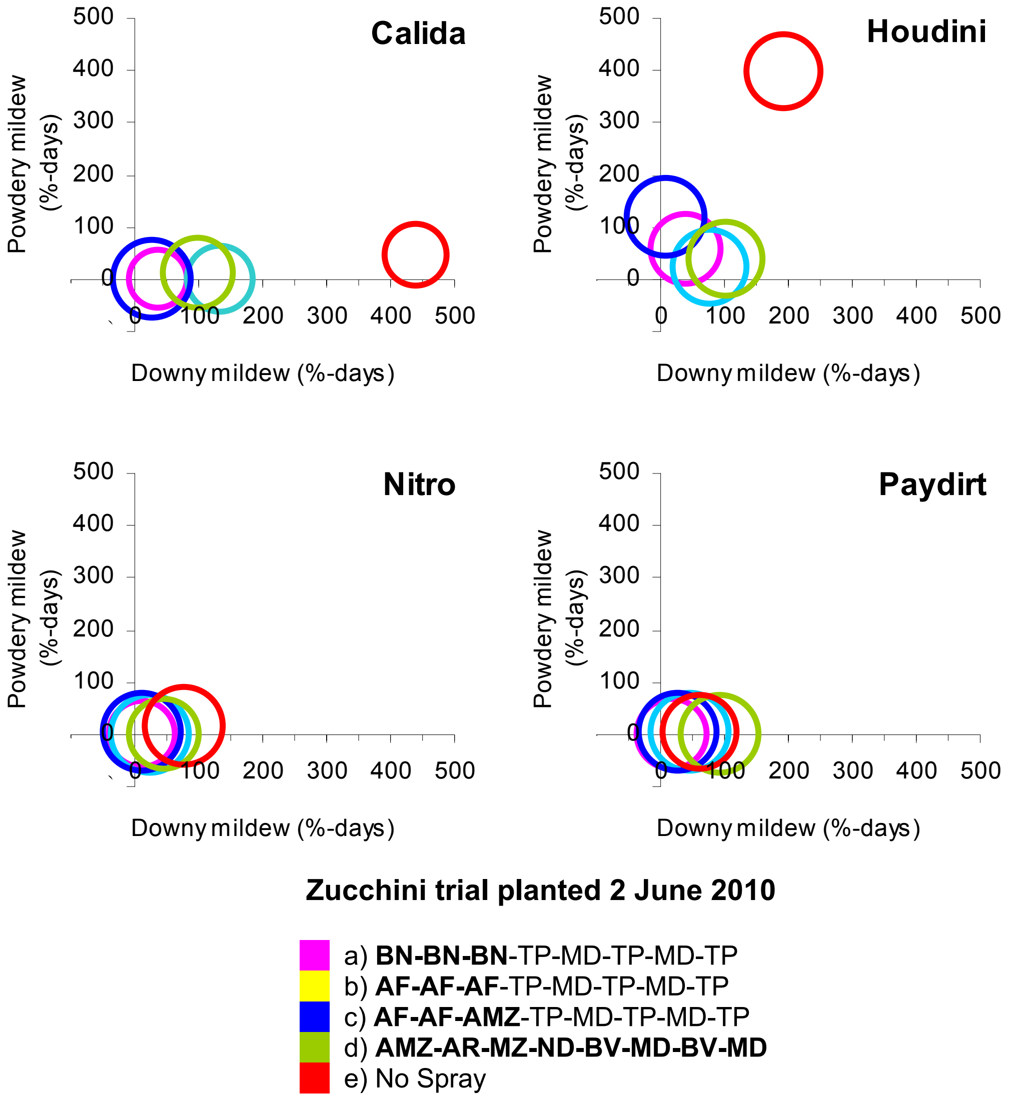

Figure 31. Cumulative severity (AUDPC) of **powdery mildew and downy mildew** in four zucchini cultivars under five spray programs for foliar disease management. Zucchinis were planted in Ayr, Qld, in **2 June 2010**. Programs of weekly sprays with conventional and/or alternative fungicides are indicated with different colours. See Materials and Methods section for acronyms used for these weekly sprayed products. Diameters of the circles are proportional to total fruit yields in t/ha.

Table 37. Cumulative severity of **powdery mildew** (AUDPC in %-days) in four zucchini cultivars planted in Ayr, Qld. in **2 June 2010** and where natural infections of foliar diseases were managed with five spray programs.

	Cultivar (%-days)			
Spray program	Calida	Houdini	Nitro	Paydirt
a) **BN-BN-BN**-TP-MD-TP-MD-TP	1 b	56 b	0 b	0 b
b) **AF-AF-AF**-TP-MD-TP-MD-TP	1 b	23 b	0 b	5 b
c) **AF-AF-AMZ**-TP-MD-TP-MD-TP	0 b	119 b	4 b	3 b
d) **AMZ-AR-MZ-ND-BV-MD-BV-MD**	9 b	36 b	1 b	1 b
e) No Spray	46 b	396 a	13 b	4 b

Means with same letters are not significantly different based on least significant test (l.s.d.) at 5% level of probability. Value of 157 %-days is for multiple comparisons of means in the Spray program x Cultivar interaction, while l.s.d. of 150 %-days can be used for comparison of cultivar means within the same level of spray program.

Table 38. Cumulative severity of **downy mildew** (AUDPC in %-days) in four zucchini cultivars planted in Ayr, Qld. in **2 June 2010** and where natural infections of foliar diseases were managed with five spray programs.

	Cultivar (%-days)							
Spray program	Calida		Houdini		Nitro		Paydirt	
a) **BN-BN-BN**-TP-MD-TP-MD-TP	39	de	41	de	13	e	18	de
b) **AF-AF-AF**-TP-MD-TP-MD-TP	134	bc	78	cde	25	de	47	de
c) **AF-AF-AMZ**-TP-MD-TP-MD-TP	28	de	10	e	13	e	27	de
d) **AMZ-AR-MZ-ND-BV-MD-BV-MD**	101	cd	103	cd	48	cde	93	cde
e) No Spray	442	a	195	b	79	cde	63	cde

Means with same letters are not significantly different based on least significant test (l.s.d.) at 5% level of probability. Value of 87 %-days is for multiple comparisons of means in the Spray program x Cultivar interaction, while l.s.d. of 75 %-days can be used for comparison of cultivar means within the same level of spray program.

Table 39. **Fruit yield** (total weight harvested) in four zucchini cultivars planted in Ayr, Qld. in **2 June 2010** and where natural infections of foliar diseases were managed with five spray programs. There were differences among cultivars but no effects from spray programs.

	Cultivar (t/ha)			
Spray program	Calida	Houdini	Nitro	Paydirt
a) **BN-BN-BN**-TP-MD-TP-MD-TP	25.3	27.6	23.8	20.9
b) **AF-AF-AF**-TP-MD-TP-MD-TP	29.1	29.1	27.2	23.4
c) **AF-AF-AMZ**-TP-MD-TP-MD-TP	33.4	31.5	28.0	23.2
d) **AMZ-AR-MZ-ND-BV-MD-BV-MD**	30.1	29.1	24.8	23.1
e) No Spray	27.3	29.3	27.7	22.6
Mean	29.0 a	29.3 a	26.3 b	22.6 c

Means with same letters are not significantly different based on least significant test (l.s.d.) at 5% level of probability.

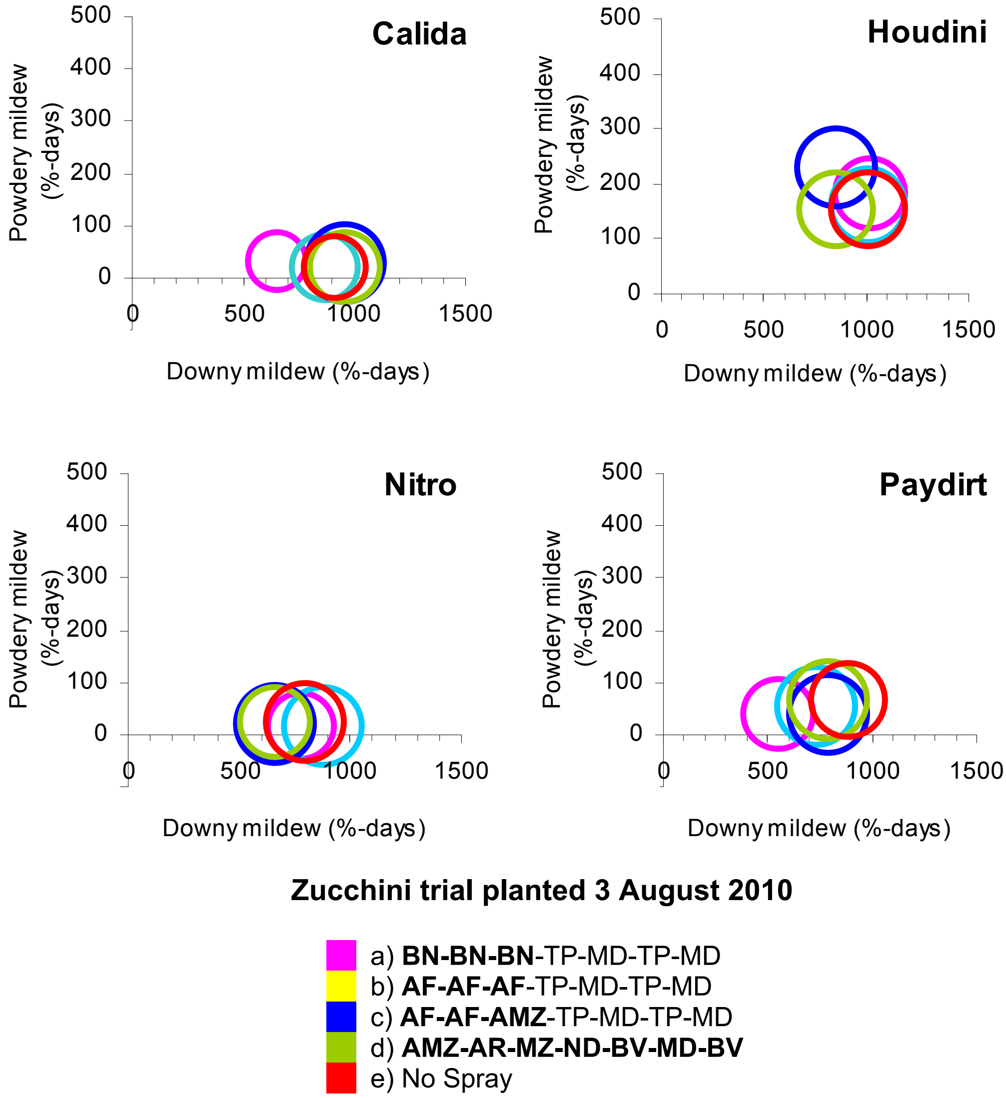

Figure 32. Cumulative severity (AUDPC) severity of **powdery mildew and downy mildew** in four zucchini cultivars under five spray programs for foliar disease management. Zucchinis were planted in Ayr, Qld, in **3 August 2010**. Programs of weekly sprays with conventional and/or alternative fungicides are indicated with different colours; see Materials and Methods section for acronyms used for these weekly sprayed products. Diameters of the circles are proportional to total fruit yields in t/ha.

Table 40. Cumulative severity of **powdery mildew** (AUDPC in %-days) in four zucchini cultivars planted in Ayr, Qld. in **3 August 2010** and where natural infections of foliar diseases were managed with five spray programs.

Spray program	Cultivar (%-days)			
	Calida	Houdini	Nitro	Paydirt
a) **BN-BN-BN**-TP-MD-TP-MD-TP	29 fg	182 b	13 g	37 fg
b) **AF-AF-AF**-TP-MD-TP-MD-TP	20 g	160 bc	14 g	52 efg
c) **AF-AF-AMZ**-TP-MD-TP-MD-TP	25 fg	228 a	20 g	39 fg
d) **AMZ-AR-MZ-ND-BV-MD-BV-MD**	18 g	152 bc	24 fg	64 ef
e) No Spray	18 g	152 bc	24 fg	64 ef

Means with same letters are not significantly different based on least significant test (l.s.d.) at 5% level of probability. Value of 43.9 %-days is for multiple comparisons of means in the Spray program x Cultivar interaction, while l.s.d. of 43.5 %-days can be used for comparison of cultivar means within the same level of spray program.

Table 41. Cumulative severity of **downy mildew** (AUDPC in %-days) in four zucchini cultivars planted in Ayr, Qld. in **3 August 2010** and where natural infections of foliar diseases were managed with five spray programs.

Spray program	Cultivar (%-days)			
	Calida	Houdini	Nitro	Paydirt
a) **BN-BN-BN**-TP-MD-TP-MD-TP	657 hi	1027 ab	781 dfgh	557 i
b) **AF-AF-AF**-TP-MD-TP-MD-TP	867 bcdefgh	1013 abc	877 bcdefg	735 fghi
c) **AF-AF-AMZ**-TP-MD-TP-MD-TP	965 bcd	858 bcdefh	665 gi	789 efgh
d) **AMZ-AR-MZ-ND-BV-MD-BV-MD**	965 bcd	858 bcdefh	665 gi	789 efgh
e) No Spray	915 bcdef	1013 ab	802 cdefgh	884 bcdef

Means with same letters are not significantly different based on least significant test (l.s.d.) at 5% level of probability. Value of 217.6 %-days is for multiple comparisons of means in the Spray program x Cultivar interaction, while l.s.d. of 168.9 %-days can be used for comparison of cultivar means within the same level of spray program.

Table 42. **Fruit yield** (total weight harvested) in four zucchini cultivars planted in Ayr, Qld. in **3 August 2010** and where natural infections of foliar diseases were managed with five spray programs. There were differences among main effect means for cultivars and for spray programs.

Spray program	Cultivar (t/ha)				Mean
	Calida	Houdini	Nitro	Paydirt	
a) **BN-BN-BN**-TP-MD-TP-MD-TP	22.0	18.9	26.7	21.4	22.2 ab
b) **AF-AF-AF**-TP-MD-TP-MD-TP	18.6	21.4	26.5	23.9	22.6 a
c) **AF-AF-AMZ**-TP-MD-TP-MD-TP	18.2	21.8	27.9	24.5	23.1 a
d) **AMZ-AR-MZ-ND-BV-MD-BV-MD**	14.1	19.0	25.3	21.5	20.0 b
e) No Spray	9.6	11.6	16.1	14.0	12.8 c
Mean	16.5 d	18.5 c	24.5 a	`21.1 b	

Means with same letters are not significantly different based on least significant test (l.s.d.) at 5% level of probability.

Table 43. Means for main effects and statistical significances for main effects and interactions of treatments "spray program" and "cultivar" affecting **powdery mildew** disease severity on four disease assessment dates; total disease severity; and yield of zucchini fruit, in a crop planted in Ayr in **2 June 2010**. Significant interaction (>0.05 in the row SP x C) indicates that cultivars responded differently when they were under the selected spray programs.

	Powdery mildew severity (%)				AUDPC	Fruit yield		
Spray program (SP)	7 July	14 July	21 July	27 July	(%-days)	(g/fruit)	(No.×1000/ha)	(t/ha)
a) **BN-BN-BN**-TP-MD-TP-MD-TP	0.1 b	0.1	0.4	1.0 c	14	286	85.5	24.4
b) **AF-AF-AF**-TP-MD-TP-MD-TP	0.2 b	0.0	0.2	1.1 c	7	300	91.7	27.2
c) **AF-AF-AMZ**-TP-MD-TP-MD-TP	0.4 b	0.7	1.3	3.0 b	31	310	94.7	29.0
d) **AMZ-AR-MZ-ND-BV-MD-BV-MD**	0.1 b	0.0	0.5	1.3 c	12	291	92.3	26.8
e) No Spray	1.1 a	3.7	3.2	9.9 a	115	290	92.4	26.7
l.s.d.	--	--	--	--	--	*12.7*	--	--
Cultivar (C)								
Houdini	1.5 a	3.5	4.3 a	11.5 a	126	306	97.9 b	29.3 a
Calida	0.0 b	0.1	0.2 b	0.8 b	11	280	103.6 a	29.1 a
Nitro	0.0 b	0.0	0.1 b	0.5 b	4	289	91.3 c	26.3 b
Paydirt	0.0 b	0.0	0.0 b	0.4 b	3	311	72.3 d	22.6 c
l.s.d.	--	--	--	--	--	*13.1*	*5.4*	*1.6*
Significance								
SP	0.042	0.136	<0.338	0.003	0.151	0.011	0.526	0.083
C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SP x C	0.311	0.019	<0.279	0.114	0.049	0.351	0.169	0.476

Disease severity based on percentage of leaf area covered with disease symptoms

Analysis of disease severity on arcsine-transformed data. Back-transformed means are presented.

Means with same letter are not significantly different at the *P = 0.050* level based on mean separation test (l.s.d.).

Table 44. Means for main effects and statistical significances for main effects and interactions of treatments “spray program” and “cultivar” affecting **downy mildew** disease severity on three disease assessment dates; total disease severity; and yield of zucchini fruit, in a crop planted in Ayr in **2 June 2010**. Significant interaction (>0.05 in the row SP x C) indicates that cultivars responded differently when they were under the selected spray programs.

	Downy mildew severity (%)			AUDPC	Fruit yield		
Spray program (SP)	13 July	21 July	27 July	(%-days)	(g/fruit)	(No.×1000/ha)	(t/ha)
a) **BN-BN-BN**-TP-MD-TP-MD-TP	0.1	0.9	2.6	28	286	85.5	24.4
b) **AF-AF-AF**-TP-MD-TP-MD-TP	5.2	3.1	5.2	71	300	91.7	27.2
c) **AF-AF-AMZ**-TP-MD-TP-MD-TP	0.1	0.7	1.9	19	310	94.7	29.0
d) **AMZ-AR-MZ-ND-BV-MD-BV-MD**	0.9	5.3	10.4	87	291	92.3	26.8
e) No Spray	6.0	8.0	32.4	195	290	92.4	26.7
l.s.d.	--	--	--	--	*12.7*	--	--
Cultivar (C)							
Houdini	2.9	4.1	10.1	86	306	97.9 b	29.3 a
Calida	4.8	6.6	22.7	149	280	103.6 a	29.1 a
Nitro	0.8	1.4	4.4	36	289	91.3 c	26.3 b
Paydirt	1.5	2.3	4.7	50	311	72.3 d	22.6 c
l.s.d.	--	--	--	--	*13.1*	*5.4*	*1.6*
Significance							
SP	0.003	<0.001	<0.001	<0.001	0.011	0.526	0.083
C	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SP x C	0.009	0.009	<0.001	<0.001	0.351	0.169	0.476

Disease severity based on percentage of leaf area covered with disease symptoms
Analysis of disease severity on arcsine-transformed data. Back-transformed means are presented.
Means with same letter are not significantly different at the *P = 0.050* level based on mean separation test (l.s.d.).

Table 45. Means for main effects and statistical significances for main effects and interactions of treatments "spray program" and "cultivar" affecting **downy mildew** disease severity on three disease assessment dates; total disease severity; and yield of zucchini fruit, in a crop planted in Ayr in **3 August 2010**. Significant interaction (>0.05 in the row SP x C) indicates that cultivars responded differently when they were under the selected spray programs.

	Downy mildew severity (%)						AUDPC	Fruit yield		
Spray program (SP)	25 Aug	31 Aug	6 Sept	21 Sept	24 Sept	1 Oct	(%-days)	(g/fruit)	(No.×1000/ha)	(t/ha)
a) **BN-BN-BN**-TP-MD-TP-MD	0	5	4	20	18	61	755	248 a	86.0 a	22.2 ab
b) **AF-AF-AF**-TP-MD-TP-MD	5	20	6	18	21	57	873	262 a	83.6 a	22.6 a
c) **AF-AF-AMZ**-TP-MD-TP-MD	2	20	3	22	17	49	819	257 a	85.7 a	23.1 a
d) **AMZ-AR-MZ-ND-BV-MD-BV**	0	4	7	46	17	51	904	253 a	78.2 a	20.0 b
e) No Spray	6	20	15	45	16	60	1115	216 b	58.8 b	12.8 c
Cultivar (C)										
Houdini	3	19	10	41	15	59	1027	224 b	81.7 b	18.5 c
Calida	2	11	5	33	22	62	922	246 a	63.9 c	16.5 d
Nitro	2	9	6	25	15	48	817	258 a	92.6 a	24.5 a
Paydirt	2	12	5	20	18	53	807	259 a	75.6 b	21.1 b
Significance										
SP	--	--	--	--	--	--	0.007	0.002	<0.001	<0.001
C	--	--	--	--	--	--	<0.001	<0.001	<0.001	<0.001
SP x C	--	--	--	--	--	--	0.006	0.611	0.468	0.066

Disease severity based on percentage of leaf area covered with disease symptoms

Analysis of disease severity on arcsine-transformed data. Back-transformed means are presented.

Means with same letter are not significantly different at the *P = 0.050* level based on mean separation test (l.s.d.).

Table 46. Means for main effects and statistical significances for main effects and interactions of treatments “spray program” and “cultivar” affecting **powdery mildew** disease severity on three disease assessment dates; total disease severity; and yield of zucchini fruit, in a crop planted in Ayr in **3 August 2010**. Significant interaction (>0.05 in the row SP x C) indicates that cultivars responded differently when they were under the selected spray programs.

	Powdery mildew severity (%)				AUDPC	Fruit yield		
Spray program (SP)	24 Aug	1 Sept	7 Sept	14 Sept	(%-days)	(g/fruit)	(No.×1000/ha)	(t/ha)
a) **BN-BN-BN**-TP-MD-TP-MD	1.8	0.0	3.2	3.1	65	248 a	86.0 a	22.2 ab
b) **AF-AF-AF**-TP-MD-TP-MD	4.5	0.0	2.3	2.1	62	262 a	83.6 a	22.6 a
c) **AF-AF-AMZ**-TP-MD-TP-MD	5.2	0.0	3.8	2.1	78	257 a	85.7 a	23.1 a
d) **AMZ-AR-MZ-ND-BV-MD-BV**	2.6	0.6	3.2	1.3	64	253 a	78.2 a	20.0 b
e) No Spray	6.2	1.1	1.2	0.9	65	216 b	58.8 b	12.8 c
Cultivar (C)								
Houdini	7.3	0.9	11.5	9.8	168 a	224 b	81.7 b	18.5 c
Calida	2.4	0.2	1.5	0.7	35 bc	246 a	63.9 c	16.5 d
Nitro	3.1	0.0	0.1	0.0	18 c	258 a	92.6 a	24.5 a
Paydirt	3.4	0.0	2.2	1.4	46 b	259 a	75.6 b	21.1 b
Significance								
SP	--	--	--	--	0.657	0.002	<0.001	<0.001
C	--	--	--	--	<0.001	<0.001	<0.001	<0.001
SP x C	--	--	--	--	0.001	0.611	0.468	0.066

Disease severity based on percentage of leaf area covered with disease symptoms
Analysis of disease severity on arcsine-transformed data. Back-transformed means are presented.
Means with same letter are not significantly different at the *P = 0.050* level based on mean separation test (l.s.d.).

Table 47. **Prices of spray products** used in selected disease management programs for powdery mildew and downy mildew control.

Commercial product tested	Amount unit container		Price[z] ($/unit container)
Agri-Fos 600®	20	L	175
Actigard® (=Bion®)	500	mL or g	1000
Tricop®	25	L	100
Acrobat SC®	5	L	352
Amistar 250 SC®	5	L	1060
Mancozeb 750®	25	kg	289
Nimrod®	5	L	290
Bravo®	10	L	236
Microthiol Disperss®	15	kg	66

[z]Prices GST inclusive obtained and averaged from two large resellers in North Qld. Prices may vary with reseller and location and may be lower with large quantity orders.
Price of Actigard estimated from overseas (USA) data (price ranged from 1.3 to 2 $/g).

Table 48. **Estimated costs per hectare** of sprayed products in selected disease management programs (8-week period) for powdery mildew and downy mildew control, in two zucchini crops planted in Ayr. The disease management scenarios included the use of fungicide alternative products, conventional systemic and protectant fungicides, a combination of both, and no spray for disease control.

Weeks from planting	1	2	3	4	5	6	7	8	Cost ($/ha)
Dates of sprays									
First crop planted 2 June 2010	10 June	17 June	24 June	1 July	7 July	14 July	21 July	28 July	
Second crop planted 3 Aug 2010	13 Aug	19 Aug	26 Aug	2 Sep	9 Sep	16 Sep	23 Sep	--	
Spray program^z									
a) BN-BN-BN-TP-MD-TP-MD-TP	BN	BN	BN	TP	MD	TP	MD	TP	
Amount used (kg or L)	*0.050*	*0.060*	*0.070*	*7.9*	*11.2*	*10*	*11.2*	*10*	
Unit price ($/L or kg)	*2000.00*	*2000.00*	*2000.00*	*4.00*	*4.40*	*4.00*	*4.40*	*4.00*	
Cost of product ($/ha)	*100.00*	*120.00*	*140.00*	*31.60*	*49.28*	*40.00*	*49.28*	*40.00*	***570.16***
b) AF-AF-AF-TP-MD-TP-MD-TP	AF	AF	AF	TP	MD	TP	MD	TP	
Amount used (kg or L)	*0.450*	*0.450*	*0.563*	*7.9*	*11.2*	*10*	*11.2*	*10*	
Unit price ($/L or kg)	*8.75*	*8.75*	*8.75*	*4.00*	*4.40*	*4.00*	*4.40*	*4.00*	
Cost of product ($/ha)	*3.94*	*3.94*	*4.93*	*31.60*	*49.28*	*40.00*	*49.28*	*40.00*	***222.96***
c) AF-AF-AMZ-TP-MD-TP-MD-TP	AF	AF	AMZ	TP	MD	TP	MD	TP	
Amount used (kg or L)	*0.450*	*0.450*	*0.225L +1kg*	*7.9*	*11.2*	*10*	*11.2*	*10*	
Unit price ($/L or kg)	*8.75*	*8.75*	*351.50 +11.54*	*4.00*	*4.40*	*4.00*	*4.40*	*4.00*	
Cost of product ($/ha)	*3.94*	*3.94*	*90.63*	*31.60*	*49.28*	*40.00*	*49.28*	*40.00*	***308.66***
d) AMZ-AR-MZ-ND-BV-MD-BV-MD	AMZ	AR	MZ	ND	BV	MD	BV	MD	
Amount used (kg or L)	*0.18L +0.8kg*	*0.1438*	*1kg*	*0.474*	*2.5*	*10*	*2.5*	*10*	
Unit price ($/L or kg)	*351.50 +11.54*	*212.00*	*11.54*	*58.00*	*23.60*	*4.40*	*23.60*	*4.40*	
Cost of product ($/ha)	*72.50*	*30.49*	*11.54*	*27.49*	*59.00*	*44.00*	*59.00*	*44.00*	***348.02***
e) No spray	--	--	--	--	--	--	--	--	
Cost of product ($/ha)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	***0***

^{z}BN: Bion (acibenzolar-s-methyl); TP: Tricop (copper octanoate); MD: Sulphur (micronized sulphur formulation); AF: Agri-Fos (potassium salts of phosphorous acid); AMZ: Acrobat.
Prices GST inclusive obtained from different resellers in North Qld. Prices may vary with reseller and location and may be lower with large quantity orders. Actigard price estimated from overseas (USA) data.

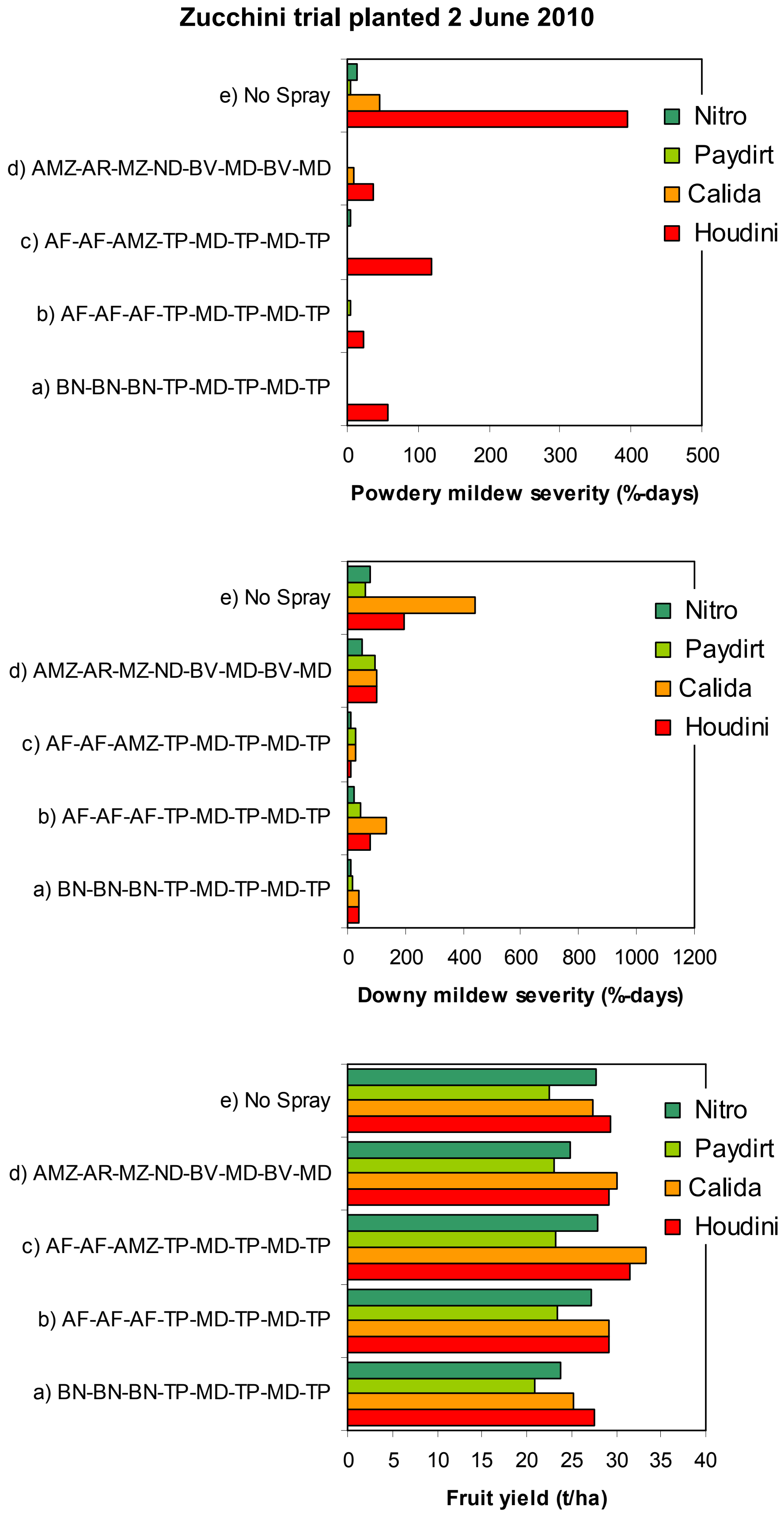

Figure 33. Efficacy of spray programs on **powdery mildew and downy mildew, and total fruit yield** in four zucchini cultivars planted in Ayr in **2 June 2010**.

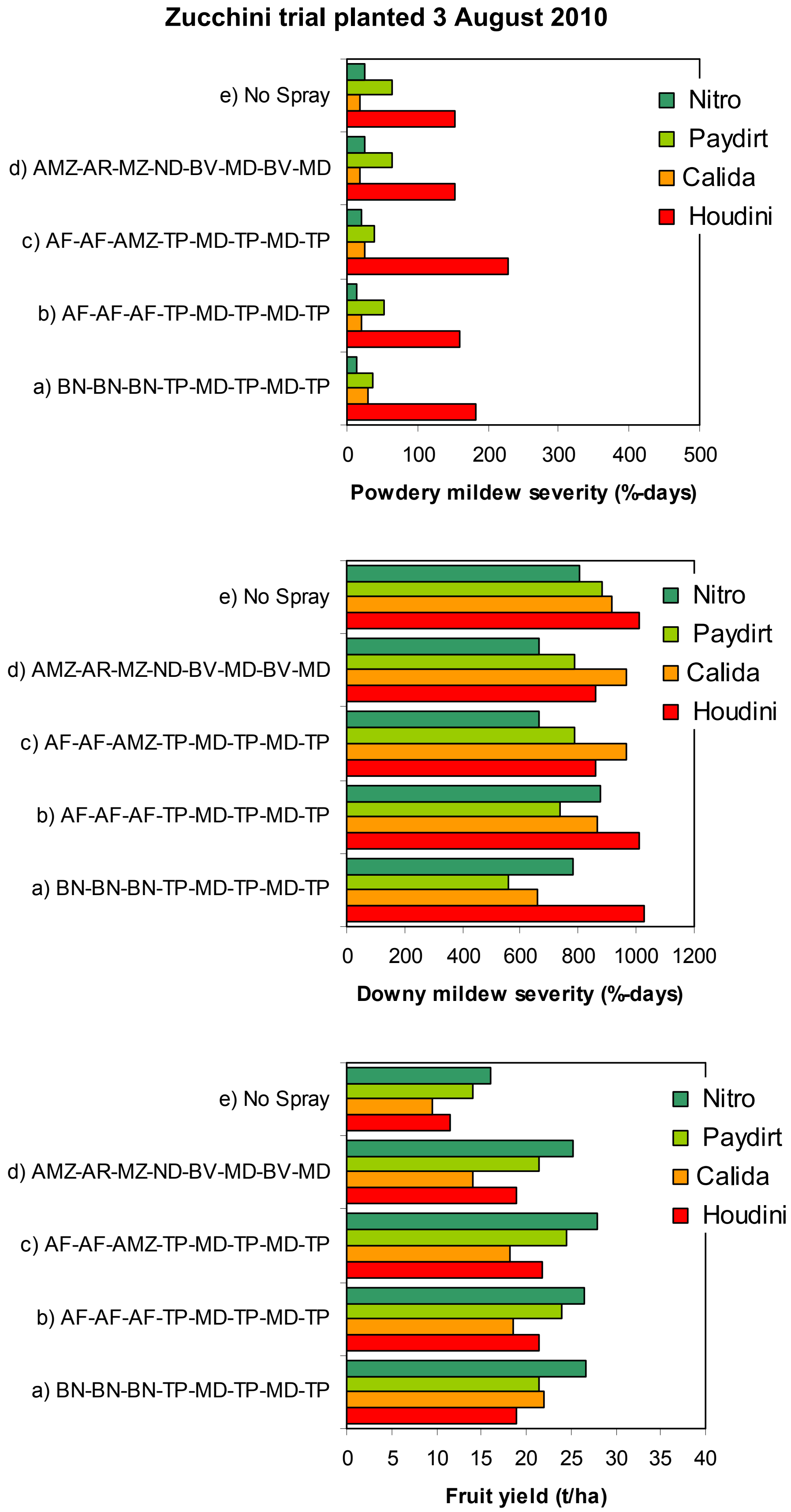

Figure 34. Efficacy of spray programs on **powdery mildew and downy mildew, and total fruit yield** in four zucchini cultivars planted in Ayr in **3 August 2010**.

Conclusion and final remarks

A single disease control practice, such as fungicide sprays, cannot effectively manage foliar diseases in the long term. A more lasting efficacy of a disease management program should integrate several available practices, where each practice contributes to an overall acceptable level of disease control. Research on cucurbits explored the use of plant genetic resistance and spray products alternative to conventional fungicides in order to minimise the number of sprays of conventional systemic and contact fungicides.

From the several cultivars and spray products that were evaluated, it was possible to identify some that would be more effective for use in an integrated disease management program. It will be important to continue screening cultivars for their reaction to foliar diseases and further evaluate alternative products that would lead to low disease severity levels in cucurbits.

A list of selected cultivars of zucchini, squash, cucumber and pumpkin indicating their relative sensitivity to foliar diseases was prepared using information gathered from 10 field trials conducted in north Queensland (Table 24). In these trials, crops were subject to natural infections of the pathogens and no fungicides were used to control the diseases.

A list of selected products alternative to conventional fungicides indicating their relative effectiveness to foliar diseases on zucchini and cucumber was prepared using information gathered from 4 field trials conducted in north Queensland where crops were subject to natural infections of the pathogens (Table 30). In these trials, crops were subject to natural infections of the pathogens and spray programs were weekly sprays of the same active ingredient.

Selected disease management programs were evaluated on zucchini in 2 field trials. Those programs which included spray products alternative to fungicides used in combination with cultivars with moderate resistance to powdery mildew and downy mildew were effective for keeping foliar diseases to low acceptable levels. These programs had a minimum use of conventional fungicides, with no or one spray with systemic fungicides. Such programs should also prolong the effective life of systemic fungicides because they will mitigate resistance development to fungicides by pathogen strains.

Information included in this report should assist with the development of integrated management of programs that target foliar diseases in cucurbit crops. The following list includes several issues that growers and crop advisors should take in consideration when using information presented in this report:

Plant genetic resistance to foliar diseases.

- It is important to try to determine why a high disease severity is present on the crop. This can be challenging. For example, high disease severity in plants may occur because of the high susceptibility of the cultivar to the disease, an unsuccessful program of sprays, ineffective application methods, fungicide resistance development by the fungal pathogen, high amounts of inoculum present when plants are young, favourable conditions for disease infection, or a combination of the above.
- Cultivars sourced from seed companies and evaluated in this project were not tested in all possible environments where cucurbits are grown in Australia, thus their reaction to diseases and yields may vary.

- Overseas there may be other cultivars with good performance that have not been tested in Australia.
- Cultivars may react well against one foliar disease but may respond poorly to other/s. It is important to judge which disease is more difficult to manage and which is the one that appears more frequently at a certain time of the year. Different cultivars can be used in a sequence of plantings when diseases typically affect crops at different times of the production season.
- After a couple years or less, results from variety trials may not include updated, relevant information. This includes new cultivars that may have appeared on the market since the completion of the trials. In addition, commercialisation of some cultivars with good traits may also have been discontinued by seed companies.
- Cultivars with high tolerance to a foliar disease (e.g. powdery mildew) may seem attractive to growers because yields may be adequate despite the canopy being affected severely. However, high disease severity will build up inoculum that (in the case of powdery mildew) will be transferred to subsequent cucurbit crops and to other farms.
- We used the term “moderate resistance” to indicate that there is *some* level of resistance; however, no was *completely* immune to a disease.
- Complete plant genetic resistance to a foliar disease is unlikely to exist, and it will not be the best option if used as a single disease control tool because resistance will be eventually overcome by a pathogen strain.
- Although some cultivars may react very well against one or more foliar diseases, they may not be the best choice for the grower if marketable yields are low and/or fruit characteristics are not those demanded by the market or buyer.
- Reaction to insect pests (such as silvering from whitefly feeding), resistance and tolerance to plant viruses, desired upright plant architecture (which makes harvesting easier), fruit quality (e.g. size, colour, flavour and shape), and postharvest shelf life are some of the additional characteristics that the grower will consider when selecting a cultivar.

Alternative fungicides for foliar diseases.

- Some of the alternatives to fungicides tested may not be registered or have a permit for use in some or all cucurbit species grown in Australia. Always check with the APVMA for the most recent information regarding pesticides that can be used in crops.
- There are alternative products used overseas that were not tested in this project.
- There are also biological organisms for use in foliar disease management. These have not been sourced for testing foliar diseases in cucurbits grown in the field. Many of these products have shown some success in protected cropping conditions.
- Alternative products to conventional fungicides used as a single spray product throughout the season may not be as effective as a spray program with conventional fungicides. Alternatives to fungicides are meant to be used alternating sprays with different active ingredients, or possibly in combination with other conventional fungicides. Spray combinations of alternative and conventional fungicides have not been tested in this project.
- Although many alternative products may not be as effective as conventional fungicides, they may be the only option for crops grown under organic standards. The addition of plant genetic resistance will improve disease control in this growing system.
- Many small cucurbits are harvested once or twice daily (e.g. fruits or flowers of squash and zucchini). Therefore, effective products with withholding periods longer than a day can only be used early in the growing season. Several alternative products can be selected for use during the harvest season.

- Efficacy of products on short term crops (i.e. zucchini and squash) may be different when the products are used more times in crops with longer growing periods such as pumpkins and melons. Always check the product label for information on the maximum amount of product that can be applied to the crop.
- It was not possible to evaluate all combinations of sequences and rates of the sourced alternative products and in every cucurbit species. There remain many possible scenarios that need to be further evaluated.
- We applied recommended rates identified on the label or by the manufacturing company (usually the highest recommended rate). Most of the alternative products tested have a contact action and their effectiveness is greatest when the plant canopy surface is completely covered with the product. We used a high spray volume (1000 L/ha) and pressure (90 to 100 PSI). We recognise that this may not be common spray conditions for a number of growers. The amounts of sprayed products depended on the floor surface sprayed and was adjusted as the plant canopy increased in size.
- The high cost of some effective alternative products may deter its potential use. When we evaluated active ingredients in spray programs, we did not evaluate combinations of spray treatments that would be effective for disease control and at the same time have the smallest application costs.
- In these trials, some spray products were found to lead to phytotoxicity; this may be avoided if lower spray rates are used.

***Development of spray programs for use with cultivars with moderate genetic resistance*.**

- We tested five spray program scenarios in zucchini, using four cultivars with different levels of tolerance to two foliar diseases. It was not feasible to evaluate all possible spray sequences of alternative products; combined programs that include all conventional fungicides; and scenarios with cultivars with different levels of tolerance to every disease in every cucurbit species.
- There is a great variation in what growers would consider a standard chemical program. Different products are used, at different times, and some growers mix contact action fungicides together with systemics. The efficacy of the spray equipments used is also very diverse.
- Results from our cultivar screening trials with zucchini, squash, cucumber, and pumpkin indicated that there are sufficient differences in cultivar reaction to foliar diseases that can be used for managing the disease. However, yield decrease in cultivars is not always related to the accumulated disease severity over time (AUDPC). In our trials, we noticed that with short term crops such as zucchini, downy mildew was the most serious foliar disease that could lead to considerable yield decreases. Growers we visited indicated that they were more concerned about controlling powdery mildew in crops with a longer season such as pumpkins and melons.
- Total fruit yield in cucurbits, mainly in those that require multiple harvests, depend on the length of the harvest period, which in most cases is determined by market prices and demand. The implementation of specific spray programs will be affected by the expected crop returns.
- The disease management programs (i.e. the group of strategies that aim for a minimum of disease severity and damage to crops) can be different if the programs are developed and used at a farm level or a wider geographical region of vegetable production. At a farm level, the success of disease control may be greater when managing downy mildew and anthracnose, two diseases where spores are mainly disseminated from plant to plant by water splashing. Management at a farm level will be more complicated with powdery mildew (a pathogen with air borne spores) because, despite applying good disease

management practices, spores can be transported to the farm from distant locations.

Communications

Project findings were reported:

To growers, seed company representatives and crop consultants:

1. ***"2009 North Queensland Annual Pest & Disease Seminars"*** held at Bowen (15 people attended), Ayr (24 attended), and Walkamin (18 attended), on 31 March, 1 and 2 April of 2009, respectively. Presentation of project updates and results from the 2008 season to growers and other industry stakeholders, as well as the Queensland Primary Industries and Fisheries staff. These presentations covered: a) a brief description of the problems that arise from using systemic fungicides as the only method to manage foliar diseases, b) objectives of the work in VG07127, and c) results from 2008 trials, where cultivars were screened for foliar disease resistance in zucchini, cucumber, squash and pumpkin. The spray products identified in the review as alternatives to systemic fungicides were also discussed. The comments given by growers and other industry representatives about the presented information were similar in the three seminar locations. The remarks included: a) the importance of monitoring for the development of disease resistance to current systemic fungicides, b) the significance of investigating for means to delay the development of resistance to fungicides, and c) in addition to resistance to foliar diseases should also record and report cultivar reactions to viruses, susceptibility to leaf silvering, and fruit yield.
2. ***"VEGEPATH Update newsletter"*** was distributed during the 2009 Annual Pest & Disease Seminars, the 2009 Vegetable Industry Conference in Melbourne and the National Vegetable Expo at Werribee. This newsletter carried updates on the VG07127 project trial results among other ongoing vegetable project trials, including a feature information section on fungicide resistance management.
3. ***"2010 North Queensland Annual Pest & Disease Seminars"*** held at Ayr and Bowen, on the 30 and 31 March of 2010, respectively, with a combined location attendance of 50. Presentation of results for the monitoring of powdery mildew resistance to systemic fungicides in cucurbit grower fields since 2008. Results suggested the development of powdery mildew strains with resistance to the current systemic fungicides. This may partly explain ineffective control with these chemicals at some locations. These findings generated good discussions with the audience and reinforced the urgent need for managing foliar diseases using an integrated approach in order to prolong the effective life of the fungicides. Presentation of results from the field trials carried out in the growing seasons 2008 (cultivar genetic resistance to foliar diseases) and 2009 (alternative spray products to conventional fungicides). This was followed with discussions on the proposed trials for the 2010 season. Results presented during these seminars also led to follow up separate meetings with representatives of three chemical companies. Information of the overall project results will be presented to growers in the seminars conducted in 2011.
4. ***"Workshop Meeting for Vegetables: Latest research on IPM of diseases and soil health management"*** held at Gympie (46 people attended) and Gatton (45 people attended) on 11 and 10 August 2010. To focus the oral presentations on the interest of the attendants, growers were first asked about the crops they grow and plant disease problems they commonly encounter in their farms. Downy and powdery mildews in zucchini came out

as one of the main topics of interest in both seminar locations. Presentation included results from past years such as the monitoring work for resistance of powdery mildew to systemic fungicides and foliar disease management using cultivar resistance and fungicide alternatives. The results indicated that it was possible to manage zucchini crops with low disease levels and obtain acceptable yields with just one application of systemic fungicides when using an integrated program that included the use of cultivars with moderate resistance to the diseases and different fungicide alternatives. The reduction in the use of conventional fungicides would delay the development of resistance to the different fungal strains and thereby prolong the life of the systemic fungicides.

5. ***Visits to cucurbit trials in Ayr and Bowen.*** Throughout the 2008-2009 cropping seasons, growers and seed company representatives had the opportunity to examine the performance of a wide range of cucurbit cultivars and products alternative to conventional fungicides.
6. ***"Zucchini field day"*** held at the DEEDI Ayr Research Station on 4 August 2010, where zucchini growers from the Burdekin Delta region were invited to visit and were able to assess disease severity on field plots that had cultivars with different levels of resistance, under different spray programs with fungicides and fungicide alternatives. A discussion of treatments and results followed the field visit.

To professional bodies:

1. Presentation at Vegetable Pathology program Workshop in Sydney on 21 May 2008. The progress of the project initiation was outlined.
2. Discussions on project progress with the overall Vegetable Pathology Program during the HAL workshop in Melbourne on 27-28 Nov 2008.
3. Project overview and progress update of the whole project across different commodities and regions as part of the Vegetable Pathology IPM Program the National Vegetable Conference on 4-6 May 2009 in Melbourne. In the presentation, project objectives and brief season results from the first year trials were presented to growers and other industry stakeholders.
4. Attendance to the 2010 AUSVEG National Convention, Trade Show and National Awards for Excellence in the Gold Coast from 27-30 May 2010. Participation in discussions related to findings as well as challenges in the vegetable disease program.
5. End of project team meeting in Brisbane on 26 Oct 2010. This meeting brought together collaborating scientists from Queensland, Victoria, South Australia and Tasmania to discuss strategies for integrated management of foliar diseases in the specific commodities. Each collaborating institution shared their project results and team discussions helped in deciding the set of Fact Sheets to be produced for distribution and a suitable period for pending workshops.

To research communities:

1. A report was accepted for publication in the Plant Disease Management Reports of the American Phytopathological Society. (Jovicich, E., C. Akem and G. MacManus. 2009. Powdery mildew resistant pumpkin cultivar evaluation, Bowen, Australia, 2008. Plant Disease Management Reports. Report No. 3:V020). Other reports and manuscripts are on preparation and will be submitted to scientific journals. Articles will be prepared for vegetable industry publications.
2. Posters related to the plant genetic resistance results from Queensland and Victoria were presented during the 17th biannual APPS Conference in Newcastle, NSW, in September 2009.

3. Abstracts for oral and poster presentations of the project findings were submitted accepted for presentation at the joint Asian and Australasian Conference of Plant Pathology scheduled to take place in Darwin from April 24-28, 2011. The titles of the presentations are:
    a. Tolerance to foliar diseases in zucchini, squash, cucumber and pumpkin cultivars in north Queensland;
    b. Efficacy of fungicide alternatives in managing powdery and downy mildew on cucurbits;
    c. Integrated management of powdery and downy mildew in zucchinis in north Queensland.

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Use of Fungicide Alternatives to Control Foliar Diseases of Cucurbits

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Use of Fungicide Alternatives to Control Foliar Diseases of Cucurbits

Zucchini and Pumpkin Varietal Resistance Evaluations to Powdery mildew

Summary
There are large numbers of varieties of zucchinis and pumpkins supplied by a number of seed companies Australia wide with various claims of tolerance or resistance to either powdery or downy mildew or to both diseases. Only through field trials and relying on natural occurring infections, it is possible to assess the reaction of cultivars to foliar diseases at the same time that fruit yield and quality are recorded. Twelve (12) zucchini and 13 pumpkin varieties were assessed in spring and autumn plantings at Gatton, in the Lockyer Valley. From the zucchini varieties evaluated, there were no outstanding cultivars with moderate resistance to the either powdery or downy mildew and that at the same time produced greater yield than standard tolerant cultivars. Overall, all zucchini cultivars produced fruit even if infected with powder mildew. The varieties Amanda, Calida, Crowbar and Paydirt had similar levels of powdery mildew infection during the spring and autumn season, whereas Congo, Regal Black and JTZ905 had higher disease severity during the autumn planting. Fruit yields, although lower in autumn, had similar differences of disease severities among cultivars. The Jap type pumpkins had low reactions to both mildews, but in particular to powdery mildew. Disease severity of mildews was greater in the Jaradale types, while the butternuts were by far the ones with the highest disease severity. As with the zucchinis, the pumpkins yielded far less fruit during the autumn trial.

Spring 2008 Trials conducted in Gatton

Introduction

Cucurbits can be found growing 12 months of the year somewhere in Australian. They can be found growing in the tropical north during the autumn, winter or spring months, or the temperate highlands of the Granite Belt during spring, summer and autumn. Due to the diverse range of growing regions, varietal selection can be an important consideration with respect to disease management. Time of the growing season is an important factor to consider when planting your crop. Warm humid conditions of spring are more favourable to powdery mildew but not downy mildew. Cool wet conditions found during autumn will result in the development of downy mildew as well as powdery mildew. Long periods of rainy weather is not conducive to powdery mildew development but will favour downy mildew, so having some idea of future weather patterns can also help in determining just when the best time to plant a cucurbit crop would be.

The AUSVEG web site has two such cucurbit crops, pumpkins worth $49.8M to the Australian economy at the farm gate (2007/08) with over 915 growers, and zucchini/squash worth $47M at the farm gate with 552 growers Australia wide. The trial work carried out at the Gatton Research Station looked at a selection of pumpkin and zucchini varieties for their tolerance/resistance to firstly powdery mildew during spring and then again during autumn when downy mildew was expected to be an issue.

Materials and Methods

This first trial was conducted at the Agri-Science Queensland Gatton Research Station with seedlings being planted 22nd September with final assessment mid December. Twelve zucchini and eleven pumpkin varieties were selected and planted using a Randomised Complete Block Design with 4 replications for the zucchinis and 3 replications for the pumpkins. Those varieties grown are listed in Table 1.

Table 1. Varieties of Zucchini and pumpkin grown during the Spring 2008 trial.

Seed Company	Seed Type	Variety
Jarit Vegetable Seeds	Zucchini	JTZ 905, JTZ 911, JTZ 913
	Pumpkin - Jap	JTP 546
	Pumpkin - Grey	Carbine, Gunsynd, Sweet Slice*
	Pumpkin - Butternut	JTP 511*, JTP 534, JTP 539
Syngenta	Zucchini	Paydirt, Crowbar
Lefroy Valley	Pumpkin - Jap	Ooak
	Pumpkin - Butternut	PUB 6506
	Zucchini	Regal Black
Clause (Henderson)	Zucchini	Amanda, Calida, z5702
	Pumpkin - Jap	Dynamite
Terranova	Zucchini	TZU 1759(Colt), TZU 54001
	Pumpkin - Grey	Sampson

*Indicates insufficient number of plants established to adequately analyse the data.

The trial site was prepared using plastic mulch and trickle irrigation T-Tape. Each zucchini plot was planted out with 5 plants of a particular variety and an additional known susceptible variety (Congo) planted either end of the 5 plants. Plants were spaced 55cm apart. The pumpkins were planted 1m apart with 4 plants planted per plot. Standard agronomic practices for irrigation, weed control, insect pest management and fertigation was undertaken by the farm staff. No fungicides were applied to allow natural infection of powdery mildew to develop.

Zucchini analysis

Disease severity on the zucchini varieties was assessed on the stems and leaves of 4 tagged data plants within each plot. Powdery mildew on the leaves was given a rating on a 0-5 scale as indicated in Table 2 below. Ratings were given to 2 upper canopy leaves that were fully expanded, but not the youngest ones, and 2 lower canopy leaves that were not showing signs of senescing or necrosis. PM was assessed on both the upper and lower surfaces of the leaves. The stem infection was rated as a percentage infection (0%, 25%, 50% 75% or 100%). The effect of disease severity on yields was determined by harvesting fruit 3 days a week from all 5 plants in each plot over a 6 week period. Number of fruit and weight of fruit were recorded for each variety.

Table 2. Powdery mildew disease severity ratings on the leaves of zucchini and pumpkins.

Severity levels	Area of leaf covered (%)
0	0
1	0.3 - 4.7
2	5 - 9.7
3	10 - 29.7
4	30 - 74.7
5	75 - 100

Pumpkin analysis
Four plants of each variety were planted 1m apart in plots 5m long by 3m wide. Four vines were selected either side of the plot with the 9th fully expanded leaf back from the growing point used for assessment. This leaf was used to assess PM on the upper and lower surface of the leaf as per the zucchini assessment and rating scale shown in Table 2. The effect of disease severity on yield was determined by harvesting the fruit per plot and recording the total number and weight of fruit per plot.

Results

Zucchini
There were significant (P=0.05) differences in disease severity among varieties evaluated. The commercially available varieties Amanda, Calida, Congo, Crowbar and Paydirt had significantly less powdery mildew on the stems and petioles than Regal black and the majority of the newer coded varieties (Figure 1 and Table 3). Powdery mildew was most prevalent on the lower canopy (Figure 2), with Congo, Calida and Paydirt exhibiting significantly less powdery mildew than the majority of the other varieties. The incidence of powdery mildew on the upper canopy leaves was very low as seen in Figure 3, with the average disease ratings less than 1 or 5%. This made it difficult to compare significant differences between varieties. A tabulated form of the results can be seen in Table 4 below. There was no significant difference between varieties in the number of fruit picked per plant as shown in Table 5 and Figure 4.

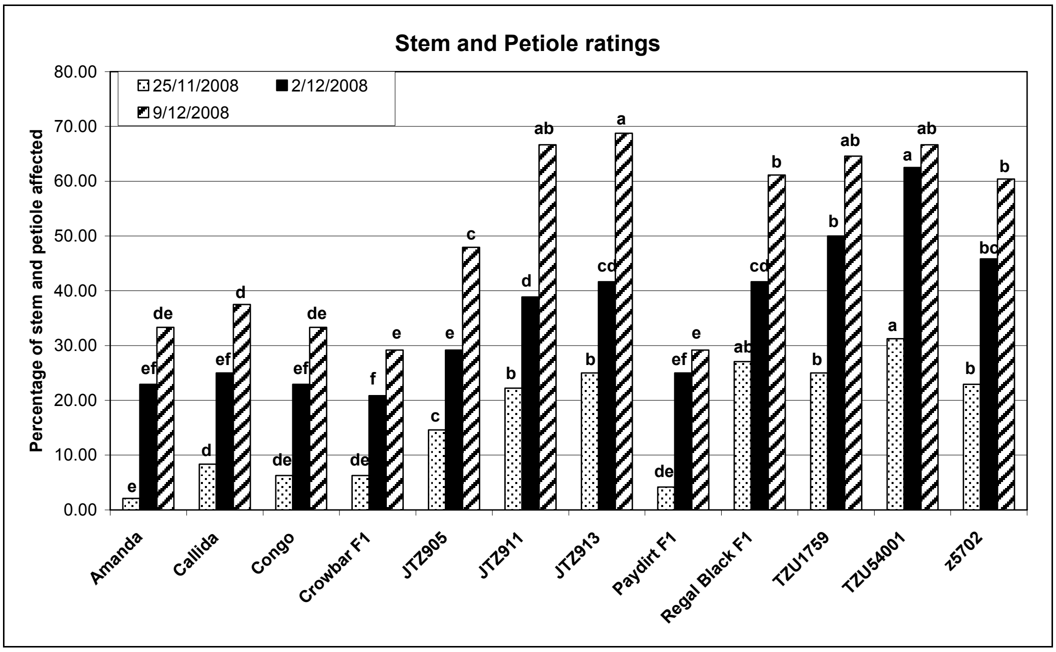

Figure 1. Percentage infection on the stems and petioles of Zucchini varieties at Gatton Research Station spring 2008.

Table 3. Prevalence of powdery mildew on the stems and petioles of zucchini varieties from when it was first observed.

Varieties	Assessment dates					
	4/11/2008	11/11/2008	19/11/2008	25/11/2008	2/12/2008	9/12/2008
Amanda	0.00	0.00	0.00	2.08 e	22.92 ef	33.33 de
Calida	0.00	0.00	0.00	8.33 d	25.00 ef	37.50 d
Congo	0.08	0.00	0.00	6.25 de	22.92 ef	33.33 de
Crowbar	0.00	0.00	0.00	6.25 de	20.83 f	29.17 e
JTZ905	0.00	0.00	2.08	14.58 c	29.17 e	47.92 c
JTZ911	0.00	0.00	11.11	22.22 b	38.89 d	66.67 ab
JTZ913	0.00	0.00	0.00	25.00 b	41.67 cd	68.75 a
Paydirt	0.00	0.00	0.00	4.17 de	25.00 ef	29.17 e
Regal Black	0.00	0.00	2.08	27.08 ab	41.67 ab	61.11 b
TZU1759	0.00	0.00	6.25	25.00 b	50.00 b	64.58 ab
TZU54001	0.00	0.00	29.17	31.25 a	62.50 a	66.67 ab
z5702	0.00	0.00	10.42	22.92 b	45.83 bc	60.42 b

Variety ratings followed by the same letter are not significantly different from one another at the (P=0.05).

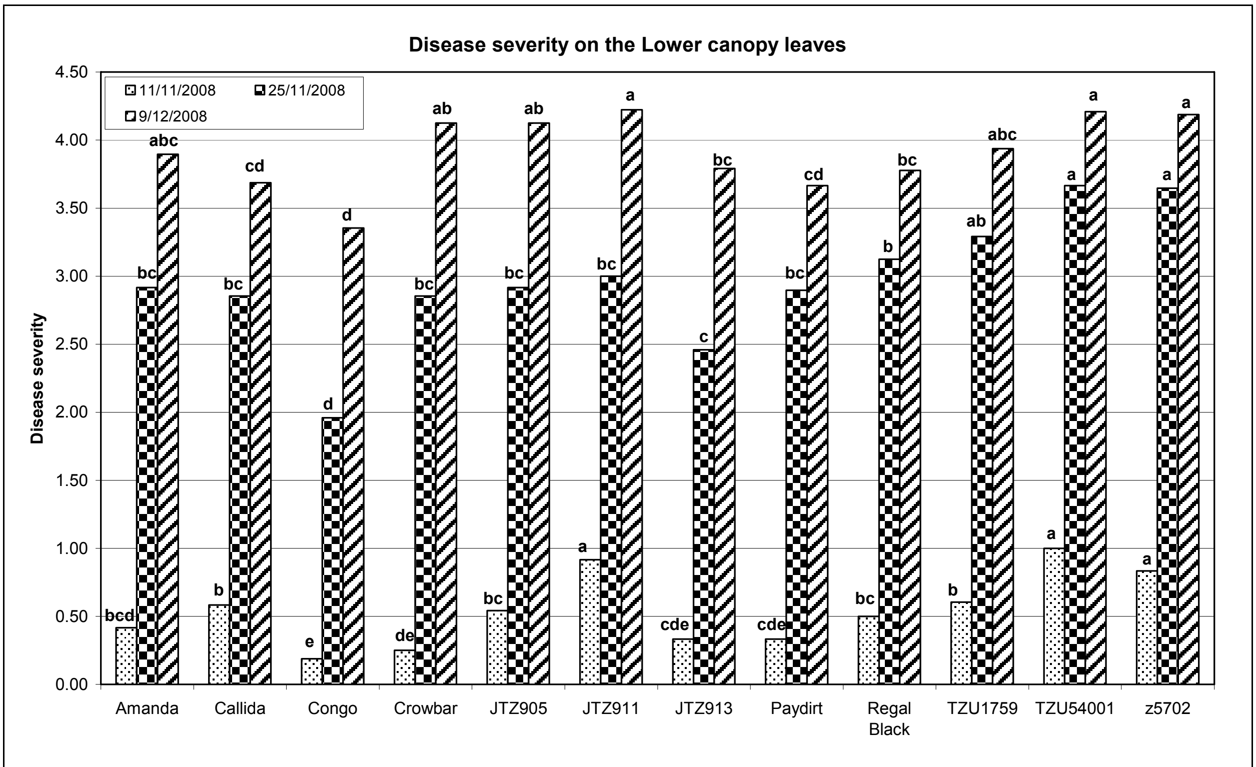

Figure 2. Disease severity levels on the lower canopy leaves of Zucchinis recorded during the last 3 weeks of the life of the crop. Varieties followed by the same letter are not significantly different from one another (P=0.05).

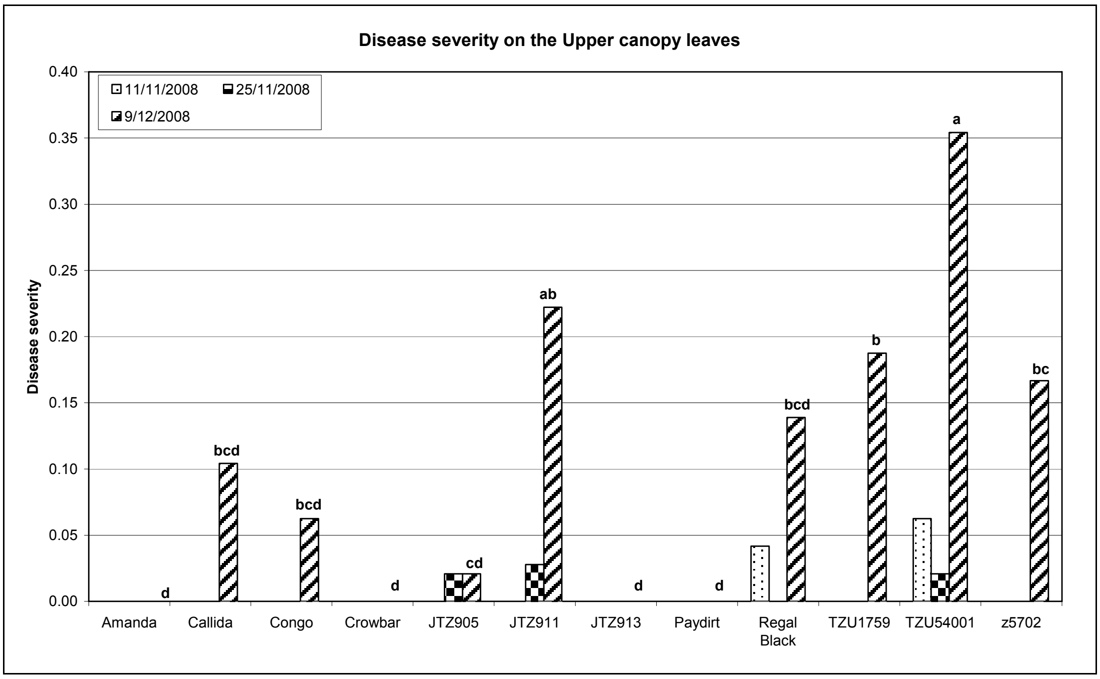

Figure 3. Disease severity levels on the upper canopy leaves of Zucchinis recorded during the period of harvest and the life of the crop. Varieties followed by the same letter are not significantly different from one another (P=0.05).

Table 4. Average disease severity ratings for the upper and lower canopy of the zucchini plants from when powdery mildew was first detected approximately 6 weeks after transplanting.

Varieties	4 Nov 2008		11 Nov 2008		19 Nov 2008		25 Nov 2008		2 Dec 2008		9 Dec 2008	
	Upper canopy	Lower canopy	Upper canopy	Lower canopy	Upper canopy	Lower canopy	Upper canopy	Lower canopy	Upper canopy	Lower canopy	Upper canopy	Lower canopy
Amanda	0.00	0.15 bcde	0.00	0.42 bcd	0.00	1.35ef	0.00	2.92 bc	0.02	3.94 d	0.00 d	3.90 abc
Calida	0.00	0.13 cde	0.00	0.58 b	0.00	1.67 cde	0.00	2.85 bc	0.08	4.31 bcd	0.10bcd	3.69 cd
Congo	0.00	0.10 de	0.00	0.19 e	0.00	0.71 h	0.00	1.96 d	0.04	3.40 e	0.06bcd	3.35 d
Crowbar	0.00	0.21 bcde	0.00	0.25 de	0.00	1.38 ef	0.00	2.85 bc	0.00	4.19 cd	0.00 d	4.13 ab
JTZ905	0.00	0.25 abc	0.00	0.54 bc	0.00	1.33 ef	0.02	2.92 bc	0.06	4.13 cd	0.02 cd	4.13 ab
JTZ911	0.00	0.23 bcd	0.00	0.92 a	0.06	1.97 c	0.03	3.00 bc	0.22	4.39 cd	0.22 ab	4.22 a
JTZ913	0.00	0.15 bcde	0.00	0.33 cde	0.00	0.81 gh	0.00	2.46 c	0.04	4.35 abc	0.00 d	3.79 bc
Paydirt	0.00	0.13cde	0.00	0.33 cde	0.00	1.14 fg	0.00	2.90 bc	0.02	3.92 d	0.00 d	3.67 cd
Regal Black	0.00	0.08 e	0.04	0.50 bc	0.00	1.42 def	0.00	3.13 b	0.04	4.21 cd	0.14bcd	3.78 bc
TZU1759	0.00	0.27 ab	0.00	0.60 b	0.00	1.83 cd	0.00	3.29 ab	0.08	4.73 a	0.19 b	3.94 abc
TZU54001	0.00	0.38 a	0.06	1.00 a	0.10	3.02 a	0.02	3.67 a	0.35	4.73 a	0.35 a	4.21 a
z5702	0.00	0.38 a	0.00	0.83 a	0.02	2.58 b	0.00	3.65 a	0.02	4.71 ab	0.17 bc	4.19 a

Variety ratings followed by the same letter are not significantly different from one another at the (P=0.05).

Table 5. Total number if Zucchini fruit harvested over a 42 day period for each variety assessed at the Gatton Research Station from 22nd October until 12th December 2008.

Variety	Total No. fruit	Number of fruit/plot	Number of fruit/plant
Amanda	363	90.75	18.15
Calida	452	113.00	22.60
Crowbar	399	99.75	19.95
JTZ905	404	101.00	20.20
JTZ911	300	100.00	20.00
JTZ913	365	91.25	18.25
Paydirt	337	84.25	16.85
Regal Black	410	102.50	21.58
TZU1759	463	115.75	23.15
TZU54001	405	101.25	20.25
z5702	324	81.00	17.05

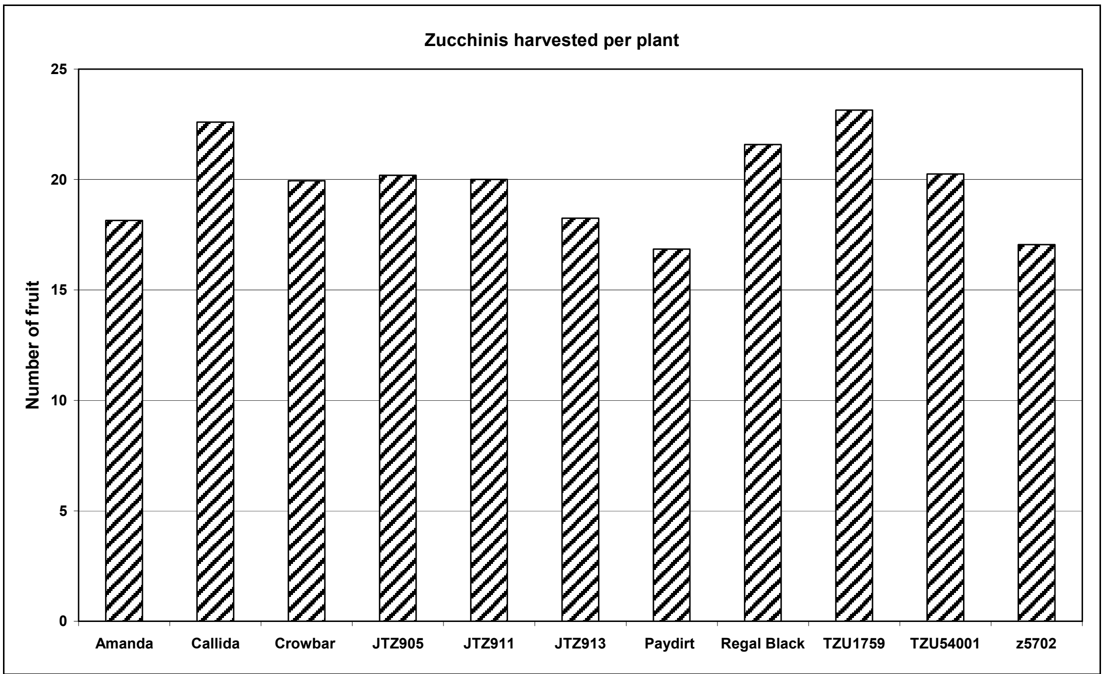

Figure 4. Average number of zucchinis per variety harvested from the 22nd October until the 10th December 2008 at the Gatton Research Station.

Pumpkins

Powdery mildew was first recorded on the pumpkin leaves from the 5th November but at very low levels. It was not until the 15th November that levels were wide spread enough to be compared statistically. There was significant (P=0.05) differences in powdery mildew incidence on the leaves of the pumpkin varieties evaluated. The variety Carbine had significantly more mildew than all the other varieties (Table 6 and Figure 5). The Jap varieties Dynamite, Ooak and JTP546 had significantly less mildew on the leaves than the large greys Carbine, Gunsynd or Sampson or the butternut pumpkins JTP534, JTP539 or PUB6506. Two other varieties Sweet slice and JTP511 could not be statistically compared with the other varieties as there was only one replication of these varieties. They have been added to the table below to compare with the other varieties only and are shaded in grey.

Table 6. Disease severity ratings starting 8½ weeks after transplanting the seedlings.

VARIETY	Disease severity ratings				
	19-Nov	25-Nov	2-Dec	9-Dec	15-Dec
Carbine	0.34	0.88 A	2.78 A	2.59 A	2.34 A
Gunsynd	0.44	1.06 A	1.72 BC	2.25 AB	1.41 BC
Sampson	0.41	0.88 A	1.97 B	2.16 AB	1.47 BC
Sweet Slice	0.44	1.69	3.06	2.25	1.69
Dynamite	0.19	0.44B C	0.75 DE	0.69 C	0.56 E
JTP546	0.13	0.47 BC	0.78 DE	0.38 C	0.75 DE
Ooak	0.25	0.31 C	0.34 E	0.72 C	0.41 E
JTP511	0.63	1.19	2.13	2.31	2.19
JTP534	0.44	1.00 A	2.06 B	1.88 B	1.63 B
JTP539	0.34	0.75 AB	0.91 DE	1.75 B	1.13 CD
PUB6506	0.47	0.78 AB	1.25 CD	1.84 B	1.66 B

Variety ratings followed by the same letter are not significantly different (P=0.05)
Shaded varieties are represented by one replication only.

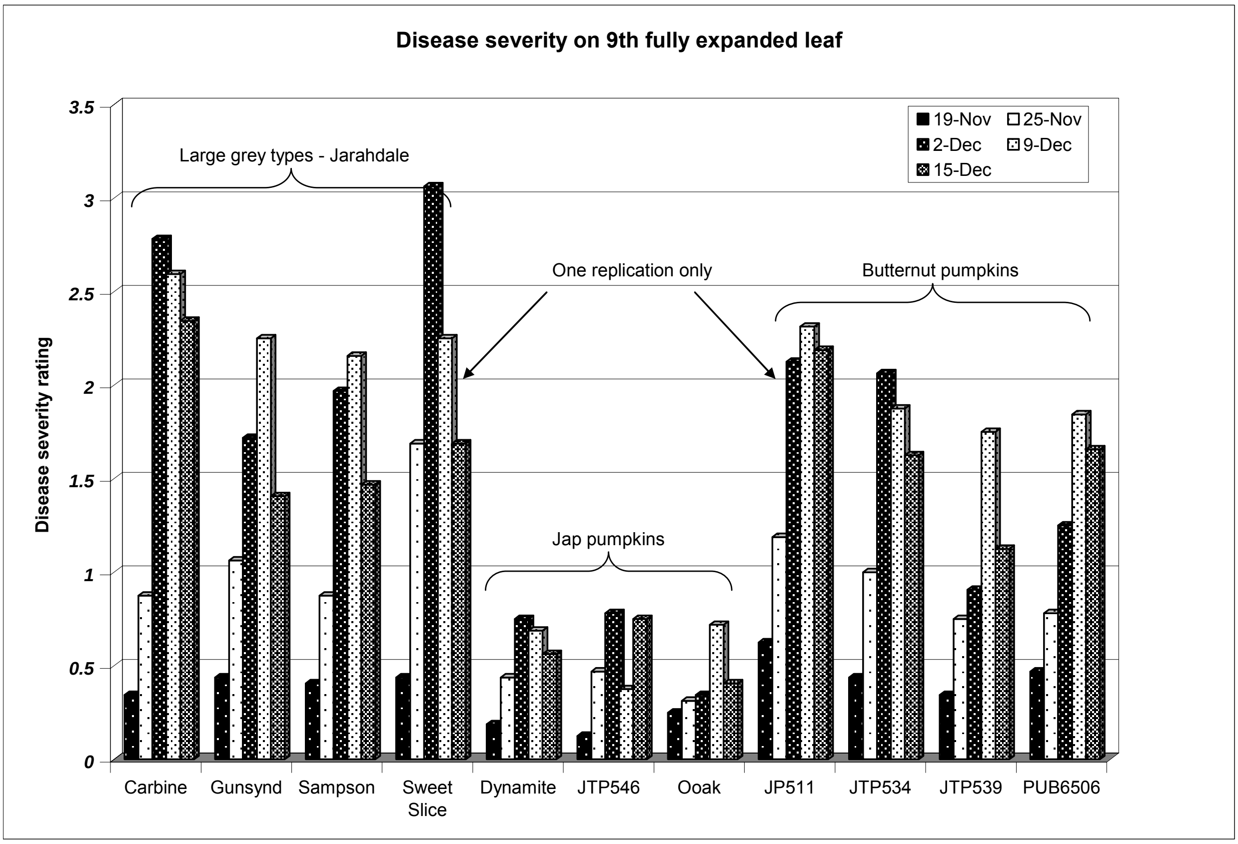

Figure 5. Disease severity results for the three types of pumpkins grown at the Gatton Research Station from 22nd September until the 15th December 2008

Pumpkin yields varied considerably across types with only slight differences within types. As a result each pumpkin type was assess separately. Of the large grey pumpkins, Sweet Slice produced the larges weight of fruit per plot and the largest number of fruit per plant. As there was only one replicate of this variety it is only a comparison with the other varieties. There was no significant differences between the other varieties, although Carbine produced the least number of fruit and Sampson the heaviest fruit per plot. There was no significant difference between the Jap type pumpkins or the butternut pumpkins, although PUB6506 did appear to produce more pumpkins than the other butternut pumpkins JTP511, JTP534 and JTP539 as seen in Figure 6 and Table 7.

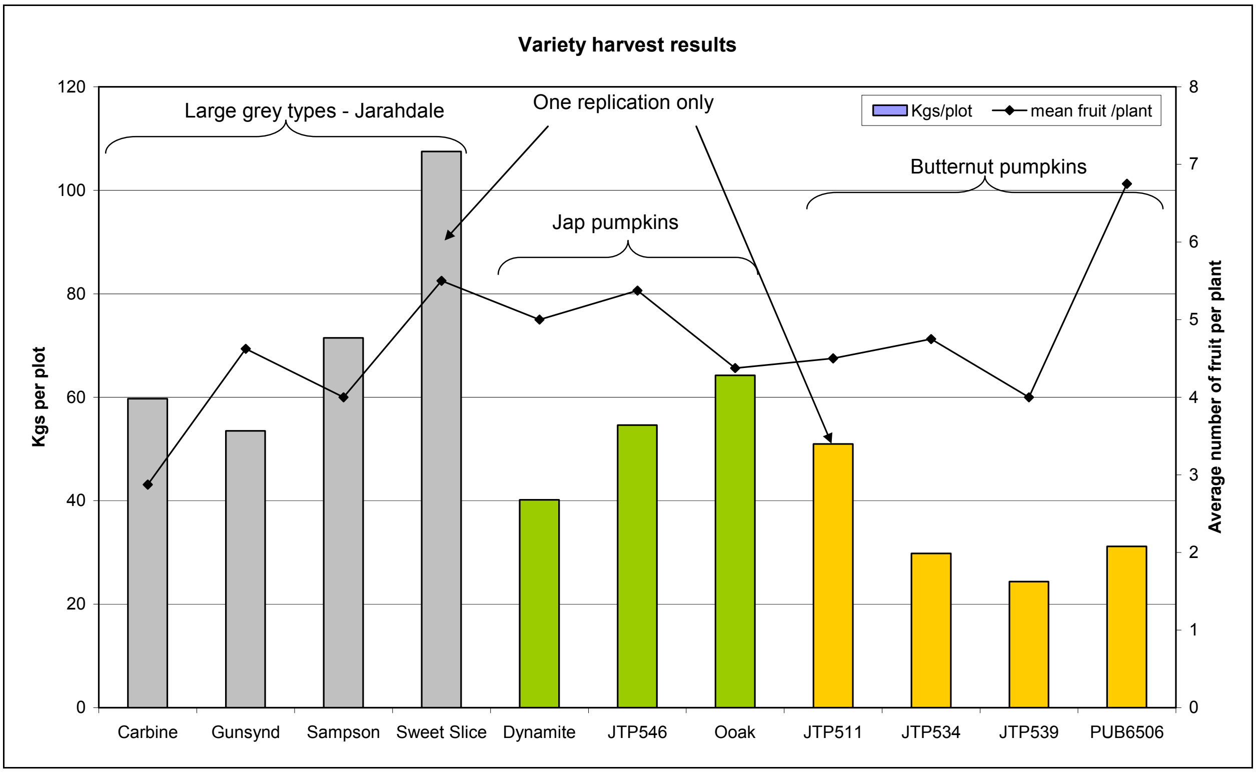

Figure 6. Harvest results for the 3 types of pumpkins looking at the weights per plot and the number of pumpkins per plant. Included are the 2 varieties that are represented with only one replication (Sweet Slice and JTP511).

Table 7. Harvest results for each variety including those varieties with only one replication.

Varieties	Weight of fruit/plot (Kgs)	Number of fruit/plot	Mean wt /pumpkin(Kgs)	Mean fruit /plant
Carbine	59.70	11.50	5.32	2.88
Gunsynd	53.51	18.50	2.93	4.63
Sampson	71.46	16.00	4.40	4.00
Sweet Slice	107.47	22.00	4.89	5.50
Dynamite	40.17	13.00	3.09	5.00
JTP546	54.63	21.50	2.71	5.38
Ooak	64.22	17.50	3.68	4.38
JTP511	50.95	18.00	2.83	4.50
JTP534	29.82	19.00	1.56	4.75
JTP539	24.37	15.50	2.28	4.00
PUB6506	31.21	27.00	1.14	6.75

Variety ratings followed by the same letter are not significantly different (P=0.05)
Shaded varieties are represented by one replication only.

Discussion

Zucchini
There was no obvious variety that was an outstanding performer when dealing with powdery mildew. The coded varieties appeared to have more powdery mildew present on the leaves than the commercially available varieties such as Congo, Paydirt and Calida. These varieties along with Amanda and Crowbar had significantly less powdery mildew on the stems and petioles which correlates to some extent with the data collected from the leaves. The only exception is the variety Regal Black which had far more mildew on the stems and petioles. Regal Black it would appear is more susceptible to powdery mildew. The lower incidence of powdery mildew in these commercially available varieties did not however equate to significantly higher yields. The variety TZU1759 produced on average more than 23 fruit per plant while Amanda produced just over 18 fruit per plant on average, with the majority of varieties producing between 16 and 22 fruit per plant. Paydirt which was one of the better performers yielded the lowest fruit count of 16.85 fruit per plant.

Pumpkin
The three types of pumpkins showed significant differences between susceptibility to powdery mildew. The Jap type pumpkins were the least susceptible, while the large greys and the butternuts were of similar susceptibility. There was very little relationship between disease severity and yield within each type of pumpkin. There were trends within types with Carbine exhibiting more disease and fewer fruit per plant than Gunsynd and Sampson, while the butternut variety PUB6505 produced the lightest fruit but more fruit per plant even though the levels of disease were similar across the other butternut varieties. The three Jap type pumpkins performed similarly with respect to disease severity and yield although Ook appeared to produce heavier fruit. All varieties still produced fruit even though they still contracted powdery mildew infection.

Autumn 2009 Trials

Introduction

This second varietal trial was looking at the added effect of downy mildew on varietal performance as downy mildew prefers wet cooler conditions to flourish and autumn is traditionally a time of higher rain fall and cooler conditions especially at night. the data collected from this trial would add to that already obtained from the spring planting and would go a long way to helping growers decide the best time to plant zucchinis or pumpkins depending on the expected disease pressure. The limitations are that this data may not be as relevant in other regions as it is possible that conditions will vary from growing region to growing region. Varieties that perform best in the Lockyer Valley may not necessarily perform well elsewhere. So care must be taken when interpreting these results.

Materials and Methods

This trial was conducted at the Agri-Science Queensland Gatton Research Station with seedlings being planted 10 March 2009 with final assessment mid May 2009. Thirteen zucchini and twelve pumpkin varieties were selected and planted using a Randomised Complete Block Design with 4 replications. Those varieties grown are listed in Table 8.

The trial site and beds were prepared using plastic mulch and trickle irrigation T-Tape. Each zucchini plot was planted out with 5 plants spaced 55cm apart. The pumpkins were planted 1m apart with 3 plants per plot. Standard agronomic practices for irrigation, weed control, insect pest management and fertigation were carried out. No fungicides were applied to allow natural infection of powdery and downy mildew to develop.

Table 8. Varieties of Zucchini and pumpkin grown during the Autumn 2009 trial.

Seed Company	Seed Type	Variety
Jarit Vegetable Seeds	Zucchini	JTZ 905, JTZ 911, JTZ 913
	Pumpkin - Jap	JTP 546
	Pumpkin - Grey	Carbine, Gunsynd, Sweet Slice
	Pumpkin - Butternut	JTP 511, JTP 534, JTP 546
Syngenta	Zucchini	Paydirt, Crowbar
Lefroy Valley	Pumpkin - Jap	Ooak
	Pumpkin - Butternut	PUB 8912, 8913, 8856
	Zucchini	Regal Black
Clause (Henderson)	Zucchini	Amanda, Calida, z5702
	Pumpkin - Jap	Dynamite
Terranova	Zucchini	TZU 1759 (Colt), TZU1770*, TZU 54001
	Pumpkin - Grey	Sampson
Seminis Seeds	Zucchini	Congo

*Indicates insufficient number of plants to adequately analyse the data; one replicate only.

Zucchini analysis

Powdery mildew disease severity on the zucchini varieties was assessed on the stems and leaves of 3 tagged data plants within each plot. Powdery mildew on the leaves was given a rating on a 0-5 scale as indicated in Table 9 below. Ratings were given to 2 upper canopy leaves that were fully expanded, but not the youngest ones, and 2 lower canopy leaves that were not showing signs of senescing. Powdery mildew was assessed on both the upper and lower surfaces of the leaves. The stem and petiole infection was rated as a percentage infection (0%, 25%, 50% 75% or 100%).

Table 9. Powdery mildew and downy mildew disease severity ratings on the leaves of zucchini and pumpkins.

Severity levels	Area of leaf covered (%)
0	0
1	0.3 - 4.7
2	5 - 9.7
3	10 - 29.7
4	30 - 74.7
5	75 - 100

Downy mildew (yellow spotting) was rated in a similar manner on the leaves only and only on one side of the leaf, with one rating per leaf, using the same rating scale as in Table 9. Ratings were given to 2 upper canopy leaves that were fully expanded, but not the youngest ones, and 2 lower canopy leaves that were not showing signs of senescing.

The effect of disease severity on yields was determined by harvesting fruit 3 times a week from all 5 plants in each plot over a 5 week period. Number of fruit and weight of fruit was recorded for each variety.

Pumpkin analysis

Three plants of each variety were planted 1m apart in plots 6m long by 6m wide. Three vines were selected either side of the plot with the 9th fully expanded leaf back from the growing point used for assessment. This leaf was used to assess powdery mildew and downy mildew with powdery mildew assessment on the upper and lower surface of the leaf and the downy mildew on the whole leaf as per the zucchini assessment and rating scale in Table 9. Three central leaves were also selected from each plot and assessed in a similar manner. The effect of disease severity on yields was determined by harvesting the fruit per plot and recording the total number and weight of fruit per plot, the number of fruit per plant and the weight per fruit.

Results

Zucchini Powdery Mildew

Powdery mildew was most prevalent on the lower leaves (Table 10 and Figure 7) with only low incidence on the upper canopy (Table 11). Paydirt had significantly less powdery mildew on the leaves than the majority of the other varieties but was not significantly different from Amanda and Calida on most of the assessment dates. The coded varieties had significantly more powdery mildew on most assessment dates as did the variety Regal Black. The varieties JTZ905 and JTZ911, which had a denser and bushier canopy, were not significantly different from the known varieties Calida and Regal Black by the final assessment on the 6th May 2009. However they were significantly worse than Amanda, Congo, Crowbar and Paydirt. The variety JTZ913, which was a more open variety was not significantly different from the known varieties Calida and Regal Black by the final assessment but was still significantly worse than the other known varieties Amanda, Congo, Crowbar and Paydirt. Incidence of powdery mildew on the stem and petiole was significantly less on the varieties Amanda, Calida, Crowbar and Paydirt as shown in Table 12 and Figure 8. The varieties TZU54001 and Z5702 had significantly more powdery mildew than any of the other varieties.

Table 10. Mean disease severity ratings per leaf for powdery mildew on the lower canopy of the zucchini varieties during Autumn 2009.

VARIETY	1st April	8th April	14th April	22nd April	29th April	6th May
Amanda	0.1042 e	0.3125 e	1.167 h	2.521 ef	4.500 bcd	4.688 b
Calida	0.1875 de	0.6042 de	1.458 gh	1.750 g	4.104 e	4.971 a
Congo	0.1667 e	0.5833 de	1.375 gh	2.750 de	4.104 e	4.708 b
Crowbar F1	0.2292 cde	1.0000 c	1.896 def	3.125 cd	4.375 de	4.667 b
JTZ905	0.3958 ab	1.1042 bc	2.187 cd	3.562 ab	4.889 a	4.936 a
JTZ911	0.5417 a	1.6042 a	2.500 bc	3.792 a	4.812 abc	4.999 a
JTZ913	0.4375 ab	0.9583 c	1.979 de	3.104 cd	4.833 ab	5.038 a
Paydirt F1	0.2083 cde	0.5000 e	1.708 efg	2.125 fg	4.479 cd	4.250 c
Regal Black F1	0.3333 bcd	0.8333 cd	2.271 cd	3.167 bc	4.500 bcd	4.984 a
TZU1759	0.2083 cde	0.5833 de	1.521 fgh	2.562 e	4.250 de	4.600 b
TZU54001	0.4167 ab	1.3958 ab	2.750 ab	3.938 a	4.917 a	4.979 a
z5702	0.3542 bc	1.0625 c	2.937 a	3.542 ab	5.000 a	5.005 a
LSD	0.1494	0.2951	0.3756	0.4014	0.3513	0.1920

NB: Means with same subscript are not significantly different at the P = 0.050 level
Shaded columns depicted graphically below.

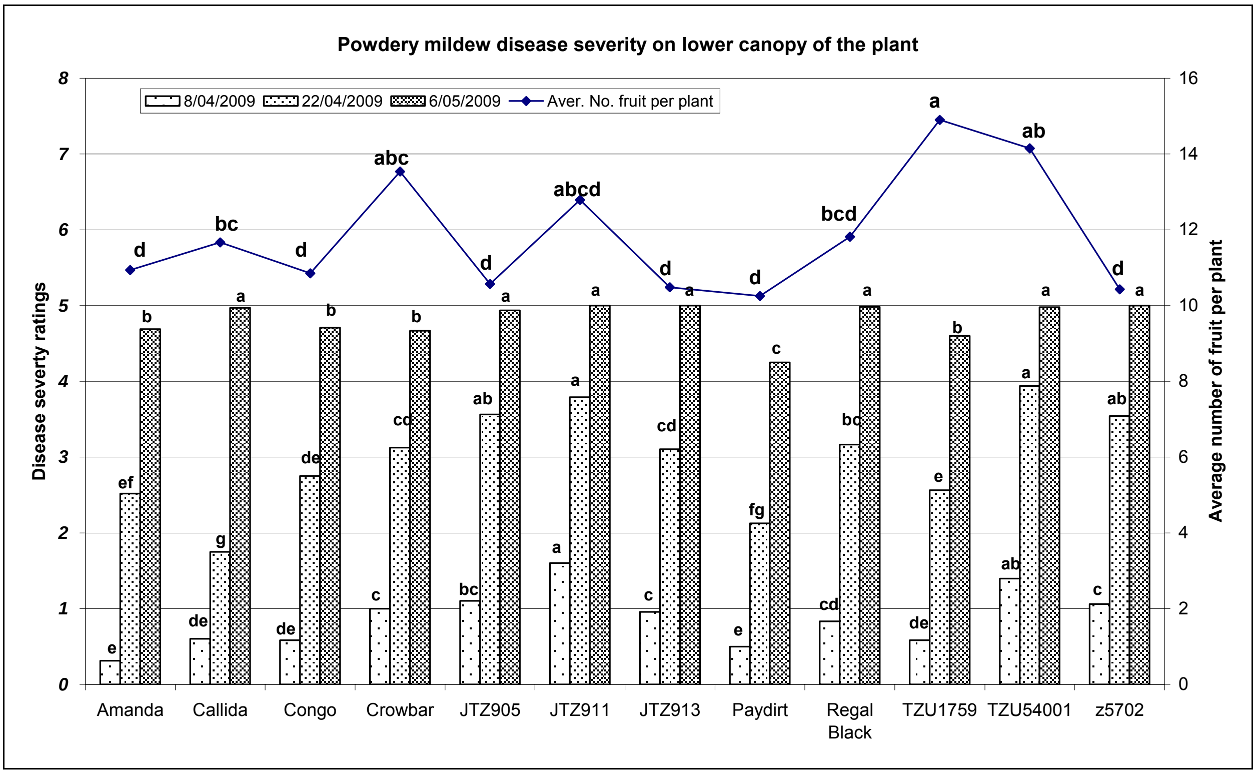

Figure 7. Disease severity ratings and average yields per variety during the autumn 2009 trial at the Gatton Research Station.

Table 11. Mean disease severity ratings per leaf for powdery mildew on the upper canopy of the zucchini varieties during Autumn 2009.

VARIETY	1st April	8th April	14th April	22nd April	29th April	6th May
Amanda	0.000	0.000	0.000	0.000	0.0187 c	0.1458 de
Calida	0.000	0.000	0.000	0.000	0.0000 c	0.1458 de
Congo	0.000	0.000	0.000	0.000	0.0625 c	0.7500 b
Crowbar F1	0.000	0.000	0.000	0.000	0.0208 c	0.2292 de
JTZ905	0.000	0.000	0.000	0.042	0.6071 a	0.3898 cd
JTZ911	0.000	0.000	0.000	0.000	0.0208 c	0.2500 de
JTZ913	0.000	0.000	0.000	0.000	0.0783 c	1.4988 a
Paydirt F1	0.000	0.021	0.000	0.000	0.0033 c	0.0000 e
Regal Black F1	0.000	0.021	0.000	0.042	0.1697 bc	0.5838 bc
TZU1759	0.000	0.000	0.000	0.000	0.3750 ab	0.0417 e
TZU54001	0.000	0.021	0.021	0.021	0.5000 a	0.7292 b
z5702	0.000	0.000	0.000	0.000	0.1667 bc	0.6042 bc
LSD		0.029	0.017	0.036	0.2747	0.2814

NB: Means with same subscript are not significantly different at the P = 0.050 level

Table 12. Mean disease severity ratings for powdery mildew on the stem and petioles of zucchini plants.

VARIETY	1st April	8th April	14th April	22nd April	29th April	6th May
Amanda	0.00	0.00	0.00	3.33 ef	13.75 c	31.25 d
Calida	0.00	0.00	0.00	2.50 f	16.25 c	38.33 cd
Congo	0.00	0.00	0.00	7.92 def	26.25 bc	60.42 ab
Crowbar F1	0.00	0.00	0.00	12.50 cd	22.08 bc	28.75 d
JTZ905	0.00	0.00	0.00	19.17 bc	15.51 c	64.52 ab
JTZ911	0.00	0.00	0.00	18.33 bc	21.67 bc	54.17 bc
JTZ913	0.00	0.00	0.00	12.08 cd	23.75 bc	54.19 bc
Paydirt F1	0.00	0.00	0.00	11.25 cde	19.58 bc	23.75 d
Regal Black F1	0.00	0.00	0.00	7.92 def	21.67 bc	67.37 ab
TZU1759	0.00	0.00	0.00	15.83 bcd	35.00 b	58.33 ab
TZU54001	0.00	0.00	7.08	39.58 a	66.67 a	75.00 a
z5702	0.00	0.00	0.00	22.50 b	55.00 a	75.00 a
lsd			5.00	8.362	15.74	17.07

NB: Means with same subscript are not significantly different at the P = 0.050 level
Shaded columns depicted graphically.

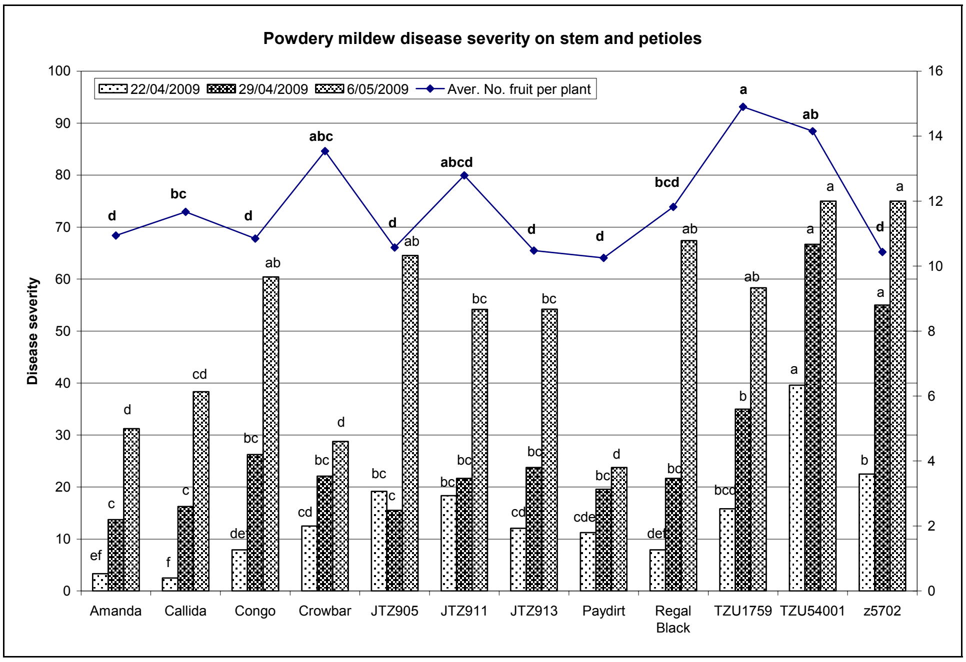

Figure 8. Disease severity found on the stem and petioles of the variety during the autumn 2009 trial at the Gatton Research Station.

Zucchini Downy Mildew

Downy mildew rapidly infected the lower canopy of the plants with average infection ratings of three plus appearing in a very short period of time. As a result the lower leaves become completely infected within a three week period as shown in Table 13 below. Downy mildew was most severe on the lower canopy of the plants with only mild symptoms near the top of the plant as shown in Table 13 and Figure 9 below. No variety was significantly better than any other, with disease severity increasing over time to the point that after a few weeks the majority of the lower leaves were almost completely infected. Infection levels on the upper canopy were mild and only obvious during the last two weeks of the trial as seen in Table 6 below. The varieties

JTZ913 and Congo did have significantly less DM on the lower leaves at the start of infection compared to the majority of other varieties assessed. This did not however continue through to harvest. JTZ913 also had significantly less infection on the upper canopy leaves than Congo JTZ905, Paydirt, Regal Black, TZU1759 and TZU54001. This variety was more open than most which may have contributed to this reduced infection level.

Table 13. Disease severity rating for Downy mildew on Zucchini varieties autumn 2009

	Mean Upper canopy rating			Mean Lower canopy rating		
VARIETY	**22nd Apr**	**29th Apr**	**6th May**	**22nd Apr**	**29th Apr**	**6th May**
Amanda	0.00	0.04	0.13 cd	3.58 de	4.38 de	5.00 a
Calida	0.00	0.42	0.04 d	3.92 bcd	4.79 abc	4.75 a
Congo	0.00	0.29	0.42 ab	3.46 ef	4.33 e	5.00 a
Crowbar	0.00	0.00	0.25 bcd	4.04 ab	4.63 bcde	5.00 a
JTZ905	0.00	0.39	0.29 bc	3.88 bcd	4.56 bcde	3.75 b
JTZ911	0.00	0.25	0.25 bcd	4.00 abc	4.63 bcde	5.00 a
JTZ913	0.00	0.00	0.05 d	3.13 f	4.54 cde	4.94 a
Paydirt	0.00	0.17	0.33 abc	3.58 de	4.67 bcd	4.88 a
Regal Black	0.17	0.04	0.30 bc	4.00 abc	4.33 e	4.88 a
TZU1759	0.04	0.25	0.54 a	4.38 a	4.88 ab	4.78 a
TZU54001	0.00	0.13	0.29 bc	4.00 abc	4.83 abc	5.00 a
z5702	0.00	0.12	0.17 cd	3.63 cde	5.00 a	4.58 a
LSD			0.2346	0.4057	0.3626	0.5167

NB: Means with same subscript are not significantly different at the P = 0.050 level
Shaded columns also depicted graphically.

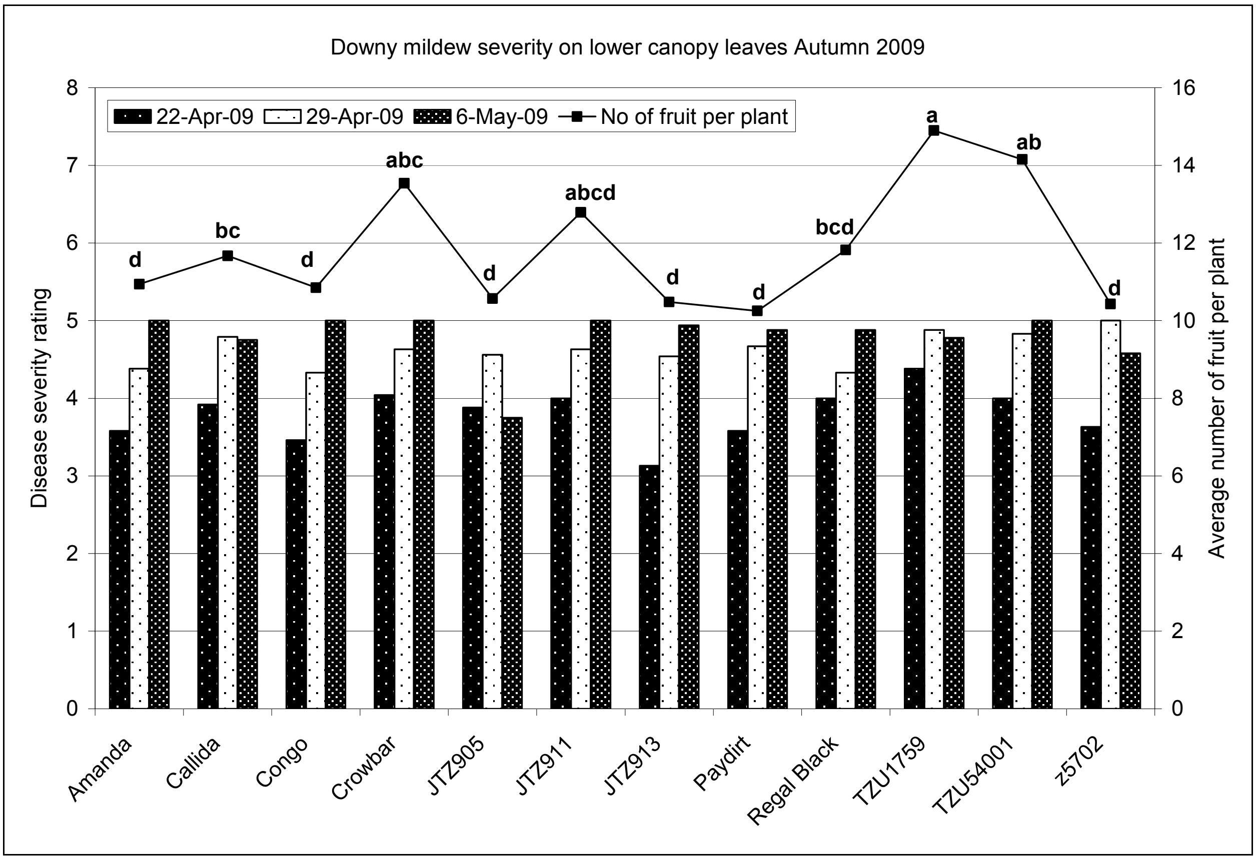

Figure 9. Disease severity ratings for downy mildew on the lower canopy and average yields per variety during the autumn 2009 trial at the Gatton Research Station.

Zucchini yield
The varieties Crowbar, TZU1759 and TZU54001 produced significantly more fruit per plant than the varieties Amanda, Congo, Paydirt, JTZ905, JTZ913 and z5702 as shown in Figures 7-9. This increase in yield was not always associated with a reduction in infection levels. Varieties Amanda and Paydirt, which had lower levels of mildew infection, both on the leaves and stems, also had significantly lower yields. The varieties TZU54001 and z5702, which had similar levels of infection, had significantly different yields.

Pumpkin Powdery Mildew
The Jap type pumpkins, Dynamite, JTP546 and OOAK, had significantly less powdery mildew on the leaves, both on the vines and in the centre of the plot, than the other two types of pumpkins. The large grey types, Carbine, Gunsynd, Sampson and Sweet slice exhibited variable results but were consistently more prone to powdery mildew than the Jap type pumpkins. They had however significantly less powdery mildew than the butter nut type pumpkins as shown in Table 14 and 15, and Figures 10 and 11 below.

Table 14. Average powdery mildew on whole 9th fully expanded leaf of pumpkin vines

VARIETIES	8th Apr	15th Apr	22th Apr	29th Apr	6th May	13th May	1st June
Carbine	0.34 def	0.70 cdef	1.04 cdef	2.02 bc	1.86 bc	1.97 bcd	2.44 d
Gunsynd	0.27 ef	0.42 ef	0.21 f	0.40 c	0.44 d	1.19 de	1.50 ef
Sampson	0.10 f	0.27 f	0.42 ef	0.38 c	0.96 d	1.35 cde	2.04 de
Sweet slice	0.29 def	0.61 def	0.63 ef	0.59 c	1.31 bcd	2.29 bc	3.80 bc
Dynamite	0.48 cde	0.83 bcde	0.75 def	0.75 bc	0.65 d	1.35 cde	1.13 f
JTP546	0.43 cde	0.63 def	0.94 cdef	0.29 c	1.15 cd	1.28 de	2.21 de
OOAK	0.56 bcd	0.67 def	0.69 ef	0.46 c	0.60 d	0.79 e	1.04 f
JTP511	0.56 bcd	1.01 abcd	1.74 abc	2.42 ab	1.98 bc	2.76 b	4.48 ab
JTP534	0.56 bcd	0.96 abcd	1.29 bcde	1.31 bc	2.04 b	2.52 b	3.60 c
PUB8856	0.77ab	1.31 ab	2.70 a	4.06 a	3.11 a	4.09 a	4.96 a
PUB8912	0.66 abc	1.18 abc	1.70 bcd	1.97 bc	1.99 bc	2.66 b	4.05 bc
PUB8913	0.90 a	1.44 a	2.02 ab	3.85 a	3.24 a	3.75 a	4.85 a
LSD	0.2841	0.4994	0.964	1.740	0.8787	0.9746	0.7699

NB: Means with same subscript are not significantly different at the P = 0.050 level
Shaded columns also depicted graphically.

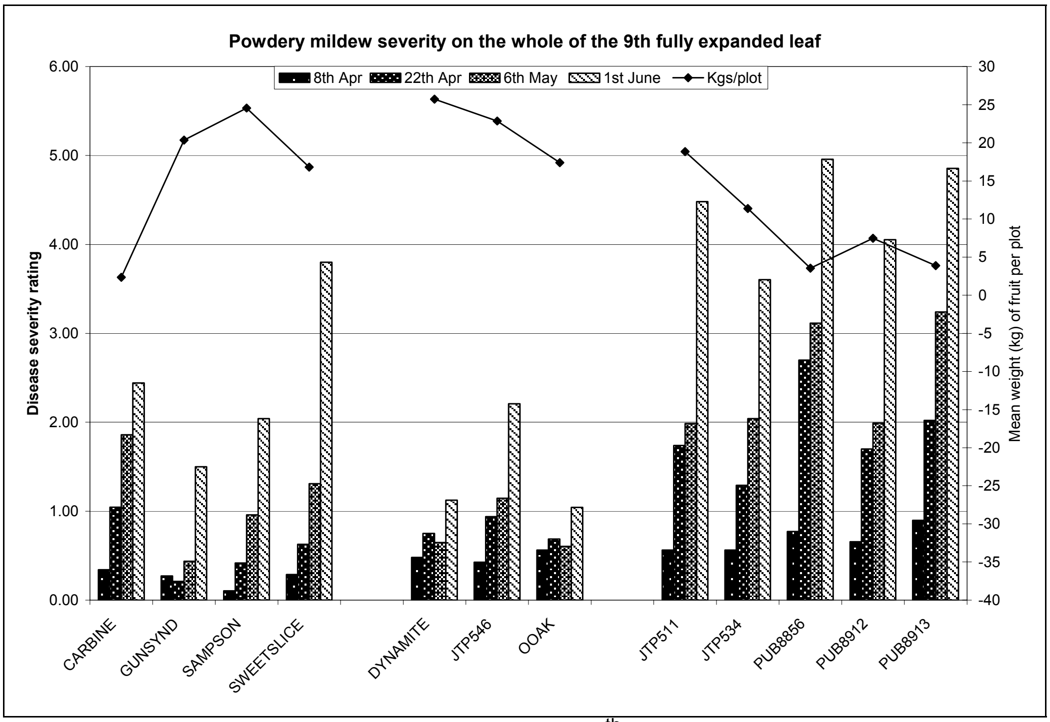

Figure 10. Powdery mildew severity on the 9th fully expanded vine or runner leaf of various pumpkin varieties with average yield per variety during the autumn 2009 planting at the Gatton Research Station.

Table 15. Average powdery mildew on the central leaf of pumpkin plant.

VARIETIES	8th Apr	15th Apr	22th Apr	29th Apr	6th May	13th May	1st June
Carbine	0.66	1.58	3.01 abc	3.81 bcd	3.36	4.06 a	5.00 a
Gunsynd	0.71	1.04	2.50 abcd	3.04 cde	2.83	2.79 bcd	5.00 a
Sampson	0.92	0.88	2.21 bcd	3.88 bc	2.83	3.67 abc	5.00 a
Sweet slice	0.35	1.08	2.04 cd	2.77 de	2.65	4.27 a	4.99 a
Dynamite	0.67	1.13	1.75 d	2.42 e	2.71	2.38 d	3.96 b
JTP546	1.02	1.50	1.92 cd	4.35 ab	3.06	2.77 cd	5.00 a
OOAK	0.92	1.46	2.58 abcd	3.92 bc	2.83	2.79 bcd	5.00 a
JTP511	0.96	1.96	3.15 ab	4.73 ab	2.69	3.67 abc	5.00 a
JTP534	0.67	1.71	2.88 abc	5.00 a	3.13	4.13 a	5.00 a
PUB8856	1.06	1.83	3.17 ab	5.00 a	3.67	4.25 a	5.00 a
PUB8912	1.23	1.75	3.58 a	4.44 ab	3.21	3.94 ab	5.00 a
PUB8913	1.13	2.00	2.92 abc	4.79 ab	3.83	4.58 a	5.00 a
LSD			1.097	1.071		1.159	0.5532

NB: Means with same subscript are not significantly different at the P = 0.050 level
Shaded columns depicted graphically.

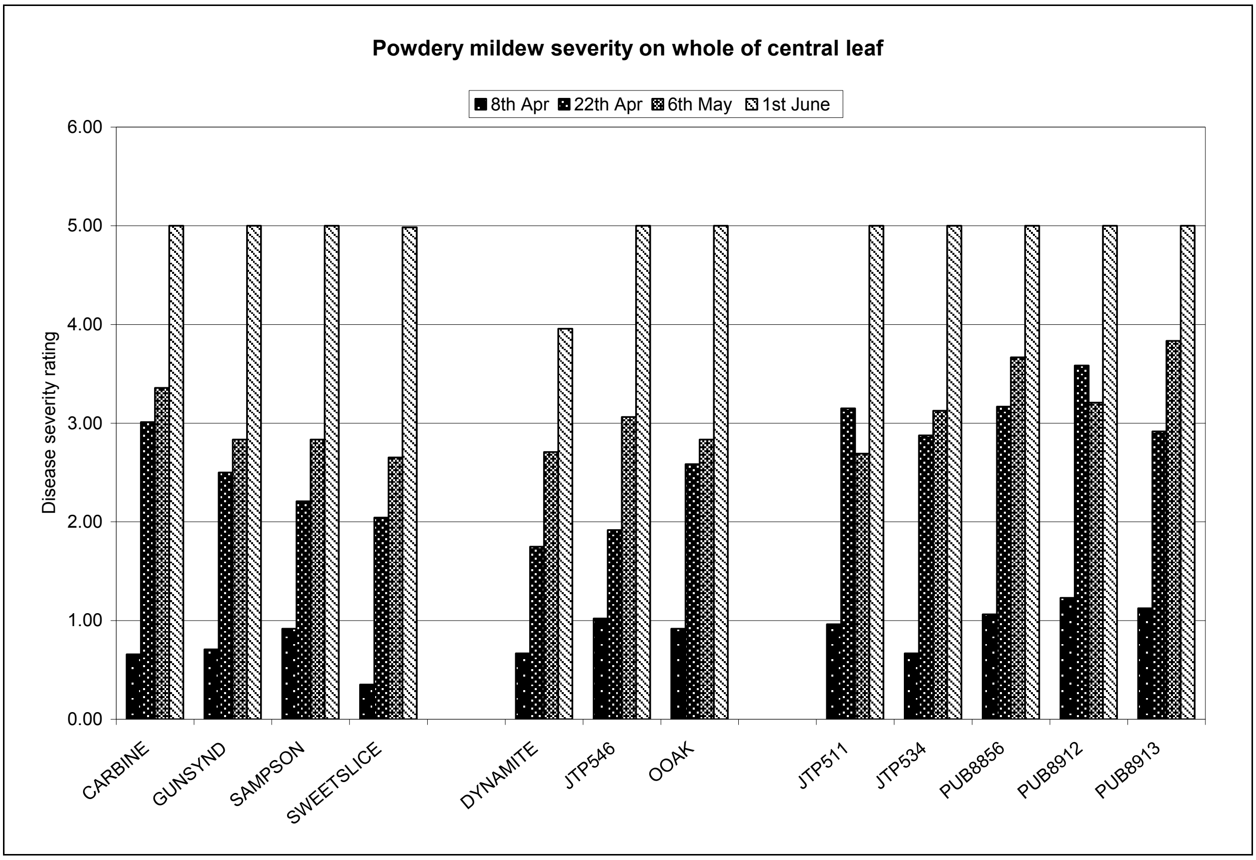

Figure 11. Powdery mildew severity on the central leaf of various pumpkin varieties with average yield per variety during the autumn 2009 planting at the Gatton Research Station.

Pumpkin Downy Mildew

The leaves at the centre of the plots quickly became infected with downy mildew with no significant differences being observed between varieties. However, the large grey type varieties appeared to have less initial infection on the leaves than either the Jap or Butternut type pumpkins. Infection quickly became uniform across all varieties in the centre of each plot. Infection levels on the 9th fully expanded leaf from the growing point of the vines exhibited light to moderate levels of infection as seen in Table 16 below. The three Jap type pumpkins performed significantly better than the variety Carbine and most of the butternut varieties and were not significantly different from Gunsynd, Sampson or the Sweet Slice varieties.

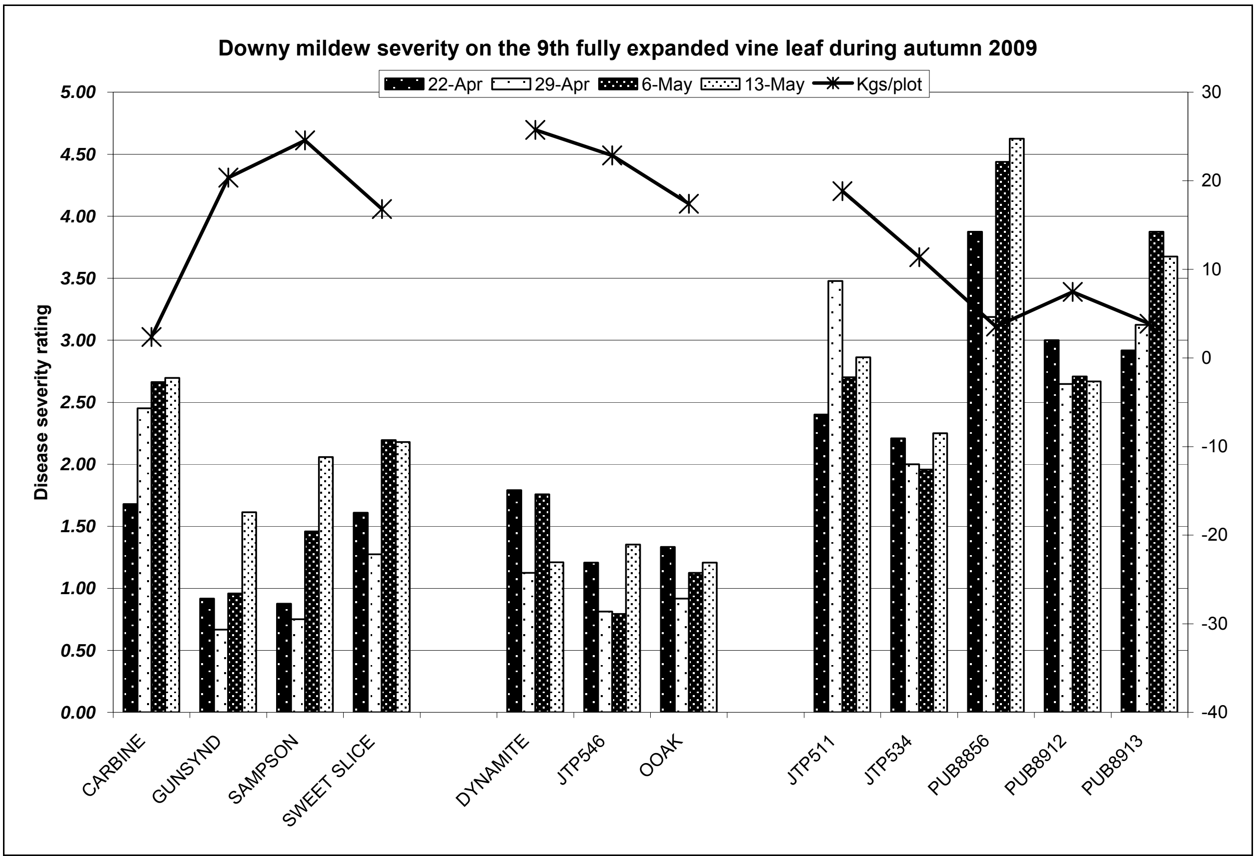

Figure 12. Downey mildew severity on the 9th fully expanded vine or runner leaf of various pumpkin varieties with average yield per variety during the autumn 2009 planting at the Gatton Research Station.

Table 16. Pumpkin downy mildew results

VARIETY	22nd April		29th April		6th May		13th May	
	Vine leaf	Central leaf	Vine leaf	Central leaf	Vine leaf	Central leaf	Vine leaf	Central leaf
CARBINE	1.7cde	2.6	2.5 abcd	3.5	2.7bc	4.1	2.7 bc	4.5
GUNSYND	0.97 e	2.8	0.6d	4.0	1.0 d	4.7	1.6 cde	4.8
SAMPSON	0.9 e	2.8	0.8 cd	4.7	1.5 cd	4.5	2.1 cde	4.8
SWEET SLICE	1.6 de	2.3	1.3 bcd	4.2	2.2cd	4.6	2.2 cde	4.7
DYNAMITE	1.8bcde	3.0	1.1 cd	4.3	1.8 cd	4.4	1.2 e	4.6
JTP546	1.2 de	3.1	0.8 cd	4.8	0.8 d	4.5	1.4 de	4.6
OOAK	1.3 de	3.1	0.9 cd	4.4	1.1 d	4.7	1.2 e	4.5
JTP511	2.4 bcd	3.4	3.5 a	4.6	2.7 bc	4.0	2.9 bc	4.9
JTP534	2.2 bcd	3.5	2.0 abcd	4.6	2.0 cd	3.9	2.3 cde	4.8
PUB8856	3.9 a	4.1	3.2 ab	3.8	4.4 a	4.8	4.6 a	5.0
PUB8912	3.0 ab	3.8	2.6 abc	4.8	2.7 bc	4.5	2.7 bcd	4.8
PUB8913	2.9 abc	3.5	3.1 ab	3.8	3.9ab	4.6	3.7 ab	4.4
LSD	1.2	1.1	1.9	1.7	1.4	0.68	1.3	0.53

Means with same subscript are not significantly different at the P = 0.050 level

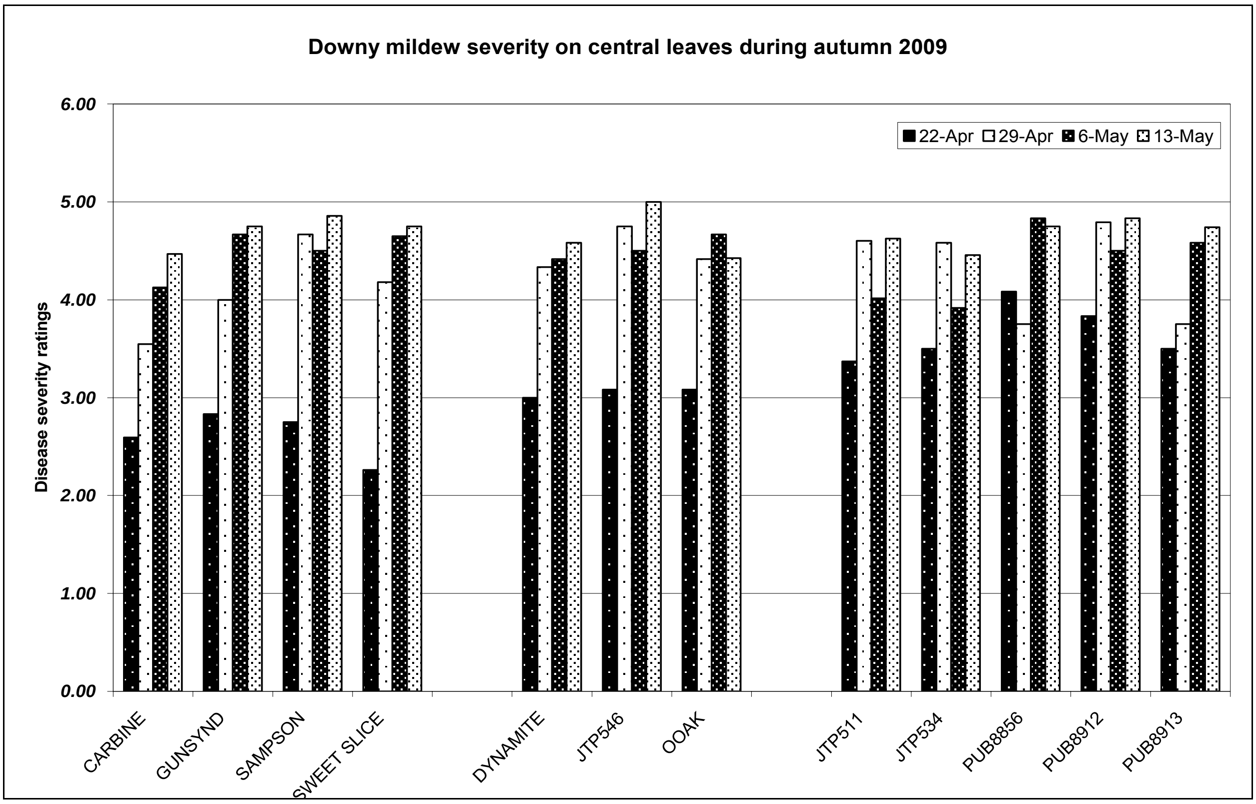

Figure 13. Downy mildew severity on the central leaf of various pumpkin varieties with average yield per variety during the autumn 2009 planting at the Gatton Research Station.

Pumpkin yield

Yield of the individual varieties revealed variable results. The grey variety Carbine was significantly lower than the other three grey varieties Gunsynd, Sampson and Sweet Slice which appeared to correlate to the amount of mildew present on the leaves. There was no significant difference in yields between the Jap type varieties. The butternut pumpkins however, showed a significant difference between JTP511 and the other four varieties. Although the level of powdery mildew on the leaves showed some significant differences between varieties this could not account for the significant yield variations between the butternut pumpkin varieties.

Table 17. Yields from pumpkin varieties at Gatton Research Station autumn 2009.

Variety	kg/plot	fruit/plot	mean yield per plant (kg)	mean fruit /plant
Carbine	2.36 b	0.5 b	1.181 b	0.25 b
Gunsynd	20.35 a	4.75 a	6.783 a	1.583 a
Sampson	24.56 a	5.25 a	8.188 a	1.75 a
Sweet Slice	16.82 a	2.834 ab	8.333 a	1.389 a
Dynamite	25.75	11	8.583	3.667
JTP546	22.87	9.50	8.4	3.5
Ooak	17.4	7.75	5.802	2.58
JTP511	18.834 a	6.75	6.278 a	2.25
JTP534	11.38 b	8.25	3.793 b	2.75
PUB8856	3.555 c	5.75	1.185 c	1.917
PUB8912	7.473 bc	10.25	2.491 bc	3.417
PUB8913	3.878 c	4.75	1.293 c	1.583

Discussion

Zucchini

Zucchini yield and disease severity did not appear to be well correlated, with varieties such as Crowbar and TZU1759 producing significantly higher yields. At the same time, high levels of mildew were present, both powdery and downy. Powder mildew appeared gradually into the crop with infection appearing on the lower leaves and only gradually infecting other lower leaves, stems and petioles. Downy mildew however was a rapid disease brought on by favourable wet conditions. One week there was almost no infection present, apart from one or two spots, to moderate to high levels of infection within the pace of a week. Once the downy mildew started, the zucchini varieties quickly deteriorated leading to a loss of all the lower leaves within three weeks of infection. Only the upper copy was relatively free from infection. This would most likely be due to the increased air flow around this part of the plant and the fact that the new foliage quickly dries out in the morning leaving little time for the downy mildew spores to germinate.

Pumpkins

The butter nut pumpkin varieties were the most susceptible of the three pumpkin types to both powdery and downy mildew. Within the three types of pumpkins there was very little difference between the Jap types, which all performed well with no significant differences in yield. The Jaradale types exhibited variable results with Sweet Slice and Carbine performing poorly against Gunsynd and Sampson which also appeared to reflect in the yield with Carbine having the least yield followed by Sweet Slice. Within the butternut type pumpkins, PUB8856 and PUB8913 were the most susceptible to the two types of mildews and as a result had some of the lowest yields. Even though the butternut pumpkins had smaller canopies they were more susceptible to mildew issues and would most certainly need some sort of fungicide treatment or alternative to try and manage these disease problems.

Conclusion

There is clearly a large number of zucchini and pumpkin varieties on offer by the various seed companies with more being available each year. Some of these have claims for mildew tolerance or resistance as well as one or more virus resistances. The numbers tested in the two trials on the Gatton Research Station is only a small number of what is currently available to growers. Of those tested there was no outstanding zucchini variety that was tolerant to the mildews with greater yields. Some varieties were more open than others but still became infected. What was clear was that once the zucchinis did become infected, particularly with powder mildew, they still produced fruit. The varieties Amanda, Calida, Crowbar and Paydirt had similar levels of powdery mildew infection during the spring and autumn season, whereas Congo, Regal Black and JTZ905 were worse during the autumn trial. The yield, although down in autumn, did show a similar trend. The fact that there was less fruit in autumn could be due to the combined effect of mildew diseases and the presence of papaya ring spot virus in the crop, which also spread rapidly once established. Future trials will look at just how important fungicide applications are to increasing the over all yield of a crop or whether doing nothing will result in the same level of fruit number from a crop.

The Jap type pumpkins appeared to be the most tolerant to the mildews, in particular powdery mildew, followed closely by the Jaradale types. The butternuts were by far the worse for contracting mildew infection. Only a small number of varieties were assessed in these trials with many more available through the seed companies. The powdery mildew infection levels were similar during the two seasons on the outer vine leaves. As with the zucchinis, the pumpkins yielded far less fruit per plot during the autumn trial even though they were grown the same way. The combination of diseases could have been a factor in the reduced yield indicating that this time of the year is not as conducive to growing pumpkins or zucchinis in this growing region.

Efficacy of Alternative Treatments to Powdery and Downy mildew Management in Zucchini and Pumpkin.

Summary
Fungicides and spray products alternatives to fungicides were evaluated in zucchini and pumpkins planted in two field trials in Gatton. Plantings were carried in spring and autumn, in order to evaluate control of powdery mildew and downy mildew, respectively. The alternative products were sprayed weekly and tested individually in spray programs. The assessments of relative efficacies of sprayed products indicated that good alternatives for powdery and downy mildew control were sulphur and phosphorous acid, respectively. Overall, conventional fungicides used on their own gave better control than any of the softer option products tested. At the spray rate used, the responses of using Bion for control of mildews in zucchini was variable. In some cases, phytotoxicity in the form of stunting and reduced yield was observed in plants. Spraying Bion led to low disease severity levels of both diseases in pumpkins. This warrants additional work to determine optimal spray rates and spray timing for Bion. These trials did not investigate spray programs that used combinations of conventional fungicides and alternative products, nor the inclusion of cultivars with moderate resistance to foliar diseases into spray programs.

Powdery Mildew Trial - Spring 2009

Introduction

Powdery and downy mildew are two of the most important foliar diseases of cucurbits. They are both obligate parasites surviving only on volunteer cucurbits or weed species within this family. Powdery mildew can however survive as cleistothecia which protect the spores within this structure enabling it to survive a range of temperatures. This disease can be found from spring through to autumn and prefers a relatively high humidity. Spores of powdery mildew are however readily washed off the plant with rainy weather or heavy overhead irrigation. Downy mildew produces spores under very high humidity and needs free moisture on the plant for germination. Wet showery weather or periods of fog or heavy dew, results in rapid development of downy mildew with temperatures between 18 and 23ºC being ideal.

Powdery mildew is most likely to develop when the plant is stressed in some way such as flowering and fruiting. The white mildew appearance is due to the presence of surface mycelium and the large numbers of spores produced by this disease which are spread by wind. Powdery mildew prefers drier conditions compared to that of downy mildew for spore germination, with the disease starting off as small white spots on the leaves usually starting on the underneath side of the leaf. This disease can also be found attacking the stem and petioles.

Spring is the most appropriate time for powdery mildew trial work as this is generally a period of low rainfall, with moderate to high temperatures and moderate to high relative humidity. Downy mildew is generally not an issue during this time as the temperature doesn’t get low enough and there is generally not a lot of rain, which is needed for the spores to germinate. Downy mildew is more of an issue during the late summer and autumn periods when wet weather accompanied by cooler temperatures is common.

Two trials were conducted at the Agri-Science Queensland Gatton Research Station (GRS) to assess the efficacy of a number of fungicide alternative treatments against powdery mildew in a spring planted crop and downy mildew in an autumn planted crop.

Materials and Methods

Trial site

The trial site was prepared using plastic mulch and trickle irrigation T-Tape. Each zucchini plot was 4m long and planted out with 6 plants of the variety Congo, which had been grown in the small pots in the glasshouse for four weeks. Plants were spaced 55cm apart. A buffer row of zucchinis was planted between each data plot.

The pumpkins which had been grown in small pots in the glasshouse for four weeks were planted 1m apart with 3 plants per plot. The plots were essentially 6m x 6m to allow for the spread of the plants. Standard agronomic practices for irrigation, weed control, insect pest management and fertigation were implemented and fungicides and fungicide alternatives were applied according to treatment allocation.

Treatments

Nine alternative treatments (Table1), a standard industry practice treatment (Fungicides), a new product formulation (Amistar Top) and an untreated control, were assessed using a Randomised Complete Block Design with 4 replications.

Treatments to zucchini plots were applied using a motorised backpack sprayer with a hand held boom. Small plants were sprayed using a two nozzle boom delivering 500L/ha, moderate sized plants were sprayed with a three nozzle boom delivering 530L/ha while the larger mature plants were sprayed with a 4 nozzle boom delivering 560L/ha. Pumpkin treatments were initially applied using the 4 nozzle hand held boom until the plants were too spread out, at which time treatments were applied by a tractor boom spray delivering 600L/ha of water. Bion treatment was applied to both zucchini and pumpkin plants before infection was present to stimulate the plants immune defence response.

Table 1: List of Treatments applied for powdery mildew control

	Active ingredient	Trade name
1	Microgranule sulfur	Thiovet Jet
2	Copper octanoate (Copper soap)	Tricop
3	Potassium bicarbonate	Ecocarb
4	Soluble silicon (potassium silicate)	Silmatrix
5	Neem (*Azaridachta indica*) oil	Azamax
6	Canola oil	Synertrol Horti Oil
7	Acibenzolar-s-methyl	Bion 50 WG
8	Chitosan (poly-D-glucosamine) [fish/sea shell protein + trace elements]	Aminogro
9	Milk powdered full-fat (5-10%)	
Controls:		
10	Fungicides program, various actives	Nimrod, Bravo, Spinflo, Amistar, Sulfur
11	Azoxystrobin + difenoconazole	Amistar Top
12	No spray	

Table 2: Spray schedule for the treatments during the life of the trial.

Treatments		**Spray dates**							
	Trade name	**6 Oct**	**13 Oct**	**20 Oct**	**4 Nov**	**11 Nov**	**18 Nov**	**25 Nov**	**2 Dec**
1	Thiovet				√	√	√	√	√
2	Tricop				√	√	√	√	√
3	Ecocarb				√	√	√	√	√
4	Silmatrix				√	√	√	√	√
5	Azamax				√	√	√	√	√
6	Synertrol Horti Oil				√	√	√	√	√
7	Bion 50 WG	√	√	√	√	√	√	√	√
8	Aminogro				√	√	√	√	√
9	Milk Powder				√	√	√	√	√
10	Fungicides				√	√	√	√	√
11	Amistar Top				√	√	√	√	√
12	Unsprayed control								

Zucchini analysis

Disease severity was assessed on the stems and leaves of 4 tagged data plants within each plot. Assessments commenced on the 12th October 2009 and continued until the 30th November 2009. Powdery mildew on the leaves was given a rating on a 0-5 scale as indicated in Table 3 below. Ratings were given to two mid canopy leaves and two lower canopy leaves that were not showing signs of senescing or necrosis. Powdery mildew was assessed on both the upper and lower surfaces of these leaves. The ratings were then averaged per leaf for the data analyses. The stem infection was rated as a percentage infection (0%, 25%, 50%, 75% or 100%). The effect of disease severity on yield was determined by harvesting fruit two days per week from four plants in each plot over a six week period. Number of fruit and weight of fruit were recorded for each treatment.

Table 3. Powdery mildew disease severity ratings on the leaves of zucchini and pumpkins.

Severity levels	Area of leaf covered with disease (%)
0	0
1	0.3 - 4.7
2	5 - 9.7
3	10 - 29.7
4	30 - 74.7
5	75 - 100


Figure 1. Zucchini plant with severe powdery mildew infection on the lower leaves. This would have been assessed as a rating 5 on the upper leaf surface.

Pumpkin analysis

Three plants of the variety Sampson were planted 1m apart in plots 6m long on beds with 6m centres. Assessments commenced on the 12th October 2009 and continued until the 7th December 2009. Three vines were selected either side of the mulched bed and a leaf midway between the crown and terminal point of the vine, equivalent to the mid canopy, was used for assessment. A leaf from each plant centre was also assessed. Powdery mildew severity was assessed on the upper and lower surface of the leaf as per the zucchini assessment and rating scale in Table 3. The effect of disease severity on yield was determined by harvesting the fruit and recording the total number and weight of fruit per plot and the number and weight of fruit per plant.

Data analysis

Rating data was averaged for the top and bottom leaf surfaces and analysed using a REML algorithm generating a spline graph.

Rating data for disease severity on zucchini stem and petiole was analysed using a general ANOVA.

Zucchini yield was assessed using the parameter Number of Fruit per Plant, and the data analysed by general ANOVA.

As with the Zucchini, pumpkin rating data was averaged for the top and bottom leaf surfaces and analysed using a REML algorithm generating a spline graph.

Pumpkin yield was assessed using the parameter, Weight of Fruit per Plant, and the data analysed by general ANOVA.

Results

Zucchini

Disease severity rating data was averaged across the top and bottom leaf surfaces and data was adjusted using a square root transformation and then back transformed to the 0-5 rating scale. There were significant differences (at the P=0.050 level) between treatments from 63 Days After Transplant (DAT). Powdery Mildew infection was higher in the lower canopy.

In the mid canopy at 63, 70 and 77 DAT all treatments were significantly better than the control. The Sulfur, Fungicides and Amistar Top were significantly better than all other treatments as shown in Figure 2. The alternative products Aminogro, Azamax, Bion, Ecocarb, Milk, Silicon, Synertrol Hort Oil, and Tricop showed little difference between each other until the last assessment 77 DAT at which time Milk and Tricop exhibited a slight improvement over Silicon, Ecocarb, Aminogro and Synertrol Hort Oil.

In the lower canopy, at 63 DAT, Milk, Tricop, Silicon, Bion, Aminogro, Sulfur, Fungicides and Amistar Top treated plots were all significantly better than the control treatment. At 70 DAT the Aminogro, Sulfur, Fungicide and Amistar Top treated plots were better than the control, but by 77 DAT only Sulfur, Fungicides and Amistar Top treatments were significantly better than the control. The Amistar Top treatment was significantly better than all other treatments on both 70 and 77 DAT across both canopy positions. The standard Fungicide regime was better than all other alternative fungicide options except for Sulfur in the lower canopy at 77DAT and mid canopy at 63DAT (see Figure 3).

Of the fungicide alternatives investigated, Sulfur gave significantly better disease control than all other alternative soft option treatments across both canopy positions (lower and mid) and all sampling dates (Figures 2 & 3)).

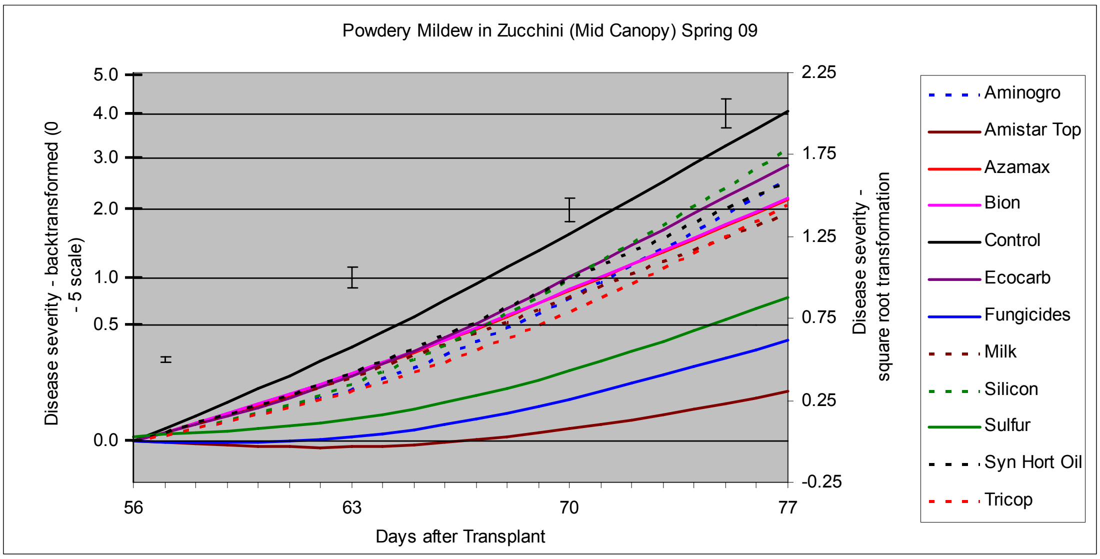

Figure 2. The effect of fungicide treatments on powdery mildew in zucchini mid-canopy, Gatton Research Station, Spring 2009.

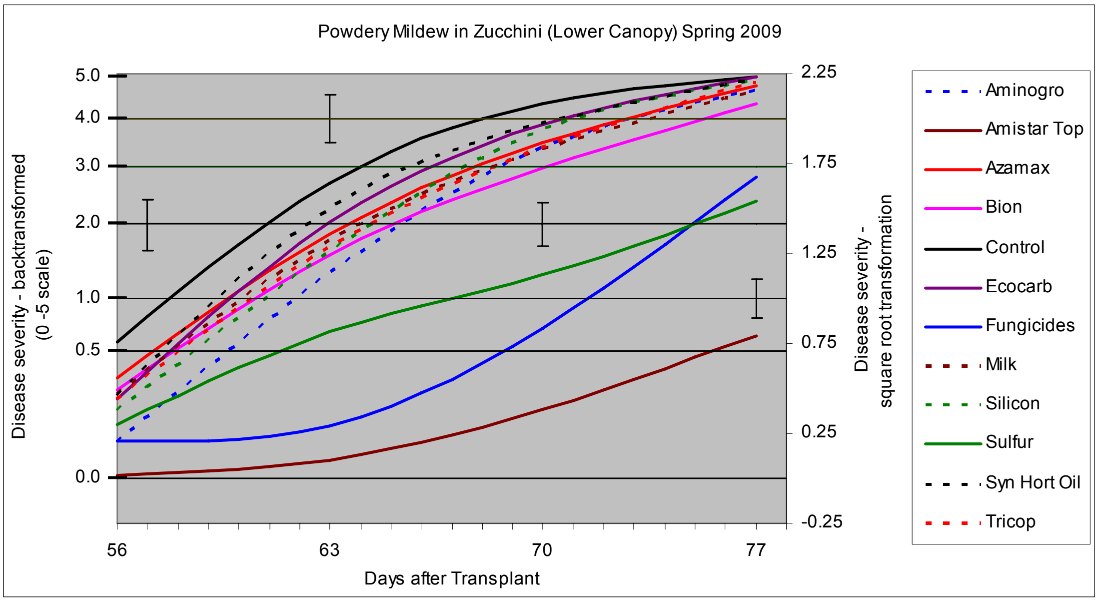

Figure 3. The effect of fungicide treatments on powdery mildew in zucchini lower canopy, Gatton Research Station Spring 2009.

Figure 4. Unsprayed Control plot of zucchini, 77 days after transplanting.

Figure 5. Sulfur treated plot of zucchini 77 days after transplanting.

There were significant differences at the P = 0.050 level in powdery mildew severity on the stem and petiole. At 70 DAT all other treatments had significantly less powdery mildew infection than the control treatment. Sulfur, Amistar Top, Bion and the Fungicide treatments were significantly better than the other treatments at 70 DAT. At 77 DAT, Milk, Azamax, Bion, Fungicides, Amistar Top and Sulfur had less powdery mildew than the control. The Fungicide, Amistar Top and Sulfur were the most effective at controlling infection (see Table 4 below).

Table 4. Powdery Mildew Severity on Stem and Petiole

70 DAT			77 DAT		
TREATMENT	mean	subscript	TREATMENT	mean	subscript
Control	33.75	a	Control	72.92	a
Ecocarb	20.42	b	Ecocarb	70.83	ab
Syn Hort Oil	19.17	bc	Aminogro	70.83	ab
Milk	14.17	bc	Silicon	70.83	ab
Tricop	13.33	bc	Tricop	70.83	ab
Aminogro	10.42	bcd	Syn Hort Oil	68.75	abc
Silicon	8.75	cd	Milk	61.25	bc
Azamax	8.33	cd	Azamax	59.17	c
Sulfur	1.67	d	Bion	45.83	d
Amistar Top	0	d	Fungicides	2.08	e
Bion	0	d	Amistar Top	0	e
Fungicides	0	d	Sulfur	0	e
LSD =	11.05		LSD =	10.73	

NB: Means with same subscript are not significantly different at the P = 0.050 level

Yield

Only one treatment, Silicon, yielded significantly more fruit than the control. The plots treated with Bion gave a significantly lower yield than those plots treated with Silicon, Sulfur and Fungicides and Amistar Top. See Table 5 and Figure 6.

Table 5: Zucchini Yield, number of fruit per plant.

Treatment	Number of Fruit per Plant	
Silicon	26.75	a
Fungicides	25.08	ab
Sulfur	25.08	ab
Amistar Top	24.08	abc
Control	23.42	bcd
Ecocarb	23.08	bcd
Aminogro	22.67	bcd
Azamax	22.67	bcd
Tricop	22.25	cd
Milk	21.92	cd
Syn Hort Oil	21.58	cd
Bion	21.17	d

Means with same subscript are not significantly different at the P = 0.050 level

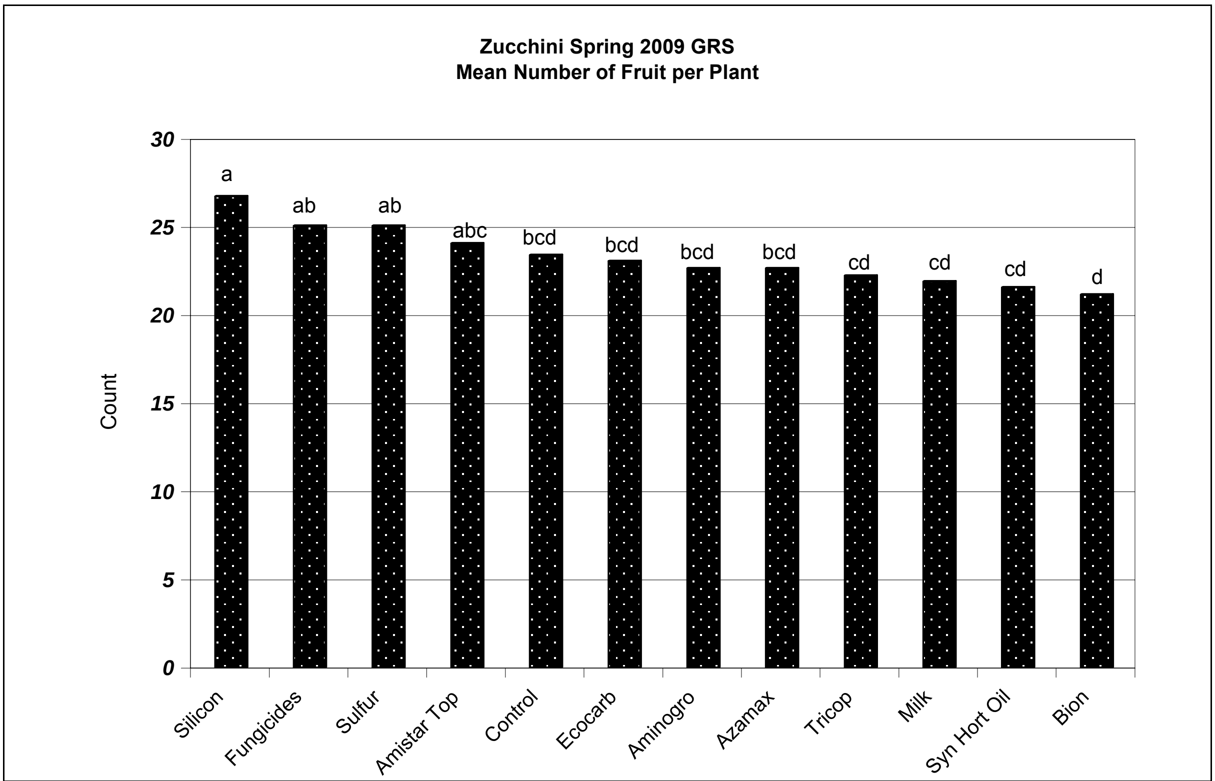

Figure 6. Zucchini Yield. Mean number of fruit per plant. Means with same subscript are not significantly different at the P = 0.050 level.

Pumpkin

Assessments were conducted until 84 DAT, 1 week prior to harvest.

Outer vine leaves and centre leaves were assessed and rated using the criteria in Table 2. There were significant differences between treatments within spray application dates (at the P=0.050 level) from 63 DAT in both the outer and centre vines.

Fungicide, Bion and Amistar Top treated plots were significantly better than the Control at all assessment dates of the outer vines (63, 70, 77 and 84 DAT). At 70 DAT Aminogro and Sulfur were also significantly better than the Control and at 77 DAT Aminogro, Sulfur, Azamax, Ecocarb and Tricop were significantly better than the control. By 84 DAT Azamax was the only alternative treatment that was significantly better than the control. (Figure 7).

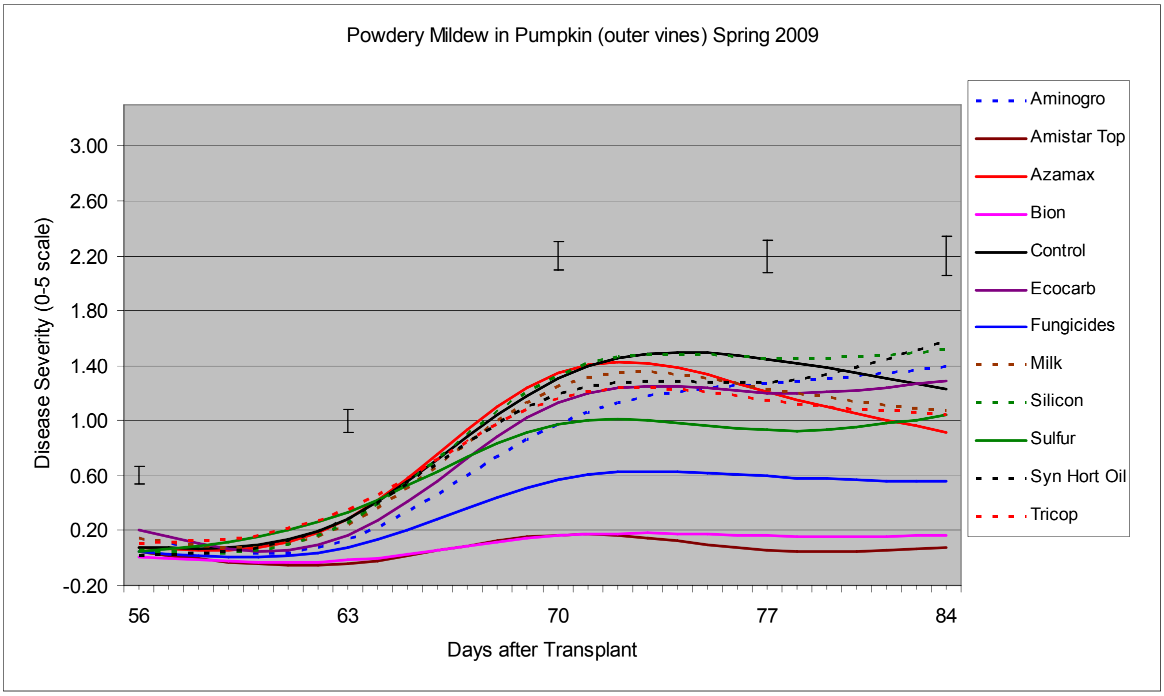

Figure 7. The effect of fungicide treatments on powdery mildew in pumpkin outer vine leaves, Gatton Research Station, Spring 2009

Assessment of the pumpkin centre leaves demonstrated that Amistar Top, Bion, the Fungicide regime and Sulfur were all more effective at controlling powdery mildew than the unsprayed control on all assessment days (63, 70, 77, 84 DAT). The only other products that were better than the control were Aminogro at 77DAT and Azamax and Milk at 84 DAT (see Figure 8). Assessment of the centre leaves was complicated by consistency of leaf selection towards the end of the sampling dates (77 and 84DAT) as older leaves became senescent and were replaced by fresh leaves.

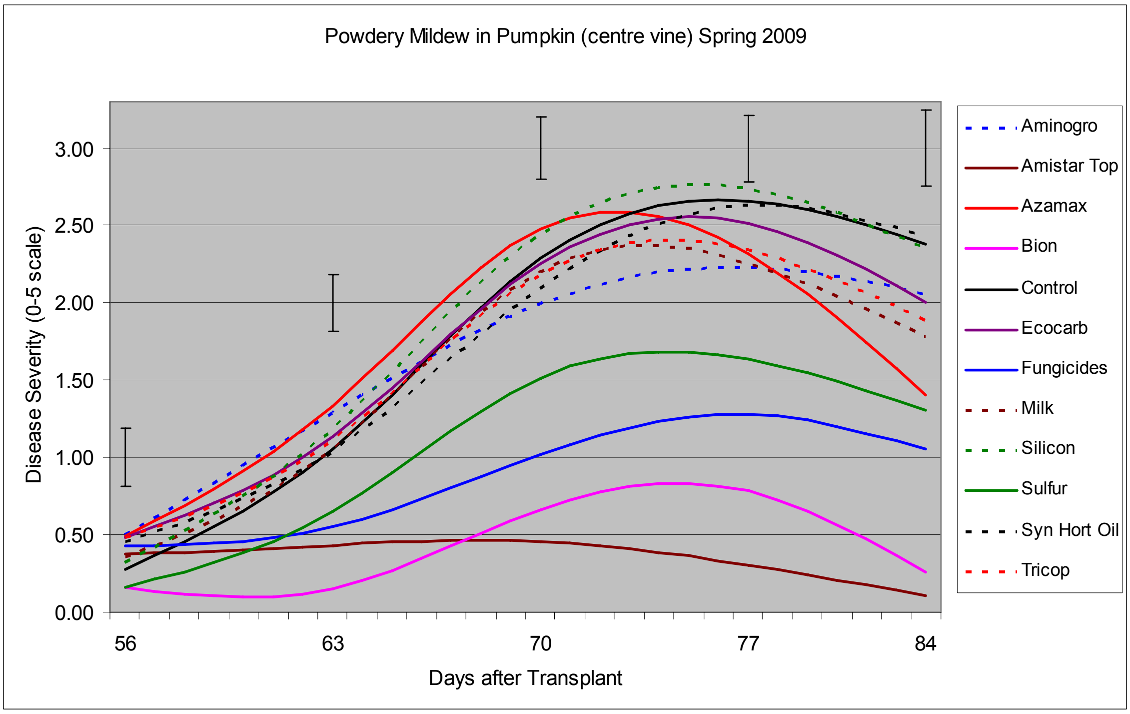

Figure 8: The effect of fungicide treatments on powdery mildew on pumpkin centre leaves, Gatton Research Station, Spring 2009

Yield

As shown in Figure 9 below, there was no significant increase in yield in any of the treated plots compared to the untreated control plots (at the P=0.050 level). Plots treated with Tricop gave significantly higher yields than the Milk and Bion treated plots but was not significantly different to the other treatments. The use of Milk for powdery mildew control was worse than most other treatments, although this was not a significant difference. Bion had half the weight that the control plots achieved and was significantly worse than all other treatments.

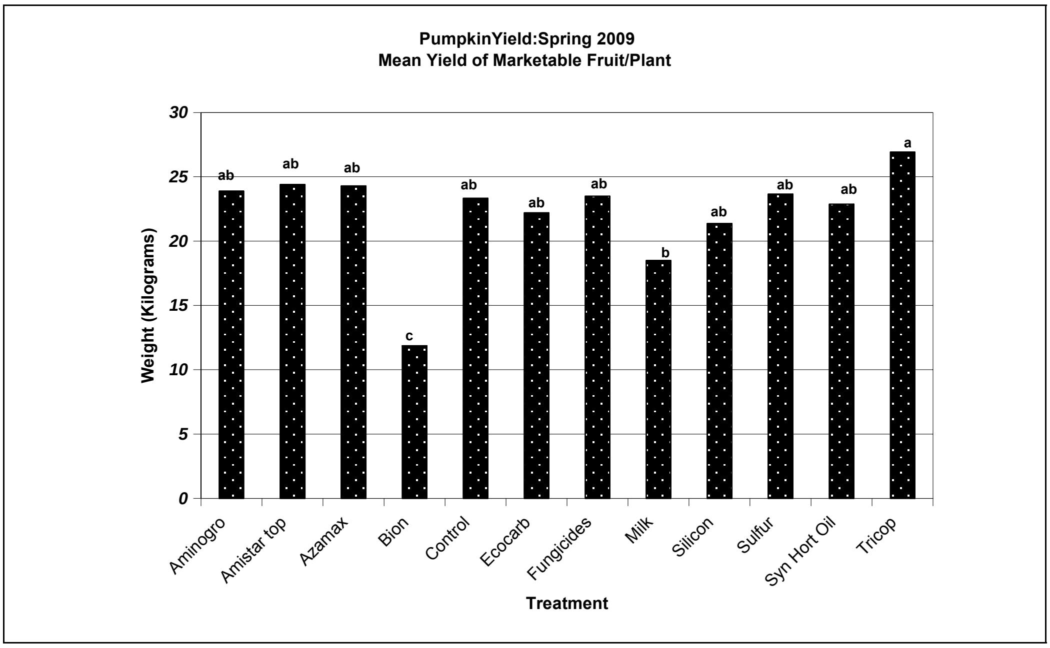

Figure 9. Mean weight of marketable fruit per plant for pumpkin, Gatton Research Station, Spring 2009.

Discussion

Amistar Top was the most effective treatment for the control of powdery mildew in both zucchini and pumpkin plots during Spring 2009. The Fungicide treatment was also highly effective in both crops. Sulphur proved to be a highly effective alternative fungicide treatment for controlling powdery mildew in zucchinis but only slightly better than the other alternative products used in the pumpkins. This may be due to the nature of the plant architecture with pumpkins producing a more dense canopy limiting penetration of the spray and limiting the deposition of spray droplets on the underneath side of the leaves where infection appears first. At 77 DAT Sulphur was as effective as the conventional Fungicide in zucchinis for controlling the disease in the lower canopy where the disease is most prevalent.

In the zucchini mid canopy all treatments were more effective at controlling powdery mildew than the unsprayed control treatment. However, the plants in all treatments except the Sulphur, Fungicides and Amistar Top treatments still exhibited moderate levels of disease. In the zucchini lower canopy, some alternative treatments were initially better than the control, however their effectiveness declined over the sampling period so that only Sulphur was significantly better by the last sampling date. This was also evident on the stem and petioles with very little mildew present in these treatments.

The use of Bion as a plant defence activator exhibited mixed results. It was very effective at controlling powdery mildew on pumpkins but was not as effective in zucchinis. Bion was as effective as Amistar Top and better than either the Fungicide of Sulfur treatments. However, during the course of the trial Bion treated plants were noticeably smaller and more stunted than other plants both for pumpkins and zucchinis. While Bion appears to give good control of powdery mildew in pumpkin, yield was significantly reduced in Bion treated plots. There was a similar response in the zucchinis with Bion having the lowest number of fruit per plant. It would appear that at the rate used in this trial, Bion has a phytotoxic effect on both pumpkin and zucchini plants. The number of applications of Bion could also have played a role in this response. Instead of eight applications perhaps only weekly applications until the first sign of infection would have been better or even fortnightly applications instead of weekly.

Figure 10. A pumpkin plot at GRS treated with Bion, 80 days after transplanting. The Biomass of these plants is noticeably less than other plots.

All other treatments, Aminogro, Azamax, Ecocarb, Milk, Silicon and Synertrol Hort Oil were all similar in their performance to the unsprayed control, they did little in the way of improving control of powdery mildew.

There was very little difference in zucchini yield between treatments, with Silicon being the only treatment that was significantly better than the unsprayed control. The mean number of fruit per plant varied from just over 21 fruit in the Bion to just under 27 fruit for the Silicon with the control in the middle with just over 23 fruit per plant. Even the best disease control treatments of Amistar Top, Fungicides and Sulfur did not have significantly better yield than the control.

Silicon was one of the worst performers with severe infection rating on the lower leaves and moderate levels of infection to the mid-canopy leaves. Whereas a relatively disease free treatment such as Amistar Top was no better at producing fruit. Therefore it appears that disease severity of up to 10% of leaf surface in the mid canopy and over 55% in the lower canopy has little effect on zucchini crop yield.

It was a similar story with the pumpkins with no clear correlation between reduced powdery mildew incidence and increased yield. Bion was the only treatment that was significantly worse than the unsprayed control treatment. All other treatments, including the use of Fungicides and Amistar Top were not significantly different from the control. As with the zucchini crop, doing nothing would still give the same result or similar. A grower needs to weigh up the costs associated with applying a treatment against the marginal increase in yield and what return might be expected from the harvested fruit.

During this trial the fungicides used in the Fungicide treatment were rotated to simulate Standard Industry Practice, while Amistar Top was applied every spray date without rotation with another fungicide. In practice this would not be done as resistance would develop rapidly to a chemical used in this manner, limiting its long term use.

To control powdery mildew in both zucchini and pumpkin crops Sulfur is an effective alternative to conventional fungicides. A standard fungicide regime gives good control and Amistar Top would be highly effective as a component in such a fungicide rotation.

However, under the growing conditions experienced during this trial, yield was not greatly impacted by the disease severity expressed during the life of the crop. The cost of applying fungicides or fungicide alternatives therefore needs to be taken into account when deciding to spray. Further research needs to be conducted to determine whether yield is adversely affected under different growing conditions before we could conclusively determine that this level of disease severity would not significantly impact yield.

Downy Mildew - Trial Autumn 2010

Materials and Methods

Trial site
The trial was conducted at the Agri-Science Queensland Gatton Research Station (GRS) to assess the efficacy of a number of fungicide alternative treatments on the fungal disease Downy Mildew.

The trial site was prepared using plastic mulch and trickle irrigation T-Tape. Each zucchini plot was 4m long and direct seeded with the variety Amanda; plants were spaced 55cm apart. A buffer row of zucchinis was sown between each data plot.

The pumpkin variety Carbine was direct seeded 1m apart with 3 locations per plot. Rows were 6m apart to allow for the spread of the plants. Standard agronomic practices for irrigation, weed control, insect pest management and fertigation were implemented and fungicides and fungicide alternatives were applied according to treatment allocation. All plots were treated with the fungicide Nimrod to suppress the disease powdery mildew, as the presence of this disease damages leaves and can interfere with the accurate rating of downy mildew severity.

The zucchini variety Amanda and the pumpkin variety Carbine were selected, as earlier trials indicated their susceptibility to downy mildew. Beds were direct seeded on the 3rd February 2010.

Treatments
Nine alternative treatments (Table 6), a Standard Industry Practice treatment (Fungicides), a new product formulation (Amistar Top) and an untreated control, were assessed using a Randomised Complete Block Design with 3 replications for zucchinis and pumpkins. Treatments to zucchini plots were applied using a motorised backpack sprayer with a hand held boom. Small plants were sprayed using a two nozzle boom delivering 500L/ha, moderate sized plants were sprayed with a three nozzle boom delivering 530L/ha while the larger mature plants were

sprayed with a 4 nozzle boom delivering 560L/ha. Pumpkin treatments were initially applied using the 4 nozzle hand held boom until plants were too spread out, at which time treatments were applied by a tractor boom spray delivering 600L/ha of water.

Table 6. List of treatments applied for downy mildew.

	Active ingredient	Trade name
1	Copper octanoate (Copper soap)	Tricop
2	Copper acetate	Liquicop
3	Potassium bicarbonate	Ecocarb
4	Phosphonic acid	Agri-fos 600
5	Hydrogen dioxide	Peratec
6	*Azaridachta indica* oil	Azamax
7	Canola oil	Synertrol Horti Oil
8	Acibenzolar-s-methyl	Bion 50 WG
9	Chitosan (poly-D-glucosamine) [fish/sea shell protein + trace elements]	Aminogro
10	Fungicides program – various actives	Amistar, Acrobat, Liquicop, Mancozeb, Polyram, Ridomil Gold
11	Azoxystrobin + difenoconazole	Amistar Top
12	Unsprayed control	

Table 7. Spray schedule for the treatments during the trial period.

Treatments		Spray date					
		20DAP	**30DAP**	**35DAP**	**43DAP**	**50DAP**	**56DAP**
	Trade name	**23-Feb**	**5-Mar**	**10-Mar**	**18-Mar**	**25-Mar**	**31-Mar**
1	Tricop	√	√	√	√	√	√
2	Liquicop	√	√	√	√	√	√
3	Ecocarb	√	√	√	√	√	√
4	Agri-fos 600	√	√	√	√	√	√
5	Peratec*	√	√	√	√	√	√
6	Azamax	√	√	√	√	√	√
7	Synertrol Horti Oil	√	√	√	√	√	√
8	Bion 50 WG	√	√	√	√	√	√
9	Aminogro	√	√	√	√	√	√
10	Fungicides	√	√	√	√	√	√
11	Amistar Top	√	√	√	√	√	√
12	No spray						

* This product was only sprayed on the zucchini trial due to a limited amount available for this trial.

Zucchini analysis

Inspection of the plants on the 22nd February showed the plants to be healthy except for isolated leaf spots of potential Downy Mildew infection. As wet weather was predicted for the following 10 days the first treatments were applied on the 23rd February. Assessment for Downy Mildew Severity and Yield commenced on the 9th March with final assessment conducted on the 29th March 2010.

Disease severity was assessed on the leaves of four tagged data plants within each plot. Downy mildew on the leaves was given a rating on a 0-5 scale as indicated in Table 8 below. Ratings were given to two mid canopy leaves and two lower canopy leaves that were not showing signs of senescing or necrosis. The effect of disease severity on yield was determined by harvesting fruit two days per week from four plants in each plot over a four week period. Number of fruit and weight of fruit were recorded for each treatment.

Table 8. Downy mildew disease severity ratings on the leaves of zucchinis and pumpkins.

Severity levels	Area of leaf covered (%)
0	0
1	0.3 - 4.7
2	5 - 9.7
3	10 - 29.7
4	30 - 74.7
5	75 - 100

Figure 11. Severe downy mildew infection in zucchini plot, untreated control.

Pumpkin analysis

Three vines were selected either side of the mulched bed and a leaf midway between the crown and terminal point of the vine, equivalent to the mid canopy, was used for assessment. A leaf from each plant centre was also assessed. Downy mildew severity was assessed on the leaf as per the zucchini assessment and rating scale in Table 8. The effect of disease severity on yield was determined by harvesting the fruit at maturity and recording the total number and weight of fruit per plot and the number and weight of fruit per plant. The pumpkins were harvested on the 20th April 2010 (76 DAP).

Data analysis

A REML algorithm generating a spline graph was used to assess the downy mildew rating results. For the pumpkin outer vines, the residual plots showed increased variance over the fitted values, so the data was transformed to stabilize these variances. Data was adjusted using a square root transformation and then back transformed to the 0-5 scale.

Zucchini yield was assessed using the parameter Number of Fruit per Plant, and the data analysed using a general ANOVA. Pumpkin yield was assessed using the parameter, Weight of Fruit per Plant, and the data analysed by general ANOVA.

Results

Zucchini Disease Severity

There were significant differences (at the P=0.050 level) between treatments from 34 Days After Planting (DAP). Downy Mildew infection was higher in the lower canopy.

In the lower canopy, Figure 12 below, the Fungicide regime was significantly better than the Control at all assessment dates and Amistar Top was better at 34, 41 and 55 DAP, while the Agrifos treatment was better at 34 DAP and the Liquicop and Bion treatments were significantly better than the Control at 55 DAP. Peratec was significantly worse than the Control at 41 and 48 DAP and Synertrol Hort Oil and Tricop were worse at 41 DAP.

In the mid canopy, Figure 13 below, Bion, Fungicides and Amistar Top were better than the Control at 41, 48 and 55 DAP. Agrifos was better at 48 and 55 DAP. At 41 DAP Ecocarb and Azamax were significantly worse than the Control. There were no significant differences between treatments in the mid canopy at 34 DAP

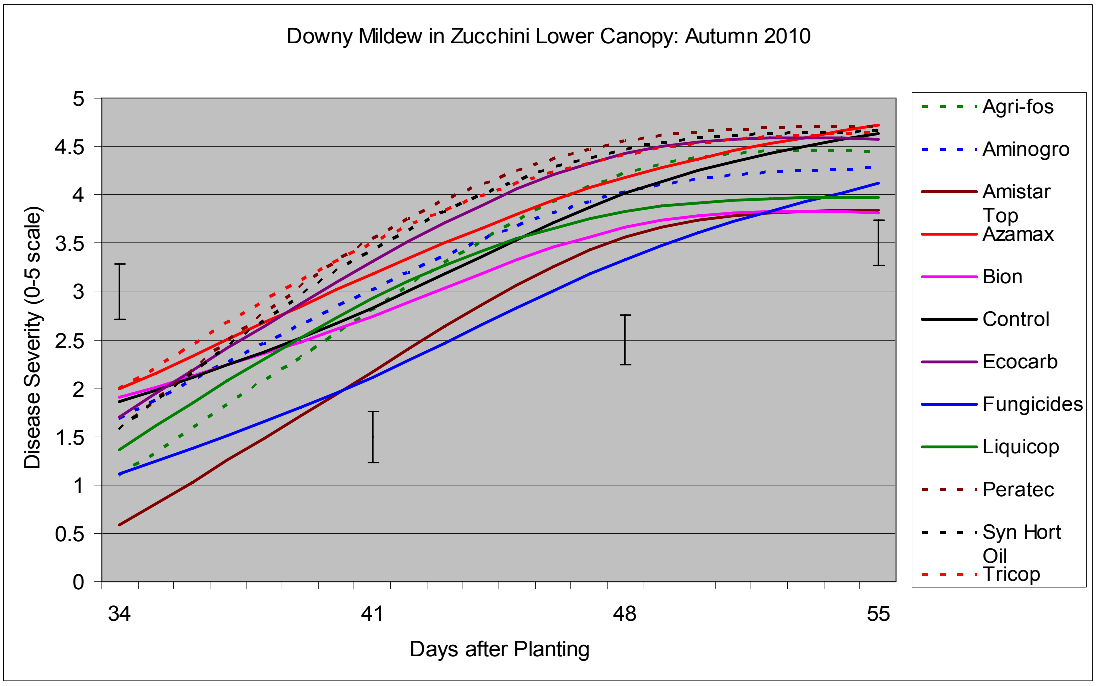

Figure 12. The effect of treatment on downy mildew severity in the zucchini lower canopy.

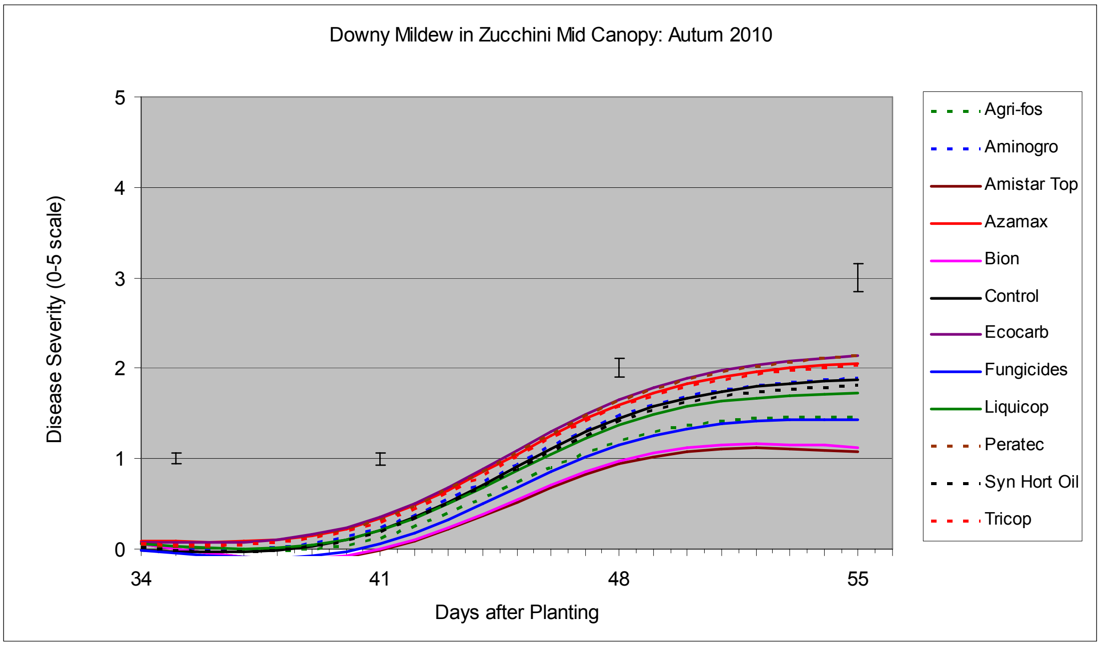

Figure 13. The effect of treatment on downy mildew severity in the zucchini mid canopy.

Zucchini Yield

Zucchini plants were only harvested over a 3 week period due to severe infection from downy mildew and virus. This is half the time that a grower would normally harvest a zucchini crop for. There were no significant yield differences between the Control treatment and any other treatment at the P= 0.050 level. Bion and Amistar Top yielded significantly more fruit than Peratec, Azamax and Aminogro.

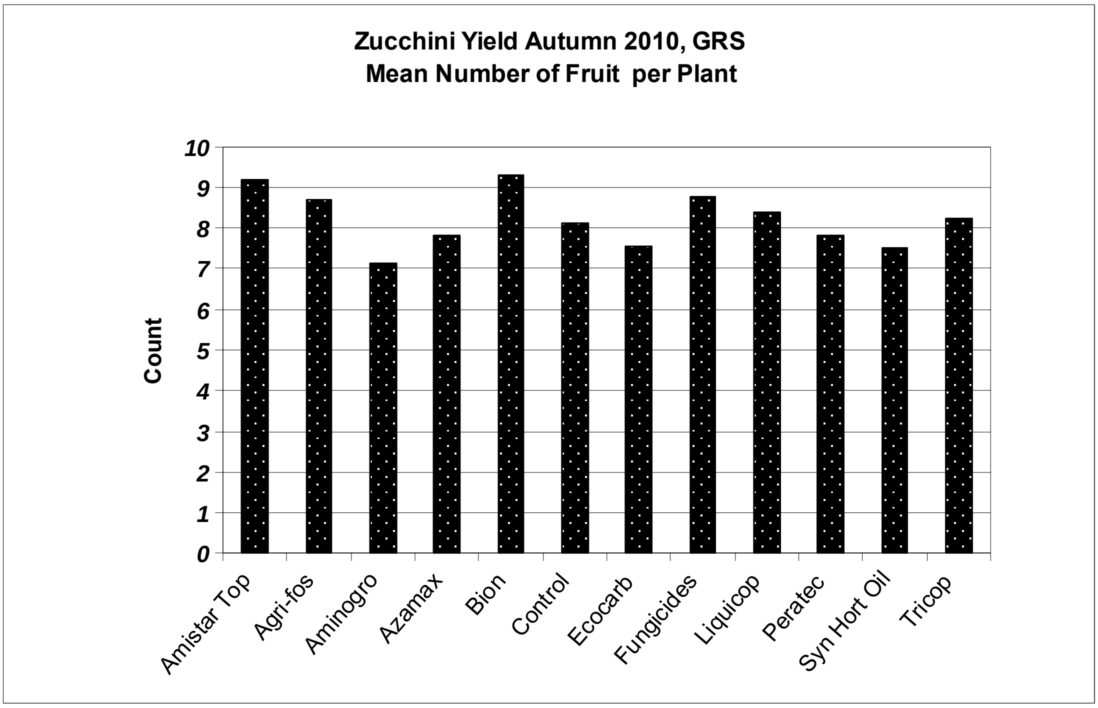

Figure 14. Mean number of fruit per plant harvested from Zucchinis at GRS in Autumn 2010.

Table 9. Mean number of fruit per plot in each treatment during life of crop, Gatton Research Station, Autumn 2010.

Treatment	Mean
Bion	9.3 a
Amistar Top	9.2 a
Agri-fos	8.8 ab
Synertrol Hort Oil	8.8 ab
Fungicides	8.8 ab
Liquicop	8.7 ab
Tricop	8.3 ab
Control	8.1 abc
Ecocarb	8.0 abc
Peratec	7.6 bc
Azamax	7.5 bc
Aminogro	6.8 c
lsd	1.4

NB: Means with same subscript are not significantly different at the P=0.050 level

Virus infection became widespread during the trial and impacted yield and assessment ratings. Table 10 shows the number of plants from a total of 12 that were showing symptoms of virus infection at the final assessment, 55DAP.

Table 10. Plants affected by virus at final assessment 55DAP.

Treatment	Number of Plants
Amistar Top	6
Agri-fos	7
Aminogro	12
Azamax	10
Bion	5
Control	11
Ecocarb	12
Fungicides	8
Liquicop	10
Peratec	12
Syn Hort Oil	6
Tricop	10

Figure 15. Zucchini plants affected by virus.

Pumpkin Disease Severity

Downy mildew severity was more pronounced on the central leaves with infection reaching nearly 4 on the rating scale while the outer vine leaves only averaged a rating of 2. Bion was significantly better than all other treatments including the untreated control at 48 DAP, 55 DAP and 62 DAP for the outer vine leaves and the centre leaves. At 69 DAP Bion was still significantly better than all other treatments on the centre leaves but there was no significant difference between the untreated control and all other treatments at 69 DAP although Bion was the better performer.

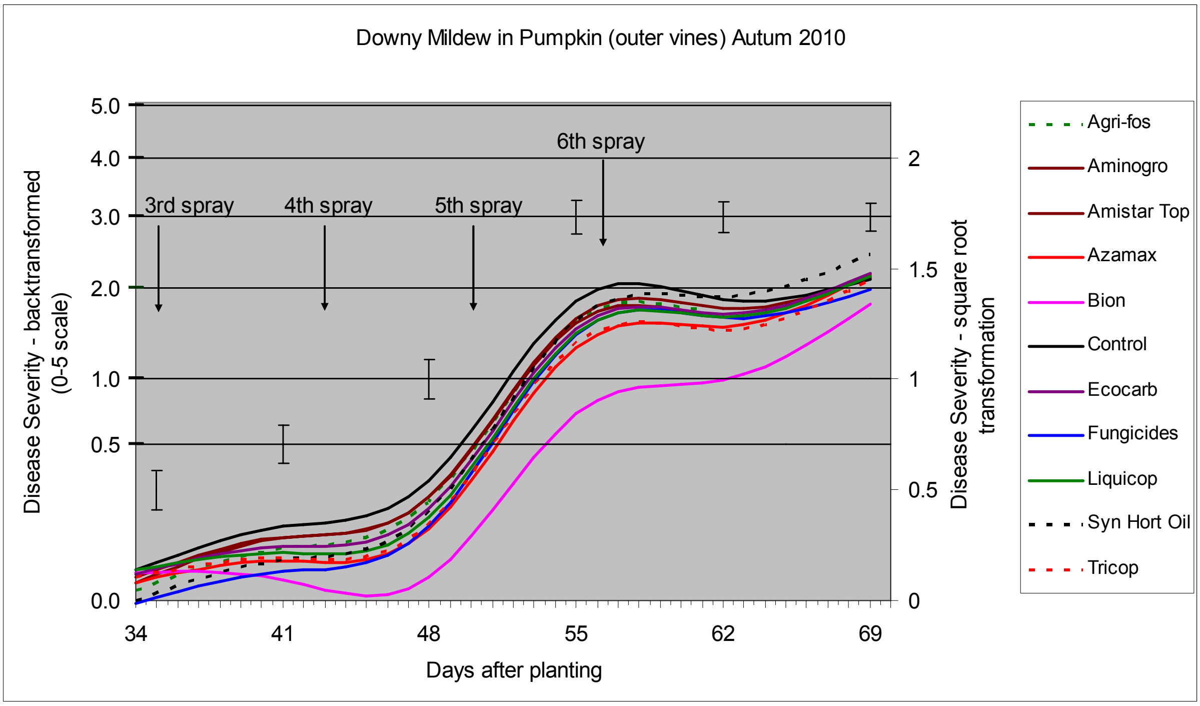

Figure 16. Downy mildew infection on the vine leaf midway from the growing point to the crown, Gatton Research Station, Autumn 2010.

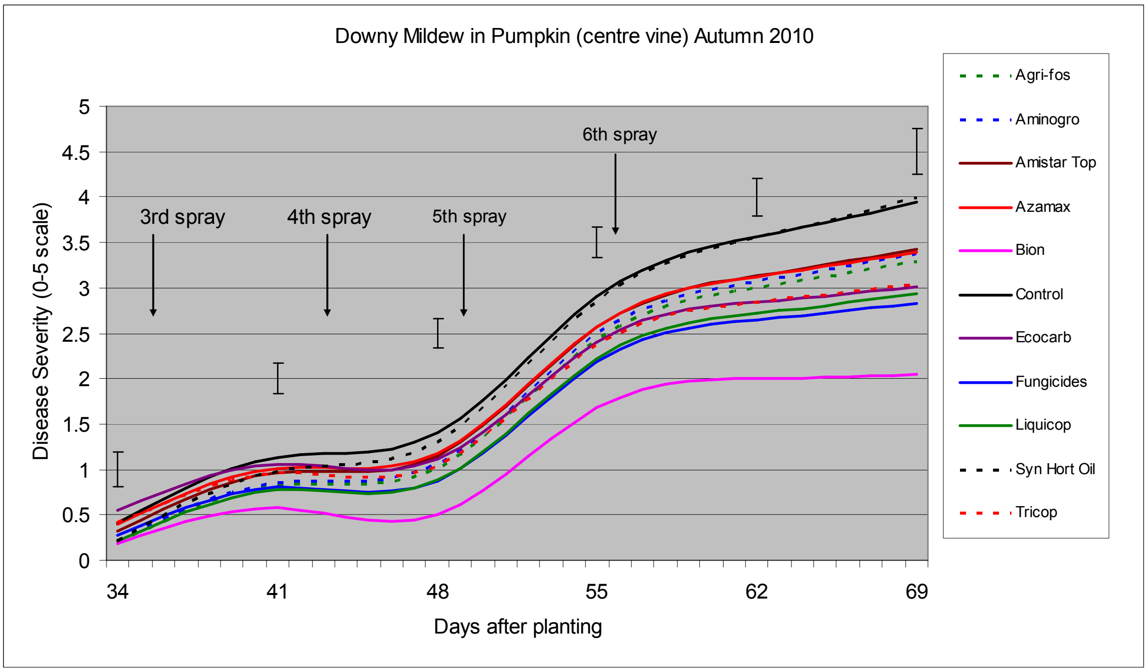

Figure 17. Downy mildew infection on the central leaf, Gatton Research Station, Autumn 2010.

The use of industry standard Fungicides significantly reduced the levels of infection in the outer vine leaves and centre leaves and on most of the assessment dates. Agri-fos, Aminogro and Liquicop significantly reduced the level of infection on the centre leaves on all but the first assessment date. This was not as evident in the vine leaves. The oils were only partially effective at reducing infection levels. Synertrol Hort Oil was no better than the unsprayed control on most assessment dates for both the vine and centre leaves, whereas Azamax was significantly better on 48, 55 and 62 DAP on the vine leaves and 62 and 69 DAP on the centre leaves.

Pumpkin Yield

Whilst the control treatment appeared to yield less than other treatments, data analysed by a general ANOVA showed no significant differences between treatments at the at the P = 0.050 level. Fungicides yielded the greatest amount of fruit per plant followed closely by Tricop. There was very little difference in weight of fruit per plant between Agri-fos, Amistar Top, Azamax, Bion, Ecocarb, Liquicop and Synertrol Hort Oil.

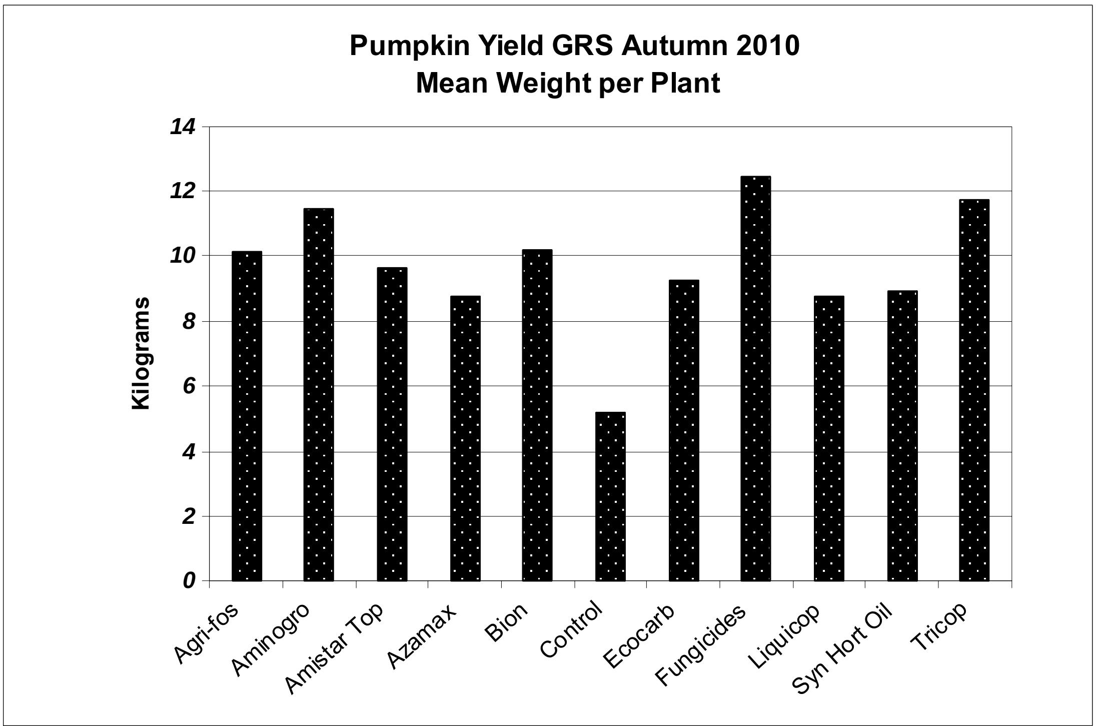

Figure 18. Mean pumpkin fruit weight harvested per plant in Autumn 2010

Table 11. Mean number of fruit per plot in each treatment during life of crop, Gatton Research Station, Autumn 2010.

Treatment	Mean
Fungicides	12.4
Tricop	11.7
Aminogro	11.5
Bion	10.2
Agri-fos	10.2
Amistar Top	9.6
Ecocarb	9.2
Syn Hort Oil	8.9
Azamax	8.8
Liquicop	8.8
Control	5.2
LSD	7.3

Figure 19. Pumpkin vines affected by virus at harvest 76 DAP.

Figure 20. Pumpkin centres showing symptoms of downy mildew at harvest 76 DAP.

Table 12. Weather Data Recorded at GRS during the period to first assessment. Data shows wet, cool and cloudy days

Date	Rainfall(mm)	Max Temp	Min Temp	Cloud 0-8
27 Feb 2010	0.4	27.4	18.1	8
28 Feb 2010	4.8	27.3	21.2	8
01 Mar 2010	9.4	29.3	22.0	8
02 Mar 2010	57.4	25.8	18.9	8
03 Mar 2010	30.2	23.5	19.0	4
04 Mar 2010	3.0	27.5	20.0	5
05 Mar 2010	0.4	26.0	21.1	8
06 Mar 2010	17.2	26.4	21.7	8
07 Mar 2010	6.6	25.6	21.4	4
08 Mar 2010	4.2	26.0	20.8	8
09 Mar 2010	0.4	26.1	18.2	8
10 Mar 2010	0.1	30.2	18.4	3
11 Mar 2010	0.8	32.5	20.6	2

Discussion

Downy mildew assessment was undertaken over a short period of time compared with the powdery mildew trial early in the season. This was due to virus infection and the rapid development of downy mildew due to wet weather (Table 12). Downy mildew ratings went from 0 to 3 or 4 in a week the space of a week.

Sampling time was therefore reduced to four weeks during this trial, compared to 6 in spring. Virus infection became rampant in the crop and inconsistencies in fruit production between affected and non-affected plants became apparent. Severely affected plants ceased producing fruit altogether.

No treatment on the zucchinis yielded significantly more or less than the Control, although Amistar Top and Bion yielded significantly more than Aminogro, Azamax and Peratec, all alternative soft option products. Amistar Top and Bion gave good control of downy mildew and therefore plants were healthier yielding more fruit.

As Papaya Ring Spot Virus (PRSV) became widespread in both zucchini and pumpkin plots during the course of the trial, impacting both yield and disease ratings, it became difficult to differentiate downy mildew from virus on affected leaves, and distortion of the new growth and flowers inhibited fruit development . Table 8 shows the number of plants affected by virus towards the end of the trial period. Whether it was just coincidence or not, Bion had the least number of plants with virus. Could Bion also initiate a response in the plant to tackle virus infection as it appears to do for downy mildew control? This is an area that warrants further investigation.

Amistar Top and Bion gave good control of downy mildew in the mid canopy and there were fewer plants in the Amistar Top and Bion plots displaying symptoms of virus (5 and 6 plants respectively), thus harvest was not compromised in these plots and mean yields were higher than those with severe virus symptoms: Peratec and Aminogro with 12 virus affected plant and, Azamax with 10 virus affected plants.

Most of the products tested in the pumpkins were either significantly better or only visibly better at downy mildew control compared with the Control, with Bion out performing all other products for most of the growing cycle of the crop. Unfortunately the yield didn't follow the same pattern. Although all treatments did perform better than the untreated control, there was not a significant enough difference for the statistical program that we used. The Fungicides treatment yielded more than the Bion treatment whereas the Synertrol Hort Oil also produced a greater weight of fruit than the Control. The yields seemed to be inconsistent with leaf disease control. This inconsistency could be due to the virus also being well established within the crop early, affecting fruit set and quality.

Conclusion

More work needs to be undertaken with the use of Bion due to the inconsistency of results from the powdery mildew trial and the downy mildew trial. The powdery mildew trial had two more applications of Bion applied to the crops and earlier which would have added to the phytotoxicity observed in the plants in the form of stunting and possibly reduced yield in both crops during the spring trial. Bion was consistent across both types of mildew in the pumpkins and therefore warrants additional work carried out on its benefits to induce a systemically acquired resistance in plants.

The use of fungicides to manage both mildew diseases are by far superior to the softer option products tested in these two trials. Sulfur and phosphorous acid are very good alternatives for powdery and downy mildew control respectively, whereas the other softer option products showed quite variable results which would be difficult to justify to growers. It is vitally important to start applying fungicides at the first signs of infection of even when conditions favour infection. Once downy mildew started it only took a few weeks before the leaves were severely infected even when using fungicides. Powdery mildew infection was not as bad with some level of control. There was also a distinct difference between crops as to control levels. Pumpkins were an easier crop to manage than zucchinis. This is most likely due to the crops architecture with the pumpkin leaves all being exposed to the sprays being applied where the lower zucchini leaves are partially protected by the upper leaves as the plant grows up and not out as with pumpkins. It is debatable whether higher volumes would improve the performance of the various products due to plant architecture. Higher volumes would lead to higher volumes on the leaf surface, in particular the upper leaf surface which would also lead to greater run off of the fungicides on to the ground. Perhaps improved application would improve the control of these diseases, such as air assist or even the use of small droppers within zucchini crops.

Communications

Throughout the project, information from trials was presented to growers and industry representatives on field days at Gatton.

Presentations with results from all trials will be given in meetings at Stanthorpe and Gatton on the 29th and 31st March 2011, respectively.

Acknowledgements

We would like to thank Madaline Healey, Ron Herman and Lara Senior for their valuable assistance with monitoring and harvesting of these trials. We would also like to thank the Gatton Research Station staff for their dedication in growing these crops.

Use of Fungicide Alternatives to Control Foliar Diseases of Lettuce

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Technical Report

Introduction

Lettuce (*Lactucae sativa*) is one of the major vegetable crops in Australia with production primarily in Queensland (34%) and Victoria (32%). The gross value of lettuce grown in Australia is $168 million (AusVeg, 2008) but there are sharp fluctuations in yields in individual states from year to year. The majority of production costs are associated during and after harvest but like many other vegetable crops, disease management is an integral component of production.

Two major fungal diseases of lettuce are downy mildew and anthracnose. Downy mildew is a disease caused by a fungus-like organism *Bremia lactucae.* The fungus is an obligate pathogen, i.e. it can only infect and reproduce on a living host. It is capable of infecting lettuce at any stage of development from seedling to mature plants at harvest. Symptoms include yellow patches on the upper leaf surface that eventually turn brown. Spores of downy mildew appear on the underside of the leaf as a white, fluffy growth (Figure 1). Downy mildew is favoured by high relative humidity and optimum temperatures around 15-20°C, particularly when there are heavy morning dews on leaves. Infection occurs primarily in spring and autumn.

Anthracnose (also known as shot-hole) is caused by the fungus *Microdochium panattonianum.* Similar to downy mildew, the spread of the disease is favoured by cool-wet conditions. It is not as frequent as downy mildew but in ideal conditions can be devastating. The fungus survives as sclerotia in soil and as hyphae in infected crop debris (Galea and Price, 1988b). Symptoms include leaf spotting often along the midrib of the leaf which enlarge to brown circular to angular spots. These spots may fall out leading to a shot hole appearance (Figure 2).

Downy mildew can be controlled by the use of resistant varieties. Resistance to downy mildew is controlled by a single dominant gene (Sequeira and Raffray, 1971) and varieties are bred to be resistant to a range of downy mildew genes. However new strains of the fungus are emerging and resistance can break down. There are currently no commercially available anthracnose resistant varieties. Ochoa et al. (1987) tested over 440 lines of *Lactuace* sp. and found limited resistance to anthracnose.

A range of protectant and systemic fungicides are used to control downy mildew and anthracnose but their effectiveness is limited and their use restricted. The use of fungicides has been unchanged for many years (Wicks et al. 1994). Commonly downy mildew infection can be high around harvest time when fungicides cannot be used and there are residue issues related to the direct consumption of lettuce leaves.

The use of alternative fungicides will reduce the reliance on the routine use of synthetic fungicides as a main method of disease control. Systemic fungicides can be both harmful to the environment and for human consumption with continued use. Additionally, resistance can occur with use of fungicide products with similar active groups. There are now a range of alternative fungicides available including biological control agents, foliar fertilizers, natural and mineral oils and hydrogen peroxide. Some may be suitable to effectively control downy mildew and anthracnose of lettuce.

Figure 1. **Symptoms of downy mildew (*Bremia lactucae*) on mature lettuce.**

Figure 2. **Symptoms of anthracnose (*Microdochium panattonianum*) on mature lettuce.**

Sub - project Aim

To evaluate a number of alternative fungicides including the use of “soft options” to control two common diseases of lettuce, downy mildew (*Bremia lactucae*) and anthracnose (*Microdochium panattonianum*).

A number of experiments were conducted to assess (i) lettuce varietal susceptibility and (ii) the efficacy of alternative fungicide products.

General Materials and Methods

Growth room experiments were conducted at the South Australian Research and Development Institute (SARDI), Waite Research Precinct, Urrbrae, South Australia. Lettuce plants were grown in a controlled environment growth room (CER) at 14°C, 12 hr light/12hr night cycle.

Field trials were conducted on a commercial horticultural property located at Murray Bridge, 64 km SE of Adelaide, South Australia (35° 07' 11" S, 139° 16' 24" E and average rainfall 346 mm). Plants were watered by irrigation although rainfall occurred more frequently than expected in 2010.

Maintenance of downy mildew and anthracnose

Several techniques were evaluated to grow and maintain *B. lactucae* and *M. panattonianum,* in non field conditions, many with limited success. Various plant stages were inoculated, including lettuce seedlings or lettuce leaf discs on blotting paper with water or nutrient solution; lettuce leaf disks in petri dishes floating on water or nutrient solution; seedlings germinated in glass or plastic tubs to 2 leaf stage; and individual leaves on potted plants. All were inoculated under a range of growing conditions. The critical success factors were determined to be temperature (<15°C), inoculum sourced from leaves with recent infection and inoculating young and freshly growing plants.

Source of inoculum

Experiments were conducted with downy mildew obtained on fresh lettuce material cv. Cobham Green from DPIVic, Knoxfield and cv. Sureshot from a commercial lettuce grower, Virginia, South Australia. Anthracnose was collected from cv. Seneca sourced from a commercial property, Virginia, South Australia. Field experiments were conducted with downy mildew and anthracnose isolates collected from infected lettuce material at the field site in Murray Bridge, South Australia.

Plant growth and maintenance

Lettuce seedlings were grown in Coco peat in either 6 cell seedling trays or MK6 square pots (60 mm X 80 mm) and maintained at 14°C in the CER. Seedlings were watered daily and fertilized with Osmocote. Pots were contained in bunding trays (30

X 43 cm) and watered in trays every two days, such that the capillary action of watering ensured foliage was not wetted.

Inoculation

Leaves showing fresh symptoms of disease were placed directly into water and shaken to remove either *B. lactucae* and *M. panattonianum* spores from infected leaves. Inoculum solution was filtered through muslin cloth into a clean bottle to remove leaf debris and spore concentration checked with a haemocytometer prior to inoculation (>1 x 10^5 spores/ml).

Lettuce seedlings were inoculated with *B. lactucae* at two leaf cotyledon stage (7-14 days old) or with *M. panattonianum* at 4-5 true leaf stage (3-4 weeks old). Leaves were sprayed with a spore suspension using a hand atomiser and plants covered with a plastic bag to induce near 100% humidity for a minimum of 24 hours.

Disease maintenance

New lettuce seedlings were inoculated every 4-6 weeks as previously described to allow maintenance of the diseases.

Disease assessment

Plants were assessed for disease incidence (number of plants infected) and severity using the rating system described in Table 1. All data were subjected to ANOVA using Statistix for Windows v. 4.1 (Analytical Software, Tallahassee, FL, USA). Least significant differences (LSD) were calculated for the appropriate variable when significant (P<0.005).

Table 1. **Disease severity rating for assessment of downy mildew (*Bremia lactucae*) and anthracnose (*Microdochium panattonianum).***

Rating	Leaf area infected (%)
0	0
1	1-10
2	11-25
3	26-50
4	51-75
5	76-90
6	91-100

Varietal reactions

Experiments were conducted in the CER to determine the relative susceptibility of lettuce varieties to downy mildew and anthracnose.

Materials and Methods

Three plants were grown in each cell of a 6-cell seedling punnet, a total of 18 replicate plants per variety (Table 2), and maintained in the CER as previously described. .

Table 2. **Lettuce varieties assessed for downy mildew (*Bremia lactucae*) and anthracnose (*Microdochium panattonianum*). Race resistance information provided by the seed supplier.**

Lettuce	**Variety**	**Source**	**Downy Mildew Race (DMR) Resistance**
Iceberg	Lily	South Pacific seeds	DMR 1-25
Iceberg	Kong	South Pacific seeds	DMR 1-25
Iceberg	Boost	South Pacific seeds	#
Iceberg	Seagull	South Pacific seeds	DMR 1-26
Iceberg	Roundhouse	South Pacific seeds	DMR 1-26
Iceberg	Boomerang	Seminis	#
Iceberg	Sure shot	Seminis	DMR 1-4
Iceberg	Constanza	Seminis	1-16, 19, 21 and 23
Iceberg	Winter Select	Seminis	none
Green coral	Explore	Rijk Zwaan	DMR 1-27
Iceberg	Alpinas	Rijk Zwaan	DMR 1-23, 25
Iceberg	Bernadinas	Rijk Zwaan	DMR 1-22,24-26
Cos	Quintus	Rijk Zwaan	DMR 1-20, 22-25
Iceberg	Fortune	Terranova	none
Red Oak	Tekero	Syngenta Seeds	DMR 1-25
Green Oak	Sansula	Syngenta Seeds	DMR 1-16, 18-24
Green Coral	Bellagio Curletta LE 290	Syngenta Seeds	DMR 1-24
Red Coral	Bellagio Robinio A	Syngenta Seeds	DMR 1-16, 18-24
Mini Green Cos	Tomos	Syngenta Seeds	DMR 1-16, 18-25
Iceberg	LE 291	Syngenta Seeds	#
Iceberg	LE 304	Syngenta Seeds	#

*Not assessed for anthracnose
unknown resistance

Downy mildew - Plants were inoculated with *B. lactucae* pathotype AUS 5 (2.6 x 10^5 spores/ml) 12 days after sowing at the two-leaf cotyledon stage with a hand-spray as described and assessed 21 days after inoculation. Pathotype AUS 5 contains a number of unknown downy mildew genes (not published).

***Anthracnose* -** Plants were inoculated with *M. panattonianum* (1.6 x 10^6 spores/ml) 21 days after sowing at 4-leaf stage as described and assessed 24 days after inoculation.

Results

Of 21 lettuce varieties inoculated with downy mildew, only four developed symptoms of infection: cvs. Fortune, Sureshot, Winter Select and Constanza. Other varieties were resistant to the downy mildew race (AUS 5) used to inoculate plants in the experiment. Sureshot and Constanza have limited downy mildew resistance.

White masses of spores were observed 11-13 days after inoculation. Disease incidence was highest in cv. Constanza and cv. Winter Select (Figure 3). All other varieties inoculated were deemed resistant to downy mildew. Analysis of mean severity showed cv. Constanza was more severely infected than other varieties (Figure 4).

Anthracnose symptoms appeared eight days after inoculation. Symptoms in the CER were similar to symptom expression in the field. Symptoms first appeared as small circular to angular lesions on leaves and on lower stems. All varieties tested were infected (Figure 5) and severity of infection was significant between the varieties (Figure 6). The cv. Explore was significantly the most susceptible (P=0.000).

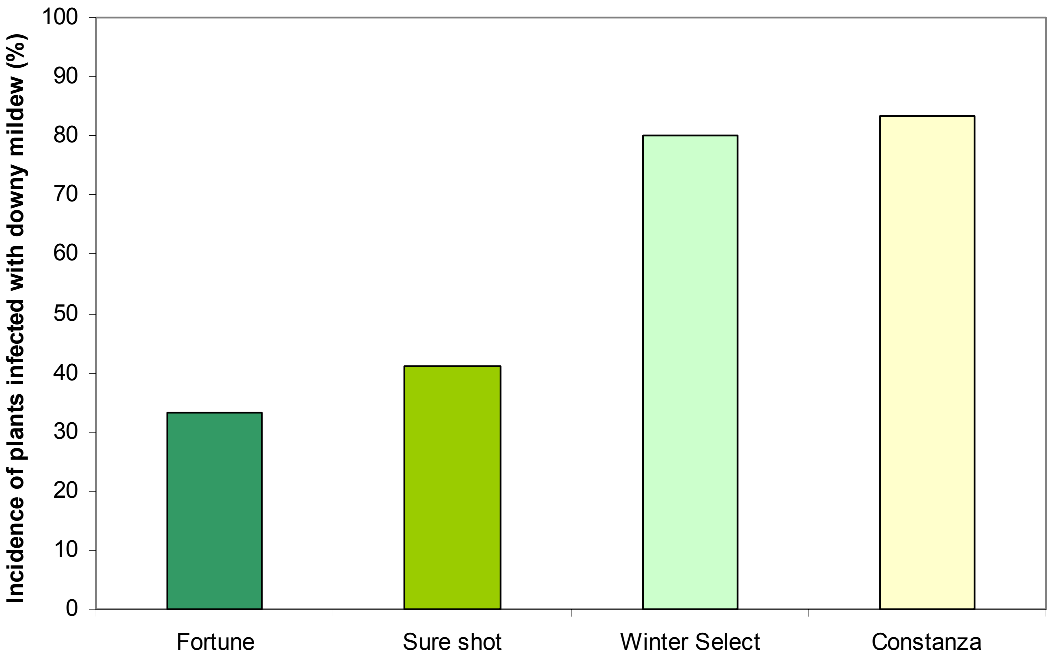


Figure 3. **Percent of plants of four lettuce cultivars developing symptoms of downy mildew 21 days after inoculation with *Bremia lactucae* spores.**

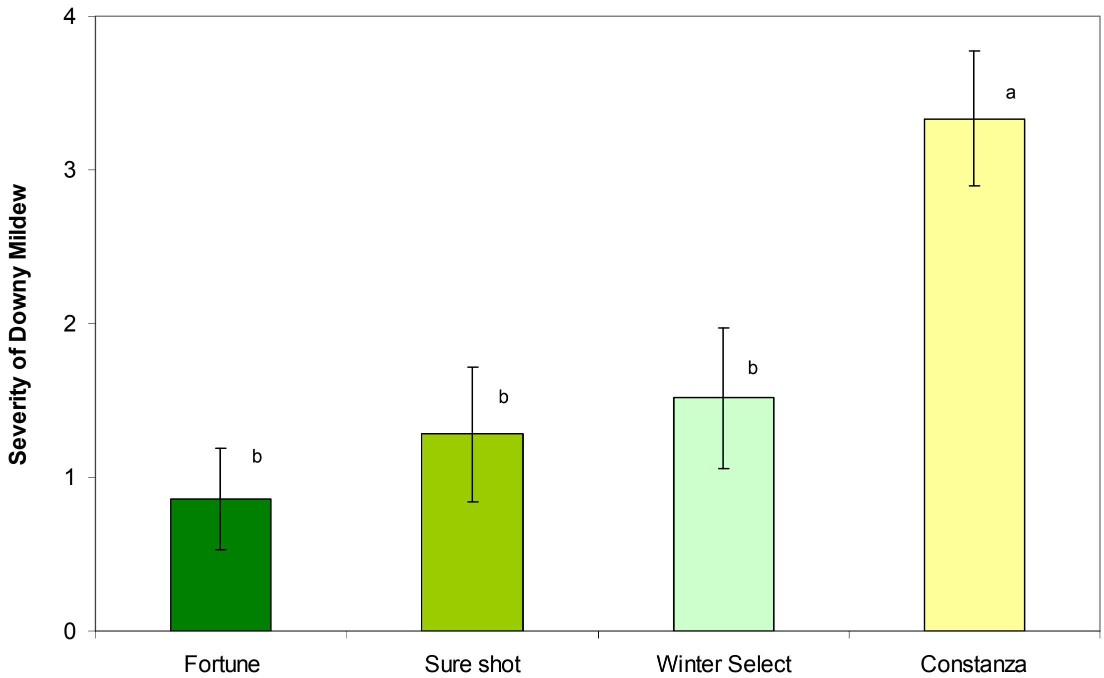


Figure 4. **Severity of downy mildew (*Bremia lactucae*) infection on inoculated lettuce varieties whereby 0 = 0%; 1 = 1-10%; 2 = 11-25%; 3 = 26-50%; 4 = 51-75%; 5 = 76-90%; 6 = 90-100%.**

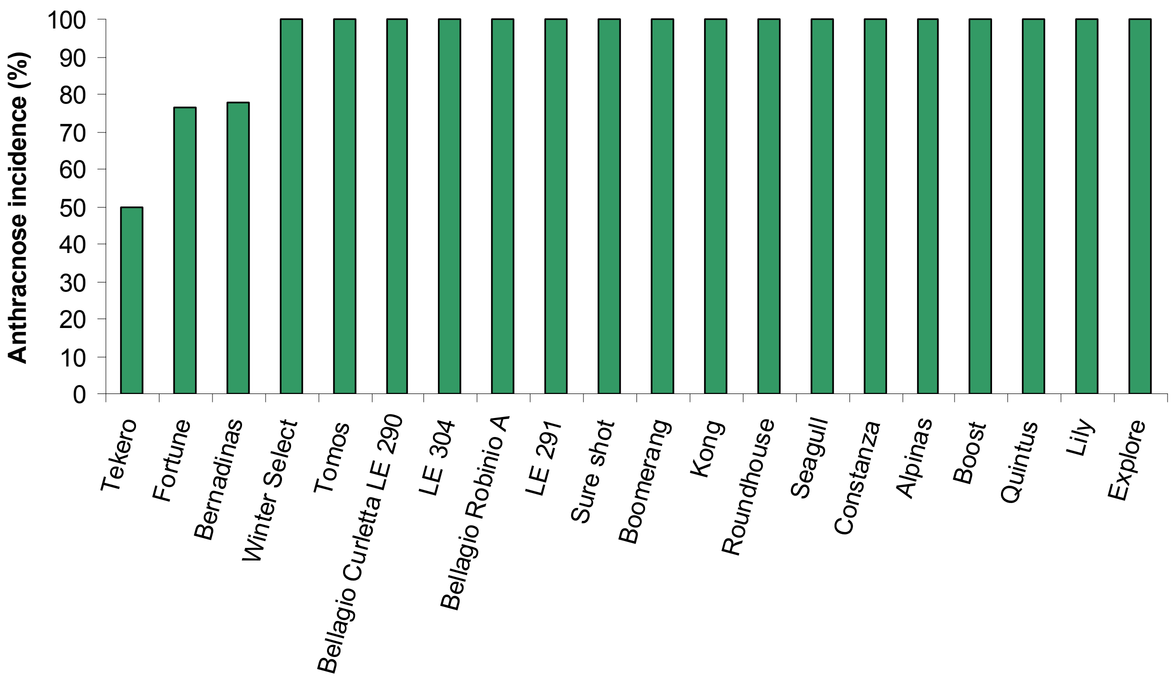


Figure 5. **Percent of plants of various cultivars with anthracnose symptoms 24 days after inoculation with *Microdochium panattonianum* spores.**

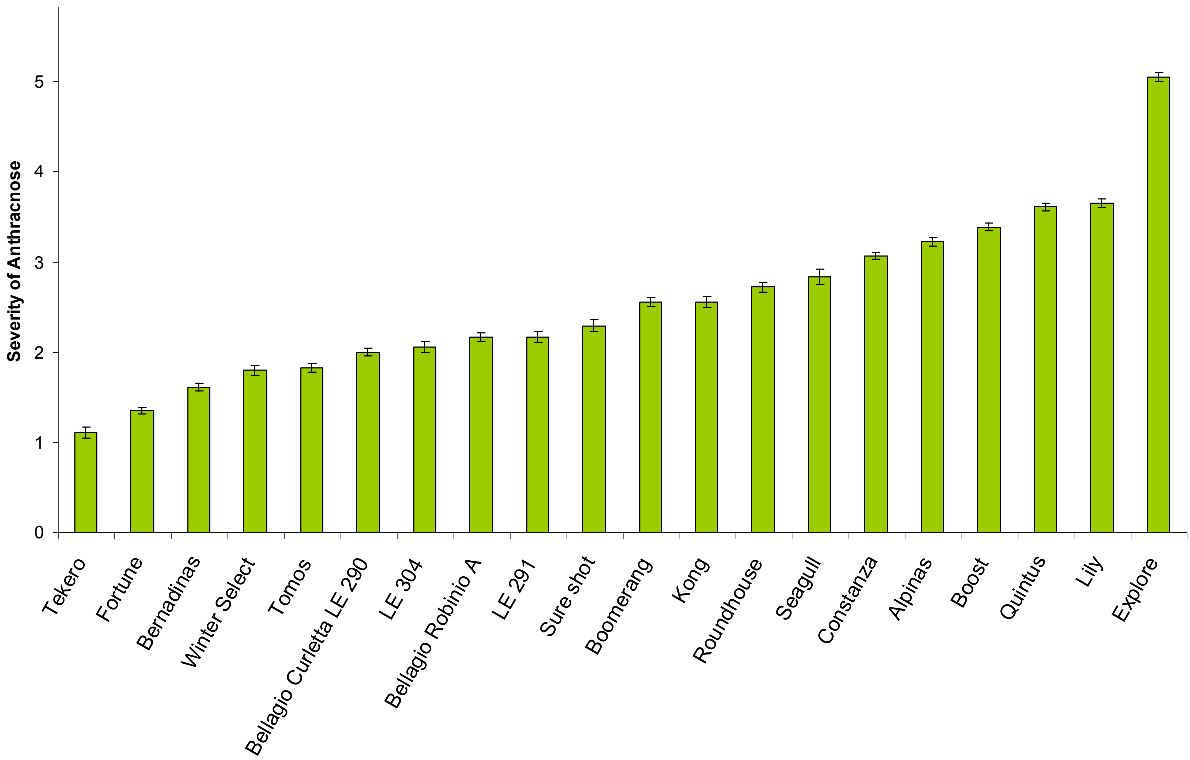


Figure 6. **Severity of anthracnose symptoms on lettuce varieties based on area on leaf infected whereby 0=0%; 1 = 1-10%; 2 = 11-25%; 3 = 26-50%; 4 = 51-75%; 5 = 76-90%; 6 = 90-100%.**

Discussion

Growth room trials showed *B. lactucae* pathotype AUS 5 was more prevalent in cv. Constanza and cv. Winter Select. Lettuce varieties contain known downy mildew resistant (DMR) genes, but new pathotypes have emerged in Australia (AUS 1-5) that comprise a wide range of downy mildew genes (Trimboli, 2004). For this reason, growers can have a severe outbreak of disease if susceptible varieties are planted.

Most lettuce varieties were susceptible to anthracnose and there has been little development in breeding for resistance (Ochoa et al.,1987). Different varieties were distinguished by disease severity. Some varieties may be more resistant to anthracnose under different climatic conditions or disease pressure.

Varietal resistance is useful as a management strategy, and most lettuce varieties produced have some level of resistance to downy mildew. However there is little resistance to anthracnose. As new varieties are continually being released to manage the changing resistance status as the downy mildew resistance breaks down, these new varieties should also be evaluated for their susceptibility to anthracnose. Galea and Price (1988) found a poor correlation between greenhouse and field trial for the disease rating of cultivars to anthracnose. Therefore the relative susceptibility of the varieties should be field tested before being recommended as part of a management strategy.

Evaluation of alternative products

A number of experiments were conducted in both the CER and field to assess alternative fungicides for control of lettuce diseases downy mildew and anthracnose. Alternatives included existing registered products, new products, natural growth enhancing products, biological formulations and *Trichoderma* and *Streptomyces* isolates (Table 3). Standard controls included fungicides commonly used to control disease on lettuce and water.

Product screening in controlled environment room

Materials and methods

In all trials, 15 replicate lettuce seedling plants were used to assess each alternative fungicide and controls. Three plants were grown in each MK6 pot with 5 pots used per treatment. Based on varietal susceptibility to disease, cv. Constanza was used for downy mildew evaluations and cv. Explore for anthracnose.

Lettuce plants were inoculated as previously described 10-14 days after germination (2-leaf cotyledon stage) with *B. lactucae* and 21-28 days after germination (4-5 leaf cotyledon stage) with *M. panattonianum.*

Application of each alternative fungicide was based on recommendation rates and freshly prepared prior to use. Plants were sprayed with a hand-held spray applicator until run off with a treatment:

- 3 days before inoculation (pre-inoculation) or
- 3 days after inoculation (post-inoculation).

Potted plants from each treatment were randomly distributed throughout the trays.

Upon symptom expression, four leaves per plant were assessed for incidence and severity of infection as previously described. Typically, downy mildew inoculated plants were assessed 14 days after inoculation. Anthracnose symptoms were evident 6 days after inoculation and plants assessed around 11 days post-inoculation.

In total, four trials were undertaken at different times to assess a range of alternative fungicides (Table 4) and another trial was conducted to assess the efficacy of several products when combined to control downy mildew (Table 5).

Table 3. **Alternative products evaluated in growth room conditions to control downy mildew and anthracnose of lettuce.**

	Treatment	Active Ingredient	Supplier
1	Acadian	Soluble Seaweed Extract	Organic Crop Protectants (OCP)
2	AGN	Paraffinic oil	Agnova
3	Agri 50	polysaccharides from plant extracts	OCP
4	AgriFos	Phosphonic acid	AgriChem
5	Aminogro	Amino Acids	OCP
6	Bas651	Copper	Nufarm
7	Bion	Acibenzolar-R-S-methyl	Syngenta
8	Curex 3	Tri base blue	Nufarm
9	EcoProtector	Potassium soap	OCP
10	EcoCarb	Potassium bicarbonate	OCP
11	Folical 19	Calcium	Omnia
12	Kocide	Cupric Hydroxide	Dupont
13	MicroPlus	Streptomyces	
14	NC224 (Shinkon)	Amisulbrom	Nufarm
15	Phostrol	Phosphorous acid	Nufarm
16	Rezist	Growth nutrient	Stoller
17	Serenade	*Bacillus*	NuFarm
18	Sentinel	*Trichoderma* LC52	Agrimm Technologies
19	Silmatrix	Potassium Silicate	OCP
20	Synertrol Horti Oil	Canola Oil	OCP
21	Tri Base Blue	Tribasic copper sulphate	Nufarm
22	*Trichoderma* TdA	*Trichoderma* spp.	SARDI
23	*Trichoderma* TdB	*Trichoderma* spp.	SARDI
24	*Trichoderma* TdC	*Trichoderma* spp.	SARDI
25-33	*Trichoderma* isolates	*Trichoderma*	Biocontrol Australia
34	*Trichoderma* Td22 commercial formulation	*Trichoderma koningii*	Biocontrol Australia
35	*Trichoderma* Td67 commercial formulation	*Trichoderma koningii*	Biocontrol Australia
36	Zoxium	Zoxamide	Nufarm

Table 4. **Growth room trials undertaken to assess efficacy of alternative fungicides to control downy mildew and anthracnose on lettuce.**

Treatment	Trial 1 DM & ANTH	Trial 2 DM & ANTH	Trial 3 DM	Trial 4 ANTH	Trial 5 DM & ANTH
Acadian		√			
Acrobat				√	
AGN		√			
Agri 50		√			√ DM only
AgriFos	√				*
Aminogro		√			
BAS651			√	√	
Bion		√			
Cabrio				√	
Curex 3			√	√	
EcoProtector		√			√ DM only
EcoCarb	√			√	
EcoCarb+HortiOil				√	
Dithane				√	
Folical 19	√				√
Kocide	√	√	√	√	√
MicroPlus					√ (n=2 rates)
NC224			√	√	
Phostrol			√	√	
Rezist	√				*
Serenade	√			√	
Serenade+DuWett				√	
Sentinel	√				
Silmatrix	√				
Synertrol Horti Oil	√				
Trichoderma TdB					√
Trichoderma TdC					√
Trichoderma isolates Td71,74,75,84,89					√ (n=5)
Tri Base Blue			√	√	
Td22 commercial formulation					√
Td67 commercial formulation					√
Zoxium			√	√	
Water	√	√	√	√	√
Total treatments	10	8	8	15	16

Td = *Trichoderma*

DM = Downy mildew

ANTH = Anthracnose
* Treatment included in anthracnose experiment

Table 5. **List of combined alternative fungicides assessed to control downy mildew.**

Trial 6 treatments	
Ecocarb & Eco Protector	Serenade
EcoCarb & Horti oil	Duwett
EcoCarb & Silmatrix	Kocide
Acadian & Aminogro	Water
Serenade & Duwett	

Results

Trial 1

Downy mildew

There was high variability in the incidence of disease and the effectiveness of fungicides. Kocide® and AgriFos® were most effective at reducing the incidence of downy mildew when applied prior to inoculation (Table 6). AgriFos® was the only product applied after inoculation to significantly reduce incidence and severity of infection. Of the alternative fungicide products, Rezist® (Stoller Inc.) reduced the infection both pre and post inoculation, however the difference was not statistically significant. EcoCarb® and Silmatrix® applied prior to infection significantly affected plant growth and increased the level of disease. Serenade® and Sentinel® had little effect on the incidence and severity of disease.

Table 6. **The incidence and severity of symptoms of downy mildew on lettuce seedlings (cv. Constanza) grown in the CER after application of fungicides 3 days before (pre-) or after (post-) inoculation. Treatments with the same letter are not significantly different from one another (*P*=0.005).**

Treatments	**Rate/100L**	**Pre Inoculation**				**Post Inoculation**			
		Incidence		**Severity**		**Incidence**		**Severity**	
Control (Water)		29.6	BC	24.3	AB	60.0	AB	36.4	ABC
Folical 19 Plus	750 ml	10.0	BC	3.3	B	26.7	AB	17.5	CD
Kocide	150 g	3.3	C	2.2	B	50.0	AB	31.6	ABC
Agri-Fos 600	100 ml	2.2	C	0.77	B	5.0	C	0.8	D
EcoCarb	500 g	63.3	A	46.1	A	46.7	AB	31.7	ABC
Rezist (xpress)	150 ml	15.0	BC	9.2	B	31.7	AB	25.5	BCD
Silmatrix	750 ml	66.7	A	47.8	A	56.7	AB	45.5	ABC
Synertrol HortiOil	200 ml	20.8	BC	18.9	AB	69.7	A	57.9	A
Serenade	600 g	47.7	AB	31.5	AB	66.7	A	46.1	ABC
Sentinel	600 g	33.1	ABC	20.4	AB	61.7	AB	51.1	AB

Anthracnose
The incidence of anthracnose on pre-inoculated lettuce was 66% for FoliCal 19 Plus™ and Kocide®, but 100% on all other plants. Every plant was infected when products were applied after inoculation (data not shown).

Fungicides were more effective at reducing the severity of anthracnose when applied 3 days before inoculation than after inoculation (Figure 7). The most effective products applied pre-inoculation were Kocide® and FoliCal 19 Plus™ yet most other treatments did not reduce the severity of infection. AgriFos® was the only treatment to provide complete control of anthracnose when applied after inoculation.

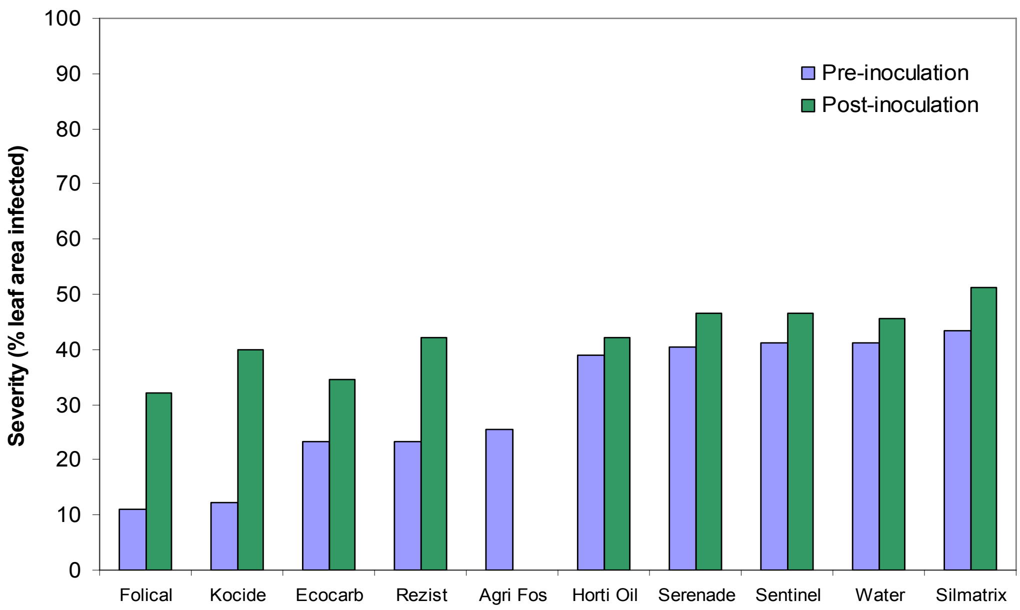


Figure 7. **Influence of fungicides on severity of anthracnose on lettuce by either pre- and post-inoculation application (cv. Explore).**

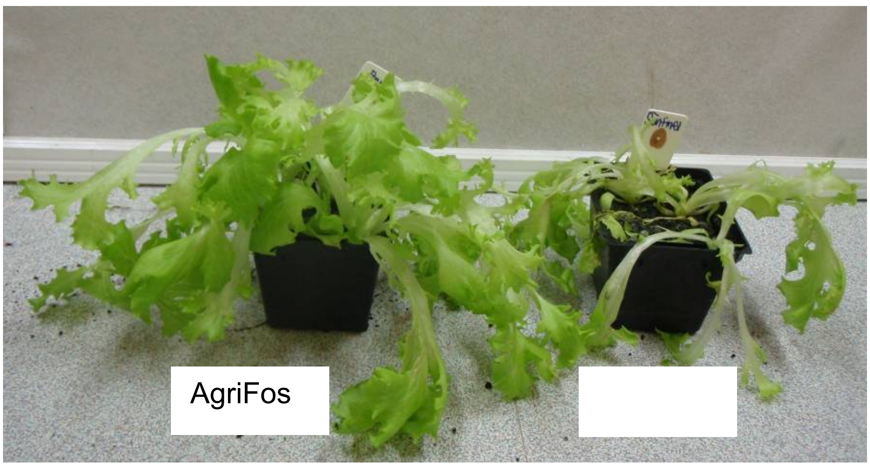


Figure 8. **Variation in severity of anthracnose causing plant stunting on lettuce (cv. Explore) treated with fungicides AgriFos® and Sentinel® prior to inoculation.**

Trial 2

Downy mildew

The incidence of disease was high in trial 2, with most treatments having >50% infection (Table 7). Treatments applied before inoculations were more effective at reducing the incidence and severity of disease on lettuce than after infection. Kocide® was most effective at reducing disease when applied prior to infection yet full control was not achieved. No products provided effective control when applied after inoculation.

Table 7. **The incidence and severity of symptoms of downy mildew on lettuce seedlings (cv. Constanza) grown in the CER after application of fungicides 3 days before (pre-) or after (post-) inoculation. Treatments with the same letter are not significantly different from one another (*P*=0.005).**

Treatments	Rate/100L	Pre Inoculation				Post Inoculation			
		Incidence		Severity		Incidence		Severity	
Control (Water)		69.2	AB	28.9	AB	90.8	A	48.0	A
Kocide	150 g	21.7	C	5.4	E	80.5	A	32.3	BC
Acadian	100 g	74.2	AB	26.2	ABC	83.3	A	35.5	AB
Agri 50	1500 ml	68.3	AB	24.4	ABCD	80.8	A	37.2	AB
AGN	1000 ml	65.8	AB	22.8	BCD	53.8	B	22.1	C
AminoGro	1000 ml	56.7	B	17.5	CD	58.3	B	26.9	BC
Bion	2.5 g	56.7	B	15.0	DE	73.3	AB	21.9	C
EcoProtector	2000 ml	81.7	A	35.1	A	71.3	AB	29.7	BC

Anthracnose

Infection rates were also high for anthracnose infected lettuce seedlings. No products were successful at reducing the incidence of infection to below acceptable levels. Kocide® was significantly better than other treatments, yet disease incidence was >50% (Table 8).

Table 8. The incidence and severity of symptoms of anthracnose on lettuce seedlings (cv. Explore) grown in the CER after application of fungicides 3 days before (pre-) or after (post-) inoculation. Treatments with the same letter are not significantly different from one another (*P*=0.005).

Treatments	Rate/100L	Pre Inoculation				Post Inoculation			
		Incidence		Severity		Incidence		Severity	
Control (Water)		93.3	AB	35.5	A	93.3	A	38.9	A
Kocide	150 g	53.3	C	8.9	D	83.3	A	21.1	C
Acadian	100 g	100	A	23.3	B	100	A	35.5	AB
Agri 50	1500 ml	80.0	AB	18.9	BC	100	A	27.8	ABC
AGN	1000 ml	100	A	33.3	A	100	A	25.5	BC
AminoGro	1000 ml	100	A	35.5	A	86.7	A	26.7	ABC
Bion	2.5 g	73.3	BC	12.2	CD	100	A	23.3	BC
EcoProtector	2000 ml	80.0	AB	15.5	BCD	93.3	A	23.3	BC

Trial 3

Downy mildew

Good control was achieved with a range of fungicides when applied prior to inoculation. In this instance, all products tested reduced the incidence and severity of downy mildew in comparison to the water treatment (Table 9). BAS 651® achieved the best control of downy mildew when applied prior to infection, with the lowest incidence and severity observed. Conversely, fungicides were not effective at reducing disease when applied after inoculation. Infection was high on all plants, with only Phostro®l applied after infection significantly reducing the incidence and severity of disease.

Table 9. **Incidence and severity of downy mildew on lettuce seedlings in the growth room (cv. Constanza) after application of various products either 3 days before (pre-) or after (post-) inoculation. Treatments with the same letter are not significantly different from one another (*P*=0.05).**

Treatments	Rate/100L	Pre Inoculation				Post Inoculation			
		Incidence		Severity		Incidence		Severity	
Control (Water)		78.3	A	30.6	A	95.8	A	47.6	A
Kocide	150 g	18.3	BC	6.1	B	88.3	AB	38.3	ABC
TriBase blue	280 ml	8.3	BC	1.7	B	85.8	AB	43.0	AB
Curex 3	500 ml	21.7	BC	6.4	B	75.4	B	30.4	CD
Phostrol	200 ml	25.8	B	7.4	B	13.3	D	3.0	E
BAS 651	50 ml	5.0	C	1.7	B	86.6	AB	35.6	BC
Zoxium	50 ml	10.0	BC	2.5	B	88.3	AB	42.2	AB
NC224	50 ml	13.3	BC	3.3	B	57.1	C	21.4	D

Trial 4

Anthracnose

The incidence of anthracnose was similar in both pre- and post-inoculated treatments. For post-inoculated, 100% of plants were infected except for those treated with Cabrio® (66%). Eleven treatment groups were 100% infected prior to inoculation except some treated with Cabrio® (30%), Curex® (83%), Dithane® (86%) and the combination of EcoCarb®® and HortiOil (93%).

Unlike other experiments where typically symptoms were less severe on pre-inoculated seedlings, severity was highly variable. Cabrio significantly reduced the incidence and severity of disease compared to all other treatments (Figure 9). Application with others products, such as Kocide®, Dithane®, Curex® and EcoCarb®, reduced the level of disease compared to the water control, however with >30% leaf area affected none of these products provided adequate control of anthracnose.

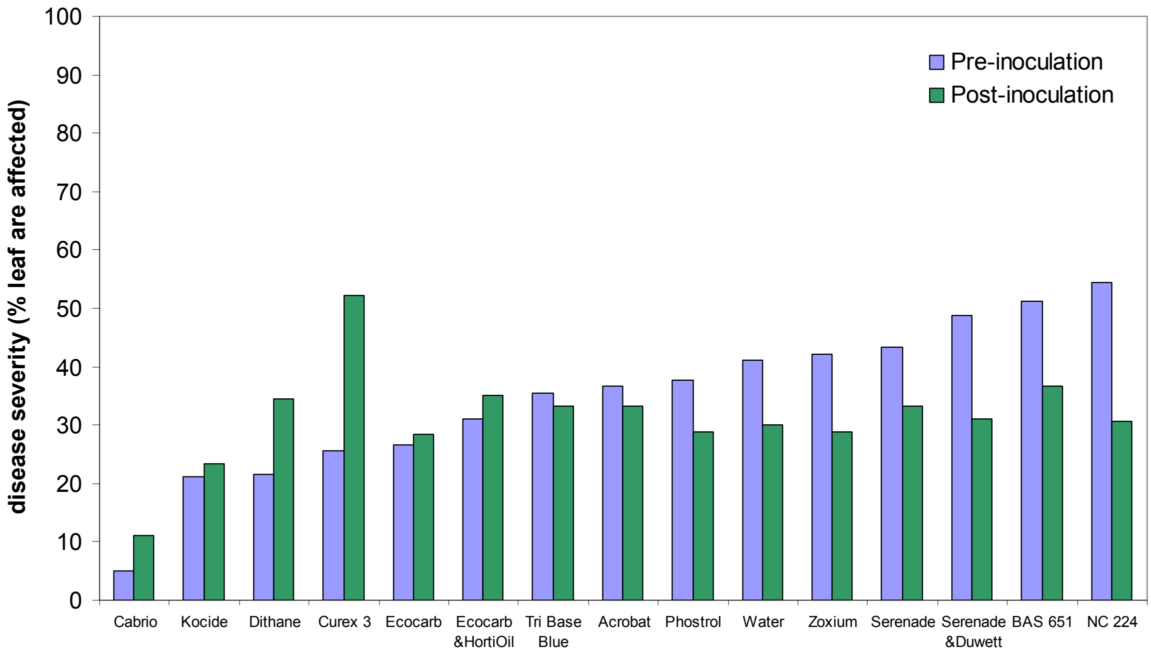


Figure 9. **Incidence and severity of anthracnose on lettuce seedlings in the growth room (cv. Explore) after application of various products either 3 days before (pre-) or after (post-) inoculation.**

Trial 5
Downy mildew
AgriFos®, Kocide®, Rezist® and FoliCal 19 Plus™ significantly reduced the incidence and severity of downy mildew when applied before inoculation (Table 10). Both Rezist® and FoliCal 19 Plus™ appear to provide effect control of downy mildew as soft options.

The incidence of downy mildew reduced when *Trichoderma* B, *Trichoderma* C and MicroPlus® were applied before inoculation compared to water. *Trichoderma* C was also effective when applied after inoculation. Other *Trichoderma* isolates did not appear effective at controlling downy mildew on lettuce and only AgriFos® provided a commercially acceptable level of control.

Table 10. **Incidence and severity of downy mildew on lettuce seedlings in the growth room (cv. Constanza) after application of various products either 3 days before (pre-) or after (post-) inoculation. Treatments with the same letter are not significantly different from one another (*P*=0.005).**

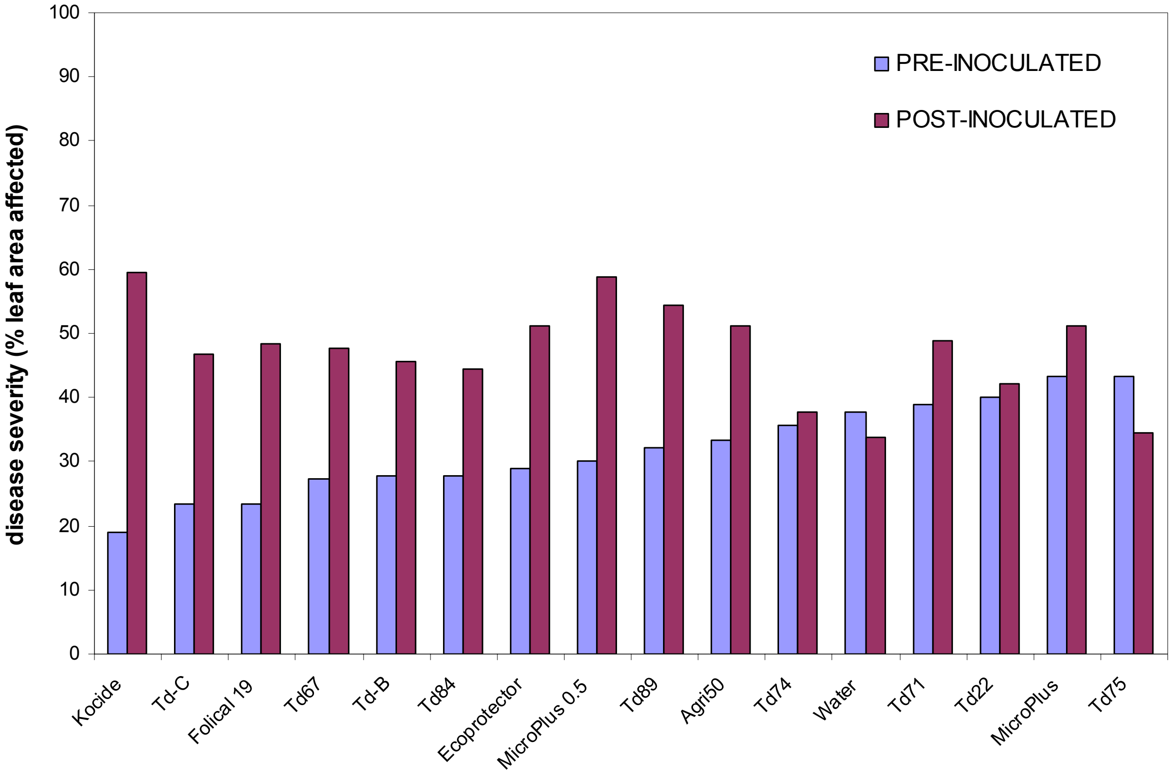
Treatments	**Rate/100L**	**Pre Inoculation**				**Post Inoculation**			
		Incidence		**Severity**		**Incidence**		**Severity**	
Control (Water)		77.7	A	39.0	AB	100	A	46.7	AB
Folical 19 Plus	750 ml	9.1	D	2.3	D	24.7	E	5.3	GH
Kocide	150 g	3.3	D	1.1	D	72.5	CD	25.1	EF
Trichoderma Td22	167 g	55.8	ABC	23.4	B	91.7	ABC	46.1	AB
Trichoderma Td67	167 g	54.0	ABC	19.4	B	91.7	ABC	43.7	ABC
Trichoderma Td71	167 g	62.7	ABC	22.9	B	81.7	ABCD	41.1	ABCD
Trichoderma Td74	167 g	59.4	ABC	18.7	B	67.5	D	35.6	BCDE
Trichoderma Td75	167 g	72.9	AB	25.4	B	73.8	BCD	33.4	CDE
Trichoderma Td84	167 g	62.9	ABC	23.5	B	92.5	AB	48.6	A
Trichoderma Td89	167 g	66.0	ABC	25.7	B	78.7	BCD	31.0	DE
Trichoderma Td-B	150 g	48.9	BC	14.6	BC	80.0	BCD	35.6	BCDE
Trichoderma Td-C	150 g	46.1	BC	15.9	B	43.9	E	17.0	FG
MicroPlus	100 g	41.5	C	16.0	B	65.0	D	29.7	DE
MicroPlus	50 g	58.2	ABC	23.1	B	80.0	BCD	40.7	ABCD
Rezist	150 ml	9.0	D	2.5	CD	70.2	D	30.8	DE
AgriFos 600	1000 ml	0	D	0	D	1.6	F	0.2	H

Anthracnose

For both pre-inoculated and post-inoculated lettuce seedlings, 100% of plants were infected with anthracnose (data not presented). The severity of disease varied with pre-inoculated plants having fewer symptoms than post-inoculated plants in most treatments. This was most obvious in Kocide® treated plants where Kocide® had little effect when applied after inoculation (Figure 10).

In terms of disease severity in pre-inoculated lettuce, Kocide® treated plants showed less severe symptoms than other treatments except *Trichoderma* C (TdC) and Folical 19. *Trichoderma* isolates provided variable disease response from 23% - 43% leaf area affected following inoculation with anthracnose.

Figure 10. **Incidence and severity of anthracnose on lettuce seedlings in the growth room (cv. Explore) after application of various products either 3 days before (pre-) or after (post-) inoculation.**



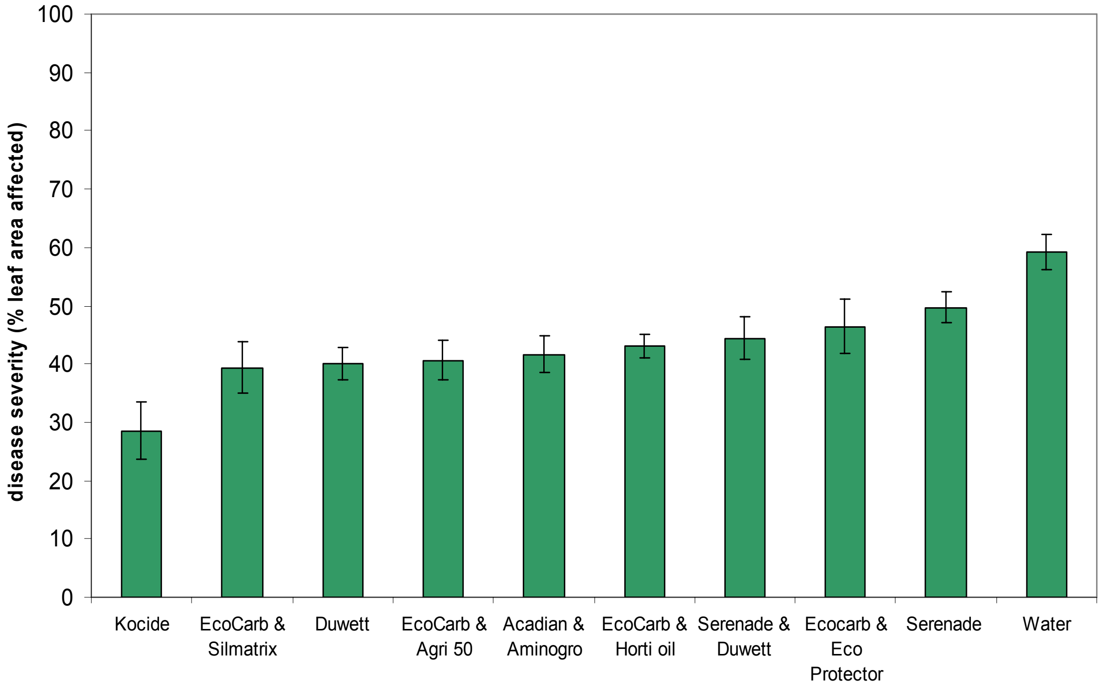
Trial 6

Downy Mildew

A range of alternative fungicide combinations were trialled to control downy mildew, however there was no significant difference in the incidence of disease on pre-inoculated seedlings (*P*=0.0724) or post-inoculated seedlings (*P*=0.355). Similarly, disease severity was not affected when plants were treated post-inoculation (*P*=0.689) (data not shown).

The most significant effect was observed when Kocide® was applied pre-inoculation. Kocide® was more effective at reducing the degree of leaf symptoms than all other treatments (Figure 11).

Figure 11. **Influence of combined alternative fungicides on severity of downy lettuce by pre-inoculation application in the growth room (cv. Explore).**



Summary and Discussion

To compare the effect of fungicides from all trials conducted in the growth room, the incidence of downy mildew was correlated to the water control by calculating the means of the treatments as a percent of the mean of the untreated control. Downy mildew infection was variable across most trials but this comparative analysis highlighted a number of products that were effective in reducing the incidence of disease. AgriFos®, Kocide®, BAS 651®, TriBase Blue®, Rezist®, FoliCal 19 Plus™ and Zoxium® provided adequate disease control (Figure 12). The incidence of downy mildew was >50% following application of all other fungicides.

The CER trials showed alternative fungicides have variable effect on downy mildew. Susceptible varieties were used to evaluate alternative products and it is possible the products are ineffective under high disease pressure. For instance, Rezist® was evaluated in trial 1 and trial 5, yet disease incidence following treatment varied considerably with 60% and 11% plants infected, respectively. Similarly, FoliCal 19 Plus ™ had 40% and 11% of treated plants infected. Both are the most promising alternative products to control downy mildew and may be considered in a spray program to reduce the reliance on systemic fungicides.

In comparison, the incidence of anthracnose infection in most trials was high and most fungicides were ineffective at reducing the incidence of disease (Figure 13). Cabrio® and Kocide® reduced disease to approximately 30% and similarly reduced the severity of disease in the growth room (Figure 14). However this level of control is deemed commercially unacceptable. There were no “soft option” alternative fungicides that provided adequate protection from infection. The best alternative product was FoliCal 19 Plus ™ where the 66% of plants were infected by anathrcanose, but disease was less severe than no treatment (27%). Other alternative products were not effective, with incidence >80% and severity >50%.

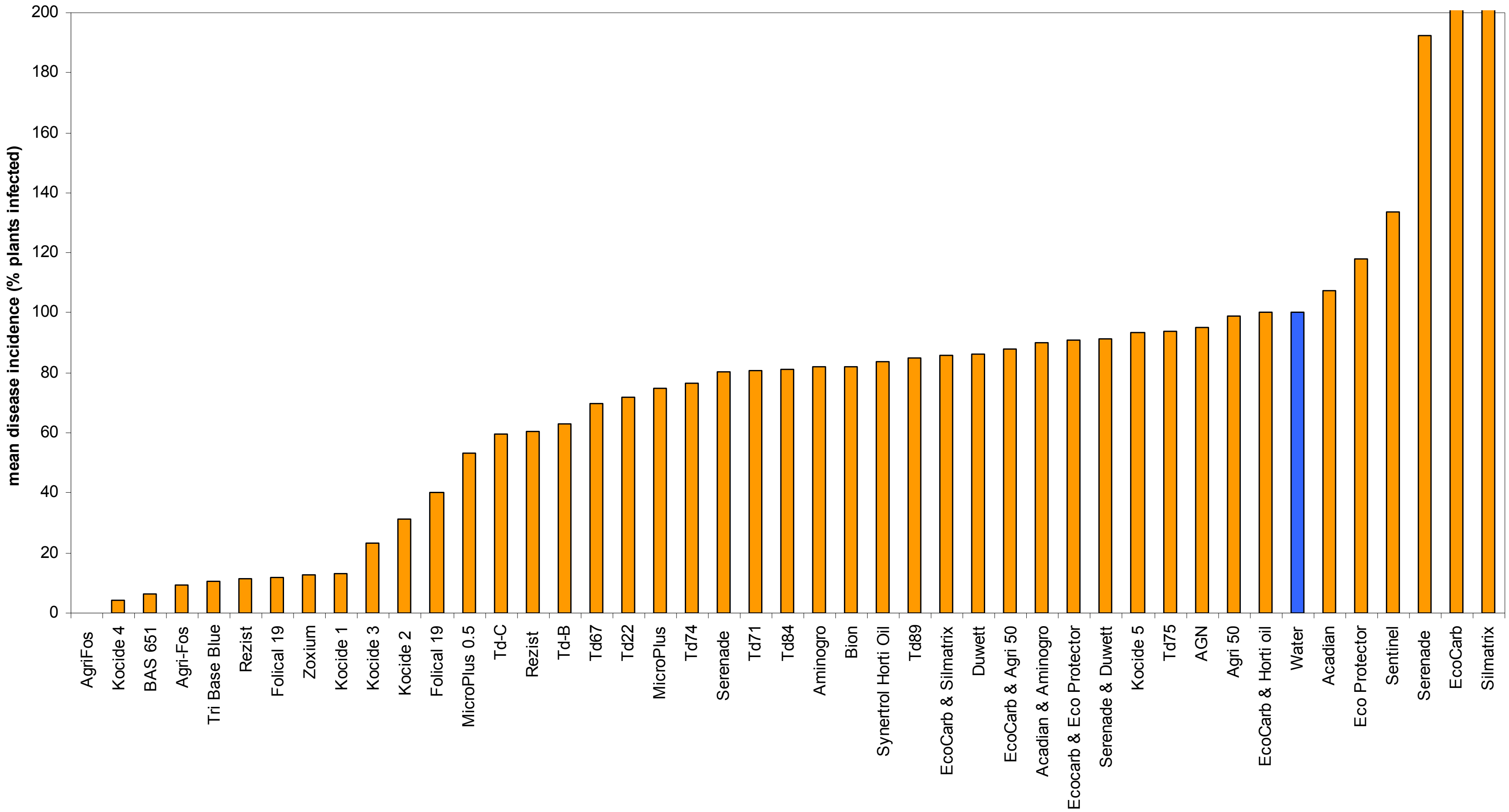
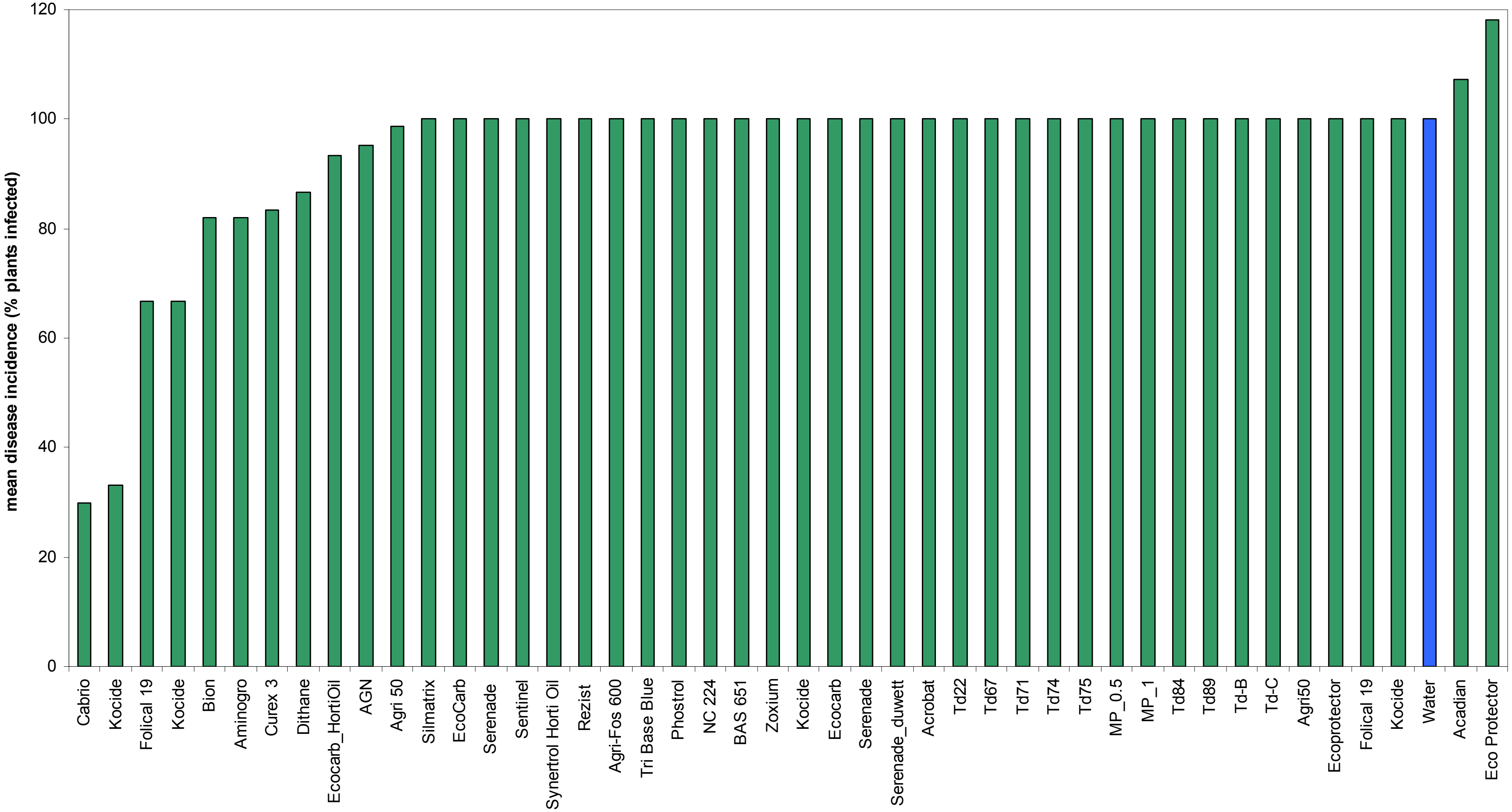


Figure 12. **The incidence of downy mildew on lettuce in relation to the water control (100%) in growth room conditions (cv. Constanza) after application of various products 3 days before (pre-) inoculation.**



re 13. **The incidence of anthracnose on lettuce in relation to the water control (100%) in growth room conditions (cv. Explore) after application of various products 3 days before (pre-) inoculation.**

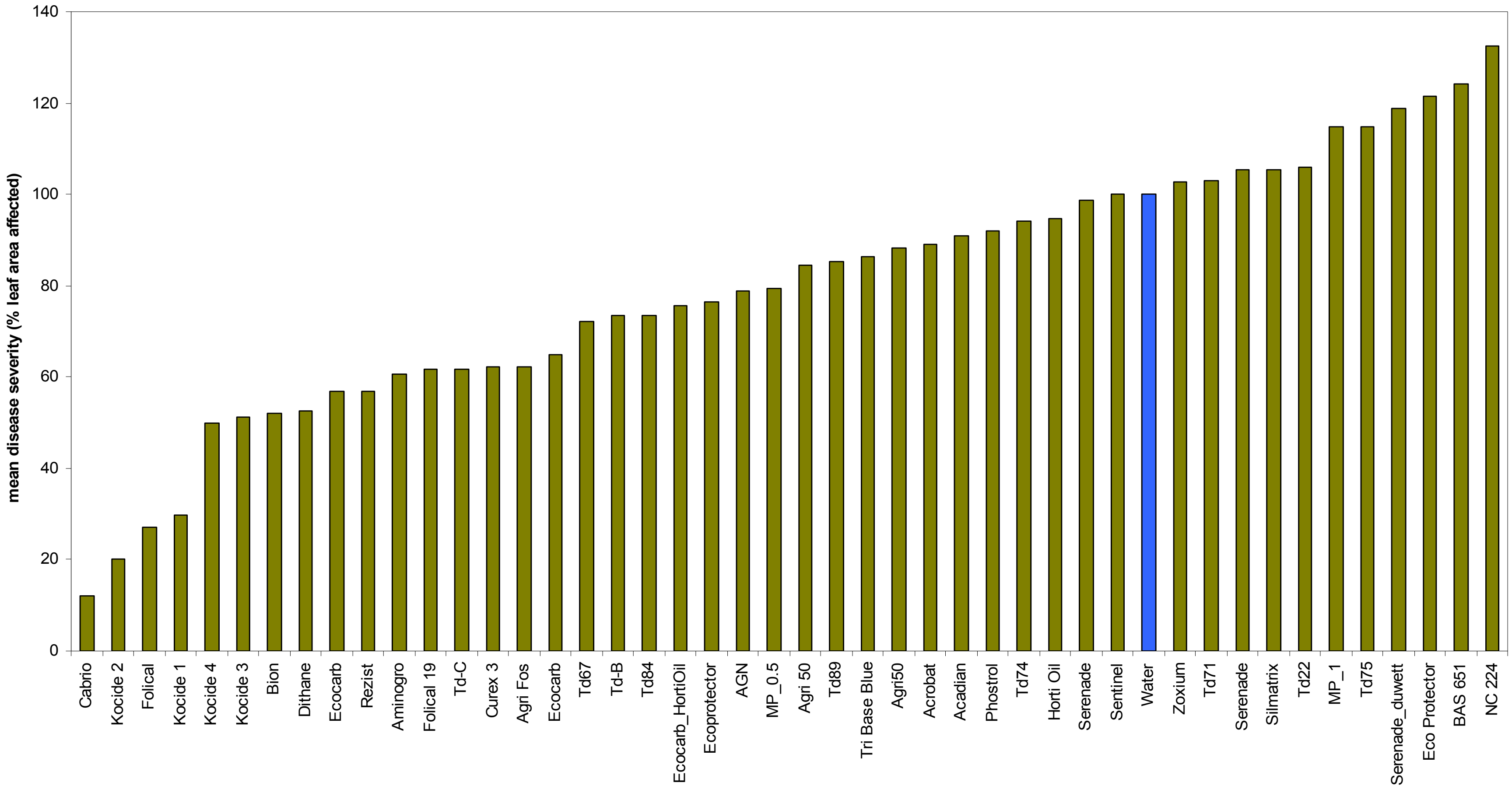


Figure 14. **The severity of anthracnose on lettuce in relation to the water control (100%) in growth room conditions (cv. Explore) after application of various products 3 days before (pre-) inoculation.**

Field evaluation

The field experiment location was based on the presence of naturally-occurring disease, timing of planting, availability of plants and grower support.

Based on incidence and disease severity in CER, seven treatments were selected for further assessment in the field under commercial growing conditions.

Materials and methods

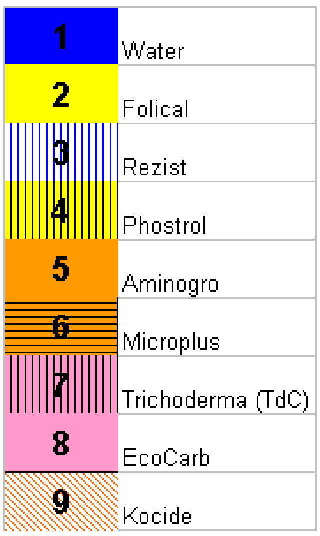
Varieties cv. Marksman and cv. Barcelona were available for the field trial. Downy mildew was collected from lettuce on the grower's property and used to inoculate seedlings (cv. Marksman and cv. Barcelona) in the CER as described.

Lettuce was commercially planted on August 6 2010. Chicken manure was incorporated into the soil prior to planting. At planting, the grower drenched individual plants with a mix of nutrient additives (Extender® and BioForge®, Stoller Inc.) and liquid Phosphorus fertilisers.

Two Crisphead varieties were selected to establish field trials in the same block (cv. Marksman and cv. Barcelona). Filan® was applied by the grower at regular intervals during the growing season to control the lettuce disease *Sclerotinia*.

Seven alternative fungicides were compared to Kocide® (a commonly used chemical fungicide) and a water control. Treatments were allocated to a completely randomised block design which was modified according to planting and soil conditions (Figures 15 and 16). For instance, soil in one area of the cv. Marksman planting was waterlogged and plants were severely affected.

Each bay (space between irrigation lines) consisted of 6 beds. Each bed had four rows of lettuce and allocated into eight plots of 2 m X 1.5 m of approximately 24 plants per replicate (Figure 17). Each treatment was replicated four times. Barrier rows were retained on either side of the trial site to minimise spray drift from neighbouring plantings.



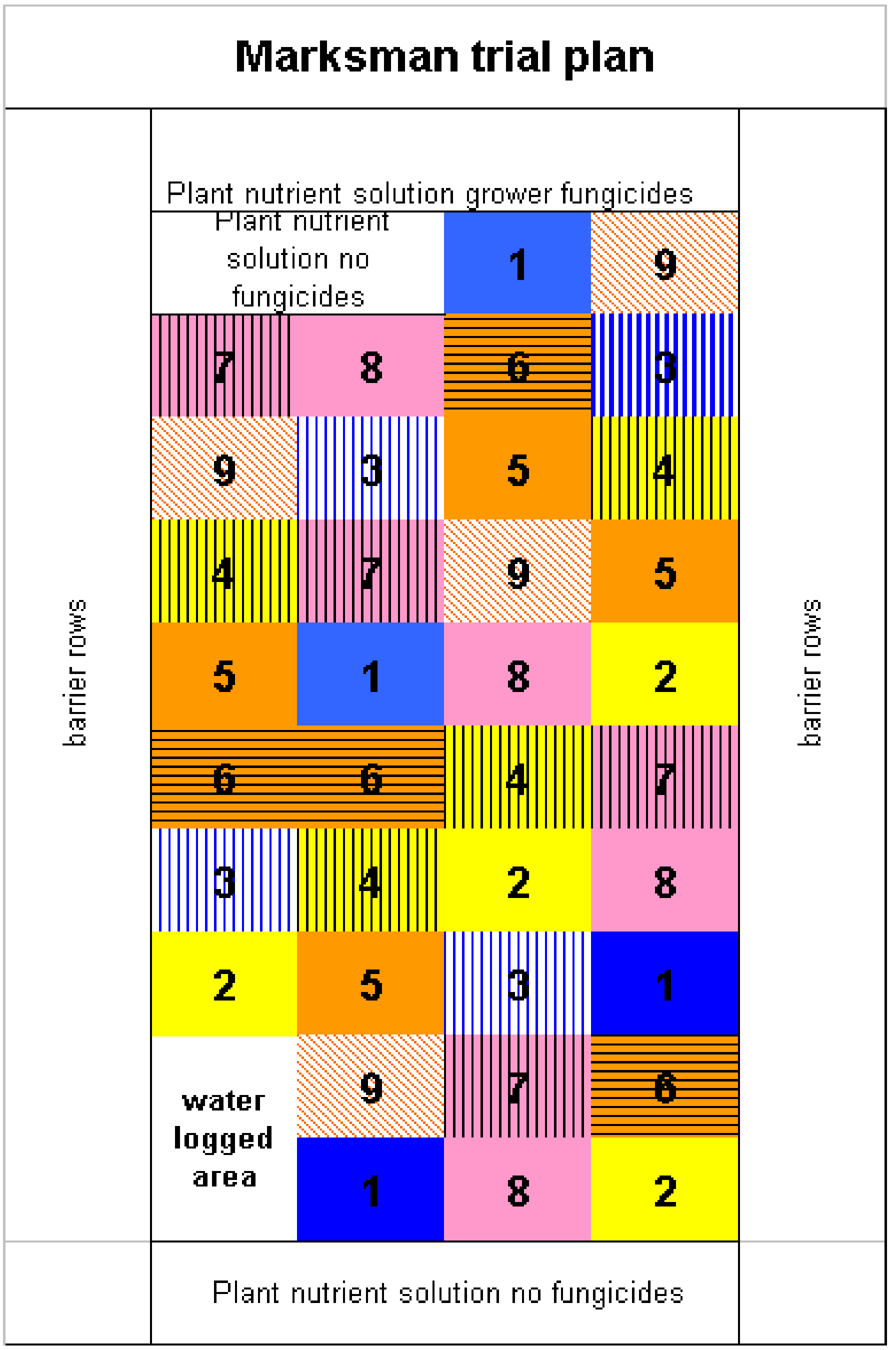


Figure 15**. Field plan of alternative fungicide trial, cv. Marksman.**

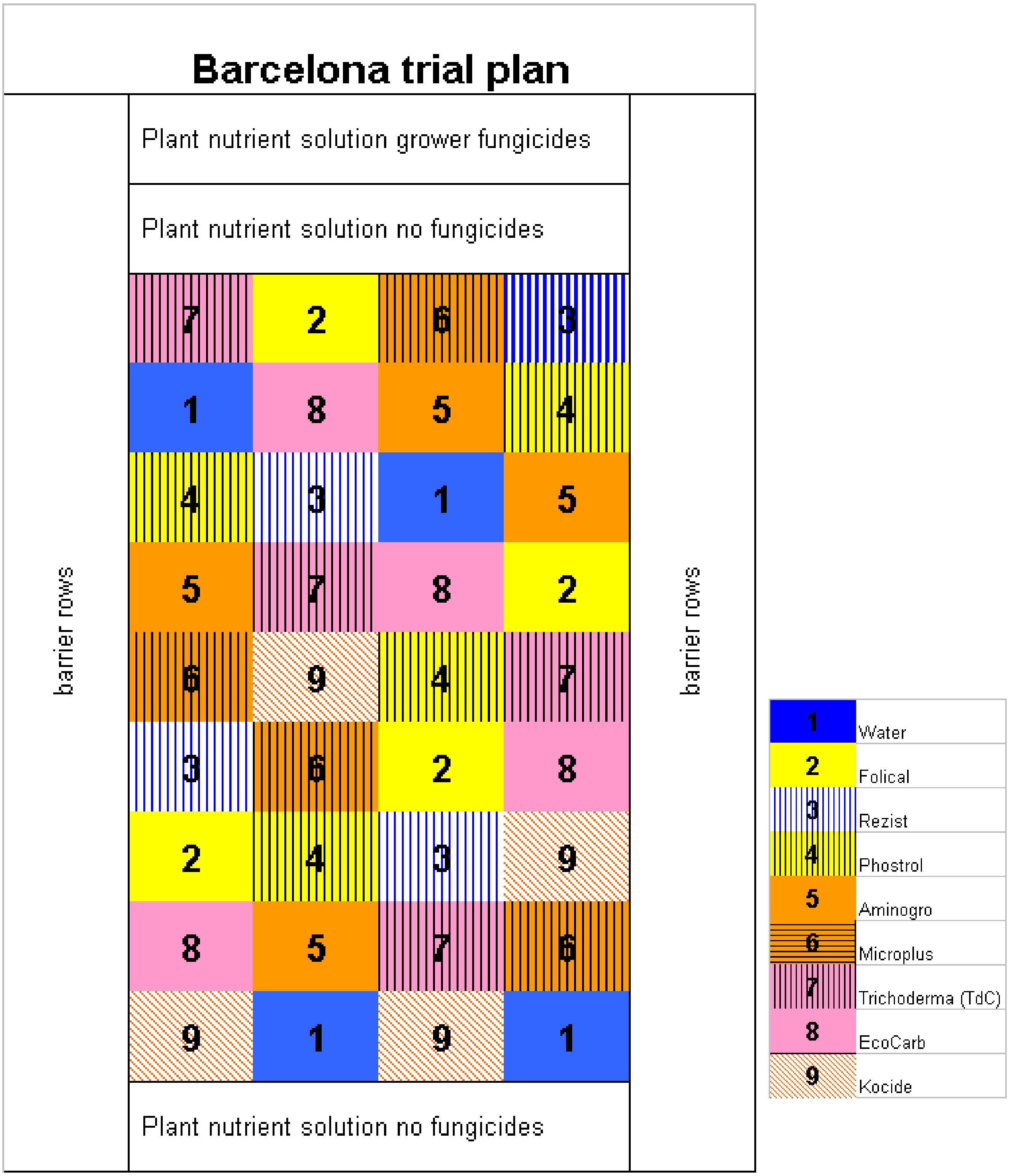


Figure 16. **Field plan of alternative fungicide trial, cv. Barcelona.**

Figure 17. **Field trial establishment August 2010.**

Figure 18. **Spray application of treatment with backpack sprayer, August 2010.**

Treatments were applied at recommended rates with motorised back pack sprayers (Figure 18) on 12 August 2010 and subsequently every 7-14 days until harvest. With grower consent, infected leaves from the same property were scattered on each plot on 2 September 2010 to replicate natural infection.

In total, spray treatments were applied six times between 12 August – 8 October 2010. Twelve plants from each replicated plot were assessed at nine weeks for incidence and severity on five mature leaves. Plants were harvested at ten weeks maturity.

Results

Downy mildew was evident in both cv. Marksman and cv. Barcelona. Anthracnose symptoms were not observed. Although preventative fungicides were used, the lettuce crop had severe *Sclerotinia* infection (Figure 19). Where possible, plants infected by *Sclerotinia* were not assessed for downy mildew or anthracnose.

Downy mildew symptoms were assessed on mature leaves. Some mature leaves were severely affected and new sporulation was observed on the lettuce head (Figure 20). The incidence of downy mildew was not significant on cv. Marksman or cv. Barcelona (data not shown). However the application of different alternative fungicides affected the severity of disease. Lettuce treated with Phostrol®, FoliCal 19 Plus™, Rezist® and Kocide® showed significantly less symptoms than those treated with water (Figure 20). Soft options Ecocarb®, MicroPlus®, Trichoderma and AminoGro® were not effective at reducing the severity of downy mildew.

Downy mildew symptoms were more severe on cv. Barcelona. Water treated plants showed the highest level of downy mildew and most treatments except MicroPlus® and *Trichoderma* spp. reduced the severity of infection (Figure 21). Rezist® was the most effective product in reducing the infection of downy mildew.

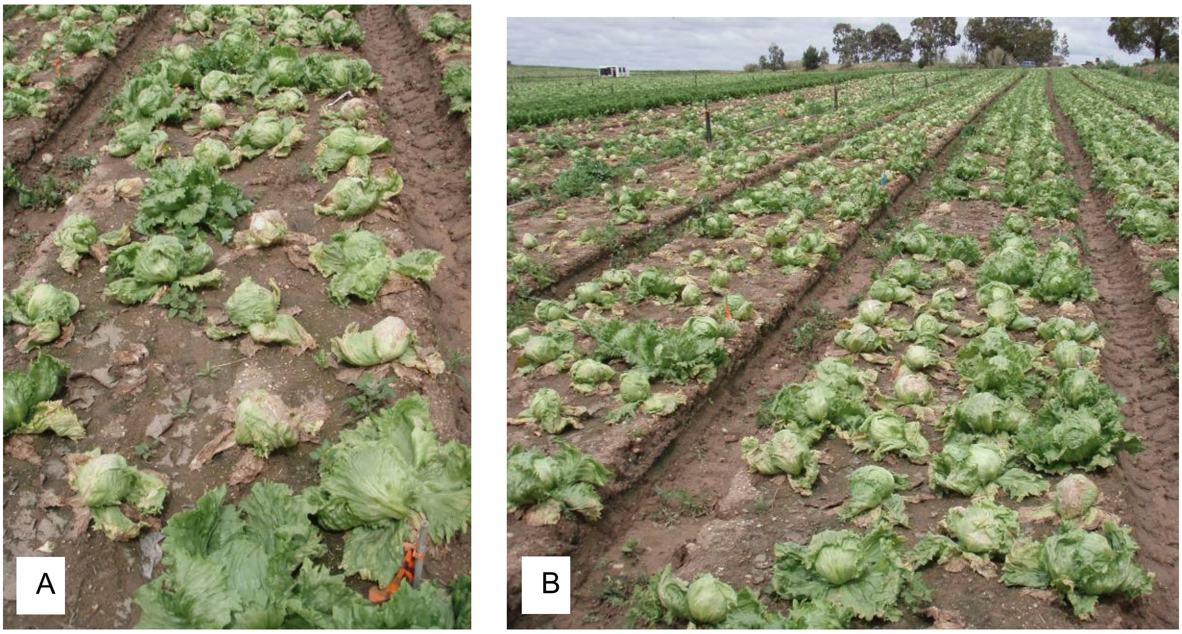


Figure 19. **Lettuce field trial severely infected by *Sclerotinia* (a) cv. Marksman and (b) cv. Barcelona.**

Figure 20. **Assessment of mature leaves affected by downy mildew cv. Marksman. Arrows depict fresh sporulation on lettuce head.**

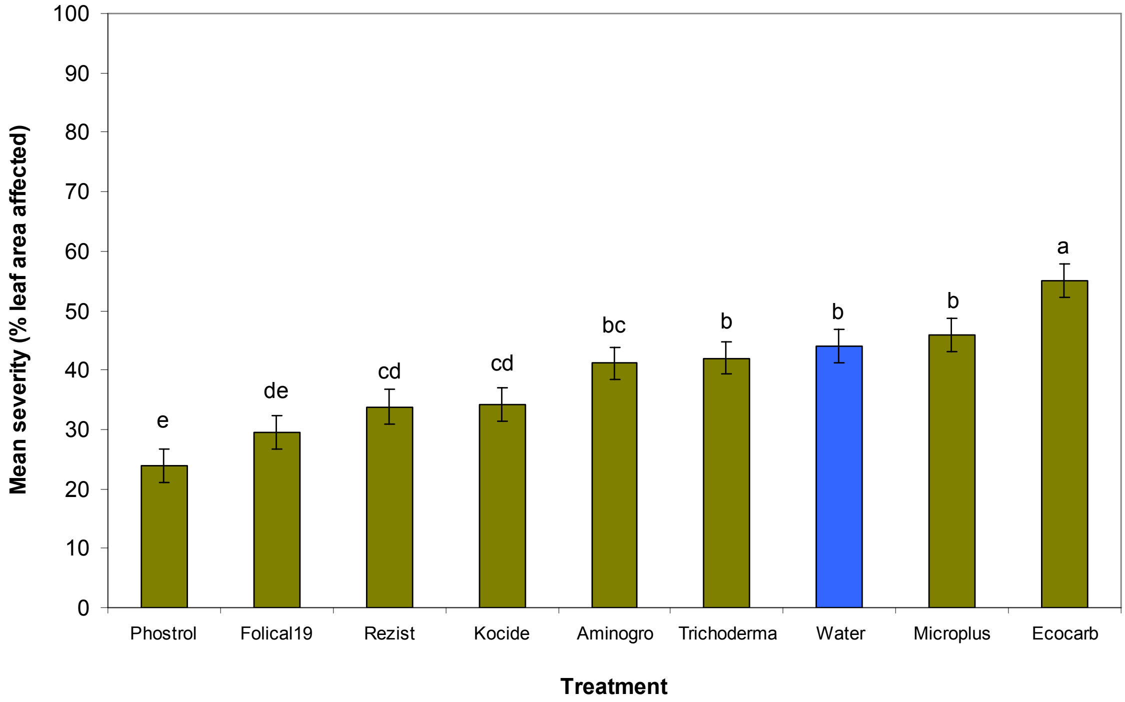


Figure 21. **Severity of downy mildew on field Crisphead lettuce (cv. Marksman) after application of various products during the growing season.**

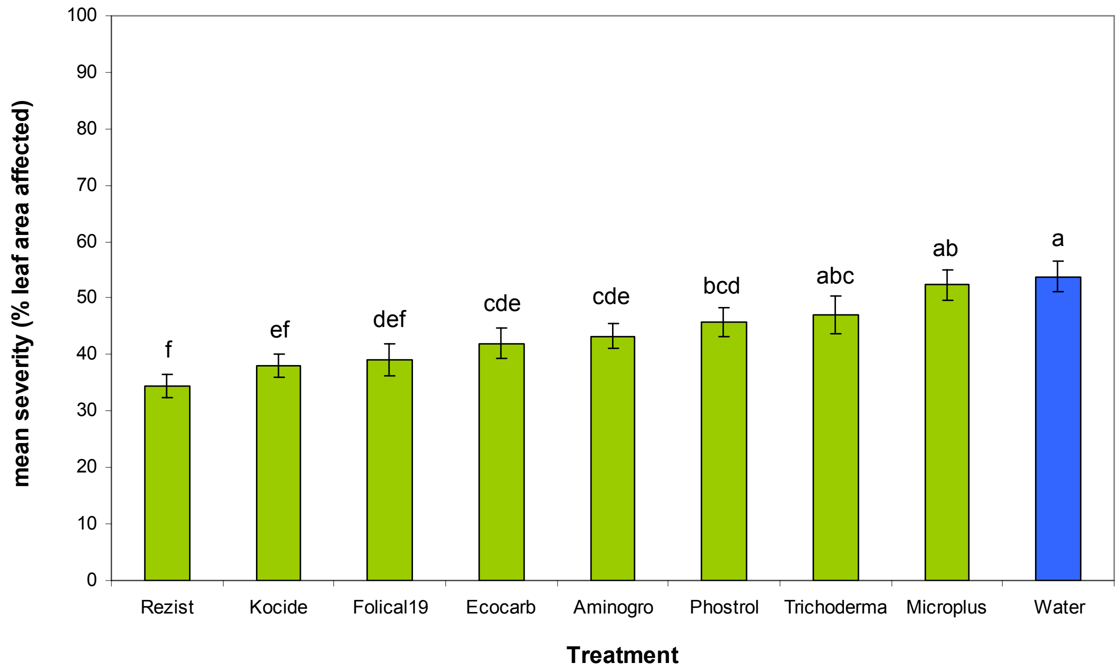


Figure 22. **Severity of downy mildew on field Crisphead lettuce (cv. Barcelona) after application of various products during the growing season.**

Discussion

These trials revealed that a number of alternative fungicides have the potential to be integrated into downy mildew control programs. In both growth room and field trials, FoliCal 19 Plus™ and Rezist® reduced the incidence and severity of disease. Both products provided good control when compared to liquid copper protectant fungicides Kocide® and Tribase Blue, and the phosphorus acid systemic fungicides AgriFos® 600 and Phostrol®. Other products such as Silmatrix® and EcoProtector® may have affected growth of the plant subsequently increasing it's susceptibility to infection when placed under high disease pressure.

Nutrients may be used indirectly to enhance the plant's natural defense to disease by affecting the tolerance or resistance of plants to pathogens (Dordas, 2008) FoliCal 19 Plus™ is liquid calcium which is boosted with natural plant elicitors to enhance natural disease resistance. Calcium is used to strengthen cell walls and enhances quality parameters. In HAL project VG07127 it was shown application of calcium may enhance the plants' defence to infection. In this study, FoliCal 19 Plus™ treated plants reduced the incidence and severity of downy mildew. Assurance of adequate calcium and avoidance of excess nitrogen and potassium will minimize disease risk.

Many products are considered a plant health product that boost plant growth and build resistance to climatic stress. Rezist® (1.75% Cu, 1.75% Mn and 1.75% Zn) is not registered as a fungicide but has been shown to indirectly increase the natural ability of the plant to withstand stress and improve resistance to disease by activating the plant's systemic acquired resistance (Bokshi, 2008). When applied on plant foliage in field conditions, Rezist® successfully reduced the extent of downy mildew on lettuce.

Trichoderma has been developed as a biocontrol agent to control fungal diseases in a variety of crops. It does this by a number of ways, including antibiosis, parasitism, inducing host-plant resistance, and competition (Howell, 2003). Commercial formulations of *Trichoderma* were used in this study, but they were not effective at reducing disease incidence or severity of lettuce diseases. Sentinel® has been developed from the strain of *Trichoderma* LC52 to protect against *Botrytis cinerea* in grapes. Likewise, *Trichoderma* Td 67 is currently registered to control *Botrytis cinerea* in grapes and *Trichoderma* Td 22 for control of onion white rot. Other isolates supplied are under screening for use as biological control agents.

Although a degree of control was observed, the extent of infection was not commercially acceptable in most trials. The level of infection will determine the use of the end product. Lettuce can be used whole, fresh cut or shredded in the processing market. Depending on the extent of infection, outer infected leaves of Crisphead varieties can be removed and the product can be sold as a fresh product sold in packaging. However high levels of infection will spoil the lettuce head and it will be unmarketable. The presence of downy mildew on other leafy varieties, such as Coral and Butter lettuce, is unacceptable and full control of the disease is required.

Conclusion

This study highlights fungal diseases can not be controlled primarily by the use of fungicides. Many products were evaluated for their efficacy to control downy mildew or anthracnose, yet commercially acceptable control was not achieved. These trials were undertaken using susceptible varieties, and many of the fungicides and soft options may provide suitable control when used in association with resistant varieties, or those with reduced susceptibility. In particular, the use of downy mildew resistant lettuce varieties provides a moderate degree of control but plants are still vulnerable to infection under high disease pressure. Use of resistant varieties still requires preventative control measures to eliminate the risk of disease. A successful disease control program must include the use of resistant varieties, sanitation, crop rotation, weed control and disease monitoring.

Consistent plant growth minimises crop stress and can be managed through the use of soil amendments, nutrients, scheduled irrigation, fungicide control and cultural practices. The use of alternative products to support crop growth may indirectly enhance the plants' natural defence system and be incorporated into an integrated disease management program.

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Use of Fungicide Alternatives to Control White Blister on Brassicas

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Victoria The Place To Be

Evaluation of commercial cultivars of *Brassica oleracea* and *Brassica rapa* for resistance to white blister rust

Introduction

Planting resistant cultivars is the most cost-effective and desirable method for white blister rust control (Santos *et al*. 2006, Li *et al*. 2007). Since the white blister rust outbreak on broccoli in 2001, there has been a complete change in commercially grown broccoli cultivars in Australia e.g. heat tolerant 'Viper' for summer cropping and 'Belstar' and 'Tyson' for winter cropping. Genetic resistance in some of the newly introduced broccoli cultivars has been gradually overcome by rapidly adapting populations of *Albugo candida*.

White blister rust also affects other *Brassica oleracea* vegetables including cauliflower, Brussels sprouts, kohlrabi and cabbage. Yield losses caused by the disease in these crops were negligible, when compared with losses in broccoli and replacement of cultivars was not necessary. There are growing concerns among growers, scientists and crop consultants about the possible escalation of white blister rust epidemic into cauliflower, Brussels sprouts and cabbage crops as the disease is known to significantly impact yields of all crops within the *B. oleracea* in Europe and the USA (Santos and Dias 2004, Santos *et al*. 2006). Limited information is available in Australia on resistance to white blister rust on *B. oleracea* crops other than broccoli. Anecdotally, cauliflower 'Forte' was suggested as contributing to the 2001/2002 white blister rust epidemic (Petkowski 2008). Local and systemic infection symptoms on seedlings and mature plants of this cultivar were of similar intensity to those on broccoli crops (Minchinton *et al*. 2007). Interestingly, until spring 2010 there was no record of white blister rust on commercial cabbage crops.

Seed of commercially grown *B. oleracea* and *B. rapa* cultivars are mostly imported into Australia. Some of these cultivars are sold with a description of their resistance to white blister rust e.g. susceptible, moderately susceptible or tolerant. Pathotypes of *A. candida* occurring on *B. oleracea* vegetables in Australia were demonstrated to be distinct from European pathotypes (Petkowski 2008), therefore their resistance label originating from Europe may be misleading.

In the *B. oleracea* group, some resistance to white blister rust is present. Pound and Williams (1963) reported resistance in broccoli *B. oleracea* var. *italica* cv Green Mountain. In contrast, screening of 14 selected European accessions of *B. oleracea* for white blister rust resistance (Leckie *et al*. 1998) found no resistance sources, apparently due to the heterogeneous nature of the accessions tested. Of 400 European *B. oleracea* accessions screened for resistance to white blister rust, 61% were completely susceptible (Santos *et al*. 1996). The nine most resistant accessions had only partial resistance with 50%-78% of seedlings resistant to white blister rust. These nine accessions consisted of kales of French origin, Italian cauliflowers, a Portuguese loose head cabbage, a Swiss savoy cabbage, a Portuguese trochuda cabbage, an Italian black broccoli and two unidentified accessions (Santos and Dias 2004). Similarly, the Brussels sprouts varieties Cantante and Niz 96-585 only showed a partial resistance (Meekes *et al*. 2000).

In the *Brassica rapa* group resistance to the host specific, Portuguese *A. candida* isolate was controlled by two nuclear genes (Santos *et al*. 2006). Screening for resistance conducted in this study, showed that out of 62 accessions of *B. rapa* var *chinensis* and *B. rapa* var *pekinensis*, only four accessions of the former had 50% of resistant plants. The latter had no resistant plants.

White blister rust resistance genes were identified in various *Brassica* species and major advances in the development of white blister rust resistant cultivars were achieved in breeding canola-quality *B. juncea* by incorporation of resistance from *B. napus* (Bansal *et al*. 1999, Sommers *et al*. 2002). Commercial canola-quality *B. juncea* cultivar Dune was released in Australia in 2007 as a result of a breeding program (Salisbury *et al*. 2004, Salisbury, *personal communication*).

This study was undertaken to identify criteria for cultivar selection of *B. oleracea* and *B. rapa* vegetables and toevaluate commercial cultivars of *B. oleracea* and *B. rapa* for their relative resistance to the Australian pathotypes of *A. candida* in glasshouse and field screening trials.

Materials and Methods

Grower survey

A phone survey was conducted with four Chinese cabbage and bok choi growers, three Brussels sprout and four cauliflower growers from Victoria, South Australia and Queensland in autumn 2008. Representatives of four seed companies distributing *Brassica* vegetable seed were also interviewed. Each person interviewed nominated preferred cultivars of cauliflower, Brussels sprouts, broccoli, Chinese cabbage, bok choi or pak choi for resistance evaluation.

Glasshouse trials

Seedlings of eight cultivars of *B. rapa* and 12 cultivars of *B. oleracea* were tested for resistance to *A. candida* collections from Chinese cabbage and broccoli, respectively in two glasshouse experiments (Table 1). Each experiment included hosts with reported susceptibility or resistance as controls. Two cabbage cultivars of known susceptibility to European pathotypes of *A. candida* were included in the *B. oleracea* experiment. In each experiment, seeds were sown in seed-raising mix in plastic multipot trays of 144 pots per tray. Seedlings were irrigated twice a day for 1 minute by overhead sprinklers. Plants were fertilised weekly with Aquasol™.

Inocula were prepared by suspending zoosporangia in sterile distilled water at the concentration of $1x10^5$ zoosporangia per mL. Prior to inoculation, the suspensions were incubated for four hours at 13 ºC to induce zoospore release. Inocula were applied twice in each of the experiments using a trigger atomiser on seedlings previously misted with sterile distilled water. The first inoculation was at the fully developed cotyledon stage and the second at the first true leaf growth stage. Seedlings were covered with plastic sheets after each inoculation for 24 hours to ensure sufficient leaf wetness for infection. White blister incidence and severity on hosts was assessed on 4 week-old and on 5 week-old seedlings in experiments with *B. rapa* and *B. oleracea*, respectively. Incidence was calculated as a percentage of the seedlings with symptoms. Disease severity was rated on seedlings with pustules using a 0-4 scale, where 0 represented a healthy plant with no pustules; 1, a single pustule on no more than two cotyledons/leaves; 2, multiple pustules on no more than two leaves; 3, multiple pustules on adaxial and abaxial sides of the leaf on at least one leaf; 4, multiple coalescing pustules on adaxial and abaxial sides of more than two leaves and coalescing pustules on leaf petioles. Experiments were designed as randomised complete blocks of treatments (12 hosts) with 8 replications (Fig 1). Data were analysed using ANOVA.

Fig 1 Screening of *B. rapa* cultivars for resistance to white blister rusts in a glasshouse at DPI Knoxfield in spring 2009.

Field trial

The trial site was located at Dairy Road Werribee, Victoria. Eight-week old seedlings of two cauliflower and six broccoli cultivars were planted in two rows of a 4m long and 1.62m wide raised bed on 23 July 2008. Each row contained 13 plants spaced 30 cm apart. The middle 10 plants of each row in each treatment plot were assessed for the incidence (presence or absence) of white blister on foliage at week 14+ (10/11/2008). The incidence data consisted of the number of plants per subplot with symptoms on foliage. This trial consisted of a completely random design for 8 treatments with 4 replications. The data was analysed using a generalised linear mixed model.

Results

Grower survey

The survey identified that agronomic qualities not the resistance to white blister rust were the main criteria for cultivar selection. Across all *Brassica* vegetables that were represented in the survey, characteristics such as high yield and appearance as well as season suitability were primary selection factors. *Brassica rapa* vegetable growers look for cultivars with resistance to bolting, size and colour suitable for versatile markets including export and processing, and resistance to clubroot.

Brussels sprouts growers prefer cultivars with high holding ability, with buttons of required colour and size, and which are easy to separate from the stem. All these features except button colour allow machine harvest. The latter is also in high demand by cauliflower growers, who seek cultivars with uniform plant frame including height, adequate head coverage with leaves and curd colour suitable for versatile markets.

Glasshouse experiments

All cultivars of *B. rapa* vegetables tested were either very or moderately susceptible to white blister (Table 1). ‘Miyako’ and ‘Walz’ were significantly more susceptible than other cultivars tested. Pak choi ‘Seven Gates’ had smaller blisters surrounded by discoloured rings of leaf tissues, indicating some level of resistance to the *A. candida* collection tested. Seedlings of Brussels sprouts ‘Abacus’and ‘Romulus’ were disease free, ‘Cyrus’ had a very low incidence (4.2 %) of seedlings with pustules and ‘Millenium’ was susceptible (36% of seedling with symptoms). All but one cauliflower cultivar, ‘Avalanche’, were susceptible (Table 1). Cabbage ‘Sting’, which is susceptible to European *A. candida*, was moderately susceptible to the Australian *A. candida*. The moderately susceptible cultivar NIZ17-1091, however, was resistant to the collection tested. White blister rust was the most severe on cauliflower ‘Forte’ followed by broccoli ‘Greenbelt’.

Field trial

In the field trial cauliflower cultivars ‘Skywalker’ and ‘Discovery’ were susceptible and broccoli cultivars ‘Tyson’ and ‘Booster’ showed good resistance to local populations of *A. candida* at the time of the trial (Fig 2).

Table 1 Incidence and severity of white blister rust on seedlings of commercial cultivars of *B. rapa* and *B. oleracea* vegetables inoculated with *A. candida* collections from Chinese cabbage and broccoli under glasshouse conditions. Within each column, means with different suberscripts are significantly different P <0.001.

B. rapa Cultivar n=96	Mean Incidence (%)	Mean Severity Scale (0-4)	*B. oleracea* Cultivar n=96	Mean Incidence (%)	Mean Severity Scale (0-4)
Miyako PC	91.3[a]	2.2 [a]	Greenbelt B*	79.8 [a]	1.7[a]
Walz ChC	80.1[a]	1.3 [b]	Forte CF*	76.6 [a]	1.9 [a]
Mei Qoing PC	72.9[b]	1.3 [b]	Highfield CF	53.6 [b]	1.1[b]
Cv 001 ChC	70.6[b]	1.1 [b]	Brittany CF	44.5 [bc]	0.9 [b]
Matilda ChC	66.9[b]	1.0 [b]	Millenium BS	35.7 [cd]	0.6[bc]
Seven Gates PC	60.5[b]	0.9 [b]	Summer Love CF	35.6[cd]	0.8[bc]
Manoko ChC	60.4[b]	0.8 [b]	Sting C	25.3 [d]	0.3[c]
Reward T*	58.0[b]	1.0 [b]	Cyrus BS	4.2[e]	0.1[c]
Torch T*	55.3[b]	1.4 [b]	Avalanche CF	0.0	0.0
Joi Choi PC	56.0[b]	0.7 [b]	Abacus BS	0.0	0.0
Kailaan ChB*	5.6[c]	0.1[c]	Romulus BS	0.0	0.0
Regent OR*	0.0[c]	0.0 [c]	NIZ17-1091 C	0.0	0.0

*) Cultivars incorporated either as positive or negative controls. Cultivars of *B. rapa* turnip rape ‘Torch’ and ‘Reward’ are positive controls. Cultivars Regent (*B. napus*) and Kailaan (*B. oleracea*) are negative controls.

Abbreviations following cultivars name are: PC, pak choi; ChC, Chinese cabbage; T, turnip rape; ChB, Chinese broccoli; OR, oil rape; B, broccoli; CF, cauliflower; BS, Brussels sprout; C, cabbage.

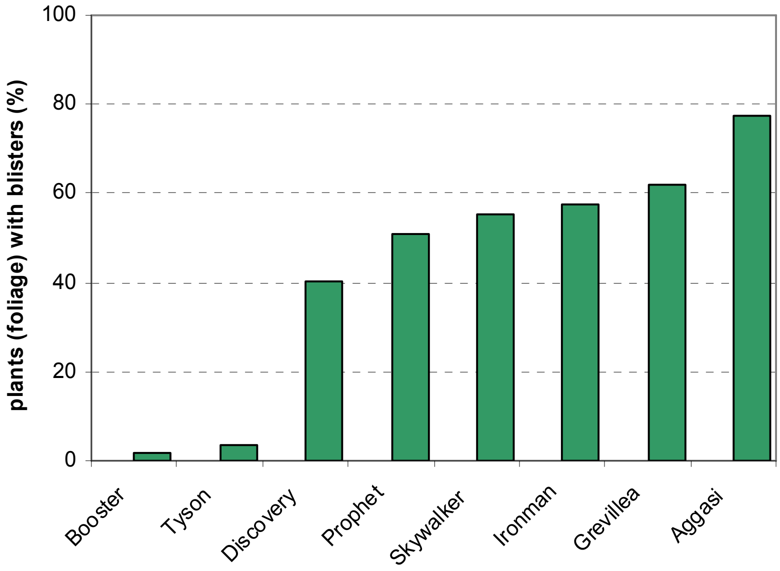

Fig 2 Incidence of white blister on leaves of commercial *B. oleracea* cultivars: Discovery and Skywalker are cauliflower cultivars, the remaining cultivars are broccoli in a field trial at Werribee, Victoria.

Discussion

Results of the phone survey indicate that cultivar agronomic characteristics rather than disease resistance are the primary criteria for cultivar selection. This study has identified commercial cultivars with resistance to white blister, including pak choi 'Seven Gates', cauliflower 'Avalanche' and Brussels sprouts 'Abacus' and 'Romulus', and confirmed resistance in broccoli 'Tyson' and 'Booster'.

Prior to this study, the information on resistance to white blister rust was either not available or based solely on resistance to European populations of *A. candida*, therefore irrelevant in Australian production systems. Growers could not make an informed decision on selection of resistant cultivars and therefore used fungicides rather than resistant cultivars for white blister rust control. Cultivars with resistance to white blister rust provide the most cost-effective disease control method.

Seedlings of pak choi 'Seven Gates' had pustules surrounded by discoloured leaf tissue, indicating some level of resistance to the *A. candida* population tested. The appearance of these rings is most likely associated with biosynthesis of antimicrobial compounds (e.g. phytoalexins, phenolic compounds) (Field *et al.* 2006) as no physical reinforcements of cell walls in discoloured leaf tissues were observed in previous studies (Petkowski 2008).

The resistant broccoli cultivars, which are currently available, are designed for cropping in cooler seasons. A resistant broccoli cultivar with good agronomic characteristics is needed for summer cropping to replace an excellent cultivar 'Viper' or 'Atomic', which has lost its resistance in 2006 (Petkowski 2008, Petkowski *et al*. 2010). Recently, there were reports from growers and crop consultants that cultivars 'Tyson' and 'Booster' were becoming susceptible to white blister rust, which confirms the gradual adaptation of the pathogen to a 'new' genetic background, therefore single cultivars should not be exclusively planted in any cropping area. Planting cultivars of variable susceptibilities prevents the breakdown of resistance. Host genetic diversity helps to maintain multiple pathotype populations varying in their pathogenicity rather than selecting for more aggressive pathogen populations.

Screening commercial cultivars of *Brassica* vegetables, sourced from various distributors/seed companies, for their resistance to the Australian pathotypes of *A. candida* provides information to growers on the best cultivar available for the cropping season. Additionally, the screening monitors changes in pathogenicity patterns of endemic *A. candida* pathotypes and allows early detection of the potential introduction or development of new pathotypes. Resistant cultivars identified in this study should be used as differential host sets in future studies. Since this study was conducted in 2008 and 2009, there was a report of white blister rust on a commercial cabbage crop in the Werribee South cropping area. In the present study, the local isolate from broccoli was pathogenic to at least one cabbage cultivar 'Sting' (sourced from the Netherlands). This could indicate continuous changes in aggressiveness of the local *A. candida* populations. The risk of introducing new pathotypes can be reduced by treating all imported seed with fungicides.

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Evaluation of alternatives to fungicides for control of white blister rust on *B. rapa* and *B. oleracea* vegetables

Introduction

Currently, the Australian *Brassica* vegetable industry relies on systemic fungicides such as strobilurin (azoxystrobin) and metalaxyl (acylalanine) for control of white blister rust disease in areas of intensive production. There is some experimental evidence of the reduced activity of metalaxyl against white blister rust in the Werribee South broccoli cropping area (Petkowski 2008). Numerous grower reports on the ineffectiveness of these fungicides in areas where they are extensively used confirm that some level of resistance to these chemicals may have developed in populations of *A. candida.* Metalaxyl (Ridomil®), a specific fungicide for oomycetes and azoxystrobin (Amistar®), which targets a broader spectrum of pathogens, were the most effective against white blister rust on broccoli in previous studies (Minchinton *et al*. 2007). Persistent and large-scale use of both of these fungicides was reported to have caused the development of resistance in *Phytophthora* (Ferrin and Rhode 1992) and downy mildews (O'Brien 1992, Heaney *et al*. 2000, Ishii *et al*. 2001, Klein 1994). *Albugo candida* is known to develop resistance after five consecutive sprays of a systemic fungicide (Liu and Rimmer 1992).

Some soft chemicals (non-target chemicals, which have no withholding periods and minimal to zero effects on the environment), such as surfactants as well as biocontrol agents and plant immune system activators, used on their own and in rotation with conventional fungicides may provide new alternative options for control of many plant pathogens, including *A. candida*.

The efficacy of various synthetic non-ionic surfactants against zoosporic plant pathogens such as some species of *Pythium* and *Phytophthora* was demonstrated by Stanghellini and Tomlinson (1987). Non-ionic and anionic surfuctants, Naiad and sodium dodecyl sulphate (SDS) tested in the glasshouse and the field conditions were as effective as fungicides against white blister rust on spinach caused by *Albugo occidentalis* (Irish *et al*. 2002). Some ionic surfactants, synthetic polymers of various functional groups (Ziv and Zitter 1992), and biosurfactants produced by bacteria eg. *Pseudomonas aeruginosa* (Stanghellini and Miller 1997), *Pseudomonas fluorescence* (de Souza *et al*. 2003) and *Bacillus subtilis* (Ongena *et al*. 2005) can potentially interrupt the infection process by interfering with the movement of motile zoospores by changing the surface tension of the leaf or by zoospore lysis caused by the destruction of the zoospore plasma membrane (Irish *et al*. 2002, Stanghellini and Millner 1997). Additionally, lipopeptides produced by *B. subtilis* are reported as elicitors of induced systemic resistance in plants (Ongena *et al*. 2007).

Similar effects were achieved using the synthetic activator of plant defence systems, benzothiadiazole (BTH). It gave protection against *A. candida* infections on 60% of *B. juncea* 'Kranti'seedlings when applied 24 hours after inoculation in a glasshouse experiment (Kaur and Kolte 2001). It also prevented development of systemic and foliage symptoms on the same host in field conditions. Two to three applications of BTH in 10-day intervals induced resistance against *A. candida* in radish (Laun 1998).

The present study aimed to identify alternatives with various action modes for control of white blister rust in *B. oleracea* and in *B. rapa* vegetables.

Materials and Methods

Glasshouse experiments

Two glasshouse experiments were conducted on seedlings of *B. oleracea* and *B. rapa* vegetables, respectively to evaluate alternative regimes for control of white blister rust at DPI Knoxfield, Victoria. Each experiment trialled two cultivars of different susceptibility to *A. candida*, the selection of which was based on cultivar evaluation results. Alternative treatments were applied twice onto seedlings of broccoli 'Greenbelt' and 'Viper' and seedlings of Chinese cabbage 'Waltz' and pak choi 'Seven Gates' 24 hours before each of the two inoculations with host specific *A. candida*. The alternative treatments included a surfactant, Du-Wett®; the polymers, Nu-Film® and VaporGard®; the plant resistance activator Bion50®WG; and biocontrol agents, *B. subtilis* (Table 1 and Table 2). Each experiment included additional treatments, an unsprayed control and a single application of systemic fungicide Amistar®, as a common industry practice.

In each experiment, seeds were sown in seed-raising mix in plastic multipot trays of 64 pots per tray. Plants were maintained on the glasshouse bench as previously described. Inocula for each experiment were prepared using zoosporangia collected from corresponding host species and applied as previously described. The first inoculation was at the fully developed cotyledon stage and the second, seven days later, at the first true leaf growth stage.

Each treatment was applied to a single tray divided in halves; each half was sown to one of each cultivar (split-plot). Each experiment had six replications. Disease and severity were assessed on 6-week-old seedlings of *B. oleracea* as previously described. Only incidence was assessed on 6-week-old *B. rapa* seedlings. In the *B. rapa* experiment, for both cultivars in order to accommodate the binomial nature of the data and the unequal numbers of assessed plants in each plot, a generalised linear mixed model was fitted to the incidence data. Treatments Amistar® and Bion50®WG were excluded from analysis, because no disease was observe on plants of each cultivar tested. Incidence data from the *B. oleracea* experiment were analysed using ANOVA. Logarithmic transformation [LOG10 ((Average Severity+1))] was applied to severity data.

Field trial on broccoli 'Rhumba'

A field trial was conducted in the Werribee South *Brassica* cropping area in autumn 2010. Grower-own broccoli 'Rhumba' seedlings (Clause Vegetable Seeds) were transplanted to two-row beds and spaced 30 cm apart on 19th April 2010. The trial was designed as a randomised complete block with four treatments and seven replications (Table 3). Treatments were: 1) control (unsprayed); 2) grower spray practice, which consisted of weekly applications of TriBaseBlue®, additionally, Amistar® was mixed with the former at week 4, 7 and 10 after transplanting (the last application of TriBaseBlue® mixed with Amistar® targeted the stage of broccoli button development); 3) weekly applications of *B. subtilis*; 4) two applications of Bion®, one at the first appearance of white blister rust symptoms and then another application a week later. Plots were 6 m long and 1.62 m wide. Plants were monitored weekly and assessed for white blister rust symptoms on heads on 15th June 2010 and for white blister on foliage on 21st June 2010.

Field trial on Chinese cabbage 'Matilda'

Chinese cabbage variety "Matilda" seedlings were planted on the 5th August 2010. The crop was grown following conventional agronomic practices by the Gatton Research Station staff. Insecticides such as Success® were applied when required to manage insect pests such as diamondback moth. Each plot, representing a treatment, was 6m long and consisted of 3 rows of plants per plot/bed with a plant spacing of 33cm. Buffer beds were also grown between each treatment bed. Treatments included: 1) Bion50®WG at the rate of 1 µM applied four weeks after transplanting and one week thereafter; 2) Bion50®WG at the rate of

10 µM applied four weeks after transplanting and one week thereafter; 3) *B. subtilis* applied every two weeks; 4) Amistar® used as a common industry practice and applied after first appearance of the disease; 5) unsprayed control. Treatments were sprayed using a motorised backpack sprayer applying the equivalent of 588L/ha through a hand held boom with 4 equally spaced twin jet nozzles.

The trial was monitored weekly for the presence of white blister by randomly checking 40 plants across the trial site. Once the disease was found in the crop there was no need to continue the weekly surveys. Weekly surveys were used to determine the timing of the first application of Bion50®WG and Amistar®.

Disease incidence and severity wer assessed at harvest. Incidence was calculated as percentage of plants with pustules. Severity assessment was conducted on the four innermost wrapper leaves using the scale of 0-4, where 0 = no blisters on wrapping leaves, 1=one leaf with pustules, 2 = two leaves with pustules, 3 = three leaves with pustules, and 4 = four leaves with pustules.

This trial consisted of a completely random design with 5 treatments with 7 replications.

Results

Glasshouse experiments

On the *B. rapa* seedlings, only Bion50®WG was effective although phytotoxic. Seedling of both *B. rapa* cultivars treated with Bion50®WG and Amistar® were disease free, and excluded from the statistical analysis (Table 2).

On broccoli seedlings, VaporGard®, Bion50®WG and *B. subtilis* significantly reduced white blister by 33%, 54% and 70%, respectively, when compared with the unsprayed control (Table 1). Interestingly, Amistar® was as effective as Bion50®WG and *B. subtilis*. Treatments had differing effects on disease incidence between the cultivars. There is slight evidence of an interaction between cultivar and treatment (p=0.056). But for severity, there was no treatment and cultivar interaction, therefore treatment means are averaged over both cultivars.

Field trial on broccoli ‘ Rhumba’

White blister rust symptoms appeared on leaves in control plots at week 7 (30/4/2010) as very small lesions surrounded by dark almost black boarders. Alternative treatments, Bion50®WG and *B. subtilis* were significantly less effective than grower spray practice against the disease on foliage (Table 3). No white blister rust symptoms appeared on heads of broccoli ‘Rhumba’ at harvest.

Table 1 Incidence and severity of white blister rust on seedlings of commercial broccoli 'Viper' and 'Greenbelt' inoculated with *A. candida* populations from broccoli and treated with alternatives to fungicides in glasshouse conditions. Means followed by different letters are significantly different at the 5% level.

Treatment	Rate/ha	Mean incidence of white blister rust on 'Viper' (%)	Mean incidence of white blister rust on 'Greenbelt' (%)	Mean severity of white blister rust on 'Viper'and 'Greenbelt' (scale 0-4)
Control	n/a	92.0[a]	86.1[a]	1.991[a]
Du-Wett®	150mL*	82.8 [a]	76.8[a]	0.983 [b]
VaporGard®	2.5L	59.7[b]	60.3 [b]	1.912[a]
Bion50®WG	1µM	30.2[c]	51.1[bc]	0.477 [c]
B. subtilis	5L	26.1[c]	27.1[c]	0.339 [cd]
Amistar®	0.3kg	20.8[c]	30.7[c]	0.269 [d]
P<0.001				
l.s.d.(%)		17.56	17.56	

*) should not be diluted in more than 250L of water

Table 2 Mean incidence of white blister rust on seedlings of commercial pak choi 'Seven Gates' and Chinese cabbage 'Waltz' inoculated with *A. candida* populations from Chinese cabbage and treated with alternatives to fungicides in glasshouse conditions. The F-test showed no overall significant effect of three alternative treatments; Du-Wett®, Nu-Film® and *B. subtilis*, when compared with control treatment. Amistar® and Bion50®WG were excluded from analysis.

Treatment	Rate/ha	Mean incidence of white blister rust on 'Seven Gates' and 'Waltz' (%)
Control	n/a	16.4
Du-Wett®	150mL*	18.3
Nu-Film®	2.5L	12.1
Bion50®WG	100µM	0.0
B. subtilis	5L	11.1
Amistar®	0.3kg	0.0

*) should not be diluted in more than 250L of water

Table 3 Incidence and severity of white blister rust on foliage of broccoli 'Rhumba' in a field trial at Werribee South in autumn 2010. Means followed by different letters are significantly different at the 5% level.

Treatment	Mean incidence of white blister rust on foliage (%)	Mean severity of white blister rust on foliage Scale (0-4)	Number of sprays
Control	50.0[a]	0.686[a]	0
Bion50®WG	49.3[a]	0.729[a]	2
B. subtilis	43.6[a]	0.686[a]	11
Grower Spray Practice	20.0[b]	0.257[b]	11
l.s.d.(5%)	14.63	0.2609	

Field trial *on* Chinese cabbage 'Matilda'

White blister first appeared at the end of August after visually assessing the plants in the field. None of the tested alternatives controlled white blister rust on Chinese cabbage 'Matilda' Table 4). The systemic fungicide Amistar® was not effective against the disease.

Table 4 Effect of alternative treatments for white blister rust control on Chinese cabbage 'Matilda' (*B. rapa* var. *pekinensis*) in a field trial at Gatton Research Station, DEEDI, Queensland. Means followed by the same letter are not significantly different at the 5% level.

Treatment	White blister rust incidence (%)	Mean severity of white blister rust Scale (0-4)*
Control	100.0[a]	3.62[a]
Amistar®	97.8[a]	3.25[a]
B. subtilis	98.2[a]	3.15[a]
Bion® 1µM	100.0[a]	3.59[a]
Bion® 10µM	100.0[a]	3.34[a]
		$P<0.001$

Discussion

This study demonstrated that two treatments, Bion50®WG and *B. subtilis* significantly reduced white blister rust on seedlings of *B. rapa* and *B. oleracea*. Bion50®WG and *B. subtilis* were as effective as the systemic fungicide Amistar® on broccoli seedlings. Bion50®WG was as effective as Amistar® on Chinese cabbage and pak choi seedlings. Neither of these treatments controlled the disease on Chinese cabbage and broccoli in field trials. The results provide experimental evidence for reduced or complete loss of efficacy of Amistar® in field trials conducted on broccoli and Chinese cabbage in Victoria and Queensland, respectively.

Only Bion50®WG and *B. subtilis* were trialled in the field because of their efficacy on seedlings grown under glasshouse conditions. There is a high possibility that factors such as plant development stage as well as rate and timing of application could have been critical in achieving better efficacy. These factors should be looked at in future studies on alternative options for white blister rust control in *Brassica* vegetables. Based on current research both alternative treatments, Bion50®WG and *B. subtilis* can not be recommended as stand-alone treatments to replace conventional fungicides in intensive production systems. They may be used in seedling and organic production, where the use of conventional fungicides is strictly limited. Being used in these systems, these alternative options provide additional means for fungicide resistance management (Staub 1991) and most importantly reduce the adverse effect of conventional chemicals on the environment.

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Project communications

Project findings were reported:

To growers, seed company representatives and crop consultants:

1) field day conducted as part of VG07070 at Werribee, 12 November 2008
2) growers meeting conducted as part of VG07070 at Cranbourne, 21 November 2008
3) field day and meeting conducted as part of VG07070 and HAL program 2 at Cranbourne, 19 June 2009
4) combined projects steering committee meeting for VG07127 and VG07070 at Werribee, 24 July 2009
5) combined project reporting meetings conducted as part of HAL vegetable pathology programs 2 and 3 in Gympie, Gatton (QLD) and in Cranbourne and Lindenow (Vic) on 11-12 August 2010 and 18-19 August 2010 respectively.

To professional bodies:

1) HAL as part of the vegetable pathology HAL program review, Melbourne 27-28 November 2008
2) research team for HAL vegetable pathology program 3.1 (VG07127) in Brisbane 2010

To research communities:

1) Petkowski JE, Thomson F, Minchinton EJ and Akem C (2009) Evaluation of commercial cultivars for control of white blister rust in *Brassica rapa* and *Brassica oleracea*. Poster presented at the 17th biennial APPS conference in Newcastle, 29 September -1 October 2009.
2) Petkowski JE, Thomson FM, Auer DP, Minchinton EJ and Akem C (2010) Evaluation of alternatives to fungicides for white blister rust control on *Brassica* vegetables. Abstract submitted for combined ACPP and APPS conference in Darwin, 26-29 April 2011.
3) Petkowski JE (2010) Evaluation of commercial *Brassica* cultivars for the control of white blister. An article in Brassica IPM National Newsletter.
4) Petkowski JE (2010) Evaluation of fungicide alternatives for white blister control on *Brassica* vegetables. An article submitted to Brassica IPM National Newsletter.

Evaluations of Products for White blister Control in Broccoli

Tasmania Research component

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Evaluations of products for white blister control in broccoli in Tasmania

Introduction

White blister caused by *Albugo candida* is a major threat to broccoli production in Tasmania. The fungal disease became widespread in Victoria in 2002, before spreading to Tasmania in 2003. The disease is now present in all major brassica production regions throughout Australia. The disease can affect all stages of plant growth and can result in substantial losses to yield. Generally, the tolerance level for broccoli head infections in a fresh market broccoli crop is less than 10%, with increased costs in sorting during and after harvest, and potential losses if the disease develops on heads in storage and in transit to their market. Broccoli heads produced for processing in Tasmania are especially prone to white blister, because the processing crops are grown longer and their heads are much larger in sizes (at least twice the width of fresh market broccoli heads).

A. candida belongs to the same group of fungi, classified as *Oomycetes,* as other fungal pathogens such as *Peronospora*, *Pythium* and *Phytophthora.* Fungicides that are active against the latter pathogens may also have activity against *A. candida*. Currently, there are very few fungicides that are available to growers for white blister control on broccoli. This problem is compounded by the use of multiple plantings of broccoli in each site in order to ensure a regular supply of the produce to the fresh market and for processing. Therefore, crops and fungicide products are exposed to the pathogen for a long period of time. Development of fungicide resistance to fungicide is a major issue, when the industry mainly relied on azoxystrobin and metalaxyl for white blister control under these conditions. The selection of additional products that can be used for white blister control in broccoli is vital to ensure that growers are able to meet market demand for quality produce. Therefore, three trial studies were conducted in Tasmania in the 2009 to 2010 growing seasons, aimed at screening and identifying products that may be suitable for use for white blister control in broccoli.

Materials & Methods

Three trials were conducted within commercial broccoli crops in Tasmania. The trial design was randomised complete block with plot size of 6 m x 3 plant rows. There were five replicates in Trial 1 at Harford and four replicates in Trials 2 and 3 at Forthside and Leith. All treatment applications were applied in two to three sprays; the first spray applied just before or at initial button stage. Spray treatments were applied with an air pressurised knapsack sprayer fitted with a 1.5 m boom and cone jet nozzles TX12 with 300 L/ha water volume and a pressure of 400 kPa. Fungicides in Trial 1 was applied without any spray adjuvant, whereas Trials 2-3 were applied with Du-Wett spray adjuvant to improve coverage and uptake of spray applications. At close to harvest, all plants in 5 m x 2 plant rows in each plot were assessed for white blister on the top five fully open leaves. The percentage of infected plants or disease incidence was tabulated by dividing the number of plants with infected leaves with the total number of plants assessed and multiplying by 100. The disease severity was based on the percentage of the top leaves infected by white blister.

Table 1. Product details

Product Name	Active Ingredient	Concn of ActiveIngredient	Formulation	Product Type
Aero	metiram + pyraclostrobin	550 g/kg 50 g/kg	Water Dispersible Granule	Fungicide
Amistar SC	azoxystrobin	250 g/L	Suspension Concentrate	Fungicide
Amistar Top	Difenoconazole azoxystrobin	125g/L 200g/L	Suspension Concentrate	Fungicide
Bion	acibenzolar-s-methyl	500 g/kg	Water Dispersible Granules	Plant resistance activator
Bozul	sulphur dioxide benzoic acid	150 g/kg 500 g/kg	Powder	Broad spectrum biocide
Du-Wett	trisiloxane ethoxylate	500 g/L	Liquid	Spray adjuvant
Micro Plus	*Streptomyces lydicus* WYEC108	(1 X 10^7 cfu/ml)	Soluble biological inoculant	Biocontrol
NUL 1935	NUL 1935	240 g/L	Suspension Concentrate	Fungicide
NUL 1955	NUL 1955	200 g/L	Suspension Concentrate	Fungicide
NUL 2111	NUL 2111	Not supplied	Suspension Concentrate	Fungicide
Polyram	metiram	700 g/kg	Dry Flowable	Fungicide
Previcur	propamocarb	600 g/L	Aqueous Concentrate	Fungicide
Ridomil Gold Plus	copper hydroxide metalaxyl-M	600 g/kg 50 g/kg		Fungicide

Table 2. Trial 1 conducted in 2009 at Harford, Tasmania

No.	Treatment	Product Rate/ha	Active ingredient Rate g ai/ha
1	Untreated control	-	-
2	Amistar 0.4 L	0.4 L	100
3	Amistar 0.4 L + Bion 30 g	0.4 L + 30 g	100 + 15
4	Aero 1.5 kg	1.5 kg	900
5	Polyram 2.5 kg	2.5 kg	1750
6	Previcur 0.3 L	0.3 L	180
7	Bozul 3.0 kg	3.0 kg	1950
8	Micro Plus 0.5 kg	0.5 kg	5×10^6 cfu

Table 3. Trial 2 conducted in 2009/2010 at Forthside, Tasmania

No.	Product	Product Rate/ha	Active ingredient Rate g ai/ha
1	Untreated control	-	-
2	Amistar 0.4 L	0.4 L	100
3	Amistar Top	0.5 L	162.5
4	Amistar 0.4 L + Bion 30 g	0.4 L + 30 g	100 + 15
5	NUL 1955	0.5 L	100
6	NUL 2111	0.5 L	-
7	NUL 1935	0.5 L	120
8	Polyram 2.5 kg	2.5 kg	1750
9	Amistar + Polyram	0.4 L + 2.5 kg	100 + 1750

Table 4. Trial 2 conducted in 2010 at Leith, Tasmania

No.	Product	Product Rate/ha	Active ingredient Rate g ai/ha
1	Untreated control	-	-
2	Amistar 0.4 L	0.4 L	100
3	Ridomil Gold Plus	2.0 kg	
4	Amistar 0.4 L + Bion 30 g	0.4 L + 30 g	100 + 15
5	NUL 1955	0.5 L	100
6	NUL 2111	0.5 L	-
7	Polyram 2.5 kg	2.5 kg	1750
8	Amistar + Polyram	0.4 L + 2.5 kg	100 + 1750

Table 5. Chronology of events

Date	Days After Planting (DAP)	Days After Last Application (DALA)	Event
Trial 1 - Harford			
17/01/09	0		Transplants planted
24/02/09	38		First sign of white blister infections on leaves - a few plants infected
6/03/09	48		1st fungicide application. Vegetative growth
13/03/09	55		2nd fungicide application. Early button stage
22/03/09	64		3rd fungicide application. Early button stage 1-1.5 cm
1/04/09	74	10	Disease assessment for leaf and head infections
3/04/09	76	12	First cut of commercial harvest outside trial area
6/04/09	79	15	Disease assessments for head infections
12/04/09	85	21	Final cuts for commercial harvest outside trial area
14/04/09	87	23	Disease assessments to compare head infections in Treatments 2-5
Trial 2 - Forthside			
30/10/09	0		Transplants planted.
23/12/09	54		1st fungicide application. Vegetative growth
30/12/09	61		2nd fungicide application. Early button stage.
30/12/09	61	0	First sign of white blister infections on leaves - a few plants infected
05/01/10	67	6	3rd fungicide application cancelled, crop to be harvested soon
05/01/10	67	6	First cut of commercial harvest outside trial area
07/01/10	69	8	Disease assessments for head infections
08/01/10	70	9	Final cut for commercial harvest outside trial area
Trial 3 - Leith			
05/03/10			Transplants planted
30/04/10	56		1st fungicide application. Vegetative growth. No white blister noted in the trial area.
06/05/10	62		2nd fungicide application. Early button stage.
13/05/10	69	0	3rd fungicide application. Early button stage 1-1.5 cm.
18/05/10	74	35	Disease assessment for leaf and head infections
19/05/10	75	36	First cut of commercial harvest outside trial area
26/05/10	82	43	Disease assessments for head infections
31/05/10	87	48	2nd head assessment

Photographs

Trial at Harford, Tasmania

White blisters on leaves

White blister on broccoli head

Results

1. Trial 1 at Harford

Trial 1 at Harford was conducted within a commercial broccoli crop that was producing heads for processing into frozen vegetables. The crop in the trial was adjacent to two other broccoli crops that were planted earlier and was infected by white blister. Therefore, plants in the trial were subjected to high disease pressure from the white blisters in the early crops. Fungicide sprays were first applied when early leaf infections were first noted on some plants, approximately one week before initial head formation or early button stage. The second and third sprays were applied at 7 and 9 day intervals. White blister incidence was very high at 74 days after planting (DAP), ranging from 54% to 100% plants infected (Table 6). Only Amistar at 0.4 L/ha, Amistar at 0.4 L/ha plus Bion at 30 g/ha, and Aero at 1.5 kg/ha reduced white blister incidence as well as severity on leaves. Polyram at 2.5 kg/ha did not reduce the disease incidence, but did significantly reduced the leaf infection severity. Amistar at 0.4 L/ha plus Bion at 30 g/ha was the most effective treatment in reducing the leaf infections.

Table 6. The incidence and severity of leaf infections in Trial 1 at Harford

No.	Treatment	No. plants assessed/plot	White blister leaf infections	
			Incidence % Plants infected 74DAP 10DALA	Severity % Top leaves infected 74DAP 10DALA
1	Untreated control	34	100 a	86 a
2	Amistar 0.4 L	31	72 c	24 d
3	Amistar 0.4 L + Bion 30 g	32	54 d	14 d
4	Aero 1.5 kg	34	88 b	34 c
5	Polyram 2.5 kg	34	99 ab	50 b
6	Previcur 0.3 L	32	100 a	91 a
7	Bozul 1%	33	100 a	89 a
8	Micro Plus 0.5 kg	32	100 a	88 a
LSD (P = 0.05)			11.6	9.7
P-value		0.7486	0.0001	0.0001

Numbers in a column followed by the same letter are not significantly different at P =0.05, Fisher's Protected LSD Test.
DAP: days after planting; DALA: days after the last spray application

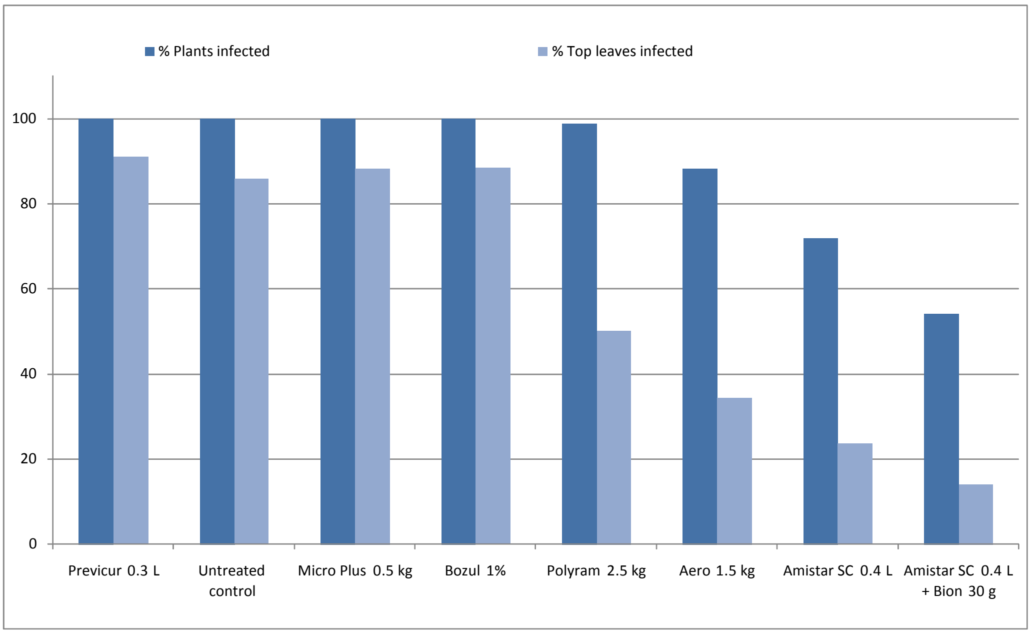

Figure 1. White blister control on leaves in Trial 1

Trial 1 at Harford (Cont.)

At 79DAP, when many heads were ready for harvest, relatively high levels of head infections were recorded in the untreated control, Previcur, Bozul and Micro Plus treatments, with 22% to 36% heads infected (Table 7). Amistar at 0.4 L/ha, Amistar at 0.4 L/ha plus Bion at 30 g/ha, Aero at 1.5 kg/ha and Polyram at 2.5 kg/ha gave excellent head infection control, with no unmarketable heads.

Table 7. The incidence and severity of broccoli head infections in Trial 1 at Harford

No.	Treatment	White blister head infections		
		% Heads infected 01/04/09 74DAP 10DALA	% Heads infected 06/04/09 79DAP 15DALA	% Unmarketable heads 06/04/09 79DAP 15DALA
1	Untreated control	5	25 b	5 a
2	Amistar 0.4 L	0	0 c	0 b
3	Amistar 0.4 L + Bion 30 g	0	0 c	0 b
4	Aero 1.5 kg	0	2 c	0 b
5	Polyram 2.5 kg	0	1 c	0 b
6	Previcur 0.3 L	3	36 a	7 a
7	Bozul 1%	1	22 b	4 ab
8	Micro Plus 0.5 kg	0	24 b	8 a
LSD (P=.05)			10.0	4.7
P-value		0.6043	0.0001	0.0013

Numbers in a column followed by the same letter are not significantly different at P =0.05, Fisher's Protected LSD Test.

DAP: days after planting; DALA: days after the last spray application

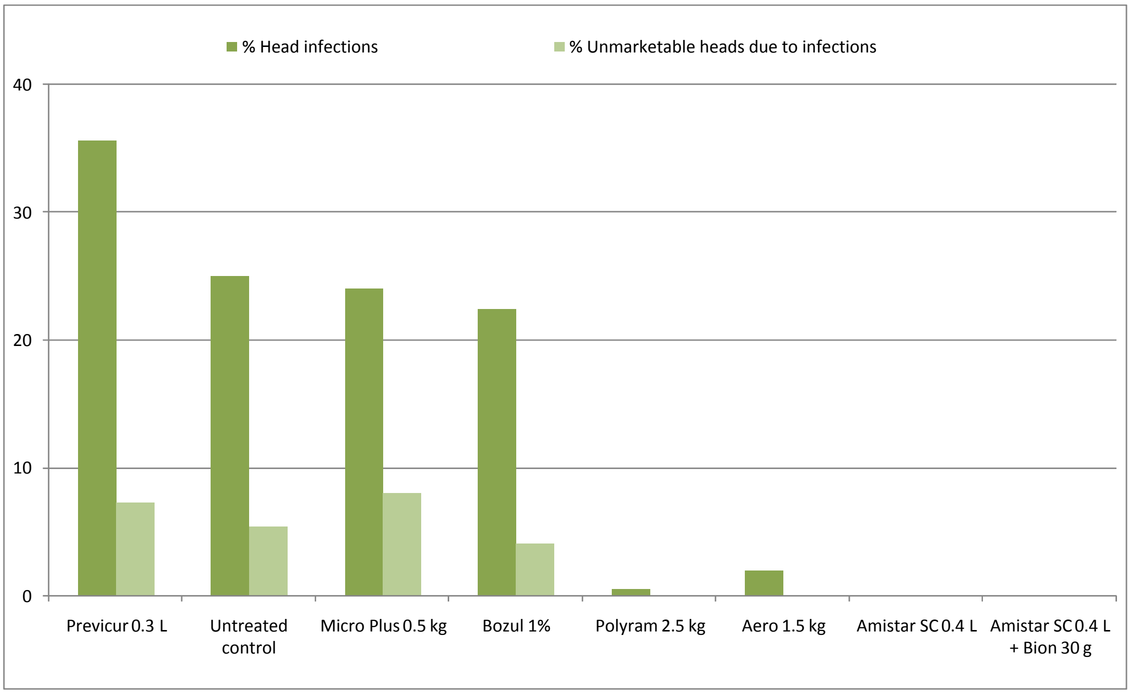

Figure 2. White blister control on heads of broccoli in Trial 1 at 79DAP

Trial 1 at Harford (Cont.)

A further assessment for white blister head infections at 87DAP, two days after the last commercial harvest outside the trial area, was conducted to compare the four most effective fungicide treatments (Table 8). Amistar at 0.4 L/ha and Amistar at 0.4 L/ha plus Bion at 30 g/ha were more effective than Aero at 1.5 kg/ha and Polyram at 2.5 kg/ha. This indicates that azoxystrobin, the active ingredient of Amistar provides longer protection than metiram, the active ingredient of Aero and Polyram. Aero also has pyraclostrobin, which is a strobilurin fungicide, same as azoxytrobin. The lower efficacy by Aero with pyraclostrobin at 75 g ai/ha compared to Amistar with azoxystrobin at 100 g ai/ha may be related to the lower rate of strobilurin that was used.

There were also downy mildew infections on broccoli heads at 87DAP. Among these four fungicide treatments, the two Amistar treatments were more effective than Polyram (Table 8). Aero also appeared to be more effective than Polyram.

Table 8. Efficacy of the four most effective fungicide treatments in Trial 1 at Harford

No.	Treatment	White blister head infections		Downy mildew head infection
		% Head infected	% Unmarketable heads	% Heads infected
		87DAP 23DALA	87DAP 23DALA	87DAP 23DALA
2	Amistar 0.4 L	5 b	0	1 b
3	Amistar 0.4 L + Bion 30 g	4 b	0	0 b
4	Aero 1.5 kg	21 a	0	6 ab
5	Polyram 2.5 kg	28 a	0	14 a
LSD (P=.05)		12.1	8.3	8.3
P-value		0.0017	1.0000	0.0120

Numbers in a column followed by the same letter are not significantly different at P =0.05, Fisher's Protected LSD Test.; DAP: days after planting; DALA: days after the last spray application

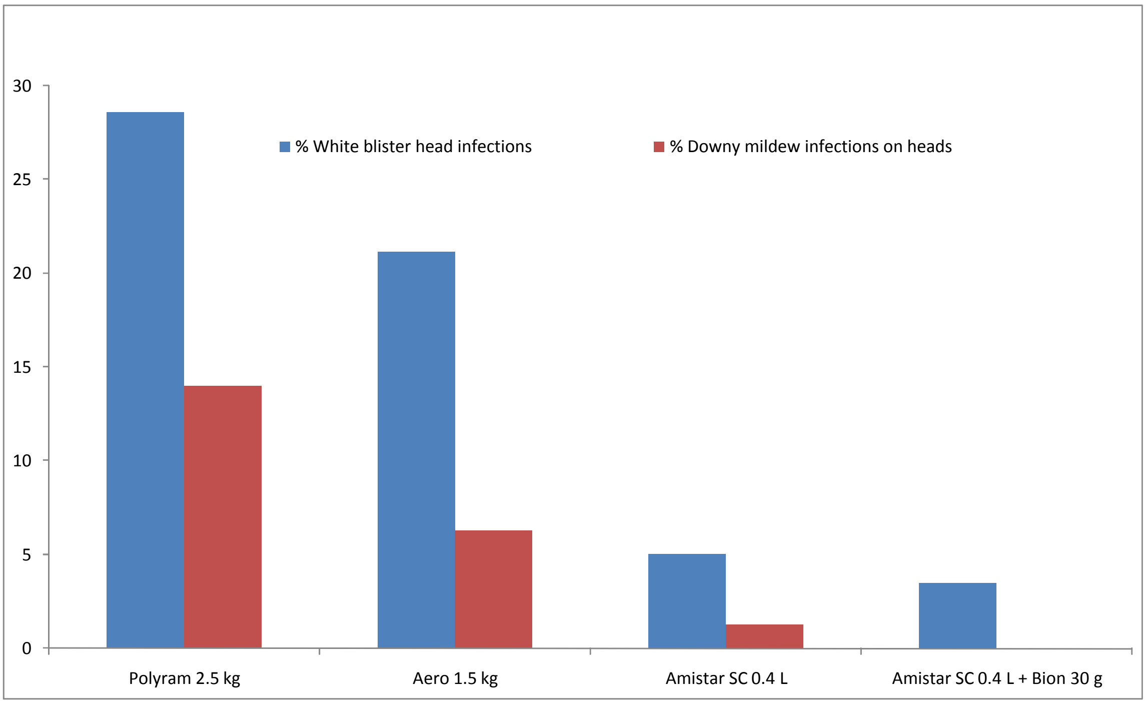

Figure 3. White blister and downy mildew control on heads of broccoli in Trial 1 at 87DAP

2. Trial 2 at Forthside

Trial 2 was conducted within a commercial fresh market broccoli crop at Forthside, Tasmania. The crop in the trial was adjacent to two other broccoli crops that were planted earlier and was infected by white blister. Therefore, plants in the trial were subjected to relatively high disease pressure from white blister in the early crops. Two fungicide sprays were applied: the first spray when early leaves infections were first noted on some plants, at early button stage. The second spray was applied at 7 days later. White blister incidence was relatively very high at 69DAP, ranging from 38% to 64% plants infected (Table 9). The incidence and severity of leaf infections were highly variable between different replicate plots, and hence there were no significance differences between all the treatments. The severity of the top leaf infections was considered to be relatively low, with only one to three lesions on the infected leaves. For the fresh market, the broccoli heads were harvested when they reached 100 to 120 mm diameter. There were no infected heads when the crop was ready for harvest. This trial had to be terminated soon after the assessments and as the rest of the crop had been harvested commercially at 70DAP, because the paddock was scheduled to be replanted in the following week. No conclusions could be drawn from this trial due to the lack of differences in the disease assessments.

Table 9. White blister control on leaves and heads of broccoli in Trial 2 at Forthside

No.	Treatment	White blister leaf infection		Head infected
		Incidence % Plants infected	**Severity % Top leaves infected**	**% Heads infected**
		69DAP 8DALA	**69DAP 8DALA**	**69DAP 8DALA**
1	Untreated control	39	11	0
2	Amistar 0.4 L	44	10	0
3	Amistar Top 0.5 L	49	14	0
4	Amistar SC 0.4 L + Bion 30 g	38	9	0
5	NUL 1955 0.5 L	50	13	0
6	NUL 2111 0.5 L	61	17	0
7	NUL 1935 0.5 L	55	17	0
8	Polyram 2.5 kg	51	23	0
9	Amistar 0.4 L + Polyram 2.5 kg	64	17	0
P-value		0.611	0.740*	1.000

Numbers in a column followed by the same letter are not significantly different at P =0.05, Fisher's Protected LSD Test.
* Data transformed using log transformation, non-transformed mean values shown in the table

3. Trial 3 at Leith

Trial 3 was conducted within a commercial fresh market broccoli crop at Leith, Tasmania. Fungicide sprays were first applied before infections were first noted, at early button stage. The second and third sprays were applied at 6 and 7 day intervals. Apart from white blister, there were no other foliar diseases. Amistar + Polyram was the grower's standard spray application in the rest of the crop outside the trial area.
The white blister incidence was 75% plants infected in the untreated control (Table

10, Figure 4). All fungicide treatments, except for Polyram alone and NUL 2111, significantly reduced leaf infections. Polyram alone and NUL 2111 had little or no effect in controlling white blister infections on leaves. Amistar at 0.4 L/ha, applied on its own or in mixtures with Bion or Polyram, were shown to be the most effective treatments in the trial. All treatments containing Amistar gave equivalent reduction in the incidence of plant infected and severity of the top leaves infections.

The lack of disease control by Polyram is not surprising, as the disease only appeared at least 30 days after the last fungicide application. Polyram is a crop protectant and must be applied onto new leaves or heads to prevent infections.

NUL 1955 at 0.5 L/ha was bioequivalent to Ridomil Gold Plus at 2.0 kg/ha for reducing white blister incidence and disease severity on top leaves (Tables 10-11, Figures 4-5). Hence, NUL 1955 could be a suitable alternative to Ridomil Gold Plus. Although not significant, NUL 2111 also appeared to reduce leaf infections.

There were no significant differences in the head infections between all the treatments, because of high levels of variability in replicate plots. All treatments containing Amistar appeared to reduced head infections at 82and87 days after planting. Amistar + Polyram appeared to have the lowest level of head infections.

Under relatively cold weather conditions during this trial in autumn, phytotoxic effects were consistently noted on leaves that were sprayed with Ridomil Gold Plus. There were no such phytotoxic effects in all the other spray treatments. Broccoli plants sprayed with copper fungicide is known to be sensitive to frost damage in autumn and winter months in Tasmania.

Table 10. White blister control on leaves and heads of broccoli in Trial 3 at Leith

No	Treatment	White blister leaf infections		White blister head infections	
		% Plants infected 74DAP, 35DALA	%Top leaves infected 74DAP, 35DALA	% Heads infected 82DAP, 43DALA	% Heads infected 87DAP 48DALA
1	Untreated control	75 a	25 a	13	33
2	Amistar 0.4 L	28 cd	6 c	7	25
3	Ridomil Gold Plus 2.0 kg	42 bc	11 bc	7	25
4	Amistar 0.4 L + Bion 30 g	34 cd	8 c	4	6
5	NUL 1955 0.5 L	43 bc	11 bc	6	27
6	NUL 2111 0.5 L	59 ab	19 ab	5	33
7	Polyram 2.5 kg	75 a	27 a	12	22
8	Amistar 0.4 L + Polyram 2.5 kg	18 d	4 c	8	16
Treatment Prob(F)		0.0001	0.0001	0.783*	0.259

Numbers in a column followed by the same letter are not significantly different at P =0.05, Fisher's Protected LSD Test.
* Data transformed using square root transformation, non-transformed mean values shown in the table

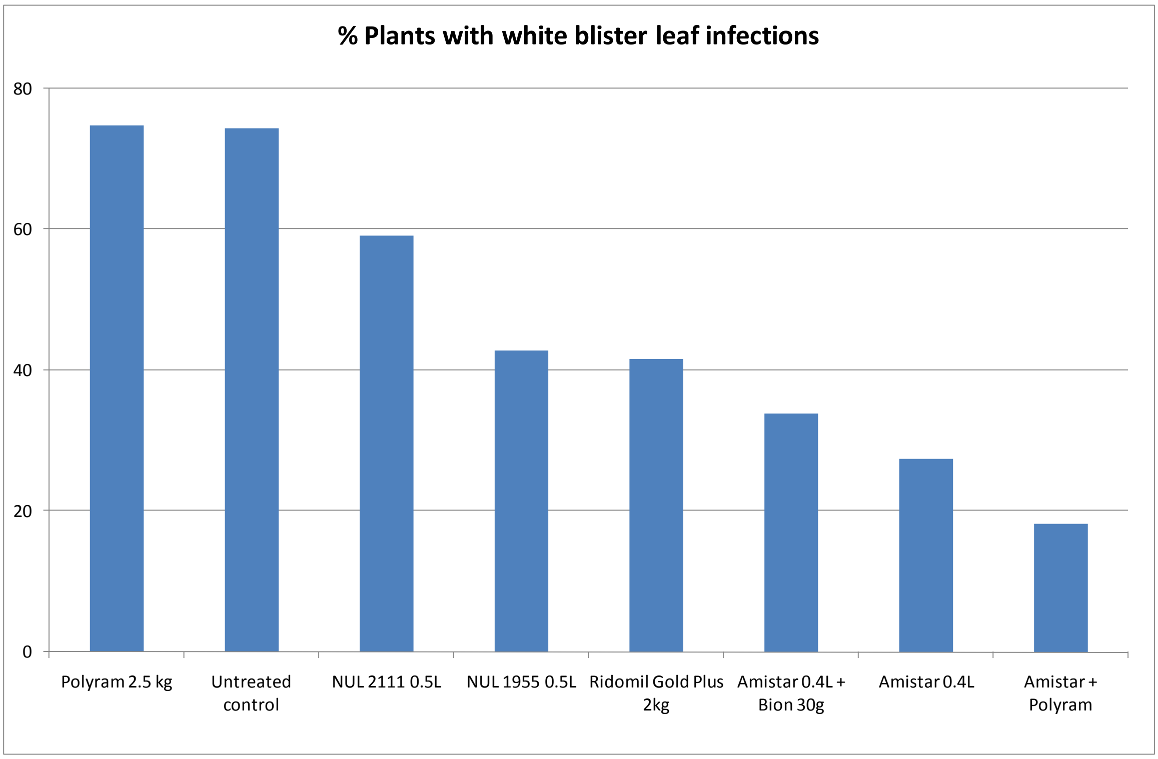

Figure 4. White blister incidence in Trial 3 at Leith at 74DAP

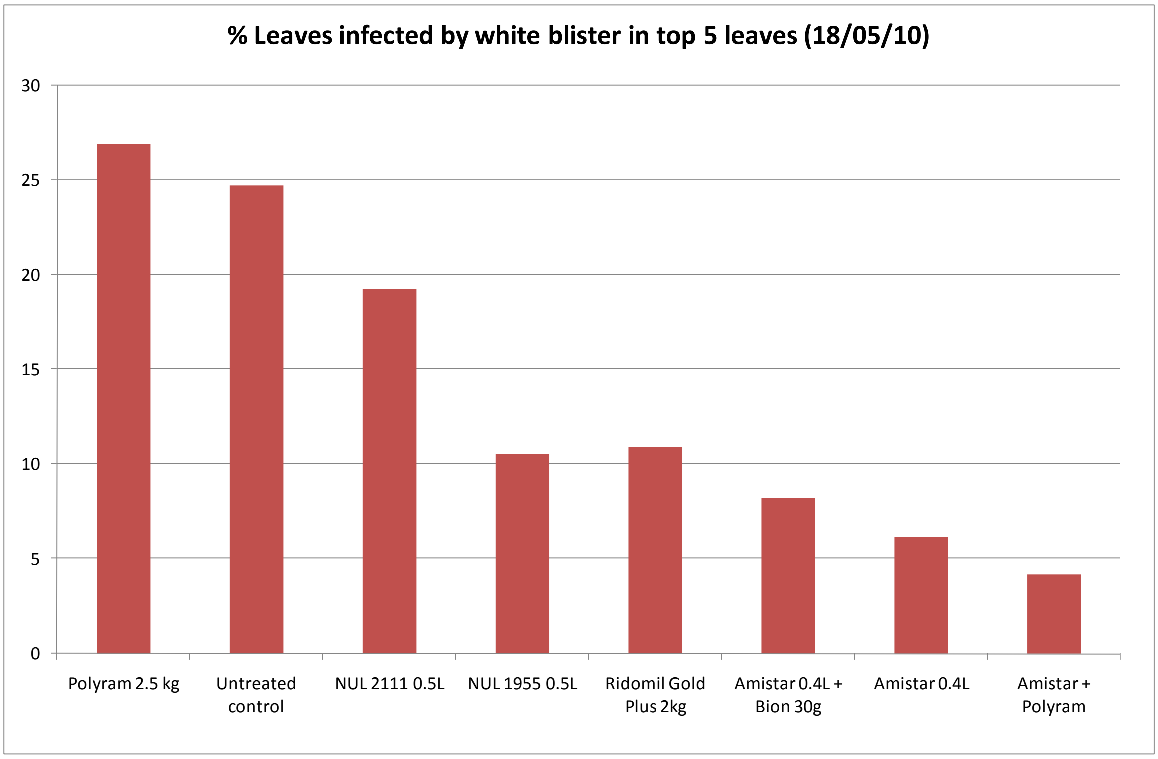

Figure 5. White blister on top leaves in Trial 3 at Leith at 74DAP

Discussion

The industry standard, Amistar, based on azoxystrobin, was shown to be an effective treatment for white blister control. Another industry standard, Ridomil Gold Plus, based on metalaxyl-M and copper hydroxide, was also effective in controlling white blister. Azoxystrobin and metalaxyl-M are systemic fungicides, which had been shown to be very effective for white blister control (Pung 2007). Copper hydroxide is a non-systemic crop protectant.

With the two industry standards, Amistar at 0.4 L/ha was shown to be slightly more effective than Ridomil Gold Plus at 2.0 kg/ha. This is not surprising, as previous trials and recent observations showed that there may be a slight loss in efficacy by metalaxyl-M because it was the sole fungicide used for white blister control for several years in Tasmania, before Amistar was also used. Even though, Ridomil is recommended for use in only up to two applications per crop, the use of multiple plantings adjacent to one another means that the pathogen was exposed to the fungicide for a much longer period of time in the consecutive crops. Amistar, is also prone to fungicide resistance if growers become more reliant on its use for white blister control.

Bion is based on acibenzolar-s-methyl, which is a plant resistance activator. When applied with Amistar, the spray mixture appeared to enhance disease control as well as provide relatively long protection to leaves and heads from infections compared to Amistar alone. Unfortunately, while there has been much interest by researchers on Bion, its use by growers remain severely restricted because of a lack of interest in developing the product for commercial use.

Polyram at 2.5 kg/ha, applied on its own was less effective in controlling white blister than Amistar or Ridomil. But, Polyram applied in combination with Amistar was shown to enhance white blister control. Polyram is a broad spectrum non-systemic fungicide, which is registered for use as a crop protectant for downy mildew (*Peronospora parasitica*) and ring spot (*Mycosphaerella brassicicola*) control in brassica crops. This makes it a convenient product for tank mix with Amistar for white blister control as well. When applied early, before or at the onset of disease, Polyram + Amistar showed good acitivity in controlling the three most common foliar diseases in the broccoli crop at Leith in Trial 3. This tank mixture is now used as a preferred industry standard by some growers in Tasmania for white blister control in place of Amistar only.

Aero at 1.5 kg/ha showed good efficacy in reducing white blister incidence and severity on leaves, as well as reducing head infections. Aero is based on metiram plus pyraclostrobin. Pyraclostrobin is a strobilurin fungicide, similar to azoxystrobin and therefore, is not a suitable alternative to Amistar. The lower efficacy by Aero with pyraclostrobin at 75 g ai/ha compared to Amistar with azoxystrobin at 100 g ai/ha may be related to the lower rate of strobilurin that was used.

NUL 1955 at 0.5 L/ha was bioequivalent to Ridomil Gold Plus at 2.0 kg/ha for controlling white blister. Hence, NUL 1955 could be a suitable alternative to Ridomil Gold Plus.

Another new fungicide, NUL 2111 also showed activity in controlling white blister. Further studies, however are needed to establish suitable application rates.

Previcur had little or no effect in controlling white blister.

Other non-fungicide and non-residual soft products such as Micro Plus (based on *Streptomyces lydicus*) and Bozul (food grade anti-fungal product based on sulphur dioxide and benzoic acid) had no effect for white blister control.

Under frosty cold weather conditions, phytotoxicity due to Ridomil Gold Plus spray applications were noted. The phytotoxicity is believed to be related to copper hydroxide. Broccoli plants sprayed with copper fungicide is known to be sensitive to frost damage in autumn and winter months in Tasmania. There were no such phytotoxic effects with Amistar, Bion, Polyram, NUL 1955 or NUL 2111 under the same conditions.

Project communications

Trial findings and white blister management strategies were extended to growers, processors and agronomic consultants at the Vegetable IPM workshop meeting on 4 August 2010 in Devonport, Tasmania.

General Discussion

The main purpose of incorporating fungicide alternatives in the management of foliar diseases in cucurbits, lettuces, and brassicas is to improve disease control in an effective and economically feasible manner, without relying solely on the use of fungicides. The research in this project (grouped by similarity of crops and foliar diseases) provided information about two available tools (cultivars with resistance to diseases and alternative product sprays to conventional fungicides) that have potential for use in integrated management of foliar diseases. However, it is important to note that in each of the crop-disease situations investigated in this project, the tools that were available and practices that were integrated to improve the overall control of foliar diseases were different.

Overall, the research indicated that there are benefits from using cultivars with moderate resistance to foliar diseases in combination with alternative spray products, although this varied across foliar diseases and vegetable crops. Further research is needed particularly with regards to newer alternative products and the integration of management practices into programs evaluated in field conditions. The alternative products that were tested separately in the majority of the trials in this project were applied on a weekly basis in order to obtain information on their relative performance. Ideally, they should be used in spray programs where different active ingredients are used alternatively, at different times in the cropping season, and with only a few sprays of systemic fungicides.

Queensland trials

Field trials in Queensland identified several cultivars of zucchini, cucumber, pumpkin and squash with moderate resistance to foliar diseases. Within the group of cultivars tested, there were more zucchini, squash, and pumpkin cultivars to select from for low reaction to powdery mildew than to downy mildew. With cucumber, powdery mildew did not appear to be a problem during the experiments carried out in North Queensland and there were more cultivars to select from for low reaction to downy mildew than to anthracnose.

A table with relative resistance to the diseases was prepared combining results from different trials in North Queensland. The information is of use to growers, and it is important that they take plant resistance to foliar diseases into account when they consider all other factors that are involved in the selection of a cultivar (such as yield, resistance to virus and silvering, and fruit type demanded by market). Some of the plant materials supplied by seed companies in these trials were lines which may or may not become commercially available in the near future. It is important to highlight that there were no cucurbit cultivars with complete resistance to one or more foliar diseases. Cultivars with moderate performance should still be used, in conjunction with other disease management practices. Even if tolerant cultivars produce high yields when they express a high reaction to foliar diseases, the diseases should be managed in order to reduce the amount of inoculum in the farm and in the region. The pathogens in the three diseases survive on live plant tissue of many cucurbit species. Abandoned crops during the summer, or after harvest is finished, will increase the amount of inoculum at the time of new plantings, thus making disease control more difficult.

From the 13 alternative products tested in North Queensland, 12 had relative efficacies that in some situations were good-to-medium or medium-to-low for control of downy mildew and powdery mildew in zucchini, and for downy mildew and anthracnose in cucumber. The options for control of powdery mildew in zucchini were few (2) in the good-to-medium range but there were several (10) with efficacies ranging from medium-to-low. Tricop, Microthiol, Bion and Agri-Fos 600 provided acceptable downy mildew control; however, Microthiol and Bion caused phytotoxicity in cucumbers. Tricop, Microthiol, Stand SHK, milk, Timorex, Synertrol Horti Oil, Agri-Fos 600, Ecocarb and Aminogro provided acceptable control of powdery mildew. A table with the relative efficacy of the tested spray products on foliar diseases was prepared combining results from different trials. As with cultivars, information regarding the efficacy of products alternative to fungicides should be updated regularly as new options appear every year.

In North Queensland, powdery and downy mildew diseases in zucchini cultivars with moderate resistance were managed to acceptable low severity levels that led to similar fruit yields as in plants treated with three conventional systemic fungicides, when sprayed with alternatives to fungicides (e.g. spray programs that included Bion®, Tricop®, Agri-Fos 600®, and/or Microthiol®), or when spray programs with alternatives to fungicides included only one application of a conventional systemic fungicide. The same spray programs were tested in two trials in which environmental conditions favoured disease infection and disease spread differed. The most severe damage on plants was always caused by downy mildew, which was difficult to control, even using conventional fungicides. Some spray programs with alternative products had estimated costs that were comparable to the costs of programs that included mostly conventional fungicides.

Monitoring for cucurbit foliar diseases starting at transplanting or plant emergence, and continuing the scouting every week is critical. Spray treatments will be much more effective at low levels of inoculum. Even if effective products are costly, they will be used in small amounts when applied in small areas at early crop developmental stages. It is critical to use high spray volumes and pressure with alternative fungicides that have contact activity, in order to ensure that the entire plant canopy is covered with the product.

<u>South Australia trials</u>
In South Australia, the research on foliar diseases on lettuce screened 21 lettuce varieties for disease resistance and found that all had resistance to downy mildew but were susceptible to anthracnose. Only fungicides Cabrio and Kocide® provided adequate control of anthracnose. A number of alternative fungicides have the potential to be integrated into downy mildew control programs. Two alternative products (FoliCal 19 Plus™ and Rezist®) were effective for reducing the severity of downy mildew. Anthracnose could be managed to low incidences using conventional fungicides, while FoliCal 19 Plus™ reduced the severity of infection. Alternative fungicides provided variable disease control and may be more effective when incorporated into a tailored spray program to reduce the reliance on systemic fungicides.

<u>Victoria trials</u>
In Victoria, outcomes from the research carried on white blister on brassicas can inform growers and plant breeders on cultivar response to current populations of *A. candida*, and researchers on pathogenicity changes in Australian populations of the pathogen. It is critical that such screenings are continued and conducted with all new varieties. Only those varieties that express adequate levels of resistance should be recommended as this will slow down disease epidemics and maximize yields. In experiments that evaluated the efficacy of alternative products to control white blister on brassicas, only Bion50®WG and *B. subtilis* were trialled in the field because they had good efficacy on seedlings grown under glasshouse conditions. It is possible that plant development stage as well as rate and timing of spray application are variables that can be managed to improve efficacy in field conditions. Based on current research both alternative treatments, Bion50®WG and *B. subtilis*, cannot be recommended as stand-alone treatments to replace conventional fungicides in outdoor intensive production systems. These products (at the tested application rates) may be used in seedlings and possibly in organic production systems, where the use of conventional fungicides is strictly limited. If efficacy of alternative spray products can be improved, these alternative options may reduce the use of conventional chemicals and will provide additional means for fungicide resistance management.

Tasmania trials

The research on white blister carried out in Tasmania identified different spray products that may be used by broccoli growers. The industry standards, Amistar and Ridomil Gold Plus, were still effective in controlling white blister. Bion, a plant resistance activator, when applied with Amistar in a spray mixture, enhanced disease control as well as provided relatively long protection to broccoli leaves and heads from infections compared to Amistar alone. Polyram, a broad spectrum non-systemic fungicide, gave good control when applied in combination with Amistar. Aero, based on metiram plus pyraclostrobin, showed good activity for white blister control, but being similar to azoxystrobin it is not a suitable alternative to Amistar. NUL 1955 could be a suitable alternative to Ridomil Gold Plus and Amistar. Another new fungicide, NUL 2111 also showed activity in controlling white blister. Previcur had little or no effect in controlling white blister. Other non-fungicide and non-residual soft products, such as Micro Plus (based on *Streptomyces lydicus*) and Bozul (food grade anti-fungal product based on sulphur dioxide and benzoic acid), had no effect on white blister control. Under frequent cold and frosty weather conditions, phytotoxicity due to Ridomil Gold Plus spray applications were noted. Overall, potential products that could be included in disease management products were identified. Some of these products require further evaluation and development in order to be used and recommended to the industry.

In summary, with cucurbits, lettuces and brassicas, the selection of cultivars with disease resistance to one or more specific pathogens combined with the use of effective non-conventional spray products with low toxicity will help provide solutions to problems that appear in conventional spray programs that rely solely on the use of fungicides. A reduction in the number of sprays of conventional fungicides will keep pesticide inputs to a minimum. These programs will also mitigate the development of resistance to fungicides by pathogen strains and therefore prolong the effective life of systemic fungicides.

Future Directions

Downy and powdery mildew management on cucurbits

The research produced important information that can be used when developing integrated management of foliar diseases in cucurbits. It demonstrated that genetic resistance is critical in management of these foliar diseases. When cultivars with moderate resistance are integrated with effective fungicide alternatives, the use of systemic fungicides can be reduced. This can provide acceptable disease control and yields; and assist lowering the risk of fungicide resistance development by fungal pathogens, and of chemical residues on harvested fruits. For some potential alternative products, such as Bion, evaluations should be done regarding spray rates used at various crop stages in the growing season, in order to minimise use (and reduce costs) and avoid phytotoxicity while providing adequate disease control.

A small number of field trials conducted at the end of this project integrated spray programs with alternative spray products and zucchini cultivars with moderate resistance. Other promising spray products and cultivars of other cucurbit species that were identified need to be evaluated in similar trials.

Future research should also target management of these foliar diseases in other vegetable production systems, such organic farming systems and protected cropping systems. Growers using these production systems in warm and humid environments at northern latitudes currently rely mainly on ineffective strategies and are continuously at risk of crop failure. Biological agents for fungal disease control (not evaluated in our field trials) may be more effective in protected cropping environments.

Effective and economically feasible management practices need to be developed as part of broader geographical area management plan for foliar diseases in regions like north Queensland, where at least six cucurbit species are grown, and all are common hosts of at least two of the diseases. These region-wide management plans for foliar diseases need to be developed. Monitoring the development of resistance to currently used systemic fungicides by pathogens is critical and requires ongoing work.

Downy mildew and anthracnose management on lettuce

The research on lettuce highlighted that more work is warranted to reliably provide the industry with an integrated disease management program for the control of downy mildew and anthracnose. This work should include field trials that evaluate disease management with the integration of soil health products, cultural techniques, and resistant varieties. Research should also focus on the evaluation of alternative products used at various stages of the growing season, spray rates, and economic feasibility studies. In this study we investigated the use of individual products and did not assess the effectiveness of combined use of products in a tailored spray program. Future studies should investigate how these alternatives to fungicides can be incorporated into spray programs to minimise reliance on protectant and systemic fungicides.

White blister control on brassicas

Only Bion50®WG and *B. subtilis* were trialled in the field because of their efficacy on seedlings grown under glasshouse conditions. Factors such as plant development stage as well as rate and timing of spray application should be investigated in future studies in order to improve efficacy in field conditions. Based on current research, both alternative treatments, Bion50®WG and *B. subtilis*, cannot be recommended as stand-alone treatments to replace conventional fungicides in intensive production systems. These products (at the tested application rates) may be used in seedlings and possibly have potential in organic production systems, where the use of conventional fungicides is strictly limited. If efficacy of alternative spray products can be improved, these alternative options may reduce the use of conventional chemicals and will provide additional means for fungicide resistance management. The studies that screened cultivars for resistance to white blister were critical for providing recommendations for improving white blister management. It is vital that such screenings are continued and conducted with all new varieties. Only those that express adequate levels of resistance should be recommended as this will slow down disease epidemics and maximize yields. To effectively manage white blister in brassicas, research work should continue in the following areas: monitoring cultivar and fungicide resistances by pathogen populations, evaluation of alternative products and new conventional fungicides, and evaluation of field trials that would integrate different practices which, used in combination, could lead to acceptable disease control levels.