# Sustainable integrated control of foliar diseases in Greenhouse Vegetables

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## Final report


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This report presents results of trials to examine how to improve the sustainability of management of foliar diseases in greenhouse vegetables.

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Cover pictures: Botrytis grey mould (left) and powdery mildew (right) on cucumbers

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# 1. Media Summary

Foliar diseases are a major problem in protected cropping and the industry requested investigations into sustainable disease management. A survey was conducted to determine growers' understanding of foliar diseases, management strategies and how these could be improved. Growers wanted alternatives to fungicides and training in recognising diseases and selecting management strategies. Almost half of the growers thought it was getting harder to manage diseases and blamed an increase in disease pressure and increasing input costs. Growers highlight the difficulty in using fungicide resistance management strategies because of the limited number of registered fungicides with suitable withholding periods.

The two main diseases were powdery mildew, present throughout the year, and Botrytis grey mould which only developed in late autumn/winter. Regular disease and climate data was collected throughout the project and provided to growers to give growers a better understanding of the climate inside their greenhouses. The majority of growers producing in low technology unheated greenhouses were already doing all they could to manage the greenhouse climate. Greenhouses with heating are an advantage; however the use of heating has to be economically justified.

Potential new fungicides, alternative products and biologicals were screened for efficacy against the diseases, both alone and in spray programs. The most effective programs were those that used protectant fungicides early and systemic fungicides later in the crop or a regular program of alternative products commencing at the first sign of disease.

Although several fungicides showed potential these are currently not registered for use in protected cropping. Agrochemical companies often do no support registration of products due lack of profitability and concerns with crop and human safety. Trials of alternative products were promising but additional data will need to be collected for registration.

None of the varieties evaluated were resistant to powdery mildew or Botrytis grey mould. Some were less susceptible and may be useful when integrated with other management strategies.

Improved disease knowledge through factsheets, newsletters, grower workshops and information sessions has helped growers to make effective and responsible fungicide choices integrated with other strategies to ensure disease management is effective and sustainable.

## 2. Technical Summary

Powdery mildew and Botrytis grey mould are the two most damaging foliar diseases in cucumber and capsicum crops grown in greenhouses in Australia. Foliar diseases cause yield loss and management requires significant investments of growers' time and money. Powdery mildew is caused by *Podosphaera xanthii* in cucumber and by *Leveillula taurica* in capsicums. Botrytis grey mould is caused by *Botrytis cinerea*, a ubiquitous pathogen that infects many plant species. Downy mildew, caused by *Pseudoperonospora cubensis* was also considered by growers to be an issue on cucumbers in winter, however very few infected plants were observed during the project and it was not included in the experimental component.

At the commencement of the project 43 greenhouse vegetable growers were surveyed to determine their understanding of foliar diseases, the management strategies they currently employed and their opinion on how disease management could be improved. Fortnightly disease assessments were made and climate data collected from four commercial greenhouses from 2006-2010.

Fifteen trials were conducted in the research greenhouse to evaluate the protectant and eradicant activity of various fungicides, alternative products and biologicals against powdery mildew and Botrytis grey mould. Two trials were undertaken in the research greenhouse and four in commercial greenhouses to evaluate various programs of fungicides and alternative products applied at 7 and 14 day intervals for efficacy against the diseases. Seven trials were also conducted to determine the relative susceptibility of the varieties to powdery mildew and Botrytis grey mould.

Key findings of this research were:

- 50% of growers considered that foliar disease management could be improved through access to a wider range of fungicides, alternatives to fungicides and training in what to spray and when.
- 48% of growers surveyed considered disease management was becoming more difficult due to increased disease pressure and increasing input costs.
- 27% of growers didn't know the source of their foliar diseases and 43% didn't know how the diseases spread.
- Growers producing in low technology greenhouses without active ventilation or heating were manipulating the greenhouse climate as much as possible within the limitations of their infrastructure.
- Cucumber flowers were most susceptible to Botrytis grey mould infection 1 and 2 days after opening at temperatures under 15°C.
- Powdery mildew infected plants were seen in greenhouse crops at all times of the year.
- Many effective fungicides were not supported for greenhouse use by the agrochemical companies.
- Colliss® and Vivando® were the only fungicides for which efficacy data for greenhouse registration was actively sought by the chemical company but reliable data were not generated during this project.

- The alternative products Silmatrix™ and Ecocarb®+Synertrol® Horti Oil were very effective against powdery mildew in commercial greenhouse trials. Silmatrix™ is not registered for use in protected cropping. Ecocarb® has a permit for various greenhouse-grown vegetables valid until September 2012.
- The sanitiser Path X™ was extremely effective in commercial greenhouse trials when applied at first signs of powdery mildew and then at 14 day intervals. This product is not currently registered for use on food crops.
- Spray programs of alternative products alternated with currently registered fungicides provided good disease control.
- For disease management the most effective programs were those that used protectant fungicides early and systemic fungicides later in the crop or a regular program of alternative products commencing at the first sign of disease.
- Alternative products require application at less than 14 day intervals if disease pressure is high.
- 14 day programs were less effective than 7 day programs but any programs that reduce the severity of powdery mildew to under 20% may be acceptable when growing a short crop (under 10 weeks), as higher levels of disease may be tolerable as yield may not be affected.
- The efficacy of biological products including *Trichoderma* and *Bacillus* were highly variable but one *Bacillus* isolate demonstrated good control of Botrytis grey mould in trials in the research greenhouse.
- *Trichoderma* was less effective as the strains evaluated did not grow as well as the *Botrytis cinerea* at the lower winter temperatures.
- All cucumber varieties were susceptible to powdery mildew, however the variety Palermo had a delayed onset of disease and Panama and Myrthos had less disease in the mature plant.  This may assist with management of the disease by giving growers more time to apply a spray.
- All varieties of cucumber were susceptible to Botrytis grey mould and differences in susceptibility may reflect suitability to climatic conditions under which trials were conducted.

# 3. Introduction

The protected cropping industry is the fastest growing food production sector in Australia (Australian Vegetable Protected Cropping Industry Strategic Plan, 2007). Foliar diseases are a major problem in vegetable crops in protected cropping and are usually managed with regular applications of fungicides, with varying efficacy. The fungicides used for these diseases are effective but overuse and misuse can rapidly lead to resistant populations of the fungi. There is also a lack of registered products with suitable with-holding periods. Many new fungicides are available to control these diseases in other crops and overseas. The greenhouse industry is a small market for the major agrochemical companies and they are often reluctant to seek registration for products for greenhouse use. This project arose at the request of industry to investigate sustainable integrated management of foliar diseases in greenhouse vegetables. The aim was to decrease the industry's reliance on fungicides and look at more integrated approaches to disease management.

A grower survey was conducted to determine the current management strategies used and how the effectiveness and sustainability of disease management could be improved. Alternative management strategies such as climate manipulation and resistant varieties were examined and trials undertaken to evaluate new fungicides and alternatives to fungicides including biologicals and alternative products alone and in programs.

# 4. Technical report

## 4.1. Grower surveys

A total of 43 greenhouse vegetable growers in the Northern Adelaide Plains (NAP) and Murray Bridge (MB) regions of South Australia and the Sydney Basin (SB) in New South Wales were surveyed to collect information on vegetable production in greenhouses. The purpose of this survey was to identify what growers perceived to be the main foliar diseases in cucumber, capsicum and eggplant crops, and to collect information on what they understood about those diseases. The survey collected data on greenhouse type and technology level and the crops and varieties grown by each grower surveyed. If growers had more than one type of greenhouse they were questioned separately on disease issues in different types of greenhouses. Grower's observations on incidence and severity of foliar diseases, information on how they manage foliar diseases and their ideas on how they could improve disease management were recorded. Growers were also questioned about their knowledge of disease cycles and understanding of the conditions that favour disease development. An example of the survey used to collect information is included in the Appendix.

Results from growers who grew tomatoes only are shown only in the Appendix as tomatoes were not included in this project as they tomato growers do not pay the levy that funded this research. This included all the growers in the Murray Bridge region as well as some growers from the other two regions.

### 4.1.1. Greenhouse details

A total of 29 growers were surveyed on the Northern Adelaide Plains, 19 of those had only one type of greenhouse and 10 had more than one type (Table 1). Low technology soil growing predominated in the Northern Adelaide Plains and growers with high technology greenhouses were only growing tomatoes in hydroponics (see Appendix). Seven growers in the Sydney Basin were surveyed; all production was in hydroponics and ranged from low to high technology greenhouses. Three growers in this region grew tomatoes exclusively. The technology level of greenhouses was classified based on the levels defined by researchers from NSW Department of Primary Industries (see Appendix).

**Table 1 Greenhouse type, technology level and production systems used in growing cucumbers and/or capsicums on Northern Adelaide Plains and Sydney Basin**

| Region[1] | Low tech | | | | Medium tech | | | High tech |
|---|---|---|---|---|---|---|---|---|
| | Plastic | | Glass | Shade | Plastic | | Glass | Plastic |
| | Soil | Hydro | Soil | Soil | Soil | Hydro | Soil | Hydro |
| **NAP** | 8 | 1 | 10 | 5 | 6 | 1 | 3 | 0 |
| **SB** | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| **Totals** | 8 | 3 | 10 | 5 | 6 | 1 | 3 | 2 |

[1] NAP = Northern Adelaide Plains; SB = Sydney Basin

### 4.1.2. Crops and varieties

Of the 15 growers surveyed who grew cucumbers, 11 growers grew Lebanese; two grew continental varieties and two green or slicer varieties (Table 2). Many growers grew more than one variety simultaneously or in rotation.

Of the 20 growers surveyed who grew capsicums 16 grew the variety Remy. Only one eggplant grower was surveyed. While tomatoes were not included in the project, 26% of growers surveyed grew tomatoes either simultaneously or in rotation with cucumbers and/or capsicums. Varietal choices were based on what was suited to the time of year the crop was being grown and what the market demanded.

**Table 2 Cucumber, capsicum and eggplant varieties grown on Northern Adelaide Plains and Sydney Basin**

| Cucumber | | | | Capsicum | Eggplant |
|---|---|---|---|---|---|
| Lebanese | | Continental | Green/slicer | | |
| NAP | SB | NAP | NAP | NAP | NAP |
| Khassib[1] (1) | Khassib[1] (2) | Reko[2] (2) | Caman[1] (2) | Remy[3] (16) | Bonica[3] (1) |
| Mascot [1] (6) | | | | Solar[3] (3) | |
| Montanta[1] (3) | Cobra[1] (1) | | | Requena[1] (1) | |
| Cobra[1] (1) | | | | Traviatta[1] (1) | |
| Yaqout[1] (2) | | | | | |

[1]Rijk Zwaan; [2]South Pacific Seeds; [3]Syngenta seeds; NAP = Northern Adelaide Plains, SB = Sydney Basin; Number of growers growing each variety shown in brackets.

### 4.1.3. Foliar Diseases

Powdery mildew, Botrytis grey mould and downy mildew were the main foliar diseases recognised by growers. Growers were asked to rate the severity of foliar disease in each crop type on a rating scale where 0=none, 1=slight, 2=moderate, 3=bad and 4=severe. According to growers the worst foliar disease in all crops was powdery mildew (Table 3; Table 4) (see Foliar diseases section for symptom description). All cucumber growers and 85% of capsicum growers said powdery mildew was a problem. The severity of powdery mildew in cucumbers and capsicums ranged from slight to bad. Growers were unsure of the yield loss caused by powdery mildew because it did not directly infect the fruit. Anecdotal evidence suggests that in many cases crops will continue to grow and produce fruit even with high levels of powdery mildew infection.

Sixty percent of cucumber growers considered downy mildew a problem in crops with the severity ranging from slight to severe (see Foliar Diseases section for symptom description). Downy mildew was most common in late winter/spring.

*Botrytis cinerea*, which causes the disease Botrytis grey mould, was a problem for 10% of cucumber growers and the severity was slight. Twenty three percent of capsicum growers said Botrytis grey mould was a problem and the severity was slight. Botrytis grey mould was generally only seen by growers in crops grown during late autumn/winter (see Foliar Diseases section for symptom description).

Some growers do not tolerate any disease and would spray regardless of the level of disease often adhering to regular fortnightly or weekly spray programs. However for diseases like powdery mildew that have an indirect effect on yield, some growers wanted to know how much disease is too much, that is, at what point a disease is actually causing yield loss and therefore costing them money, and how much money? Further, how can they be sure, they are getting an economic benefit from implementing management strategies such as fungicides?

**Table 3 Mean severity of foliar diseases in cucumber crops as rated by grower**

| Disease | Low tech | | | | Medium tech | | | High tech |
|---|---|---|---|---|---|---|---|---|
| | Plastic | | Glass | Shade | Plastic | | Glass | Plastic |
| | Soil | Hydro | Soil | Soil | Soil | Hydro | Soil | Hydro |
| **Powdery mildew** | 3.2 | 1.5 | 2.8 | 3 | 3 | 2 | 3 | 1 |
| **Botrytis grey mould** | 0 | 0 | 0 | 0 | 0.5 | 0 | 1 | 0 |
| **Downy mildew** | 2.4 | 0.5 | 1.8 | 1 | 0 | 0 | 0 | 1 |
| **Number of surveys** | 5 | 2 | 4 | 1 | 2 | 2 | 1 | 2 |

Disease severity rating: 0=none, 1=slight, 2=moderate, 3=bad, 4=severe.

**Table 4 Mean severity of foliar diseases in capsicum as rated by growers**

| Disease | Low tech | | | Medium tech | |
|---|---|---|---|---|---|
| | Plastic | Glass | Shade | Plastic | Glass |
| **Powdery mildew** | 2.8 | 1.6 | 0.8 | 2.4 | 1.3 |
| **Botrytis grey mould** | 0.6 | 0.1 | 0.3 | 0.6 | 1 |
| **Number of surveys** | 5 | 8 | 4 | 5 | 3 |

Disease severity rating: 0=none, 1=slight, 2=moderate, 3=bad, 4=severe.

Growers perceived the severity of cucumber powdery mildew to be similar between glass and plastic houses, however the severity of capsicum powdery mildew was thought to be higher in plastic houses than in glass houses. Downy mildew in cucumbers was rated as more severe in plastic greenhouses than glasshouses. Growers attributed this to increased humidity in plastic greenhouses compared to glasshouses. Botrytis grey mould ratings were very low in all greenhouse types (Table 3; Table 4).

### 4.1.4. General knowledge of disease issues

When asked about the source of foliar diseases 50% of growers named crop residues as a source of disease and 19% knew that weeds could be alternate hosts for diseases. Old crops on neighbouring properties were named as a source by 9.5% of growers. However, when asked how they disposed of their own crops, 35% of cucumber growers and 32% of capsicum growers said they put them in a rubbish pile on their own properties. Of the 43 growers surveyed, 27% didn’t know the source of their foliar diseases.

The majority of growers (93%) understood that high humidity was favourable to some foliar diseases and understood why Botrytis grey mould and downy mildew were generally only a problem in winter and spring. Ninety five percent of growers could name at least one factor that favoured the development of foliar diseases. When asked if they knew how diseases spread, 29.3% knew wind could play a role, 14.6% knew that workers and equipment could spread disease and 46.3% of growers weren't sure. Thirteen per cent of cucumber growers and 32% of capsicum growers said at some point they had a disease that they couldn't identify. Most growers sought help from more than one source to identify diseases including consultants (65%), government diagnostic services (41%), re-sellers (12%) and neighbours (12%). Two growers did not seek help from anywhere to identify diseases as the issue had only occurred once and was not severe.

### 4.1.5. Disease management strategies

All the growers surveyed used fungicides to manage foliar diseases. Ninety three percent of growers used crop monitoring to decide when to spray fungicides and 19% also sprayed preventatively if conditions were favourable for certain diseases. Thirty per cent of growers sprayed weekly for diseases and 39% said they were only spraying as required. The majority of the growers surveyed were in low-medium technology greenhouses and sprays were applied with a hand-held spray wand and spray pumped via long hoses from 200 litre drums located inside or at the greenhouse door. For most growers spraying was labour intensive, and somewhat unpleasant, as conditions can be hot and humid at warmer times of the year and when crops are mature. Growers were interested in alternative methods such as through drippers, through misting systems or the use of sulphur pots for powdery mildew. The main factors that influenced fungicide selection by growers were fungicide efficacy (44%), withholding period (35%) and resistance management (35%). A common comment made by growers was that effective fungicides have been withdrawn from use and not replaced with another option.

Growers considered they could improve disease management if they had access to a larger range of fungicides and alternatives to fungicides. There are a limited number of registered or permitted fungicides available for protected cropping. Where available, growers were using fungicides registered for the disease and the crop. However, the survey identified some problems with fungicide selection which could be explained by label confusion, misdiagnosis of the disease or a lack of choice. For example, Bravo® is not registered for control of powdery mildew in cucurbits but the critical comments on the label state that when applied at higher rates it will suppress powdery mildew. Some growers were confusing downy mildew with powdery mildew and so products registered for downy mildew in cucurbits were being used against powdery mildew. In some cases, particularly in capsicum crops, a lack of registered or permitted fungicides led to growers using products registered for powdery mildew in other food crops. Most growers were aware fungicide rotation was important but at the time the survey was conducted there were no fungicides registered for powdery mildew in capsicums. Bayfidan® had a permit, which is now expired. So growers were being told to rotate fungicides but had very little choice.

All growers surveyed used fungicides in combination with at least one other management strategy. All growers attempted to use venting to reduce humidity in the greenhouse and make the environment less favourable for diseases like Botrytis grey mould and downy mildew. Other strategies used by growers included practising good greenhouse hygiene and sanitation

(47%) and pruning lower leaves to increase airflow around plants (77%) which could remove a significant amount of diseased material from the plant as powdery mildew begins on the lower leaves of cucumbers and capsicums. However, not all growers removed the pruned material from the greenhouse so the inoculum source remained in the greenhouse. Resistant varieties were used by 14% of growers and 16.3% managed Botrytis grey mould issues by not growing over winter when the disease was generally worst. Half of the capsicum growers and 47% of cucumber growers disposed of old crops by burning. Capsicum crops were ploughed into the soil by 27% of growers in South Australia but this was not an option for cucumber crops because removing the support strings from old crops was not economical. The majority of growers that ploughed crops in said they would only do so if they had had minimal or no disease issues in that crop.

Half the growers surveyed thought that their management of diseases could be improved. Suggestions from growers included access to a larger range of fungicides (43%), alternatives to fungicides (29%), training in when to spray (29%) and what to use (24%), and in recognising diseases (24%). Almost half of the growers surveyed thought it was getting harder to manage diseases. Fungicide resistance and over-use was cited by 45% of growers as reasons that disease management was becoming more difficult. However, only three of the 43 growers surveyed said they had experienced fungicide resistance. Increased disease pressure (35%), increasing input costs (30%) and lack of registered fungicides (25%) were also cited as reasons disease management was becoming more difficult. Three growers on the NAP said they thought soil health had declined so much that plants were generally less healthy and therefore more susceptible to diseases.

### 4.2. Observations from property visits

Throughout the project, greenhouse growers producing cucumbers, capsicums and tomatoes in New South Wales, Western Australia and overseas were visited and information on disease issues and management strategies was collected. These visits by the project leader and principal investigator were invaluable as it gave access to range of greenhouse growers and enabled the collection of information that would not normally be accessed by growers in other regions or other states. Foliar disease issues were the same for all Australian growers and powdery mildew and Botrytis grey mould were their main concerns. Some of the effective management strategies used by these growers are outlined below. **The strategies outlined below were not tested in this project and are not endorsed in any way.**

<u>Powdery mildew in cucumbers</u>

A cucumber grower in medium to high technology heated greenhouse was having success with applying the following mix:

- wettable sulphur 100g/100L
- magnesium sulphate 100g/100L
- duWett 30mL/100L

The mix was applied through the greenhouse misters in the late afternoon, with sprays commencing in the third week of the crop. Spray frequency was three times per week when disease pressure was high and once per week when disease pressure was low.

Cucumber growers in low tech greenhouses in the Almeria region in Spain were managing powdery mildew using phosphite either as foliar sprays or through the drippers.

Botrytis grey mould in cucumbers

A cucumber grower was using Ecocarb® to manage Botrytis grey mould. The overnight temperature in the greenhouse was also set at 18°C.

Powdery mildew in tomatoes

A grower in a high tech greenhouse was dusting sulphur on the pipe and rail heating system in the greenhouse to release the volatiles from the sulphur to manage powdery mildew.

Botrytis grey mould in tomatoes

A grower in a high tech greenhouse had painted pruning wounds with Scala® with some success.

A grower in a low tech greenhouse in the Almeria region in Spain kept planting densities low (1.2 plants/$m^2$) to ensure adequate ventilation within the crop canopy and minimise Botrytis grey mould. He had calculated that he achieved the better outputs at the lower planting density because he had less problems, less costs involved in solving problems and higher quality yields.

Powdery mildew in capsicums

A grower in low-medium tech greenhouses was using potassium silicate through the drippers for powdery mildew with some success.

### 4.3. Outcomes

The survey identified ways in which disease management could be improved which helped shape this project and identify future research needs (Table 5). Most growers surveyed said they were comfortable diagnosing their main foliar disease problems. Some growers had difficulty distinguishing between downy mildew and powdery mildew and between Botrytis grey rot sporulation and non-pathogenic fungi sometimes found on senescing leaves. Accurate diagnosis is critical to effective disease management and there was a need for factsheets so that all growers could confidently diagnose the main foliar disease problems and to know where to get diagnoses for other diseases.

The main foliar diseases in greenhouse vegetables, powdery mildew, Botrytis grey mould and downy mildew have a high risk of developing fungicide resistance (www.croplifeaustralia.org.au). In addition, many of the fungicides used to manage these diseases in greenhouses have a single site mode of action (Group 1, 3 and 11) and are most at risk of developing resistance. Powdery mildew in cucumbers is caused by the same fungus that infects zucchinis, melons and all cucurbit crops. Trials in Queensland in field grown cucurbits showed that resistance has already developed to Amistar® and Bayfidan® in some regions (MacManus et al. 2009). Thirty five percent of growers said they were making fungicide selections based on resistance management strategies. However, growers highlighted the difficulty in using resistance management strategies because they are restricted by the number of registered fungicides and with-holding periods. In summer cucumber crops growers often harvest daily making it impossible to use fungicides that have any with-holding period. All the growers surveyed were using more than one strategy for disease management and understood that using multiple strategies was more effective and sustainable than relying only on one strategy. More investigation was needed to evaluate the effectiveness of the other strategies being used, such as climate manipulation.

Pesticide use is protected cropping is intensive and often frequent and there is unlikely to be a lot of movement of strains of pathogens between greenhouses which increases the selection pressure for developing resistance. Also, the greenhouse industry is not a major market for agrochemical companies compared to field crops and there are residue and safety issues associated with spraying in an enclosed environment where products potentially don't breakdown as rapidly as they do in the field. For ubiquitous pathogens like *Botrytis cinerea*, agrochemical companies don't want to risk resistance developing in the greenhouse sector that could cross into the viticulture sector, a major section of their market.

Although automated spray equipment exists in high technology greenhouses spraying in low-medium technology greenhouses is a labour intensive process and is often unpleasant for the operator. Infrastructure limits the type of spray technology that can be used, for example the wheels of spray units will not easily run on bare ground producing soil crops but the use of weed mat may improve access. The spray coverage achieved by any spray unit is a major consideration and units need to be adaptable to crops as they grow. Spraying products via the greenhouse misting system may be an option for some growers but this also depends on the technology level of the greenhouse, the coverage that can be achieved and the products that are to be sprayed.

To ensure disease management is sustainable, the greenhouse industry needs alternative fungicides as well as alternatives to fungicides and needs to continue to approach disease management with an integrated program of strategies. The lack of registered products, withdrawal of existing products and reluctance of agrochemical companies to support registration of new products means that integrated approaches to disease management will become increasingly important in the industry. Products that have low toxicity to non-target organisms, low risk to humans and no or short withholding periods are most desirable.

Most growers understand that management of powdery mildew with fungicides is most effective if sprays are applied early but they aren't always sure what is 'early'. If they have a certain level of disease, but only intend to grow the crop for another two to four weeks then a fungicide application may not give them an the increase in yield that justifies the cost of the fungicide application. However, if they are growing a longer term crop, there may be a significant benefit in applying a fungicide. The damage relationship is the amount of yield loss associated with different levels of disease and can be used to determine whether management strategies are economically justified and help growers reduce the number of fungicides they apply. Growers need to know the disease level at which yield loss starts, if the yield loss is irreversible or if they can implement a management strategy that will stop or reduce yield loss. Establishing damage relationships would give growers the information that they need to optimise their spray decisions.

**Table 5 Knowledge gaps identified in grower survey and summary of gaps addressed in this project**

| Knowledge gaps identified | How this project has addressed gaps |
|---|---|
| Training in recognising diseases | Factsheet: ‘Identification of greenhouse vegetable foliar diseases’<br>Distributed ‘Pests, diseases, disorders and beneficials in greenhouse vegetables: Field identification guide to growers<br>Disease workshops with growers<br>Visits to growers’ properties in SA, NSW and WA |
| Improved range of fungicides | Liaise with agrochemical companies<br>Screening of fungicides used in other crops<br>Screening of new fungicides<br>Spray trials in commercial greenhouses |
| Alternatives to fungicides | Screening of biologicals<br>Screening of alternative products<br>Spray trials in commercial greenhouses<br>Newsletter: ‘Foliar diseases in greenhouse vegetables Issue 4 & 5’ |
| Training in when to spray | Newsletter: ‘Foliar diseases in greenhouse vegetables Issue 2,4 &5’<br>Identified as future research need |
| Training in fungicide selection | Presentation ‘Managing leaf diseases in your crop’ at Australian Hydroponic and Greenhouse Association Conference Sydney, 2009<br>Newsletter: ‘Foliar diseases in greenhouse vegetables Issue 2, 4 &5’<br>Nominated as a presentation topic at Protected Cropping Association conference Adelaide, 2011 |
| Training in resistance management | Presentation ‘Managing leaf diseases in your crop’ at Australian Hydroponic and Greenhouse Association (AHGA) Conference Sydney, 2009<br>Newsletter: ‘Foliar diseases in greenhouse vegetables Issue 2, 4 &5’<br>Nominated as a presentation topic at Protected Cropping Association conference Adelaide, 2011 |
| Alternative management strategies | Surveys relating foliar disease and greenhouse climate<br>Variety trials<br>Newsletter: ‘Foliar diseases in greenhouse vegetables Issue 3’ |
| Minor use permits for fungicides | Efficacy data supplied to AgAware and APVMA and permit reviewers on request |
| Improved spray application technology | Identified as future research need |

## 4.4. General Materials and Methods

### 4.4.1. Isolate collection and culture maintenance

Powdery mildew

Powdery mildew is an obligate parasite which must be maintained on living tissue. Isolates of *Podosphaera xanthii* and *Leveillula taurica* were collected from greenhouse cucumber and capsicum crops respectively in Virginia, South Australia. Cucumber and capsicum plants were grown in 200mm pots in coco-peat and initially infected with powdery mildew by shaking or brushing conidia from infected leaves onto leaves of culture plants. Culture plants for each species of powdery mildew were grown in an isolated area in the research greenhouse to provide a consistent supply of inoculum for trials. The culture was maintained by routinely placing new plants amongst culture plants to ensure that natural infection occurred and fresh inoculum was available when required.

*Botrytis cinerea*

Plant material infected with *Botrytis cinerea* was collected from a greenhouse cucumber crop in Virginia, South Australia and placed in 100% humidity to induce sporulation. Spores collected using sterile forceps were placed onto Potato Dextrose Agar (PDA) and incubated at ~22$^{o}$C on the laboratory bench until required. As *B.cinerea* is not host specific the same isolate was used in cucumber and capsicum trials. The isolate was periodically re-invigorated by infecting cucumber plants as described below then isolated onto PDA.

### 4.4.2. Preparing spore suspensions

Powdery mildew

Leaves of cucumber or capsicum with 7-10 days old sporulating powdery mildew colonies were placed in a plastic bag or bottle containing sterile RO water and a drop of Tween 20 and shaken to dislodge conidia. The suspension was filtered through a fine mesh to remove any particulate matter and the concentration adjusted to $10^5$ spores/mL using a haemocytometer (Nebauer improved).

*Botrytis cinerea*

Spore suspensions were made by pouring sterile RO water containing a drop of Tween 20 onto 14 day old sporulating *B.cinerea* cultures and rubbing sterile forceps over the plate to dislodge conidia. The suspension was then filtered through a fine mesh to remove any particulate matter and the concentration adjusted to the desired level of $10^1$, $10^3$ or $10^5$ spores/mL using a haemocytometer (Nebauer improved).

### 4.4.3. Inoculating plants

Spore suspensions were applied to leaves or flowers of plants using a hand-held atomiser. For powdery mildew leaf inoculation, leaves were sprayed until the entire surface of the leaf was just wet. For flower inoculations with *B. cinerea* each flower was sprayed with approximately 0.5mL of the spore suspension. The viability of *B. cinerea* spore suspensions was checked by spraying 1mL of the suspension onto PDA and incubating for 7-10 days at ~22$^{o}$C on the laboratory bench.

### 4.4.4. Disease assessment

Powdery mildew – field assessment

The per cent powdery mildew on a leaf was assessed using a rating scale developed for grapevine powdery mildew (Figure 1). One leaf from the bottom, middle and top of a plant was rated and the ratings combined to give a whole plant rating. Severity ratings were transformed to percentage data using the following formula:

Severity =
((r1*0.8)+(r2*2.3)+(r3*4.7)+(r4*9.4)+(r5*18.8)+(r6*37.5)+(r7*62.5)+(r8*81.3)+(r9*89.5)+(r10*100))/n

where r1-r10 are the number of samples in that rating and n is the total number of samples.

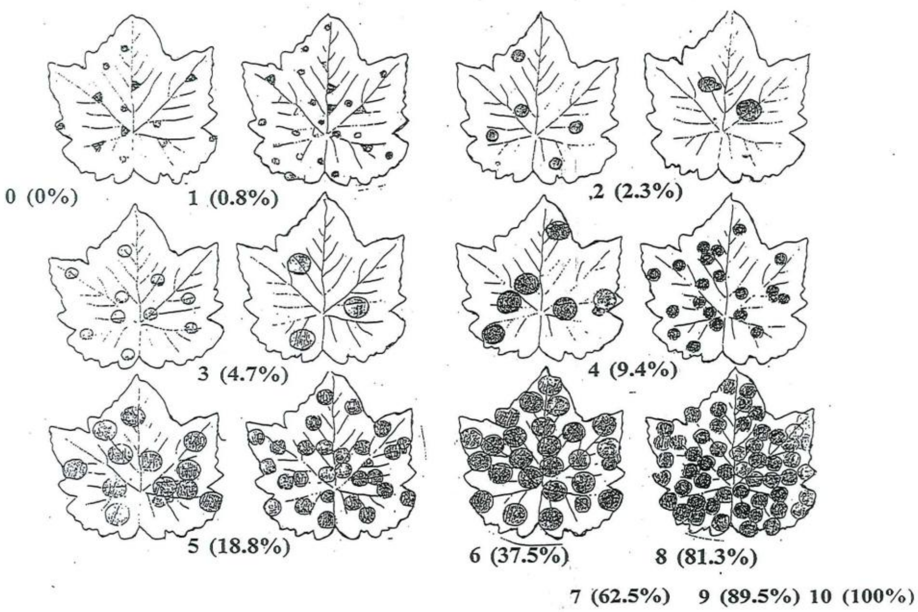



**Figure 1 Field rating scale for powdery mildew of cucumber and capsicum**

Powdery mildew – research greenhouse assessment

Assessment of powdery mildew for trials conducted in the research greenhouse used a scale adapted from (Matheron and Porchas 2003) (Figure 2). A rating of 0 was equivalent to no disease. Capsicum leaves were assessed using the same scale.

Severity ratings were transformed to percentage data using the following formula:

Severity = ((r1*2.5)+(r2*10)+(r3*25)+(r4*37.5)+(r5*75))/n

where r1-r5 are the number of samples in that rating and n is the total number of samples.

All percentage data underwent an arcsine transformation before statistical analysis was conducted. As the maximum percentage for greenhouse assessments using this rating scale could only be 75% the maximum after arcsine transformation was 84%.

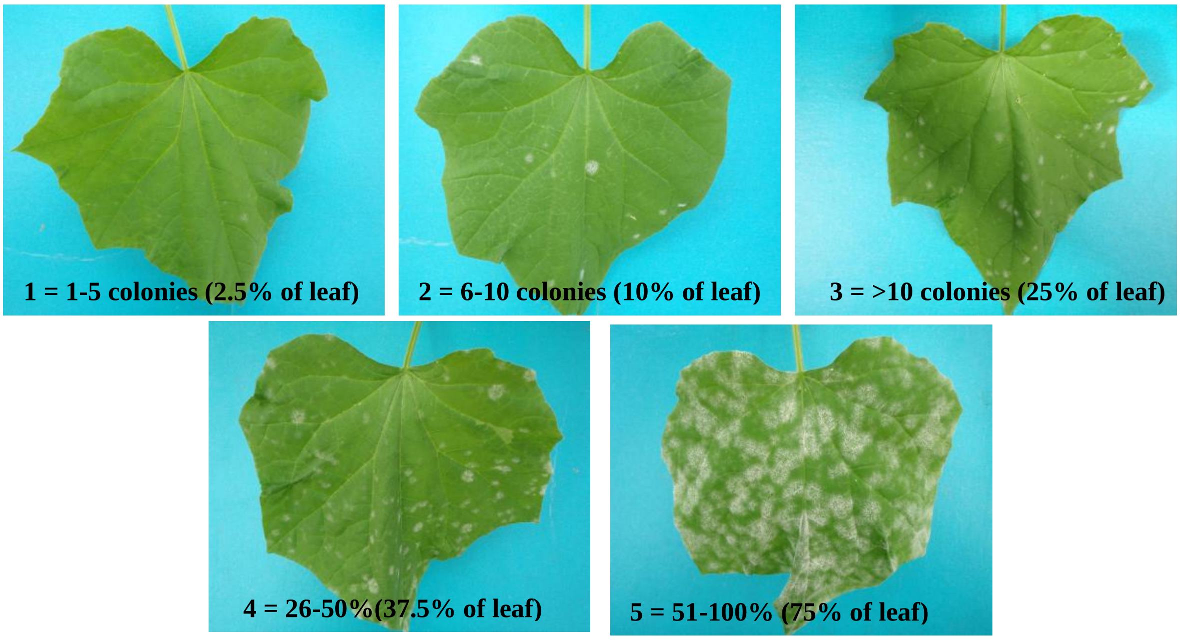



**Figure 2 Rating scale for assessment of powdery mildew in research greenhouse trials**

<u>Relative Area Under the Disease Progress Curve</u>

When several assessments of disease level are done on the same plant over time to evaluate particular treatments, like spray programs, it can be difficult to determine the overall effectiveness of treatments over time. Often, parameters such as the disease level on the last assessment date, a key stage in crop growth or each individual disease assessment are analysed to determine effectiveness. However these will only provide the effectiveness at that given point in time. Relative Area Under the Disease Progress Curve (RAUDPC) is a measure of the relative severity of disease over the assessment period. A disease severity rating of 100% for all assessments would give a value of 100. Mean severity values from plants were used to calculate the RAUDPC for treatments over the period of assessment. The formula used for calculation was:

$$RAUDPC = \{\Sigma_{i=1}^{n}[(x_{i+1} + x_i)/2]\ [t_{i+1} - t_i]\} / t_n - t_1$$

where $x_i$ and $t_i$ are disease severity and the days after inoculation at the ith assessment respectively, and n is the total number of assessments (Pscheidt and Stevenson 1986).

<u>Botrytis grey mould- field assessment</u>

In the field the severity of Botrytis grey mould on stems, leaves and flowers on the lower third, middle third and top third of the plant was pooled to give a whole plant rating. The rating scale used was:

0 = no disease
1 = slight
2 = moderate
3 = bad
4 = severe

Botrytis grey mould- research greenhouse assessment

In the research greenhouse and controlled environment room trials Botrytis grey mould infection was rated using a 1 to 4 scale, where 0 = no disease to 4 = whole fruit infected (Figure 3).

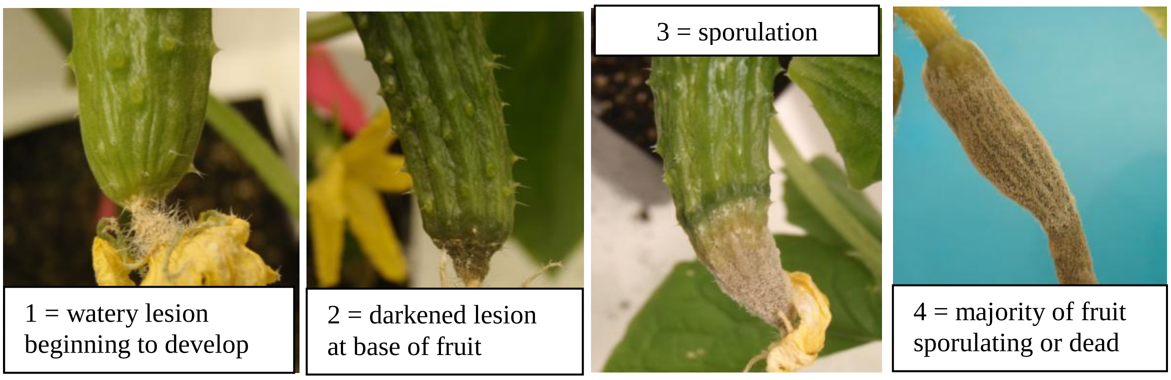



**Figure 3 Rating scale for assessment of Botrytis grey mould in the research greenhouse and controlled environment room**

### 4.4.5. Standardising flowering stages

Cucumber

Cucumber flowering stages were classified by the number of days the flowers were open (Figure 4).

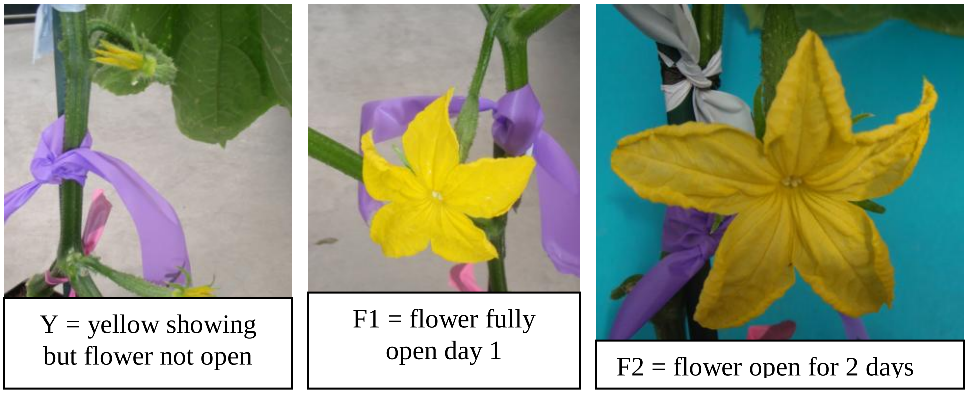



**Figure 4 Standard stages for cucumber flowers**

## 4.5. Foliar diseases

### 4.5.1. Powdery mildew

Powdery mildew primarily infects leaves of plants, reducing photosynthetic capacity and severe infections will cause leaves to drop. The causal agent of powdery mildew in cucumber is *Podosphaera xanthii* (Figure 5). Infection begins on the lower leaves, an important characteristic growers can exploit when scouting for early signs of disease. The distinctive white fluffy growth will occur readily on both the upper and lower leaf surface of the leaves. This is the sporulating stage of the fungus from which spores are released that can infect other plants. The optimum temperature for development is 20-25°C and moderate relative humidity is favourable but disease will still develop across a wide range of temperature and humidity. High temperatures >35°C are unfavourable for disease progression (Sitterly 1978).

On capsicum, powdery mildew is caused by *Leveillula taurica* (Figure 6). Symptoms appear first on the lower leaves with characteristic yellow patches visible on the upper surface. Sporulation of *L.taurica* is more prevalent on the under surface of the leaves but in severe infections will also occur on the upper surface of the leaves. The optimum temperature for development is 20°C and optimum relative humidity 50-70% (Butt 1978). Higher or lower temperatures or humidities slow the germination of fungal spores, infection of plants and progress of disease (Elad 2007). Capsicum powdery mildew is particularly difficult to manage with sprays because a significant portion of the life cycle occurs inside the leaf (Palti 1988; Elad 2007). Studies have shown that the fungus grows inside the leaf for 3 to 4 weeks before sporulation on the leaf surface (Homma et al. 1981). *L. taurica* also infects cucurbits but it is not common and will generally be outcompeted by *Podosphaera xanthii*. Powdery mildew in eggplants is generally caused by *Oidium longpipes*.


**Figure 5 Powdery mildew of cucumber *Podosphaera xanthii* on leaf (left), spores under magnification (right)**

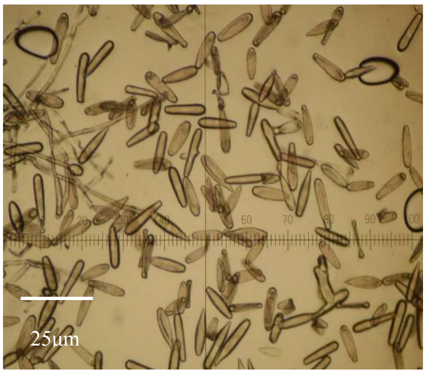



**Figure 6 Powdery mildew of capsicum *Leveillula taurica* on leaf (left), spores under magnification (right)**

### 4.5.2. Downy mildew

Downy mildew in cucumbers is caused by the pathogen *Pseudoperonospora cubensis* (Figure 7). Like powdery mildew, downy mildew infects the leaves of plants but not the fruit so effects on crop yield are indirect. The symptoms are characteristic yellow angular lesions bordered by the leaf veins. The fungus sporulates on the under surface of the leaves underneath the lesions. Spores of downy mildew need free water to germinate and infect plants so infection is favoured by high humidity and a temperature range of 10-25°C. High temperatures >30°C are less favourable (Cohen 1981).

**Figure 7 Downy mildew *Pseudoperonospora cubensis* on cucumber**

### 4.5.3. Botrytis grey mould

Botrytis grey mould is caused by the fungus *Botrytis cinerea* which infects plants through wound sites, like pruning wounds, or through flowers. The infection begins as a watery rot which develops into a characteristic grey fluffy growth. If infection occurs through flowers it can directly kill fruit. Stem infection, via pruning wounds or that develops as a secondary infection from flowers, can kill entire plants (Figure 8). *B.cinerea* spores need free water to germinate and establish new infections so high humidity and temperatures from 10-20°C are needed for an infection to develop. Sporulation of the fungus and dispersal of spores occurs at lower humidity and across a wide range of temperatures (Jarvis 1980).

**Figure 8 *Botrytis cinerea* on immature cucumbers (left), stem (centre and right)**

## 4.6. Foliar diseases and the greenhouse climate

Assessments of foliar diseases were made in commercial greenhouses throughout the project. Climate data were also collected from the greenhouses. These data were used to:

- confirm grower's observations about foliar disease problems;
- determine the incidence and severity of foliar diseases throughout the year;
- examine the relationship between the greenhouse climate and foliar diseases;
- investigate whether the greenhouse climate could be manipulated to make it less favourable for foliar diseases.

### 4.6.1. Materials and methods

Four commercial greenhouses were selected for disease surveys and logging of climate data. Greenhouses were selected based on the crops grown, types of greenhouses, management practices used and the open access policy of property owner. Studies were designed to compare low technology greenhouses with high technology, different greenhouse types on the same property and properties with different management practices. As all greenhouses were commercial properties fungicide applications were made throughout the period that disease surveys were conducted and observations were made on whatever crop was being grown at the time.

Disease assessment

Plants were assessed for disease symptoms approximately every two weeks. In each greenhouse survey rows were designated and assessments done by walking up the middle of two survey rows and randomly selecting a plant on the left near the start of the row. The next plant was selected further down the row on the right, and continued alternating sides until five plants had been assessed. A total of 50 plants were assessed in each greenhouse, five from each of the 10 survey rows. For powdery and downy mildew, individual plants were assessed by rating one lower, one middle and one upper leaf for severity using the assessment key described previously (See General Materials and Methods). The severity of powdery mildew on each plant was calculated by averaging powdery mildew severity across the three leaves. For Botrytis grey mould an assessment was made for the lower, middle and upper section of the plant using the rating scale previously described (See General Materials and Methods) and an average severity for the entire plant calculated.

Collection of climate data

Tinytag Plus2 TGP-4500 data loggers (Hastings Data Loggers) were used to record temperature and humidity in each greenhouse where disease assessments were made. Data loggers recorded every 10 minutes and data were downloaded from the loggers to a laptop at regular intervals. A modified Stevenson screen was constructed using plant pot saucers, to protect the data loggers from direct sunlight and moisture (Figure 9).

**Figure 9 Modified Stevenson screen housing Tinytag Plus 2 data logger in cucumber crop on Northern Adelaide plains**

### 4.6.2. Results and discussion

<u>Greenhouse climate</u>

All climate information collected was given to growers so they gained an understanding of how greenhouse temperature and humidity fluctuated over each day and throughout the year. One grower had a maximum/minimum thermometer but most growers were not recording climate data at the start of the project and were surprised to learn the extent of the extremes inside the greenhouse. In greenhouses without any control of temperature or humidity daily and seasonal fluctuations were large. The extremes were particularly evident during summer and winter ranging from <5°C overnight in winter to >45°C daytime temperatures in summer. There were differences in the climate in different types of greenhouses and the crop type and stage had a major influence on the greenhouse climate.

Results from three properties are used to summarise findings.

<u>Property 1</u>

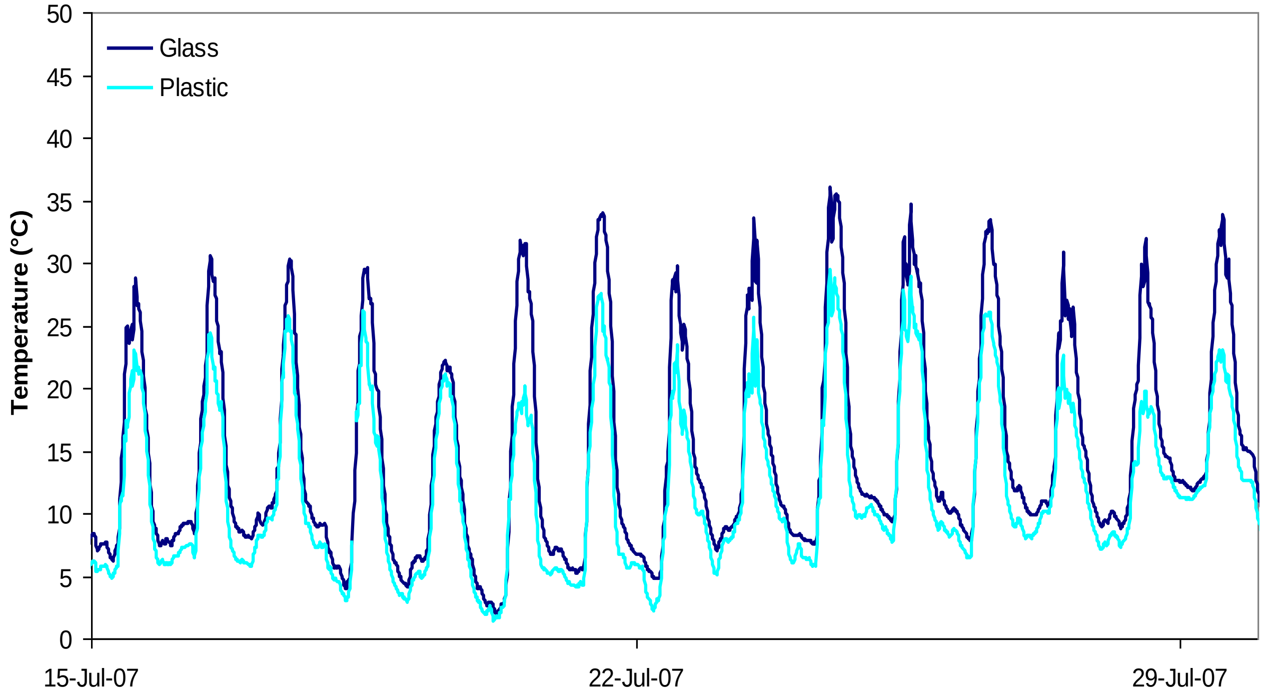
Low tech glass and plastic greenhouses producing cucumbers and capsicums in soil. Passive ventilation only. Glasshouses had doors at each end of each house that could be opened and plastic houses had vents at the top of each end. Both greenhouse types had mesh sides that could be rolled up for maximum passive ventilation (Figure 10).

**Figure 10 Low technology greenhouses on Property 1 on Northern Adelaide plains, glass (left) and plastic (right).**

The climate in plastic and glass greenhouses on Property 1 was compared during winter 2007 and 2008, and summer 2008 and 2009. Trends in winter temperatures were different between 2007 and 2008. In 2007 the glass greenhouse was warmer than the plastic greenhouse but in 2008 the plastic greenhouse was slightly warmer overall (Figure 11). These differences may be a result of the crops being grown in each greenhouse at the time climate data was collected. Transpiration by crops is a major source of greenhouse humidity. In 2007 a mature cucumber crop was growing in the glasshouse and a young capsicum crop was growing in the plastic house.

In 2008, capsicum crops of the same age were being grown in both the plastic and the glasshouse. It was not always possible to compare equivalent crops due to the planting program of the grower. In both years during winter, plastic greenhouses had higher relative humidity than glass houses (Figure 12). Differences between the humidity in glass and plastic were more evident in 2007 which is likely a reflection of the temperature differences during that year.

In summer plastic houses were generally hotter than glasshouses, particularly at the higher temperatures (Figure 13) and humidity was higher in glasshouses overnight and during the day (Figure 14).



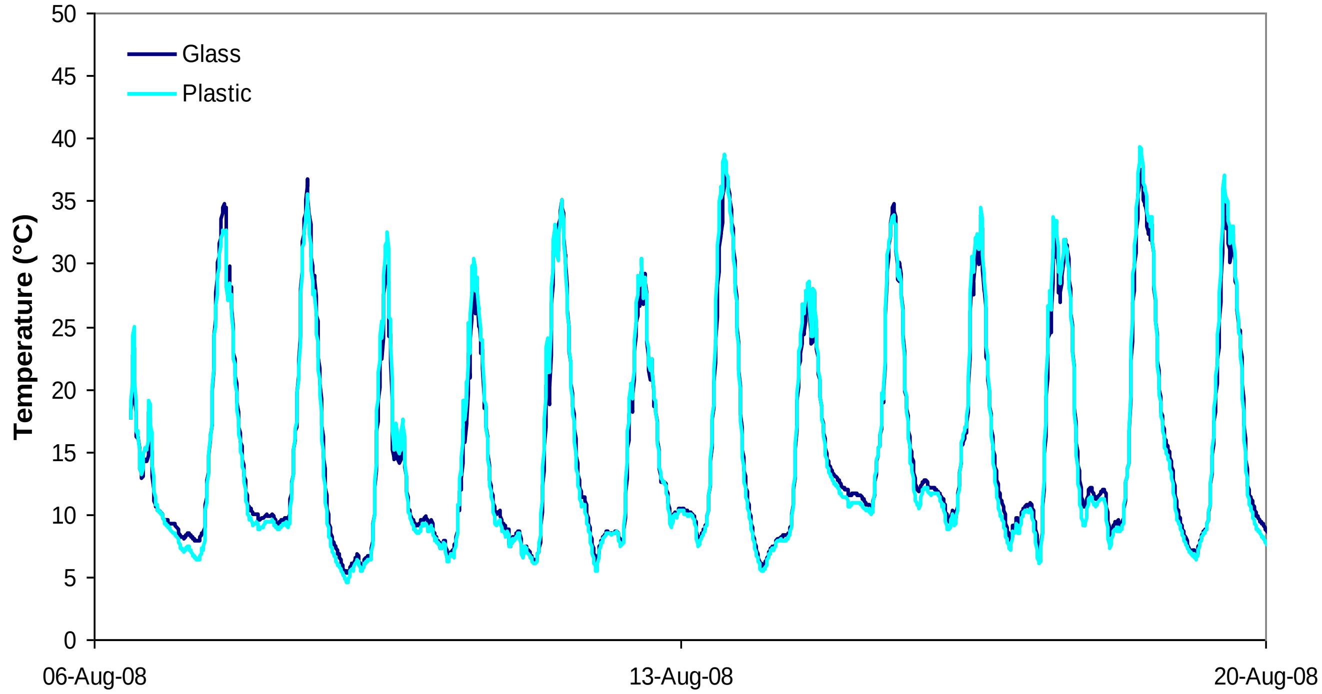




**Figure 11 Temperature in glass compared to plastic greenhouses at Property 1 on the Northern Adelaide Plains during winter 2007 (top) and 2008 (bottom)**

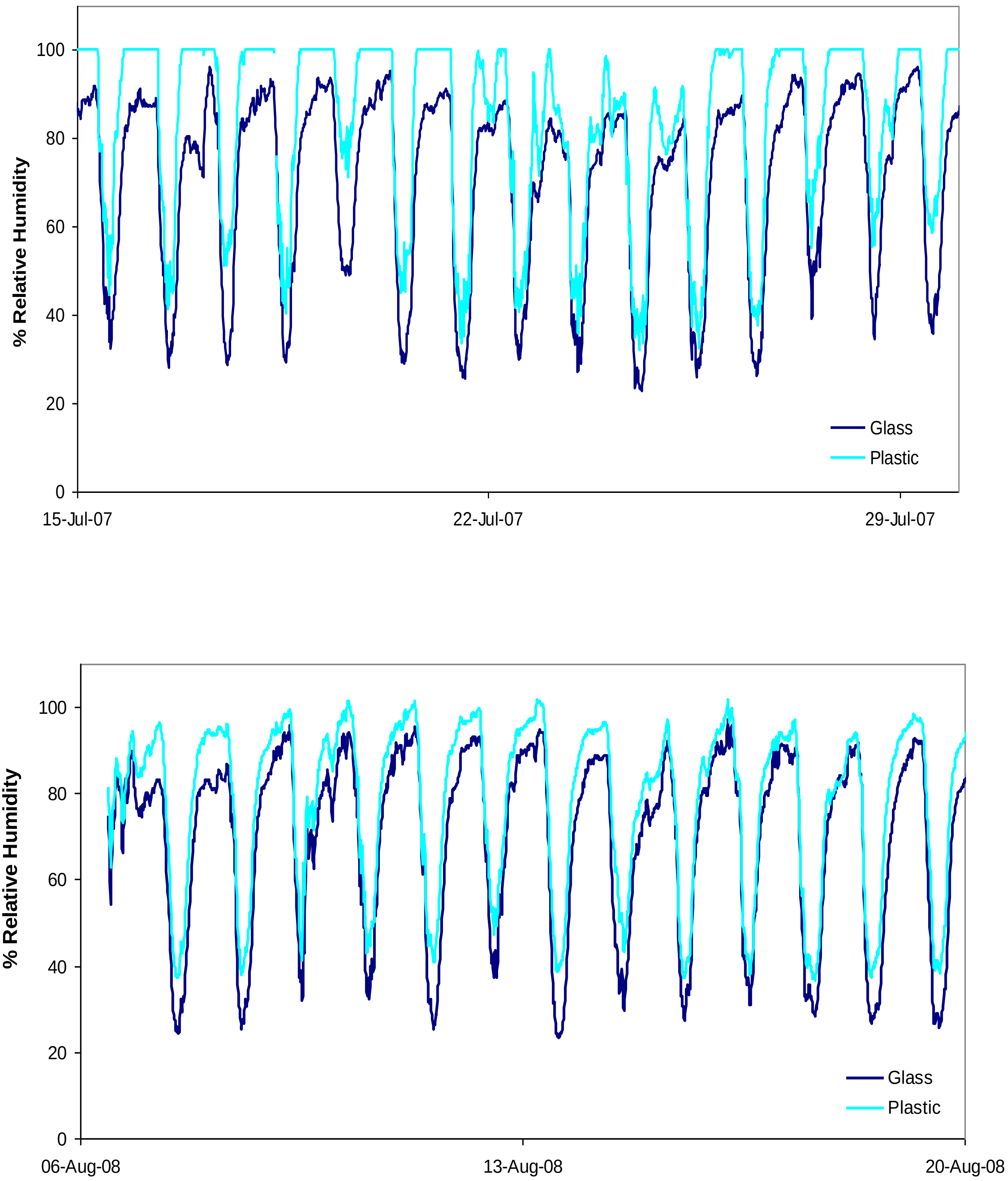
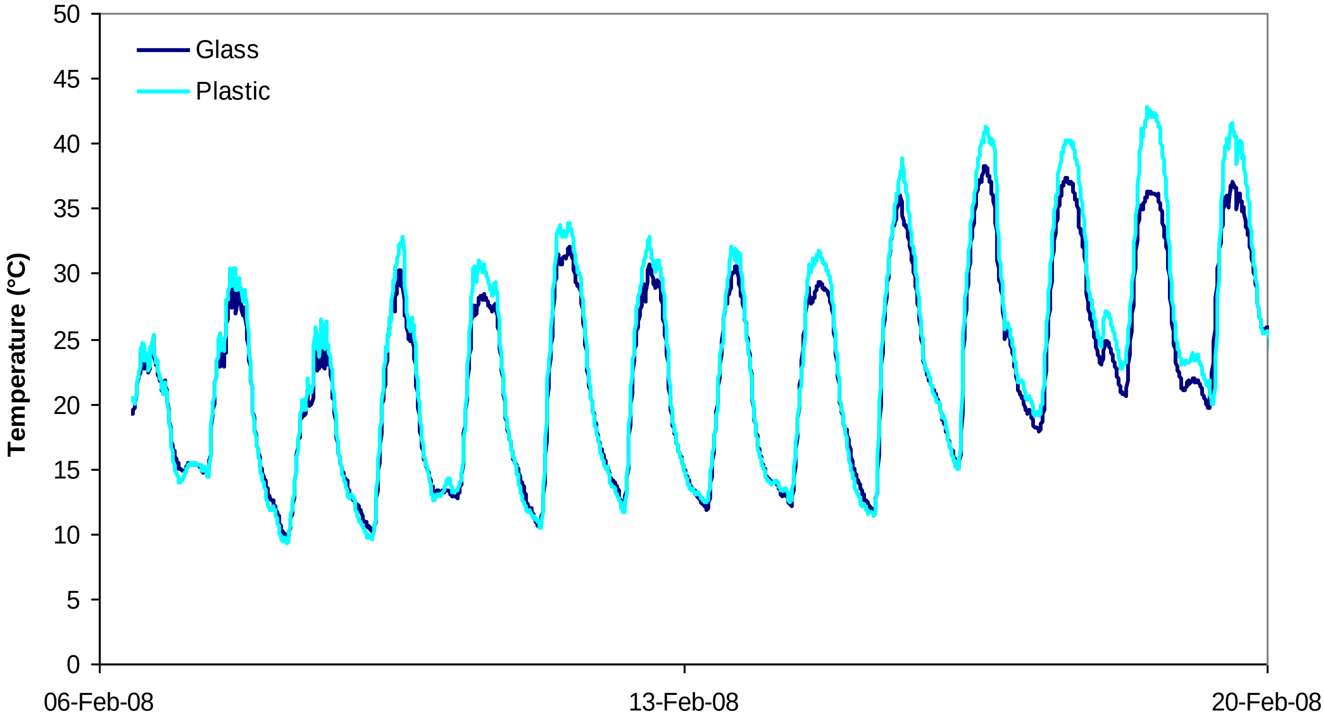



**Figure 12 Relative humidity in glass compared to plastic greenhouses at Property 1 on the Northern Adelaide Plains during winter 2007 (top) and 2008 (bottom)**



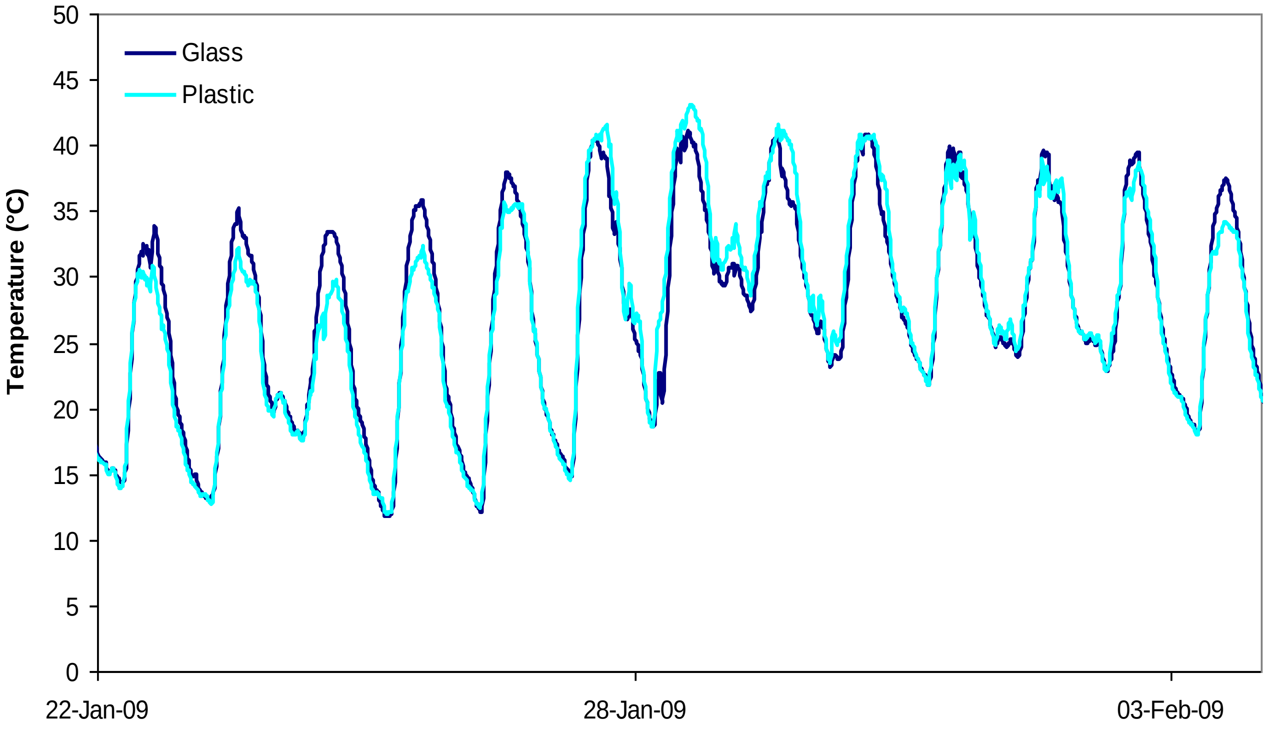




**Figure 13 Temperature in glass compared to plastic greenhouses at Property 1 on the Northern Adelaide Plains during summer 2008 (top) and 2009 (bottom)**

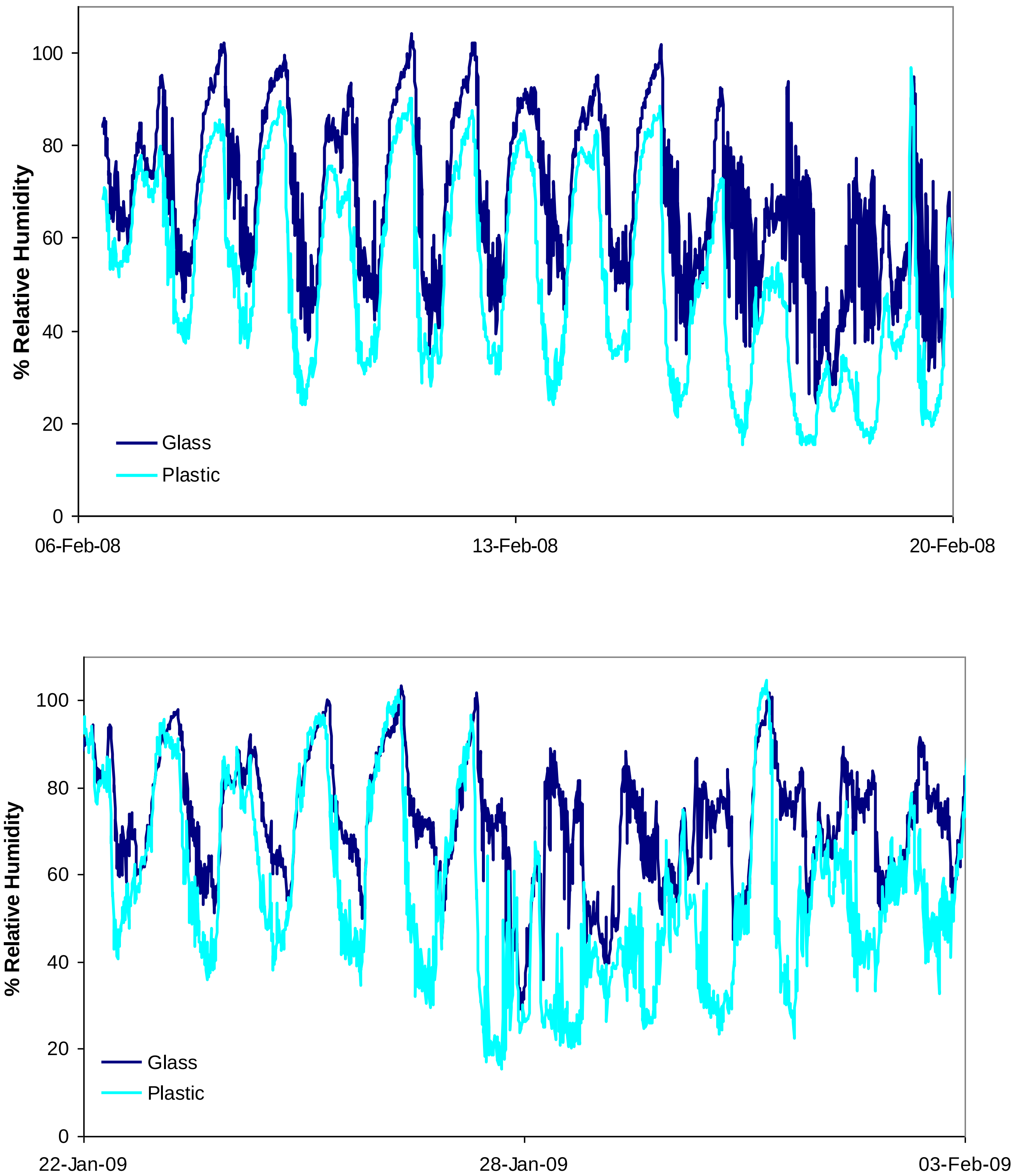



**Figure 14 Relative humidity in glass compared to plastic greenhouses at Property 1 on the Northern Adelaide Plains during summer 2008 (top) and 2009 (bottom)**

Property 2

Low tech plastic greenhouses producing cucumbers hydroponically. Passive ventilation only (Figure 15).

**Figure 15 Low technology plastic greenhouse on Property 2 on Northern Adelaide plains**

After seeing the climate data the grower on Property 2 made more vents in the greenhouses in late 2008 to attempt to reduce humidity during late autumn/winter but humidity remained well above 80% (Figure 20; Figure 22).

Property 3

In 2006/07 a capsicum crop was grown in soil without climate control and in the following two years the house was converted to hydroponic production with full climate control producing capsicums only (Figure 16).

**Figure 16 High technology plastic greenhouse with climate control on Northern Adelaide plains**

Disease

Data was collected from commercial greenhouses where growers continued their normal practises and used fungicides to manage foliar diseases, therefore climate alone was not the only influence on disease development. Researchers overseas have drawn correlations between the greenhouse climate and powdery mildew (Elad 2007). However, correlations on data collected in this project were extremely variable so it was difficult to draw conclusions about the relationship between the greenhouse climate and disease. Although direct correlations cannot be drawn with these data, climate was shown to have a major influence on development of foliar diseases.

*Cucumbers*

Disease measurements and climate data were recorded throughout the growth of two cucumber crops in 2008 and two crops in 2009 grown in plastic greenhouses on Property 2 with no climate control (Figure 17).

Powdery mildew occurred in all crops but in both years the severity of powdery mildew was higher during autumn/winter than during the spring months. Powdery mildew is not reliant on free water for infection and disease can occur across a wide temperature and humidity range (see Foliar Disease section). During late autumn/winter the climate is often highly unfavourable to plants which can mean the crop is more susceptible to disease. In some crops powdery mildew was observed soon after crops were transplanted, often on the cotyledons, and in other crops disease onset occurred later (Figure 18).

Botrytis grey mould was only observed during late autumn/winter (Figure 19; Figure 21). In both years, the mean temperature at that time was approximately 13°C and relative humidity was 100% (Figure 20; Figure 22, conditions that are highly conducive to infection with Botrytis grey mould (see Foliar Disease section).

Growers surveyed at the start of the project said that downy mildew was most common in late winter/spring. Downy mildew was observed in one cucumber crop soon after the project commenced but was not seen in any of the longer term disease and climate studies.  This may have been a combination of conditions later in the project being less conducive to downy mildew and confusion between downy mildew and powdery mildew.

**Figure 17 Cucumber crops in plastic greenhouse on the Northern Adelaide Plains**

**Figure 18 Powdery mildew on cotyledon of young cucumber (left) and older plant (right)**

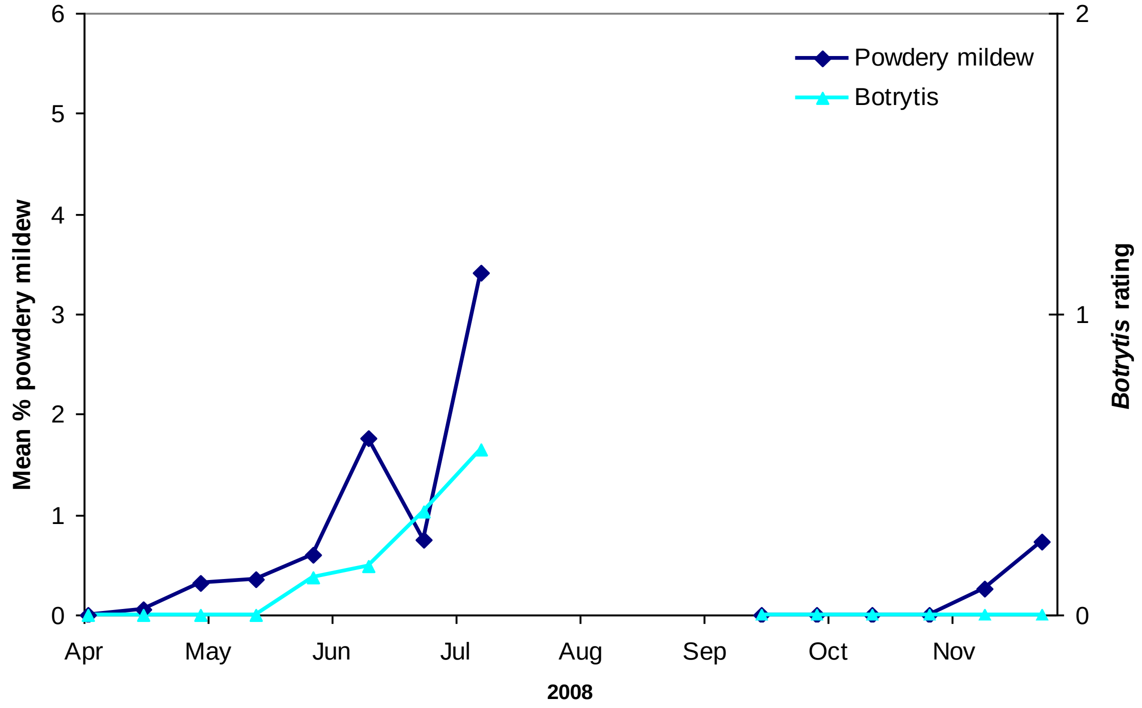



**Figure 19 Development of foliar diseases in cucumber crops in plastic greenhouses on Property 2 on the Northern Adelaide Plains 2008**

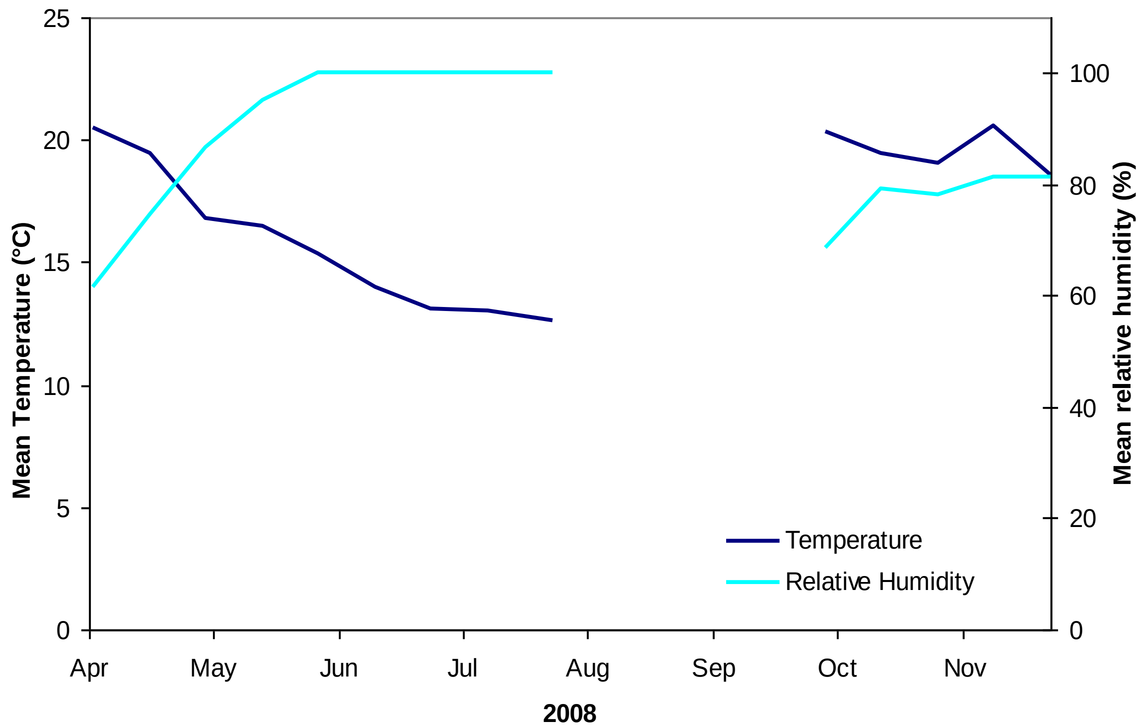



**Figure 20 Mean temperature and relative humidity in plastic greenhouse on Property 2 on the Northern Adelaide Plains during 2008**

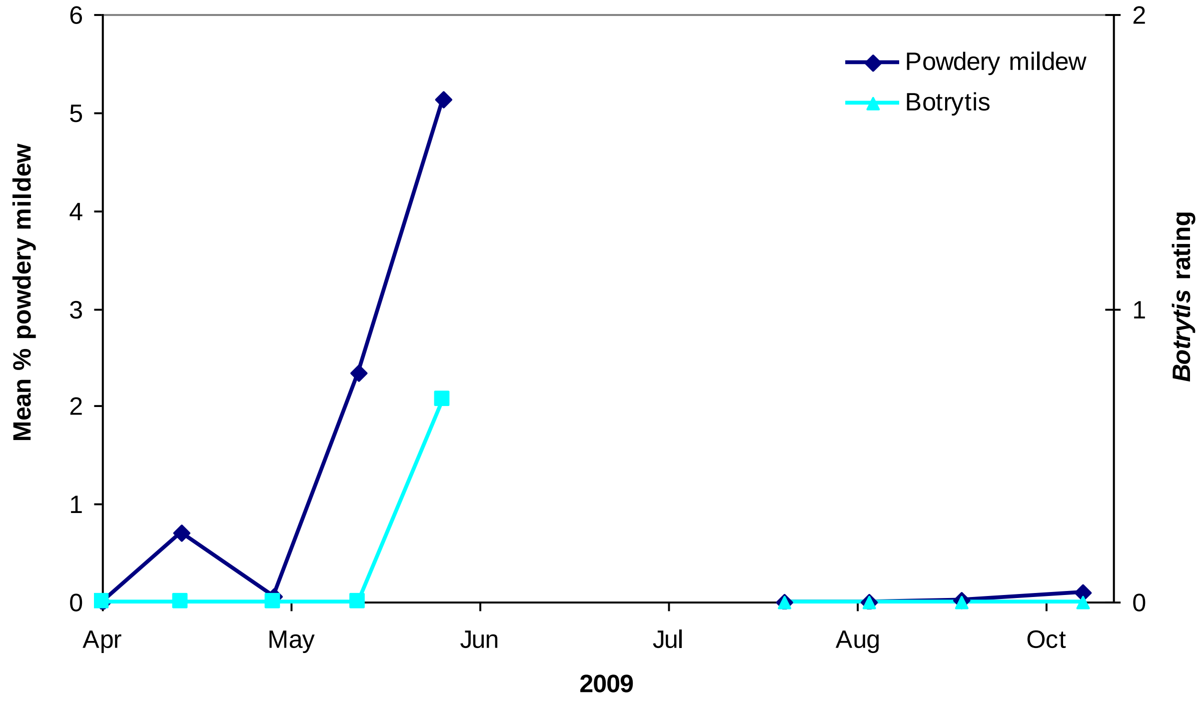



**Figure 21 Development of foliar diseases in cucumber crops in plastic greenhouses on Property 2 on the Northern Adelaide Plains 2009**

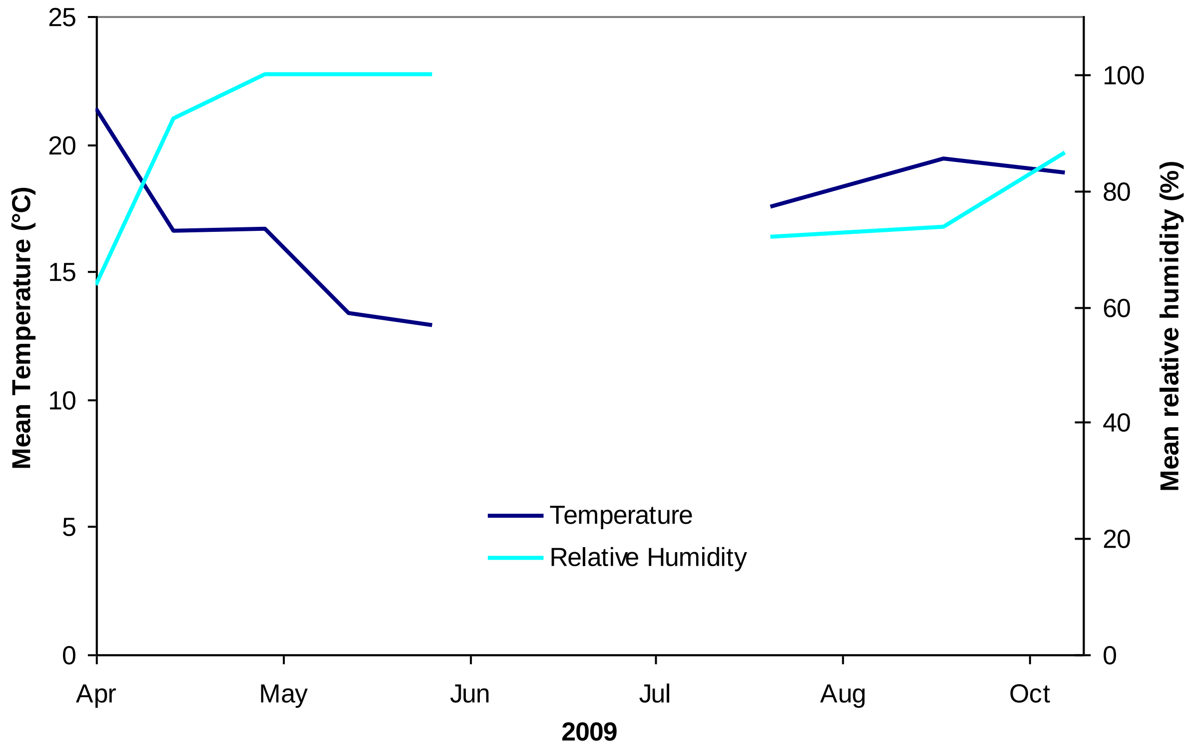



**Figure 22 Mean temperature and relative humidity in plastic greenhouse on Property 2 on the Northern Adelaide Plains during 2009**

*Capsicum*

In capsicum crops observed over three consecutive seasons there was some evidence that climate influenced the severity of powdery mildew. The first crop observed was grown in soil in a plastic greenhouse with no climate control.  Crops in the next two years were grown in the same greenhouse fully converted to hydroponics with climate control operating (Property 3).

In contrast to cucumber crops, capsicum crops did not generally show any visible signs of disease until at least 6 weeks after transplanting and symptoms always occurred first on the under surface of the oldest leaves (Figure 23). A similar disease delay in disease onset has been observed by researchers overseas (Elad 2007).

Powdery mildew severity was much higher in the first year's crop than in the subsequent years (Figure 24). Temperatures were not markedly different between each year but the relative humidity increased in the greenhouse around the time of the outbreak of powdery mildew (Figure 25). The growing system also needs to be taken into account when interpreting this data. The higher severity of powdery mildew in 2006/07 may have been a result of the different levels of stress on plants grown in soil compared with hydroponics.

The pattern of spread on individual plants was predictable for both species of powdery mildew with lower leaves always infected first; however there was no obvious pattern of initiation and spread within the crop.

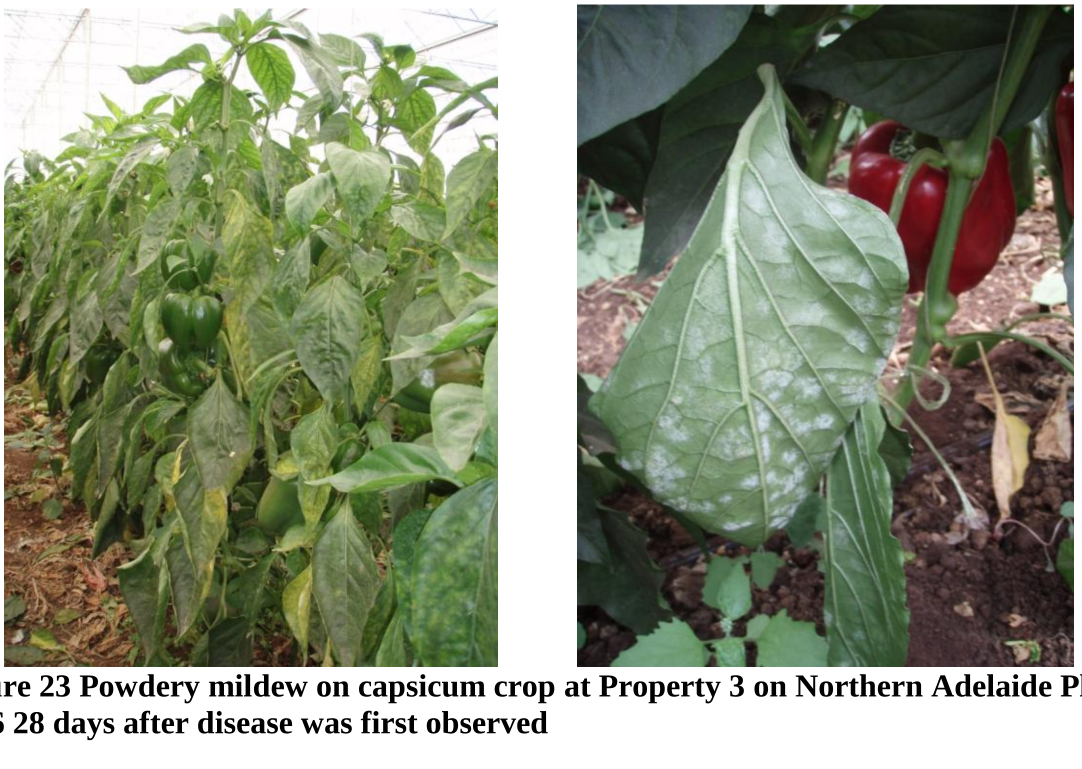


**Figure 23 Powdery mildew on capsicum crop at Property 3 on Northern Adelaide Plains 2006 28 days after disease was first observed**

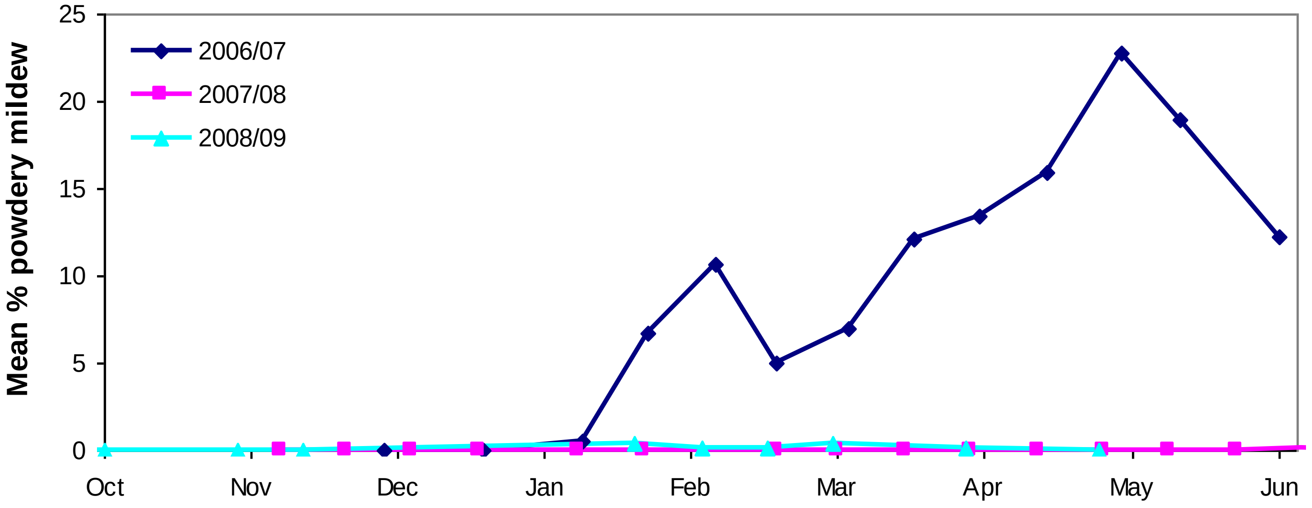



**Figure 24 Powdery mildew in capsicum crop on Northern Adelaide Plains**

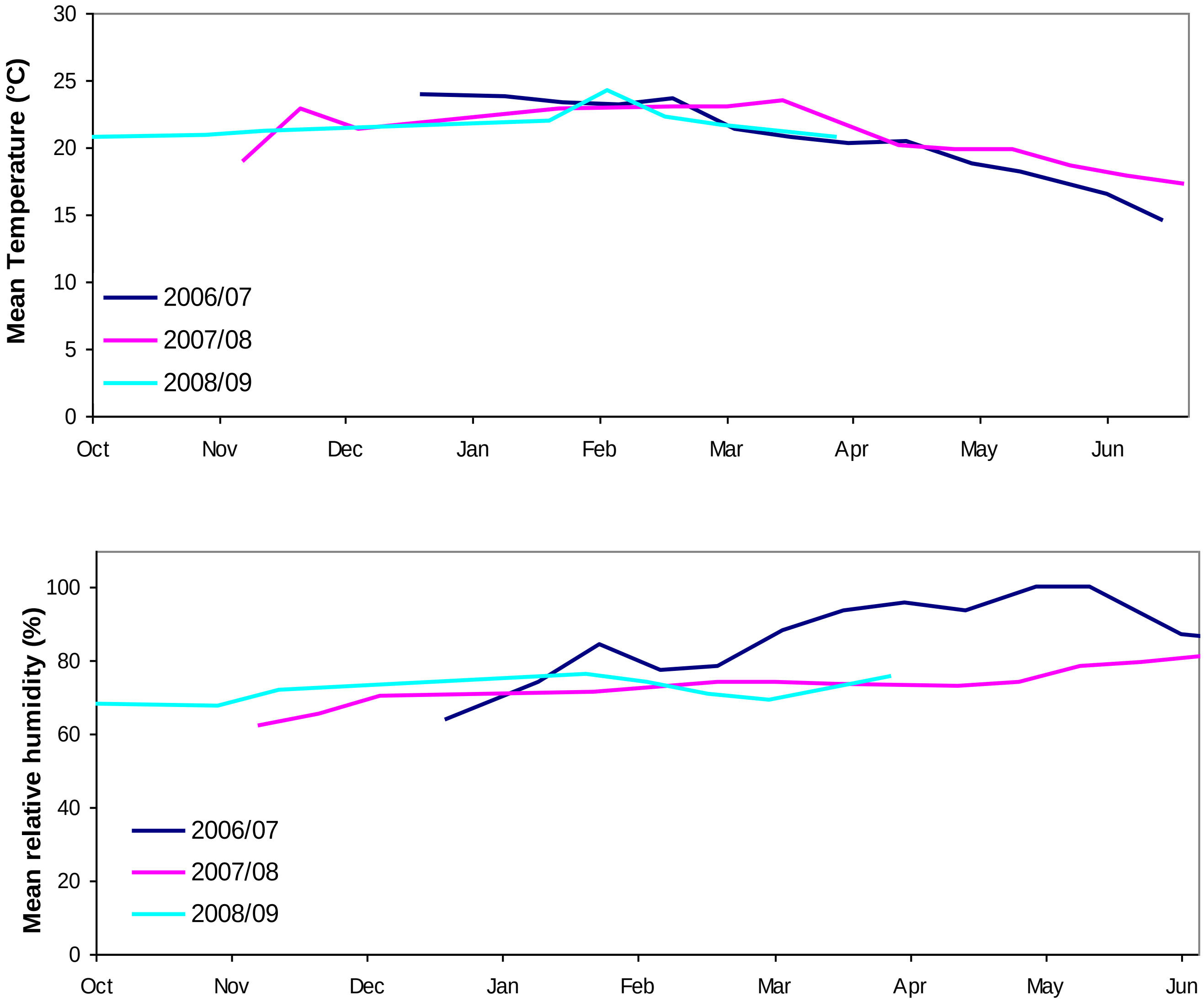



**Figure 25 Temperature (top) and relative humidity (bottom) in plastic greenhouse at Property 3 on Northern Adelaide Plains 2006-2009**

### 4.6.3. Conclusions

During winter, overnight temperatures in low tech unheated greenhouses regularly drop to below 10°C and at times below 5°C. Low temperatures combined with a lack of ventilation result in high relative humidity in the greenhouse. Root activity is greatly reduced below 15°C, which slows or stops plant growth and when humidity is high plants stop transpiring, growth slows and plant health declines. The high humidity is not adequately removed from the greenhouse and condenses on plants. This results in greenhouse climate that is unfavourable to the crop and favourable to foliar diseases like Botrytis grey mould. Although the plastic greenhouses on Property 1 may have higher relative humidity compared to glass, the levels are so high in both types of house (>90%) that that those differences may not matter. However, in summer, the differences in humidity between glass and plastic houses could be significant. Plant roots will shut down above 30°C and if humidity is too low plants will stop transpiring to restrict water loss and minimise wilting. The glass houses observed during summer tended to retain higher humidity during the day and night compared to the plastic houses which could have a positive impact on plant growth.

Recent studies in Israel found a correlation between leaf coverage with powdery mildew and high relative humidity (75-95%) in the 3-4 weeks preceding disease assessment when temperatures were <16°C (Elad 2007). Venting strategies can be used to manage humidity in greenhouses but those strategies are limited by the technology level of the greenhouse. When temperature is low and humidity is high, heating combined with ventilation is an effective way to lower humidity. Studies have also shown that increasing both the day and night time temperatures in the greenhouse reduced powdery mildew, potentially as a result of the decrease in humidity (Elad 2007). Night time heating is not always possible or practical but increasing daytime temperatures by keeping doors closed or sides down may be feasible for low tech growers. However, care is needed to ensure that increased greenhouse temperatures do not cause stress to the crop.

When temperature is high and humidity is low, closing vents to trap humidity is not an option as the temperature will quickly become unfavourable for the crop. In this situation the best option is to create artificial humidity by the use of fogging. Small droplet size ensures that the fog vaporises and does not condense on plants.

Climate impacts on disease but the majority of growers in low tech greenhouses are already managing the greenhouse climate the best they can within the limitations of their greenhouses. For most low tech growers the cost of installing and running heating or fogging systems cannot be justified. The better option was to grow short crops of cucumbers (8-10 weeks) during summer and manage planting times over winter for capsicums so that plants were not sitting dormant in cool conditions or stressed for long periods in hot conditions.

Growers make management decisions about if and where to plant crops over winter. Some growers surveyed choose not to grow a crop over winter because past experience had shown them it was not viable due to slow plant growth and the prevalence of disease. The grower on Property 1 would sometimes opt not to plant in plastic greenhouses over winter if they had the option of planting elsewhere.

## 4.7. Trials

Selection of the products for screening was made after consultation with other researchers, growers and agrochemical companies. Products that were identified in the pesticide gap analysis conducted in 2006 (HAL project MT07029 'Managing pesticide access in horticulture'), products currently registered in other crops, several products with new chemistry and products that growers had found effective in the past were included. The products trialled included fungicides from five different activity groups and also alternative chemicals like oils and plant health products. Products were evaluated for both protectant and eradicant activity.

Screening trials were undertaken on potted plants in the greenhouse to identify products that would be effective against the main foliar diseases. These included:

1. Fungicides with short withholding periods and low toxicity to non-target organisms;
2. Fungicides with long withholding periods for use early in crops before harvesting commences;
3. Alternative products that could be incorporated into spray programs to reduce the selection pressure for fungicide resistance without sacrificing control efficacy.

Selected products were examined in spray program trials in the research greenhouse and in trials in commercial greenhouses.

Growers expressed interest in the use of milk products that have been evaluated for the control of powdery mildew in other crops. A small scale trial was conducted to examine the eradicant effect of different milk products. Growers were also interested in the disease suppressive effects of compost so a small scale pot trial was undertaken to evaluate the effect of compost amendments on powdery mildew.

### 4.7.1. Screening products for powdery mildew on cucumber

Materials and Methods

*Trial 1-7*

Seventeen products were evaluated in screening trials (Table 6). For each trial 100 cucumber seeds, variety Mascot, were planted into cocopeat in 0.9L plastic pots (Masrac). Seedlings were tied to 300mm stakes as they grew and the growing tip pruned out when it reached the top of the stake. Plants were pruned to cotyledons and two true leaves. Trials commenced two weeks after seeds were planted when true leaves were beginning to expand (Figure 27).

In the protectant trials seedlings were sprayed with the product to be screened to run-off using a hand-held sprayer and inoculated as previously described with a spore suspension of powdery mildew with $10^5$ spores/mL 1, 3, 7 or 14 days later, with 5 replicates per treatment. Powdery mildew severity on the cotyledons was assessed 14 days after inoculation. In the eradicant trials seedlings were inoculated with a spore suspension of powdery mildew with $10^5$ spores/mL. Products were then applied 1, 3, 7 or 14 days later, with 5 replicates per treatment. Powdery mildew severity on the cotyledons was assessed 14 days after products were applied.

Cotyledons were assessed because the rapid expansion of true leaves during the trial period made it difficult to ensure that the surface of the true leaves was entirely covered with fungicide. Cotyledons were completely covered with spray at the commencement of each trial when they were already full expanded and no further expansion would confound results. In each trial Bayfidan® and water were used as controls.

**Table 6 Products screened for efficacy against cucumber powdery mildew in trials in research greenhouse**

| Product | Active ingredient | Rate of product | Trial |
|---|---|---|---|
| | **From pesticide gap analysis** | | |
| Cabrio® | 250g/L pyraclostrobin | 0.4mL/L | 1 |
| Ecocarb® | 940g/kg potassium bicarbonate | 4g/L | 6 |
| Ecocarb® and<br>Synertrol® Horti Oil | 940g/kg potassium bicarbonate<br>905g/L emulsifiable botanical oil | 4g/L<br>2.5mL/L | 5 |
| Flint® 500 WG | 500g/kg trifloxystrobin | 0.15g/L<br>0.2mL/L | 1<br>3 |
| Legend™ | 250g/L quinoxyfen | 0.15mL/L | 4 |
| | **Registered in other crops** | | |
| Amistar® 250 SC | 250g/L azoxystrobin | 0.8mL/L | 1 |
| Domark® 40 ME | 40g/L tetraconazole | 0.3mL/L | 2 |
| Topas® 100 EC | 100g/L penconazole | 0.2mL/L | 2 |
| Folicur® 430 SC | 430g/L tebuconazole | 0.3mL/L | 2 |
| Prosper® 500 EC | 500g/L spiroxamine | 0.6mL/L<br>0.3mL/L | 3<br>4 |
| Systhane™ 200 EW | 200g/L myclobutanil | 0.6mL/L<br>0.12mL/L | 3<br>4 |
| | **No WHP** | | |
| BioCover® | 840g/L petroleum oil | 10mL/L | 5 |
| Eco-oil® | 850g/L emulsifiable botanical oils | 3.8mL/L | 5 |
| Epsom salts | Magnesium sulphate | To EC4 | 6 |
| | **New chemistry** | | |
| Vivando® | 500g/L metrafenone | 0.5mL/L<br>0.75mL<br>1ml/L | 7 |
| Colliss® | 200g/L boscalid<br>100g/L kresoxim-methyl | 1m/L<br>1.5mL.L<br>2mL/L | 7 |
| | **Current standard** | | |
| Bayfidan® 250 EC | 250g/L triadimenol | 0.4mL/L | 1,2,3,4,5,6,7 |

*Trial 8*

Cucumber seeds, variety Mascot, were planted into cocopeat mix in 0.9L plastic pots (Masrac). Plants were tied to 300mm stakes and growing tips removed when plants reached the top of the stake. When plants were 4 weeks old they were pruned to two true leaves and inoculated as previously described with powdery mildew at $10^5$ spores/mL. One week later plants were sprayed with one of five treatments with 7 plants per treatment:

1. Full fat milk 100mL/L
2. Low fat milk 100mL/L
3. Nestle® Sunshine instant full cream milk powder
   130g powder mixed with 900mL water then diluted to 100mL/L
4. Devondale UHT full fat milk 100mL/L
5. Unsprayed control

Severity of powdery mildew was assessed on the youngest leaf using a rating scale (see General Materials and Methods) before spraying, and seven and 14 days after the sprays were applied. Disease progression curves were calculated for each treatment.

*Trial 9*

Twenty cucumber seeds, variety Mascot, were planted into cocopeat mix 6-celled punnets (Masrac). After two weeks 10 seedlings were transplanted to individual 0.9L plastic pots (Masrac) filled with UC mix amended with 20% compost (Jeffries) and 10 seedlings were transferred to pots with UC mix only. UC mix was selected for this trial as it has less nutrients than the cocopeat mix used in other trials. One day after transplanting, plants were inoculated with powdery mildew at $10^5$ spores/mL as previously described. Plants were tied to 300mm stakes as they grew. Severity of powdery mildew was assessed on all true leaves using a rating scale before inoculation, and seven, 14 and 21 days after inoculation (Figure 26). Plants had between 5-6 true leaves by day 21 and a mean disease severity was calculated for all leaves.

**Figure 26 Cucumber seedlings in trial examining the effect of compost amendment on powdery mildew severity in research greenhouse**

Results and Discussion

*Trial 1*

All the strobilurin (Group 11) fungicides were more effective as protectants than as eradicants. All fungicides protected plants from powdery mildew infection up to 14 days after spraying compared to the control (Figure 29). All fungicides applied 1,3 and 7 days after inoculation controlled powdery mildew compared with the control. Cabrio® significantly decreased powdery mildew even when applied up 14 days after inoculation (Figure 30). While Cabrio® was the most effective fungicide in both the eradicant and protectant trials symptoms of phytotoxicity including stunting, distortion and edge burning were observed on the true leaves (Figure 28).

**Figure 27 Cucumber seedlings at the stage at Day 0 (left), when fungicide screening trials commenced and Day 7 (right) in the research greenhouse**

**Figure 28 Phytotoxicity on true leaves of cucumber seedling sprayed with Cabrio® (right) compared to unsprayed seedlings (left)**

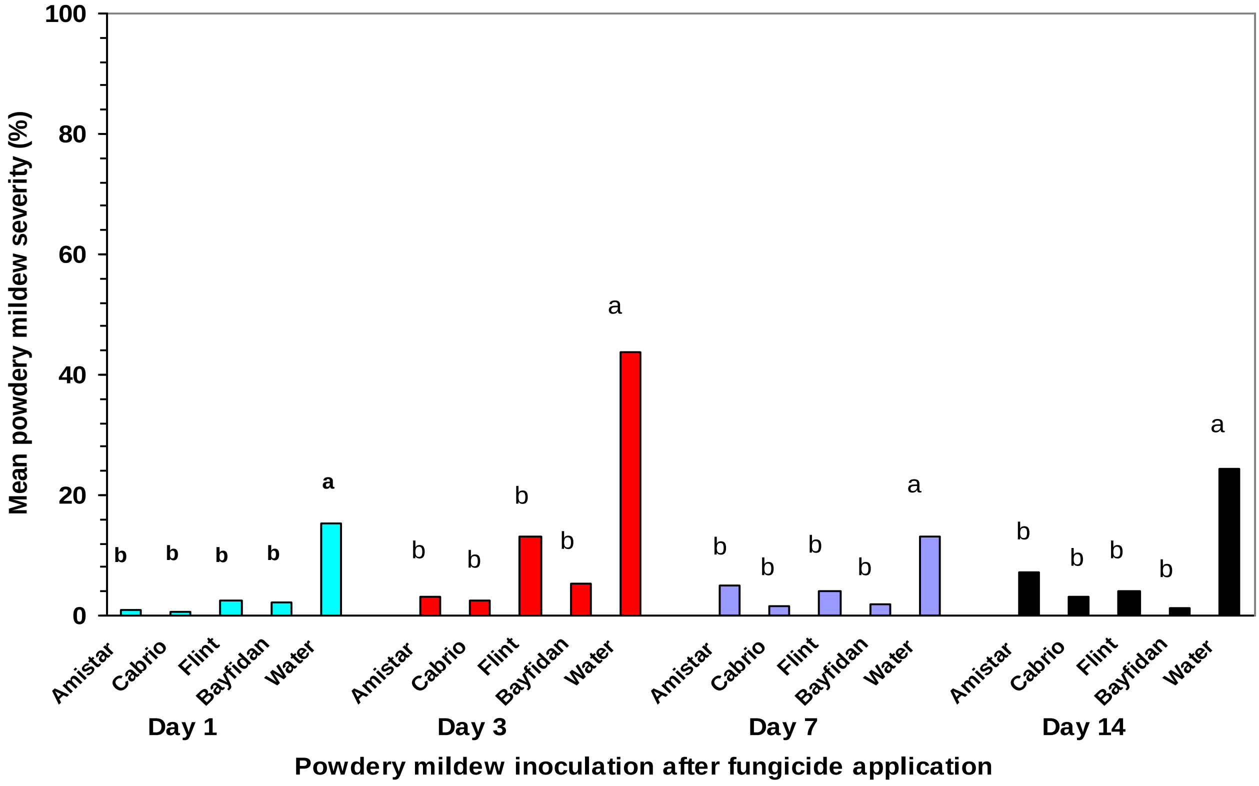



**Figure 29 Protectant Trial 1 – Evaluation of fungicides applied to cucumber seedlings 1, 3, 7 and 14 days before inoculation with powdery mildew in research greenhouse** Within individual days, treatments with the same letter are not significantly different from one another (p<0.05).

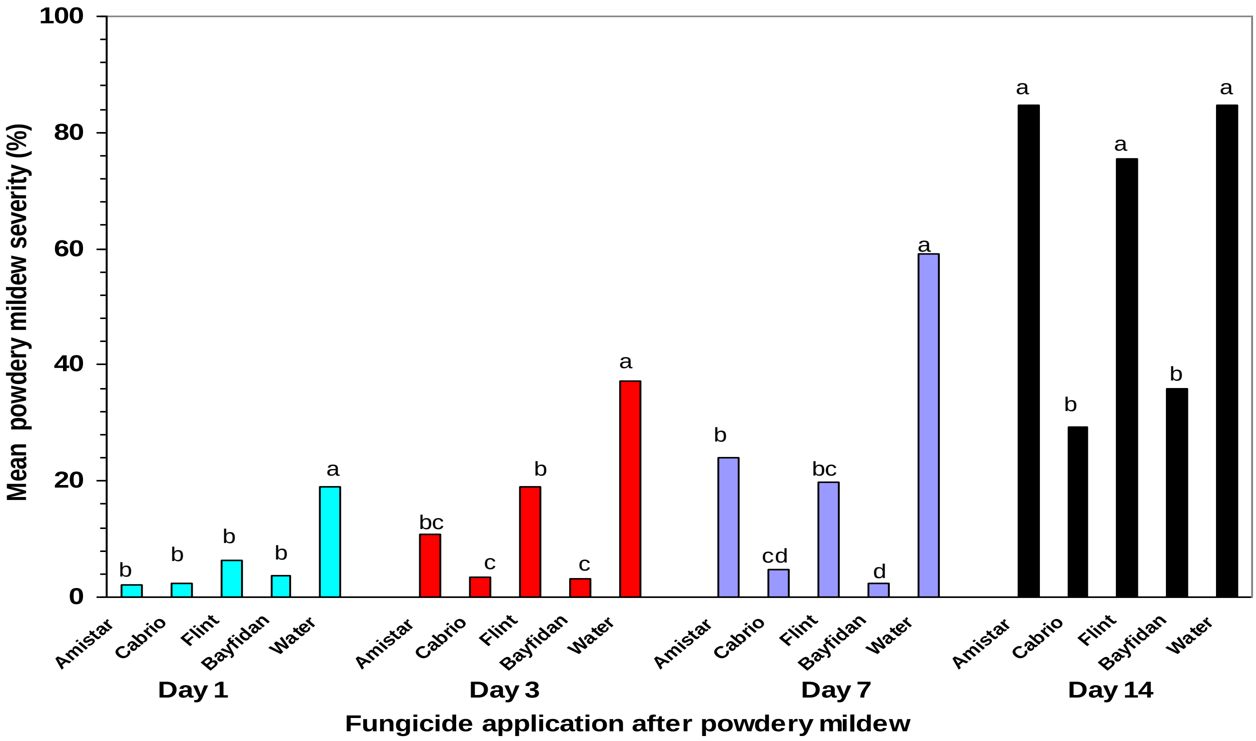



**Figure 30 Eradicant Trial 1 – Evaluation of fungicides applied to cucumber seedlings 1, 3, 7 and 14 days after inoculation with powdery mildew in research greenhouse.** Within individual days, treatments with the same letter are not significantly different from one another (p<0.05).

*Trial 2*

The dimethylation inhibitor (DMI) (Group 3) fungicides Domark®, Folicur® and Topas® significantly decreased powdery mildew severity compared with the untreated control when applied up to 14 days before inoculation. Bayfidan® was not as effective as the other fungicides in this activity group but did decrease disease severity at 1, 3 and 7 days compared to the control (Figure 31). All fungicides significantly decreased powdery mildew severity when applied 1, 3 and 7 days after inoculation compared with untreated controls (Figure 32). None of the fungicides were effective when applied 14 days after powdery mildew inoculation. Registration of Domark® and Folicur® for greenhouse use would not be supported by the relevant chemical companies due to crop safety concerns (personal communication).

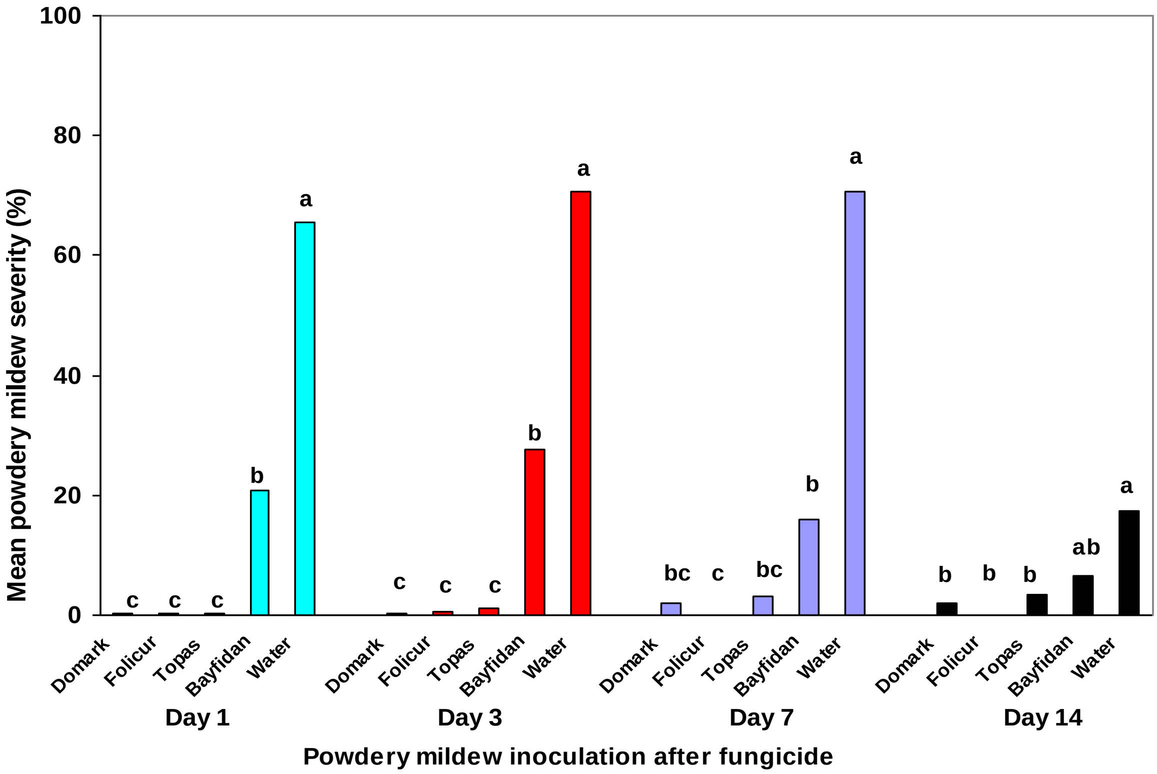



**Figure 31 Protectant Trial 2 – Evaluation of fungicides applied to cucumber seedlings 1, 3, 7 and 14 days before inoculation with powdery mildew in research greenhouse.** Within individual days, treatments with the same letter are not significantly different from one another ($p<0.05$).

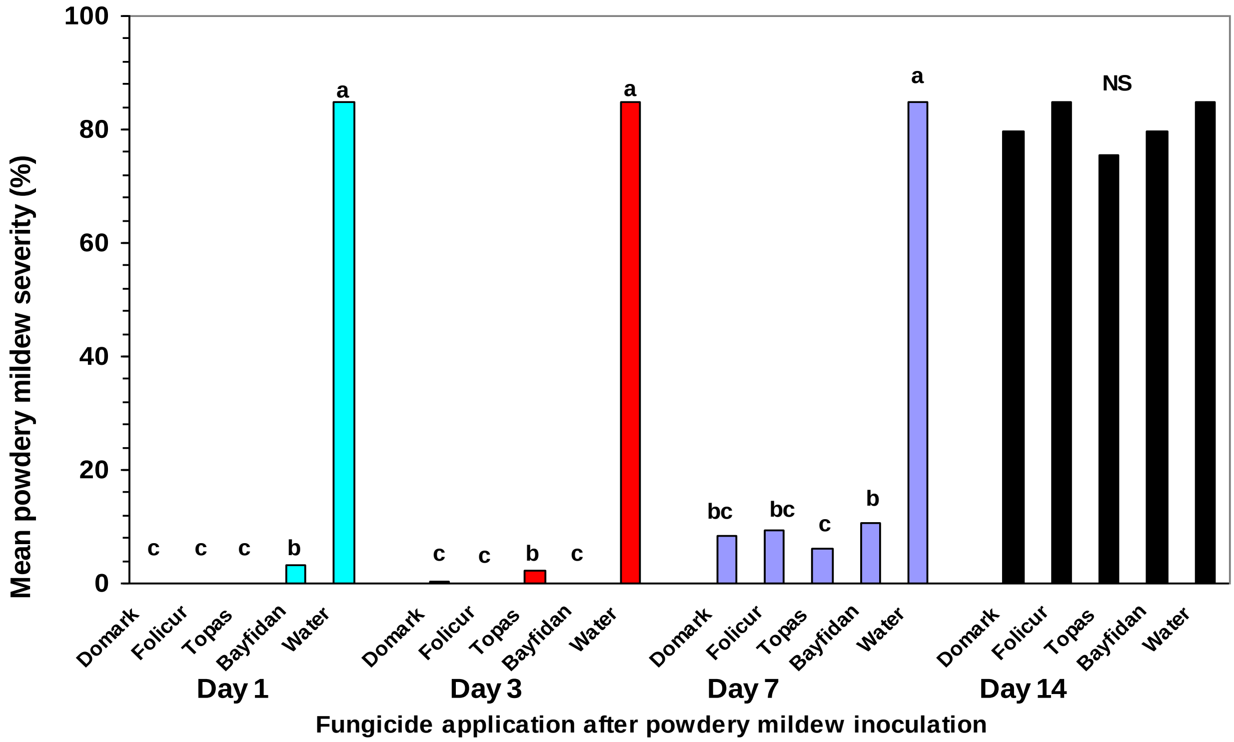



**Figure 32 Eradicant Trial 2 – Evaluation of fungicides applied to cucumber seedlings 1, 3, 7 and 14 days after inoculation with powdery mildew in research greenhouse** Within individual days, treatments with the same letter are not significantly different from one another ($p<0.05$). NS = no significant difference between treatments.

*Trial 3*

Infection in the controls was low in these trials, particularly in the protectant trial. In protectant trials all fungicides prevented powdery mildew from developing up to 14 days after spraying although only low levels of powdery mildew were observed in the untreated control at day 14 (Figure 35).All fungicides significantly decreased powdery mildew severity compared with the control when applied up to three days after plants were inoculated with powdery mildew. Prosper® and Systhane™ were still effective at day 7 (Figure 36). Plants treated with Legend® were slightly stunted (Figure 33) and plants treated with Systhane™ had stunting, distortion and edge burning (Figure 34).

**Figure 33 Untreated seedlings (left); treated with Legend® (right)**

**Figure 34 Untreated seedlings (left); treated with Systhane™ (right)**

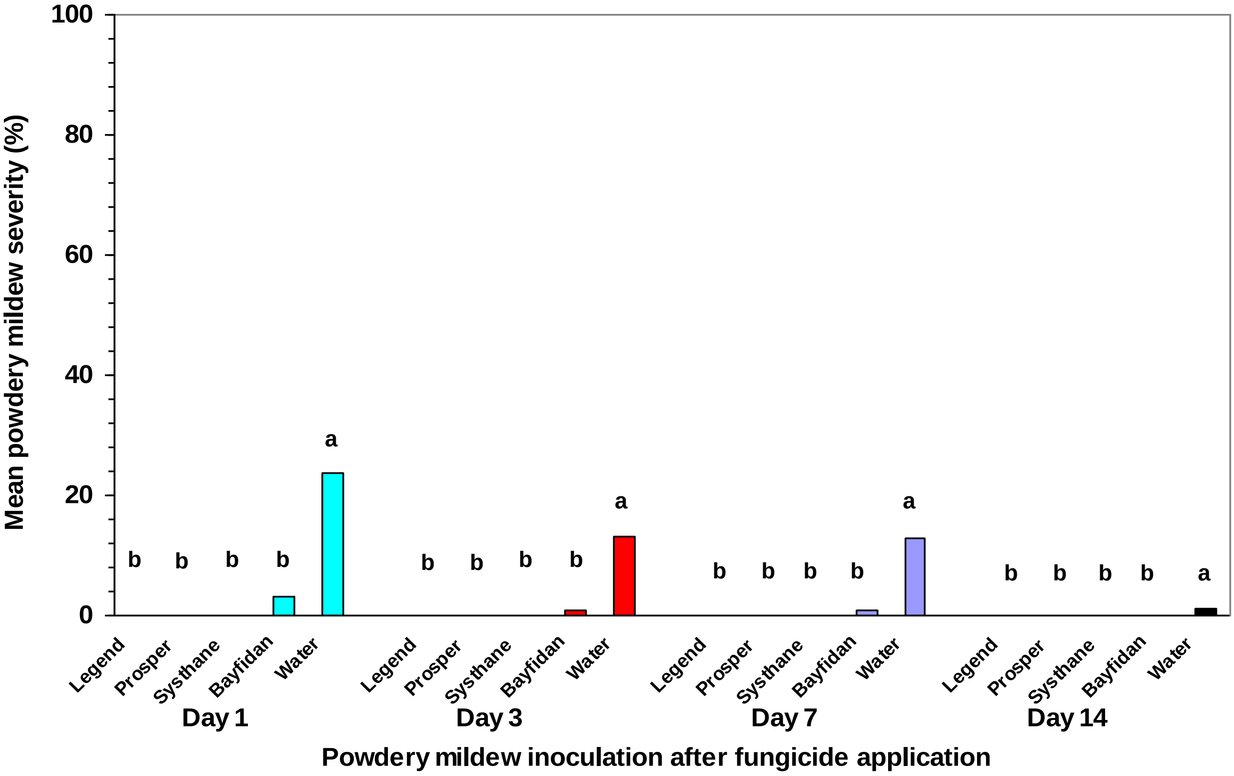



**Figure 35 Protectant Trial 3 - Evaluation of fungicides applied to cucumber seedlings 1, 3, 7 and 14 days before inoculation with powdery mildew in research greenhouse.** Within individual days, treatments with the same letter are not significantly different from one another ($p<0.05$).

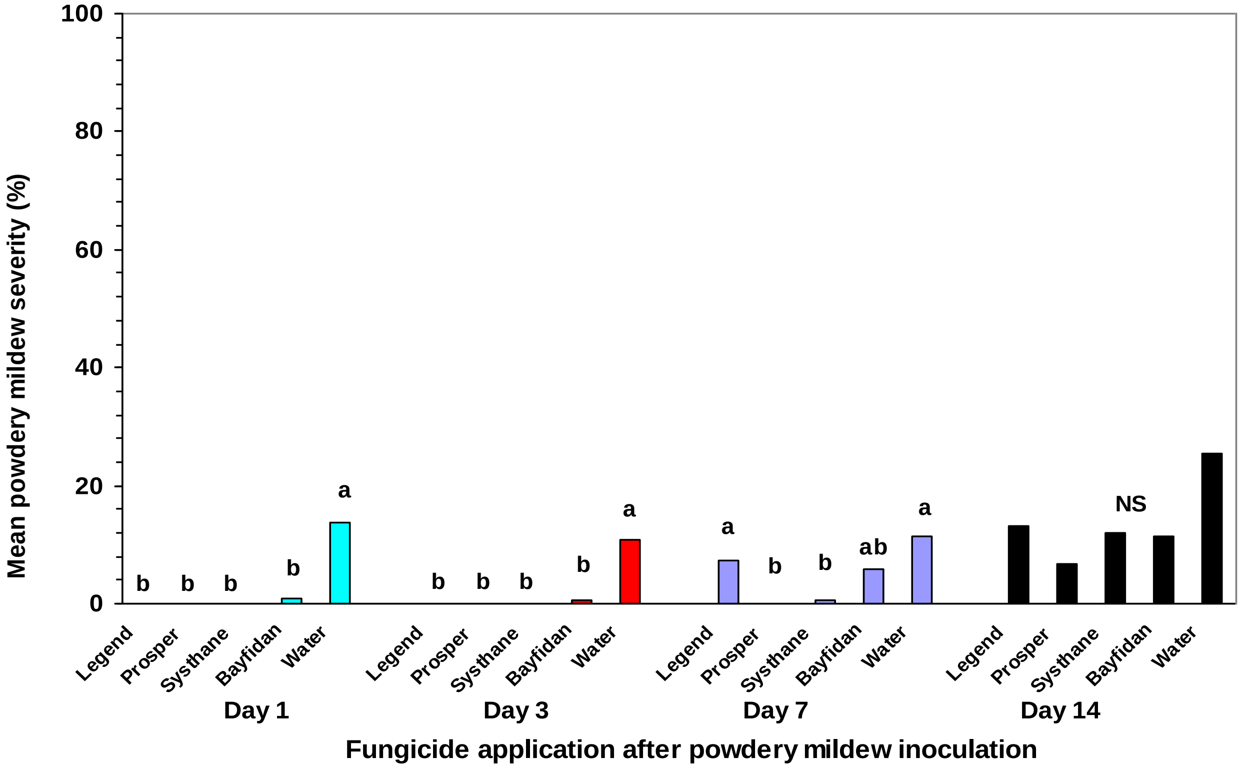



**Figure 36 Eradicant Trial 3 Evaluation of fungicides applied to cucumber seedlings 1, 3, 7 and 14 days after inoculation with powdery mildew in research greenhouse**). Within individual days, treatments with the same letter are not significantly different from one another ($p<0.05$). NS = no significant difference between treatments.

*Trial 4*

The products evaluated in Trial 3 were highly effective but several caused phytotoxicity. Therefore the products were re-trialled at lower rates to see if desirable efficacy could be achieved without phytotoxicity. All fungicides significantly decreased powdery mildew severity compared with the untreated control at all application times. Legend® and Prosper® were highly effective protectants up to day 3 and still had some effectiveness up to day 7. At the lower rates all three fungicides were very effective eradicants up to day 3. Prosper® was still effective at day 7. (Figure 37; Figure 39). Prosper was phytotoxic (Figure 38). Unfortunately, these products won't be supported by the relevant chemical companies for greenhouse use in cucumbers due to crop safety concerns and the small size of the market (personal communication).

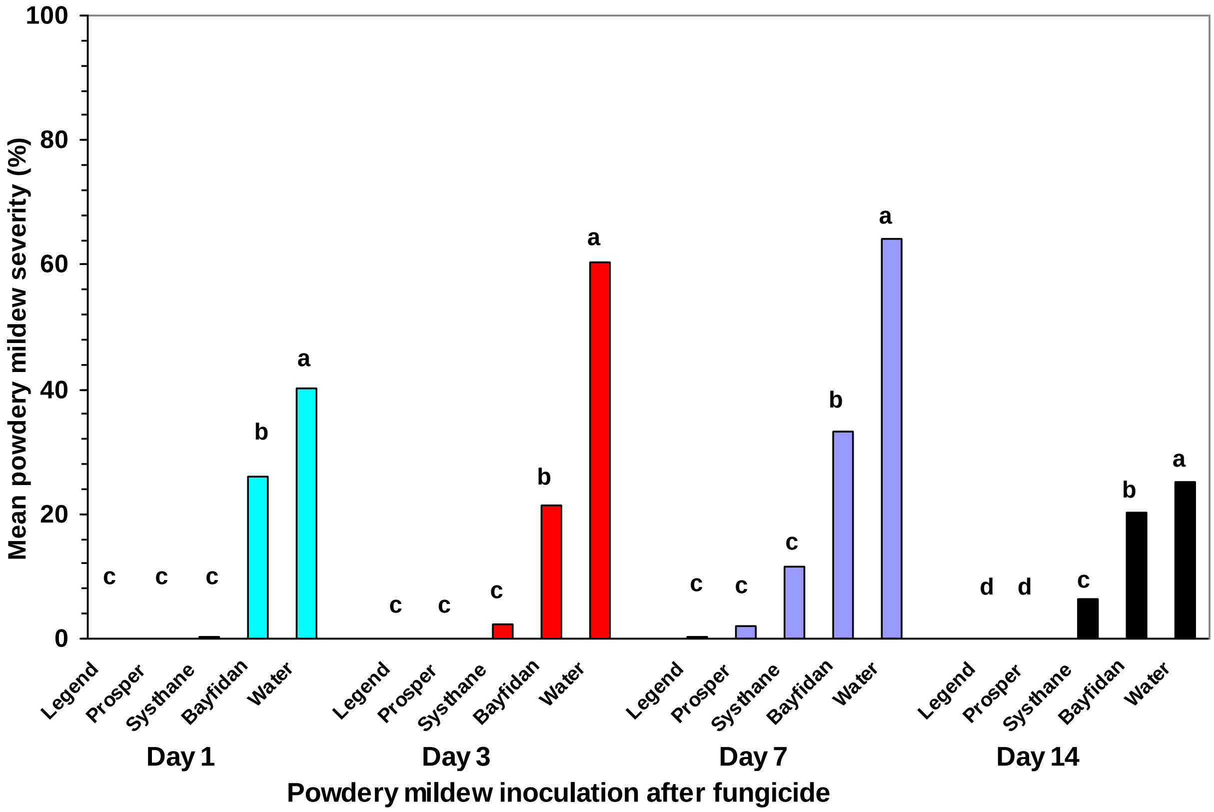



**Figure 37 Protectant Trial 4 – Evaluation of fungicides applied to cucumber seedlings 1, 3, 7 and 14 days before inoculation with powdery mildew in research greenhouse** Within individual days, treatments with the same letter are not significantly different from one another ($p<0.05$).

**Figure 38 Phytotoxicity on cucumber cotyledons 20 days after spraying with Prosper®**

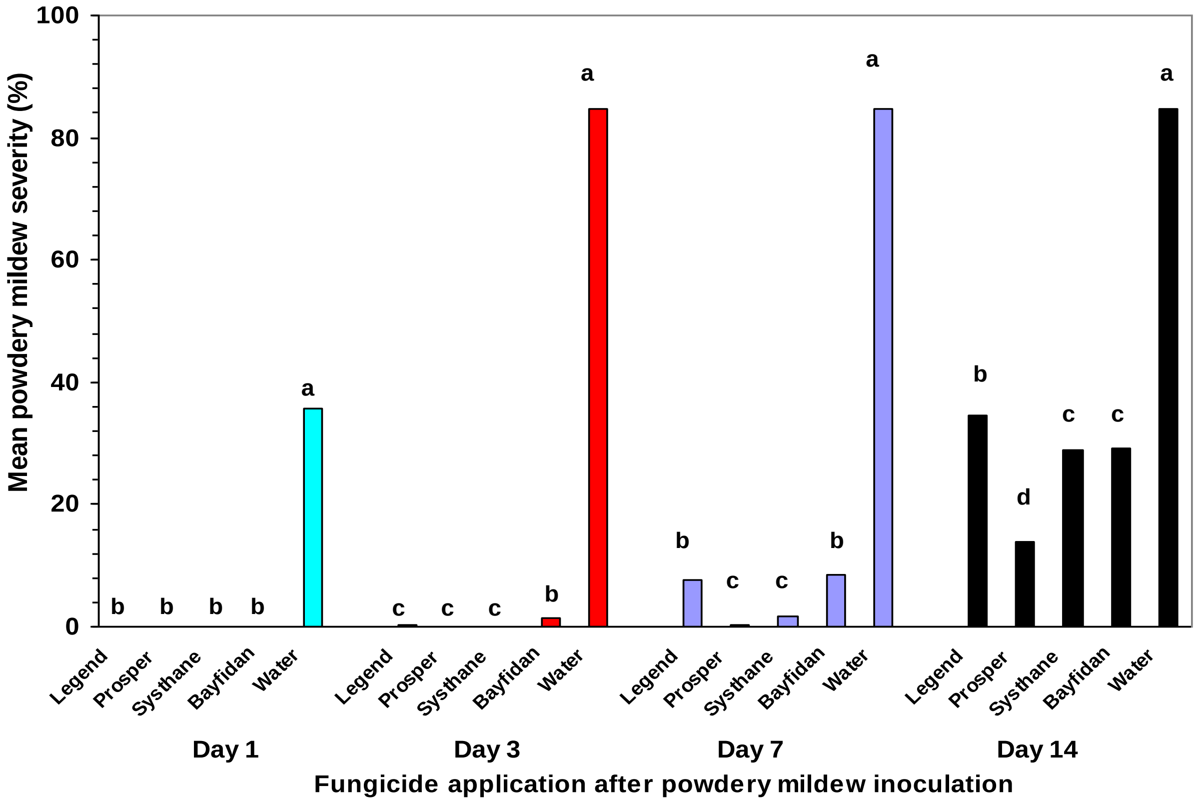



**Figure 39 Eradicant Trial 4 – Evaluation of fungicides applied 1, 3, 7 and 14 days after inoculation with powdery mildew in research greenhouse.** Within individual days, treatments with the same letter are not significantly different from one another ($p<0.05$).

*Trial 5*

All products significantly decreased powdery mildew severity compared with the untreated control when applied 1, 3 and 7 days before inoculation, or 1 day after inoculation (Figure 40; Figure 41). Eco-oil® and Ecocarb® +Synertrol® Horti Oil were most effective when used as eradicants and Biocover® was most effective as a protectant. All three products showed a small degree of protectant action for one day after application but effectiveness for Eco-oil® and Ecocarb® +Synertrol® Horti Oil decreased after that time as these products do not have any residual activity on the plants. Biocover® was an effective protectant even up to day 7.

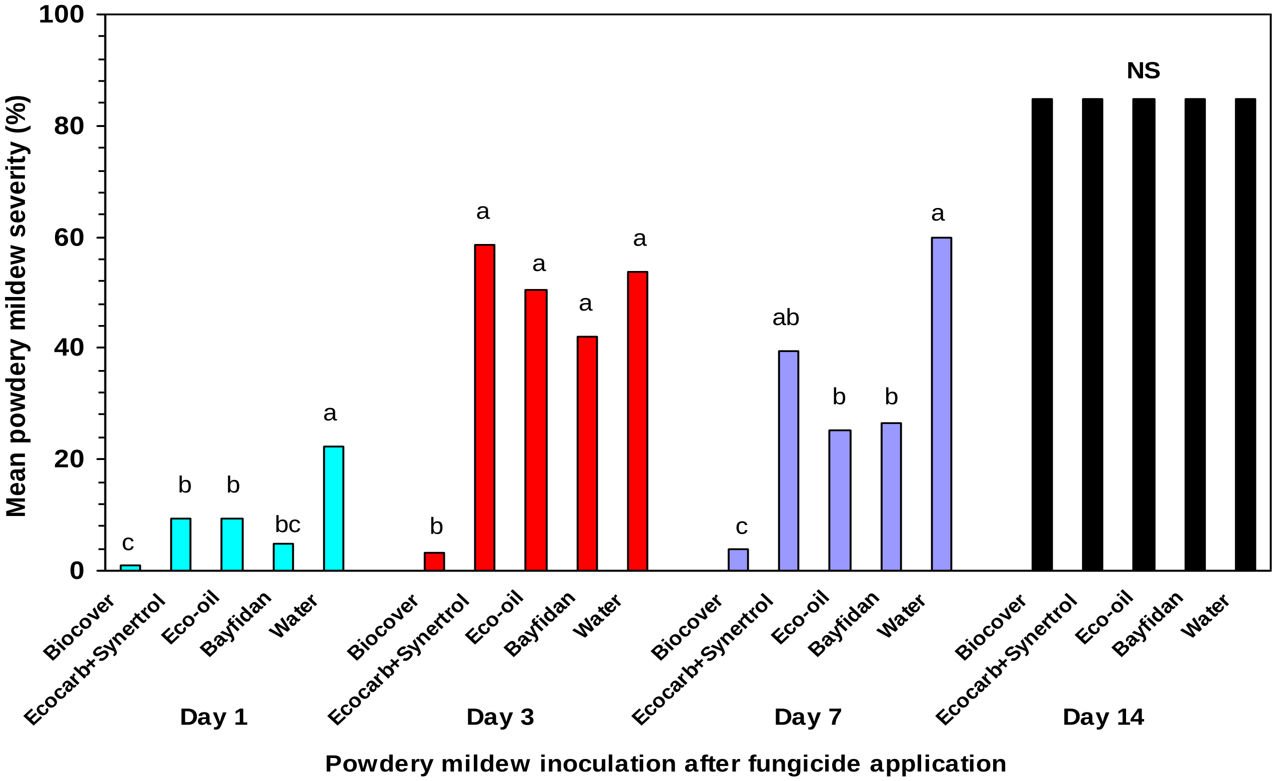



**Figure 40 Protectant Trial 5 – Evaluation of fungicides applied 1, 3, 7 and 14 days before inoculation with powdery mildew in research greenhouse.** Within individual days, treatments with the same letter are not significantly different from one another ($p<0.05$). NS = no significant difference between treatments.

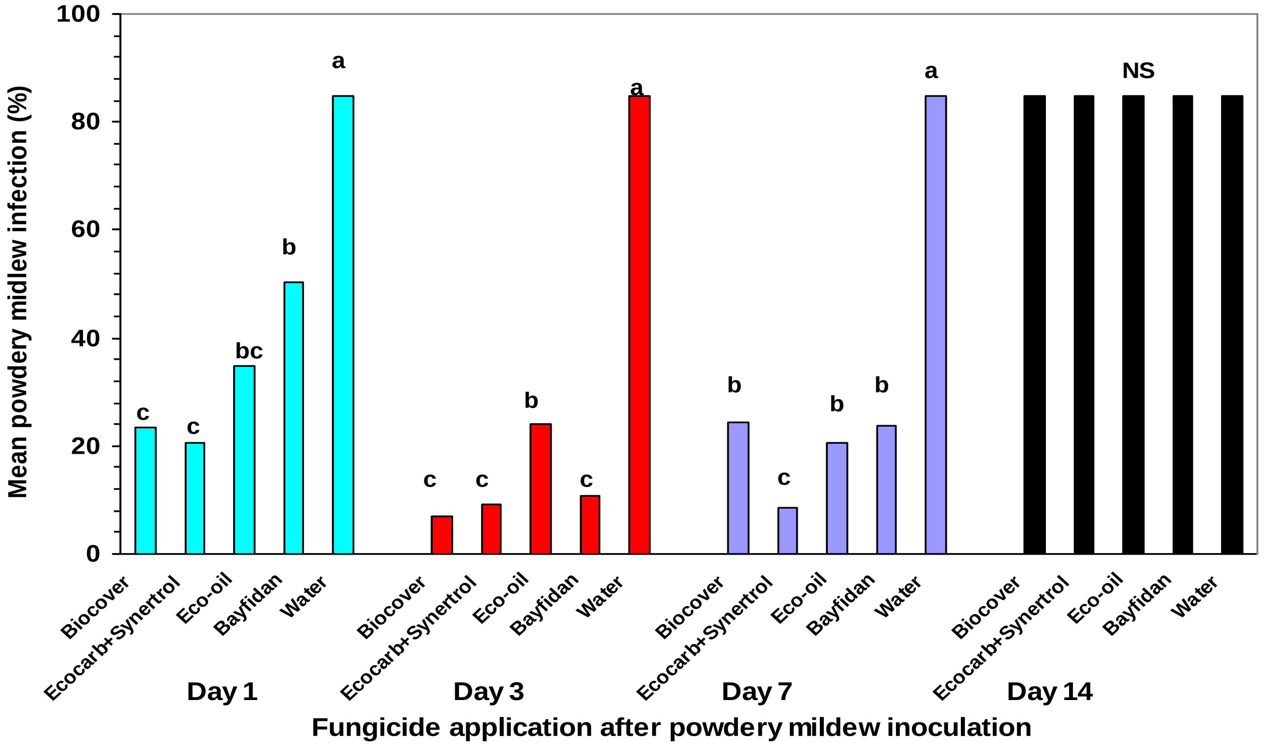



**Figure 41 Eradicant Trial 5 – Evaluation of fungicide applied 1, 3, 7 and 14 days after inoculation with powdery mildew in research greenhouse** Within individual days, treatments with the same letter are not significantly different from one another ($p<0.05$). NS = no significant difference between treatments.

*Trial 6*

Low levels of powdery mildew were observed in the protectant trial with only magnesium sulphate and Bayfidan® decreasing powdery mildew severity compared to the untreated control (Figure 42). All products significantly decreased powdery mildew severity compared with the untreated control when applied up to 14 days after inoculation. However Bayfidan® was the most effective at 14 days. (Figure 43). The levels of efficacy for the other products may be acceptable to some growers if they are more tolerant of powdery mildew infection. The addition of Synertrol® Horti Oil to Ecocarb® did not improve control when applied either before or after inoculation.

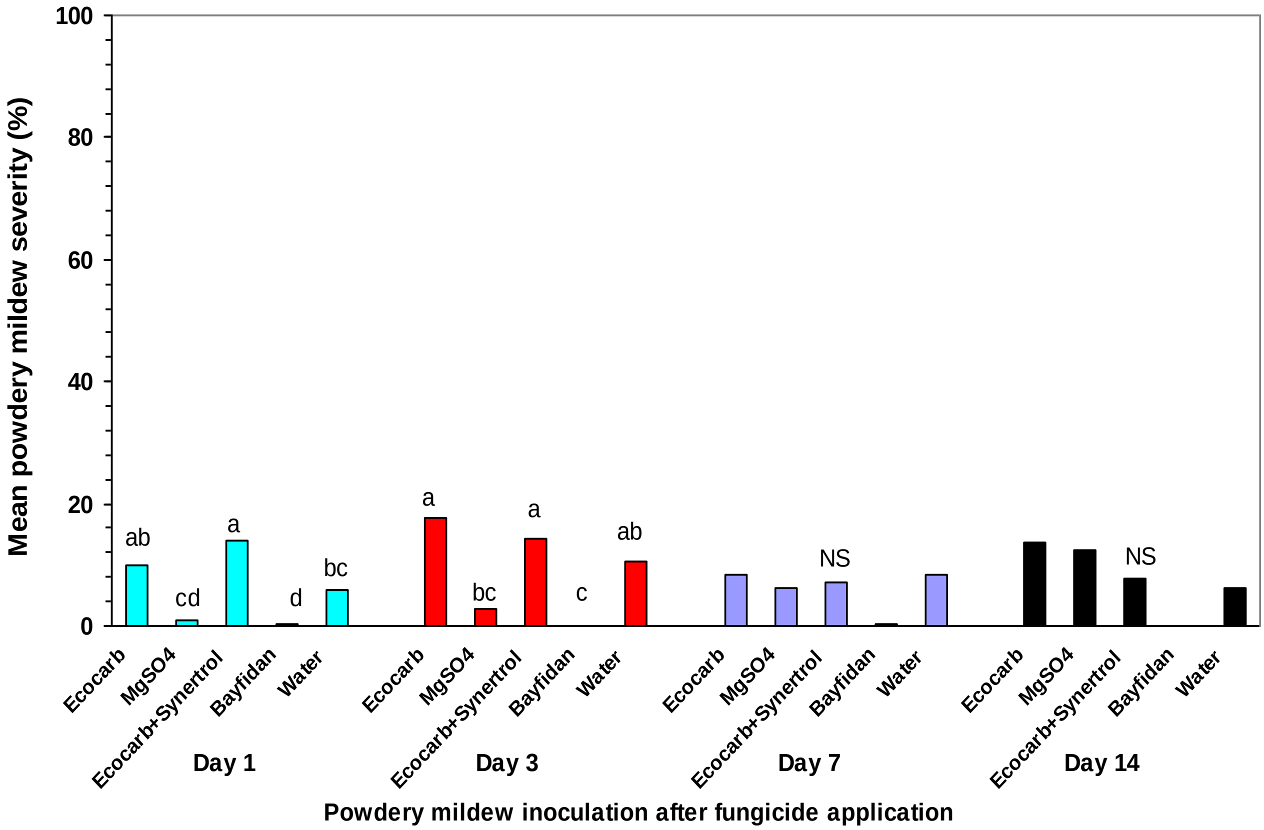



**Figure 42 Protectant Trial 6 – Evaluation of fungicides applied 1, 3, 7 and 14 days before inoculation with powdery mildew in research greenhouse.** Within individual days, treatments with the same letter are not significantly different from one another ($p<0.05$). NS = no significant difference between treatments.

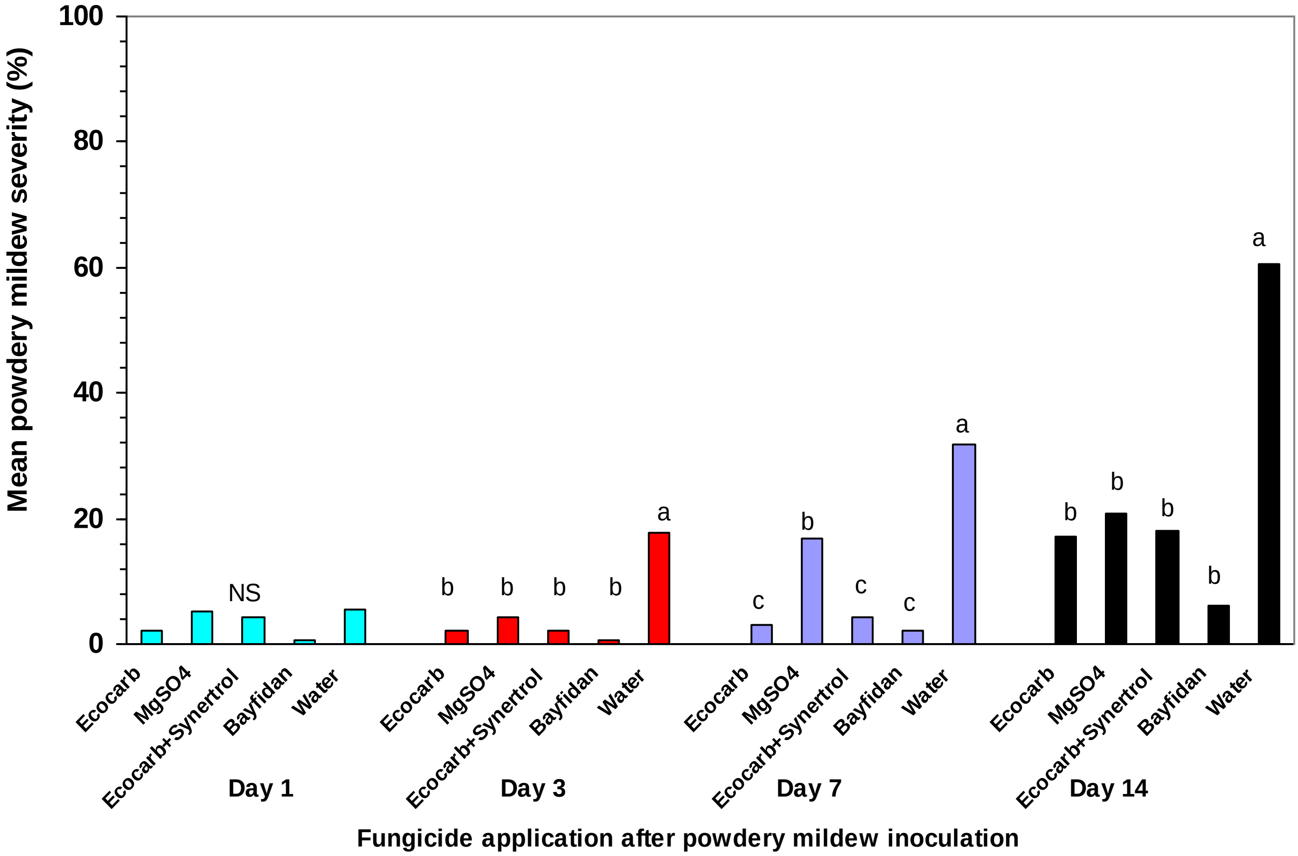



**Figure 43 Eradicant Trial 6 – Evaluation of fungicides applied 1, 3, 7 and 14 days after inoculation with powdery mildew in research greenhouse.** Within individual days, treatments with the same letter are not significantly different from one another ($p<0.05$). NS = no significant difference between treatments.

*Trial 7*

Two products with new chemistry Colliss® and Vivando® currently registered for use on grapes overseas were also screened. The data is not presented, as even though the trials were repeated results were too variable and there were problems with achieving consistent infection in the controls. However, because these products had been so successful in field trials for powdery mildew in other crops and the chemical company was willing to support greenhouse use, they were included in trials in commercial greenhouses.

*Trial 8*

The plants sprayed with a 10% solution of full fat milk had less powdery mildew two weeks after spraying than plants in the other treatments (Figure 44). The difference in severity was not statistically significant; however it does indicate that spraying with full fat milk could be effective against powdery mildew. Milk has been shown to be effective against cucurbit powdery mildew overseas (Bettiol 1999) and in Australia (Akem, personal communication). Milk was applied when plants already had low levels of powdery mildew. These studies suggest milk may be more effective if applied as a protectant rather than an eradicant.

*Trial 9*

There was no significant difference in powdery mildew severity on plants grown in compost amended soil compared to those grown without compost amendment (data not shown).

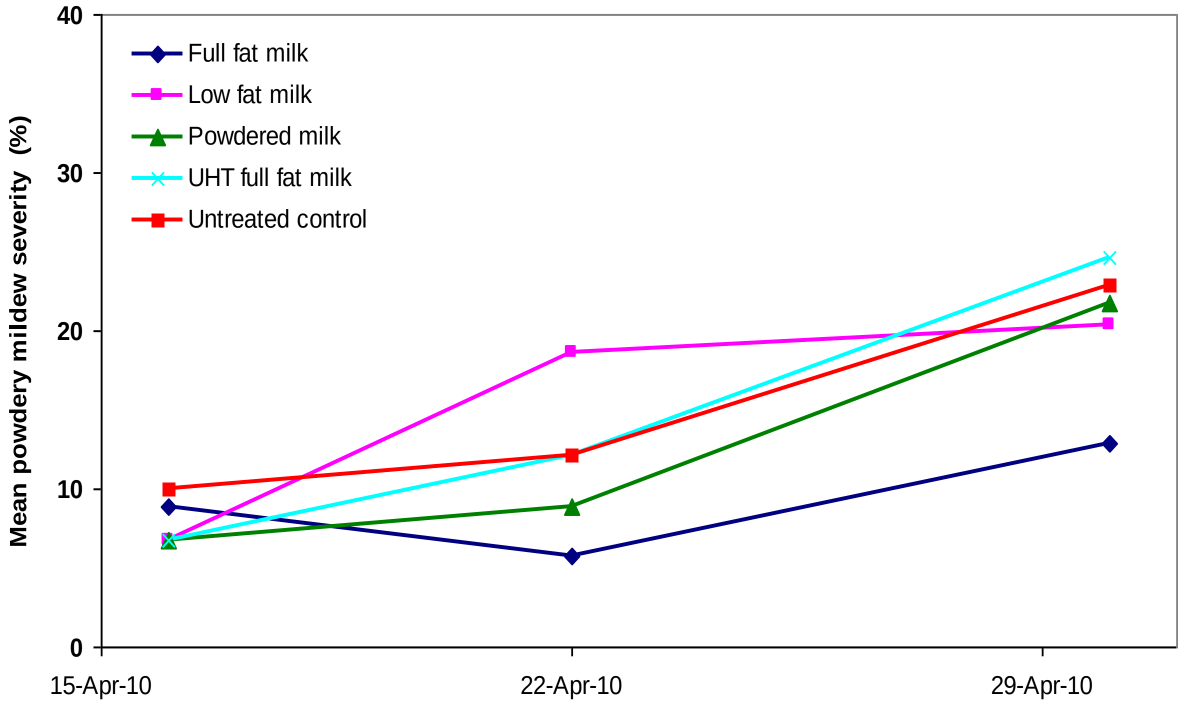



**Figure 44 Development of powdery mildew on cucumber seedlings sprayed with different milk products in Trial 8**

### 4.7.2. Spray program trials

Products effective against powdery mildew in screening trials were selected for further trials in spray programs in the research greenhouse and in commercial greenhouses. This selection process was done in consultation with the relevant chemical companies because several promising fungicides identified in the screening trials would not be supported for registration for greenhouse use.

If fungicides are approved for use against cucumber powdery mildew then growers need to know how to effectively and responsibly incorporate those products into a spray program to reduce the risk of developing resistance to newly available products. Trials were conducted using currently registered fungicides in combination with potential new products for greenhouse use and compared to standard spray programs. In Trial 10 Cabrio® was trialled in combination with registered fungicides to examine spray intervals. Trial 11 evaluated the use of alternative products alternated with registered fungicides. Several products were included in spray program trials that hadn't been previously evaluated. Morestan® and Amistar® were currently registered for use on cucumber powdery mildew. Xpress®+Sett Enhanced™ had shown efficacy against powdery mildew in trials conducted by other researchers in Queensland (unpublished) but samples of the product were only obtained after screening trials had been completed (Table 7).

Materials and methods

*Trial 10 and 11*

In each trial ninety cucumber seeds variety Mascot were planted into 200mm pots in cocopeat mix in the research greenhouse. Mascot variety was chosen because it is a standard variety for winter crops and suited to moderate conditions in the research greenhouse. When seedlings had two true leaves fully emerged all plants were exposed to natural infection of powdery mildew from infected plants in the research greenhouse (Figure 45). Two weeks later (Day 0), plants were randomly assigned to one of 9 treatments with 10 plants per treatment and the first fungicide applications were made (Table 8). Severity of powdery mildew was assessed before the first spray, before each subsequent spray and at seven day intervals up to 21 days after the last spray was applied. Only leaves that had been sprayed were assessed, new growth was not assessed. Fruit were harvested as they reached maturity and weights recorded. Disease progress curves were calculated for each spray program and differences between programs analysed by calculating the relative area under the disease progress curve (RAUDPC, see General Materials and Methods) and analysed with ANOVA (Statistix 8).

**Figure 45 Spray program trials in research greenhouse at Day 0 (left) and Day 25 (right)**

**Table 7 Products evaluated in spray program trials for cucumber powdery mildew in research greenhouse**

| Product | Active ingredient | Rate | Trial |
|---|---|---|---|
| Morestan® | 250g/kg oxythioquinox | 4g/L | 10, 11 |
| Cabrio® | 250g/L pyraclostrobin | 0.4mL/L | 10 |
| Bayfidan® 250 EC | 250g/L triadimenol | 0.4mL/L | 10, 11 |
| Amistar® WG | 500g/kg azoxystrobin | 0.8ml/L | 11 |
| Ecocarb® and<br>Synertrol® Horti Oil | 940g/kg potassium bicarbonate<br>905g/L emulsifiable botanical oil | 4g/L<br>2.5mL/L | 11 |
| BioCover® | 840g/L petroleum oil | 10mL/L | 11 |
| XPress® +<br>Sett Enhanced™ | 2% Cu 2% Mn 2% Zn<br>8% Ca 0.5% B | 1.5mL/L<br>2mL/L | 11 |

Results and discussion

*Trial 10*

All spray programs significantly decreased powdery mildew levels compared to the control and continued to provide effective control for up to 63 days after the trial commenced (Table 8; Figure 46). Programs that were sprayed every seven days had significantly lower levels of powdery mildew but some 14 day programs were also highly effective. All fungicide spray programs maintained powdery mildew infection below 20% which may be an acceptable level of control, depending on how long the grower plans to maintain the crop. Programs that included Cabrio® showed some symptoms of phytotoxicity including distortion and burning of leaves. Most plants only matured one fruit during the trial so yield data were not analysed for this trial.

**Table 8 Relative area under disease progress curve (RAUDPC) for powdery mildew achieved when various spray programs were applied on cucumbers in the research greenhouse 2007.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

| **Day 0 10/7/07** | **Day 7 17/7/07** | **Day 14 24/7/07** | **Day 21 31/7/07** | **Day 28 7/8/07** | **Day 35 14/8/07** | **RAUDPC** |
|---|---|---|---|---|---|---|
| Morestan® | Morestan® | Morestan® | Bayfidan® | Bayfidan® | Bayfidan® | **0.70 a** |
| Morestan® | Morestan® | Cabrio® | Cabrio® | Bayfidan® | Bayfidan® | **1.11 a** |
| Bayfidan® | Bayfidan® | Bayfidan® | Cabrio® | Cabrio® | Cabrio® | **1.19 a** |
| Cabrio® | Cabrio® | Cabrio® | Bayfidan® | Bayfidan® | Bayfidan® | **1.39 a** |
| Morestan® | - | Morestan® | - | Bayfidan® | - | **2.76 b** |
| Cabrio® | - | Cabrio® | - | Bayfidan® | - | **6.43 c** |
| Morestan® | - | Cabrio® | - | Bayfidan® | - | **7.93 d** |
| Bayfidan® | - | Bayfidan® | - | Cabrio® | - | **8.18 d** |
| Untreated control | | | | | | **33.9 e** |

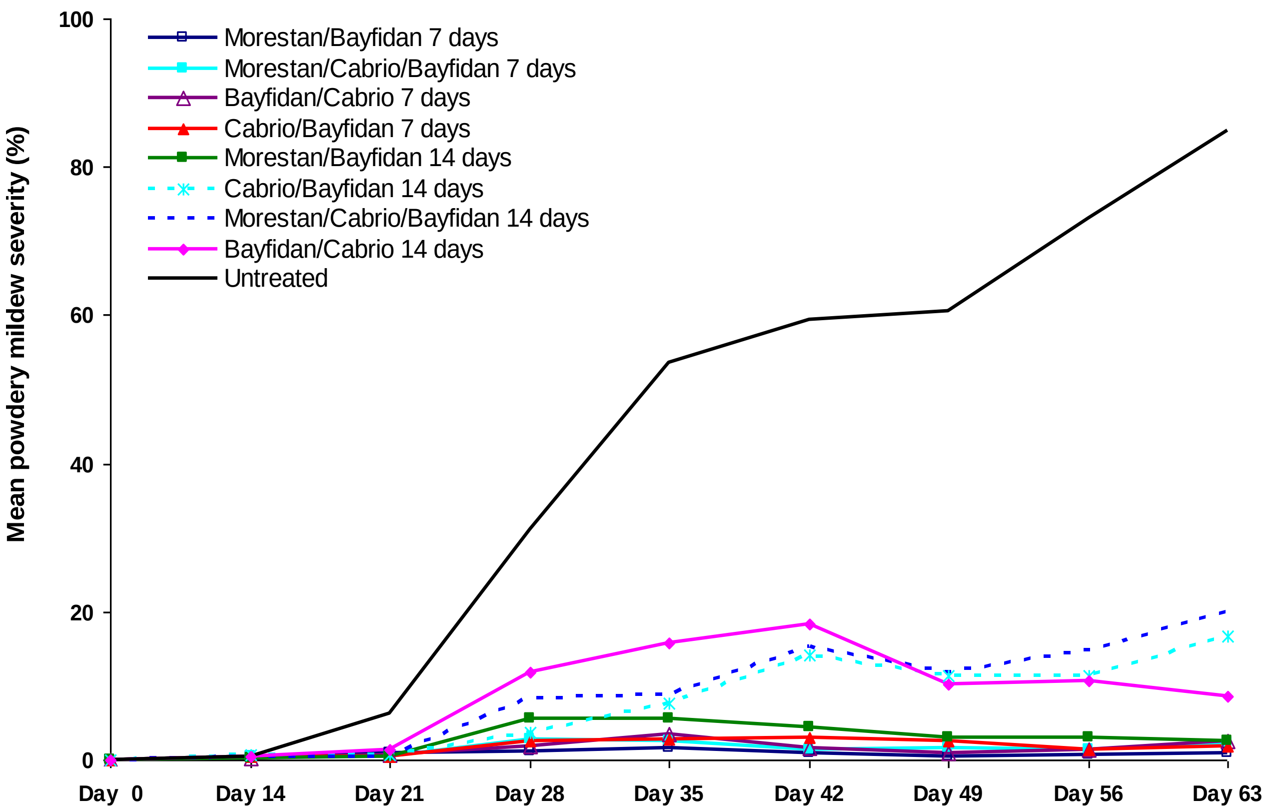



**Figure 46 Trial 10 – Development of powdery mildew in cucumber plants sprayed with different fungicides and spray timings in research greenhouse.**

*Trial 11*

All programs significantly decreased the severity of powdery mildew compared to the control and continued to be effective up to day 63. The most effective treatments were Amistar® alternated with XPress®+Sett Enhanced™ and Morestan® alternated with BioCover®. The program alternating Ecocarb®+Synertrol® Horti oil and Amistar® was the next most effective (Table 9; Figure 47). Programs that incorporated alternative products were as effective as or more effective than the standard fungicide programs of Morestan®/Bayfidan® or Bayfidan®/Amistar®. XPress®+Sett Enhanced™ was more effective when alternated with Amistar® than when alternated with Bayfidan®. All treatments maintained powdery mildew infection below 20% for the duration of the trial.

**Table 9 Relative area under disease progress curve (RAUDPC) for powdery mildew achieved when various spray programs were applied on cucumbers in the research greenhouse 2008.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

| **Day 0<br>10/4/08** | **Day 14<br>24/4/08** | **Day 28<br>8/5/08** | **Day 42<br>22/5/08** | **RAUDPC** |
|---|---|---|---|---|
| Amistar® | XPress® +<br>Sett Enhanced™ | Amistar® | XPress® +<br>Sett Enhanced™ | **4.26 a** |
| Morestan® | Morestan® | BioCover® | BioCover® | **5.15 ab** |
| Ecocarb® + Synertrol®<br>Horti oil | Amistar® | Ecocarb® + Synertrol®<br>Horti oil | Amistar® | **6.57 ab** |
| Morestan® | Morestan® | Bayfidan® | Bayfidan® | **6.92 b** |
| Bayfidan® | Amistar® | Bayfidan® | Amistar® | **7.39 bc** |
| Bayfidan® | XPress® +<br>Sett Enhanced™ | Bayfidan® | XPress® +<br>Sett Enhanced™ | **9.74 c** |
| | | Untreated control | | **21.98 d** |

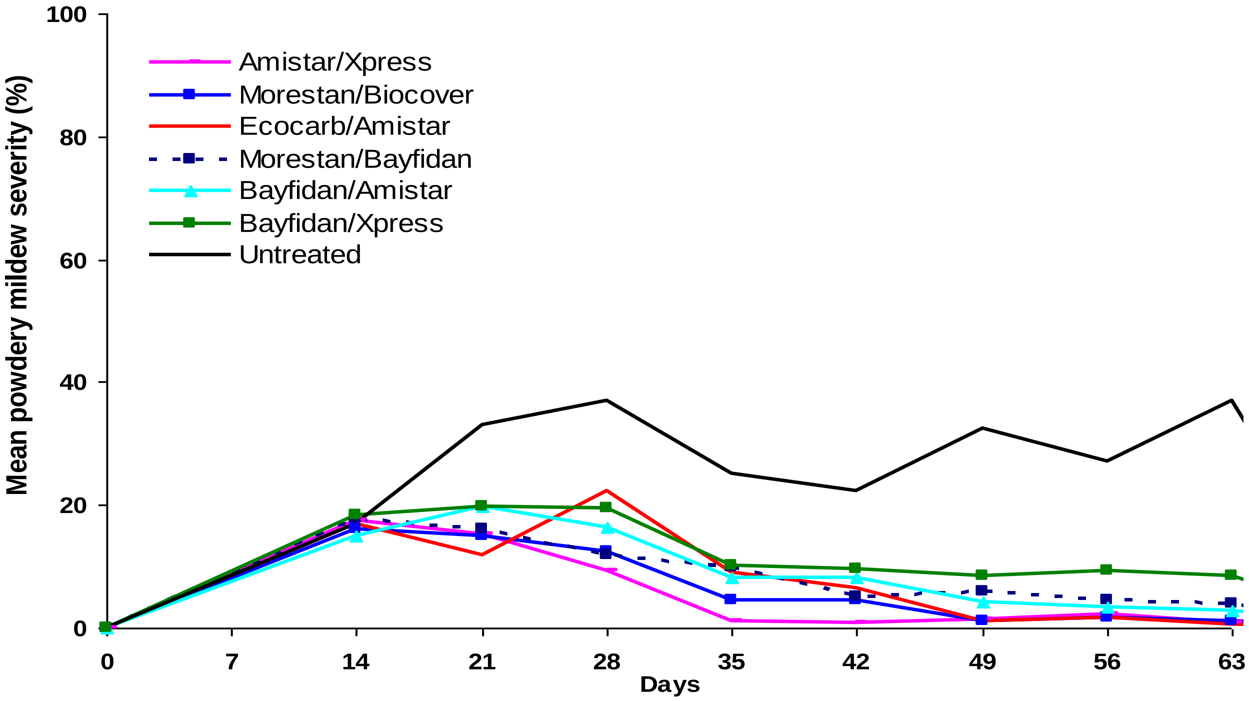



**Figure 47 Trial 11 – Development of powdery mildew on cucumber plants sprayed with different fungicides in research greenhouse**

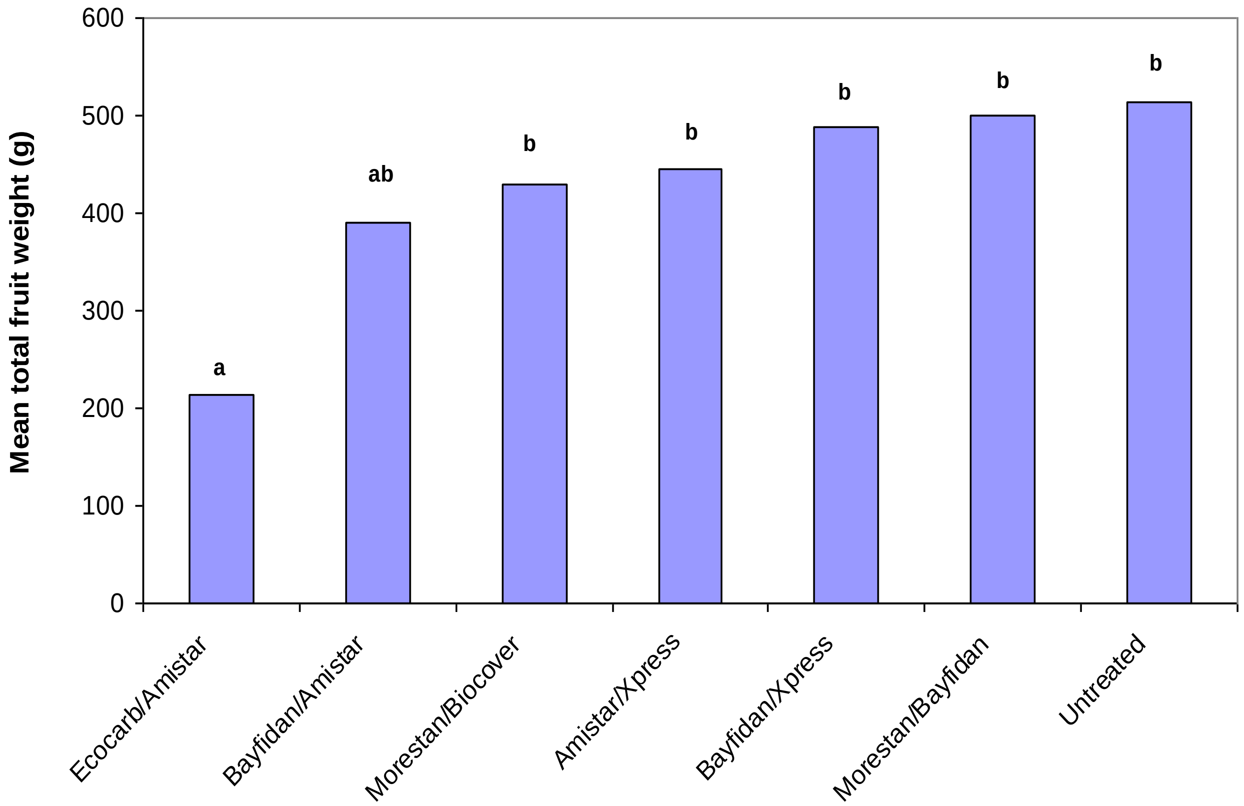



**Figure 48 Trial 11 - Mean total fruit weights from cucumber powdery mildew spray program trial in research greenhouse.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

The programs with the two lowest yields were Ecocarb®+Synertrol® Horti oil alternated with Amistar® and Bayfidan® alternated with Amistar® (Figure 48). Variation in yield between plants within treatments was quite high for all treatments with some plants maturing up to seven fruit during the trial and some not maturing any fruit. Although the untreated control had significantly more disease than all the spray programs, there was no significant difference between the yields of most spray programs. This result supports grower observations that crops will yield well even with high levels of powdery mildew.

### 4.7.3. Commercial greenhouse trials

Ten products were evaluated in five trials in spray programs for cucumber crops in commercial greenhouses (Table 10). The first two trials examined alternative products to determine if these were effective either alone or when alternated with registered fungicides. The third and fourth trials examined new chemistry for which registration may be sought for greenhouse use.

Trialling alternative products that don't require withholding periods was a high priority as this would provide growers with rapid access to alternatives to fungicides. Several products were included in these trials that had not been screened in previous trials as samples of these products were only obtained after screening trials had been completed. Silmatrix™ is registered overseas for grape powdery mildew, Xpress® +Sett Enhanced™ had shown efficacy against powdery mildew in trials conducted by other researchers (unpublished) and

CoMo is a plant health product with potential efficacy and the AgNova product is new chemistry that was not available when screening was conducted. Path X™ was also examined as there are anecdotal reports from growers that it is effective against powdery mildew and Amistar® was included as it is currently registered for cucumber powdery mildew. The use of sanitisers/disinfectants as foliar sprays for disease control is increasingly common and more work is needed to determine the effectiveness and impact of these strategies on crops. There is potential for products of this type to significantly decrease the inoculum load in greenhouses but timing and coverage is particularly crucial.

Materials and methods

Field trials commenced when at least one plant amongst the trial plants had one lower leaf with symptoms of powdery mildew. Crops had between four and six true leaves fully expanded. All trials used a randomised complete block design. A plot consisted of 12 cucumber plants across three cocopeat slabs. All 12 plants in a plot were sprayed but only the middle four plants were assessed to reduce the effects of overspray between treatments. Field trial 1 had 10 replicates per treatment (Table 11) and all remaining trials had 5 replicates per treatment (Table 12). All trials were assessed before the first spray, before each subsequent spray and up to four weeks after the last spray for severity of powdery mildew using the rating scale previously described. Disease progression curves and RAUDPC were calculated and analysed with ANOVA (Statistix 8).

**Table 10 Products trialled against cucumber powdery mildew in commercial greenhouses on Northern Adelaide plains 2009-2010**

| Product | Active ingredient | Rate | Trial |
|---|---|---|---|
| Ecocarb® +<br>Synertrol® Horti Oil | 940g/kg potassium bicarbonate<br>905g/L emulsifiable botanical oil | 4g/L<br>2.5mL/L | 1,2,5 |
| Amistar® 250 SC | 250g/L azoxystrobin | 0.8mL/L | 2,3,5 |
| Bayfidan® 250 EC | 250g/L triadimenol | 0.4mL/L | 3,4 |
| Xpress® +<br>Sett Enhanced™ | 2% Cu 2% Mn 2% Zn<br>8% Ca 0.5% B | 1.5mL/L<br>2mL/L | 1,2,5 |
| Silmatrix™ | 29% potassium silicate | 7.5mL/L | 1,2,5 |
| Colliss® | 200g/L boscalid<br>100g/L kresoxim-methyl | 0.25m/L | 3 |
| Vivando® | 500g/L metrafenone | 0.3mL/L | 3 |
| Path X™ | 120g/L didecyldimethyl-ammonium chloride | 1mL/L | 1,2 |
| AgNova product (AGN2111) | Experimental | 0.05mL/L<br>0.1mL/L<br>0.2mL/L<br>0.3mL/L | 4<br>4<br>4<br>4 |
| CoMo | 1% Cobalt<br>6% Molybdenum | | 2 |

## Results and Discussion

### *Field Trial 1*

Path X™ was the most effective product with minimal powdery mildew developing after the three sprays compared to nearly 20% infection in the unsprayed control. Ecocarb®+Synertrol® Horti Oil was the next most effective treatment with just over 1.4% infection at the end of the trial. Xpress® + Sett Enhanced ™ alone was not significantly different from the unsprayed control (Table 11; Figure 49).

**Table 11 Relative area under disease progress curve (RADUPC) for powdery mildew achieved when various spray programs were applied on cucumber crop in commercial greenhouse Northern Adelaide Plains 2009.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

| **Day 0**<br>**22/9/09** | **Day 15**<br>**7/10/09** | **Day 29**<br>**21/10/09** | **RAUDPC** |
|---|---|---|---|
| Path X™ | Path X™ | Path X™ | **0.03 a** |
| Ecocarb® +<br>Synertrol® Horti Oil | Ecocarb® +<br>Synertrol® Horti Oil | Ecocarb® +<br>Synertrol® Horti Oil | **0.42 a** |
| Silmatrix™ | Silmatrix™ | Silmatrix™ | **1.22 ab** |
| XPress® +<br>Sett Enhanced™ | XPress® +<br>Sett Enhanced™ | XPress® +<br>Sett Enhanced™ | **2.57 bc** |
| | Untreated control | | **3.13 c** |

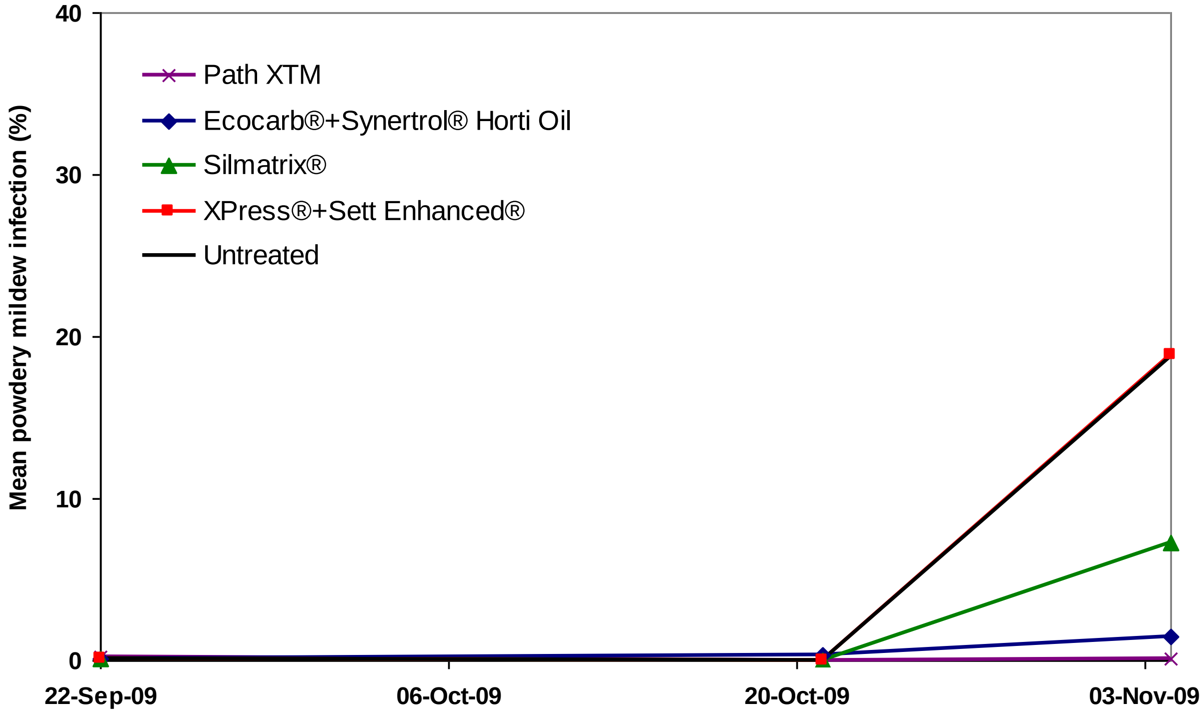



**Figure 49 Field Trial 1- Development of powdery mildew on cucumber plants sprayed with alternative products in commercial greenhouse on the Northern Adelaide plains 2009**

*Field Trial 2*

Three applications of only Silmatrix™, Path X™ or Ecocarb®+Synertrol® Horti Oil significantly decreased powdery mildew severity compared to the untreated control (Table 12; Figure 50). While some of the combinations decreased powdery mildew severity, the differences were not significantly different from the control. The treatments that included Amistar® had the highest infection with powdery mildew which can indicate a resistance issue. However, the property on which the trial was conducted did not have a history of frequent use of Amistar® which meant resistance was unlikely.

**Table 12 Relative area under disease progress curve (RADUPC) for powdery mildew achieved when various spray programs were applied on cucumber crop in commercial greenhouse Northern Adelaide Plains 2010.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

| **Day 0 19/2/10** | **Day 14 5/3/10** | **Day 28 19/3/10** | **RAUDPC** |
|---|---|---|---|
| Path X™ | Path X™ | Path X™ | **0.19 a** |
| Silmatrix™ | Silmatrix™ | Silmatrix™ | **0.54 b** |
| Ecocarb® + Synertrol® Horti Oil | Ecocarb® + Synertrol® Horti Oil | Ecocarb® + Synertrol® Horti Oil | **1.06 bc** |
| Ecocarb® + Synertrol® Horti Oil | Xpress® + Sett Enhanced™ | Ecocarb® + Synertrol® Horti Oil | **1.48 bcd** |
| Amistar® 250 SC | Xpress® + Sett Enhanced™ | Xpress® + Sett Enhanced | **1.73 bcd** |
| Amistar® 250 SC | Amistar® 250 SC | - | **1.84 bcd** |
| Silmatrix™ | Xpress® + Sett Enhanced™ | Silmatrix™ | **2.01 bcd** |
| Ecocarb® + Synertrol® Horti Oil | CoMo | Ecocarb® + Synertrol® Horti Oil | **2.58 cd** |
| Amistar® 250 SC | CoMo | CoMo | **3.22 d** |
| | Untreated control | | **6.33 d** |

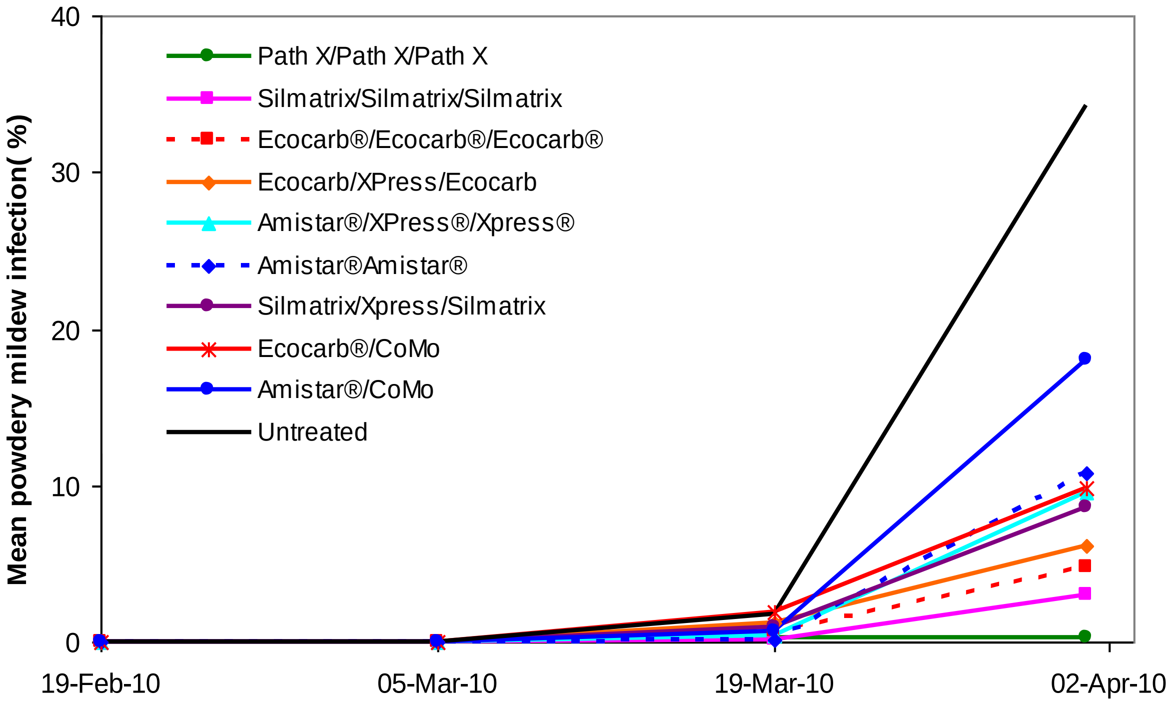



**Figure 50 Field Trial 2 – Development of powdery mildew on cucumber plants sprayed with different fungicide programs in commercial greenhouse on Northern Adelaide plains 2010**

*Field Trial 3 and 4*

Trials were conducted to examine the effectiveness of Colliss®, Vivando® and an AgNova product applied at 14 day intervals but were unsuccessful as very little powdery mildew developed during the trials (data not presented). Previous year's surveys for disease had indicated powdery mildew was prevalent during autumn when the trials were run so the lack of disease was potentially due to drift from the grower spraying the rows in the greenhouse that were not part of the trial.

*Field Trial 5*

Three sprays of Ecocarb®+Synertrol® Horti Oil, Amistar®, Xpress® + Sett Enhanced ™ and Silmatrix™ were applied at fortnightly intervals before it was discovered that the grower had sprayed over the entire trial several times. As a consequence powdery mildew severity was very low and the trial was abandoned as no meaningful data could be salvaged.

### 4.7.4. Conclusions

Fungicides were more effective when applied as protectants than eradicants. Use of fungicides as eradicants for powdery mildew, especially the high risk fungicides (Group 1, 3, 11) is not recommended. Eradicant use is less effective than protectant use and also greatly increases the chance of the fungus developing resistance by exposing a large population of the pathogen to the fungicide, often at sub-lethal doses. When approached, chemical companies indicated that many of the fungicides that were effective in screening trials would not be supported for use in greenhouses. In some cases crop and human safety concerns were cited but the low profitability for agrochemical companies in the protected cropping industry is a major factor.

With the exception of BioCover® alternative products were more effective as eradicants than as protectants.

Thirty percent of growers surveyed at the start of this project said they were spraying weekly for foliar diseases. Although fortnightly spray intervals were less effective than weekly spray intervals, fortnightly spray programs could still be highly effective in short term crops where the higher powdery mildew severity may be tolerated by growers as it may not have as much of an impact on yield. Powdery mildew can only be effectively controlled with fungicides before the disease enters the logarithmic phase (Elad et al. 1996) so once severity reaches over 50% on a leaf it is likely that fungicide applications will be less effective and leaves will not recover.

When several assessments of disease are made on the same plant over time, RAUDPC is the best indicator of the performance of a treatment over a number of assessment dates. Using parameters that provide the effectiveness at only one given point in time, such as the disease level on the last assessment date, key stage in crop growth or each individual assessment is analysed to determine effectiveness does not always provide a good comparison of the overall effectiveness of treatments.

Using RAUDPC, programs alternating alternative products with registered fungicides were shown to be as effective as standard fungicide programs. Alternative products could be used in spray programs to decrease the selection pressure for resistance to the registered fungicides.

Some alternative products were highly effective when used alone and others were more effective when used in conjunction with registered fungicides or other alternative products. The silicon based product Silmatrix™ was highly effective in controlling powdery mildew. This product is currently registered for grape powdery mildew in the United States and is undergoing approval for use by organic growers. Further research is needed into the viability of this product in the greenhouse vegetable industry.

Path X™ was highly effective in all trials and more research is needed into the use of sanitisers for foliar diseases in greenhouses vegetable crops. Effects on the crop, beneficial insects, the aquatic environment and the user need to be considered to determine if sanitisers are a cost-effective and safe solution.

Colliss® and Vivando® also warrant further investigation as the chemical company is strongly supportive of the use of these products in greenhouses if supporting efficacy data can be provided. The with-holding periods for Colliss® and Vivando® are relatively long, seven and 14 days respectively so their use will be limited to the first 4-5 weeks of cucumber crops and a maximum of two sprays per crop. Further trials are needed to determine if these products are effective alone or in a program with other protectant fungicides or alternative products. Colliss® has recently been approved for use on field grown cucurbits only and growers are strongly urged to use this new fungicide responsibly to prolong its effectiveness and availability.

The trial with milk indicated that it may have efficacy against cucumber powdery mildew as a protectant and further evaluations are warranted to determine the best use in a spray program. Trials are being conducted in postgraduate research undertaken by colleagues at The University of Adelaide to determine the active ingredient of milk that provides control of powdery mildew.

Compost amendments did not decrease the severity of powdery mildew in the small scale trials conducted in this project. The disease suppressive effects of composts on soil-borne diseases have been well documented and recent studies have indicated positive effects on foliar diseases such as Botrytis grey mould (Segarra et al. 2007). Composts enhance the overall health of crops which can help plants resist disease but as more greenhouse growers move into hydroponic production the use of composts will be limited.

Throughout the project fungicide efficacy data has been provided on request to AgAware Consulting when seeking permits on behalf of the vegetable industry (as part of HAL Project MT07029) from the APVMA directly when requested and made available to reviewers of permits submitted to APVMA for approval. Growers should regularly check the APVMA website www.apvma.gov.au so they are aware of the registered and permitted products for their crops.

### 4.7.5. Screening products for Botrytis grey mould on cucumber

Unlike leaf infection with powdery mildew which has an indirect effect on plant yield, infection with Botrytis grey mould directly reduces yield by killing flowers and young fruit and causing stem infections that kill entire plants. Products that are able to protect flowers from infection are most desirable, but products that are able to slow the rate of infection or prevent sporulation could reduce spread to other fruit and secondary stem infections that could kill entire plants. As with products for powdery mildew, selection of the products to screen for management of Botrytis grey mould was made after consultation with various chemical companies, other researchers and growers. Products that were identified in the pesticide gap analysis (HAL project MT07029) with the potential to manage Botrytis grey mould in cucumber were also evaluated. Products screened included fungicides, alternative products like soaps and sanitisers and beneficial bacteria and fungi.

Preparation of trial plants

For all trials cucumber seeds, variety Mascot, were planted into cocopeat mix in 0.9L plastic pots (Masrac). Mascot variety was chosen because it is a standard variety for winter crops and suited to moderate conditions in the research greenhouse. Seedlings were tied to a 300mm stake as they grew and the growing tip removed when they reached the top of the stake. Plants were pruned to a maximum of three leaves and three flowers per plant. Flowers were pruned to one flower per plant according to trial requirements.

Pilot trials

A review of the literature revealed seedling bioassays using leaves (Ben-Shalom et al. 2003; Segarra et al. 2007) but these techniques were not able to be reproduced reliably in this project. Other studies utilised natural infection pathways (Elad et al. 1998; Dik and Elad 1999) but a more standardised infection protocol was needed for evaluation of potential products for management. Flowers are one of the primary points of infection in the field. Pilot trials were conducted to develop a robust protocol for evaluating products for Botrytis grey mould using a flower infection bioassay on cucumber seedlings.

Climate trials

Trials were conducted to determine the optimum conditions for establishing Botrytis grey mould infections in flowers.

*Materials and methods*

Cucumber seedlings with newly formed flowers at the F1 stage were inoculated as previously described with a spore suspension of *Botrytis cinerea* with $10^5$ spores/mL. Seedlings were incubated at 14°C with mean relative humidity 83% or at 22°C with mean relative humidity of 53%. Fruit developing from the inoculated flowers observed every 2-3 days up to 32 days after inoculation and photographed when infections began to develop. These observations were used to develop the Botrytis grey mould rating scale used in subsequent trials. If fruit developed symptoms that were not obviously Botrytis grey mould they were incubated at high humidity to determine if Botrytis grey mould would develop. Control plants that had not been inoculated with Botrytis grey mould were also observed over this period under the same conditions.

*Results and Discussion*

At 14°C symptoms of infection on developing fruit were visible after six days, sporulation occurred after 12-15 days and after 32 days the disease had progressed to a secondary stem infection (Figure 51). At 22°C fruit was either not infected, developed a dry patch on the end or developed sporulation. When incubated under favourable conditions the majority of fruit with the dry end symptom developed sporulation (Figure 52). The conditions at 14°C were more reliable for establishing Botrytis grey mould infections and were used in subsequent trials. These conditions also reflect the conditions under which Botrytis grey mould develops naturally in unheated commercial greenhouses over winter (see Disease and Greenhouse climate section).

**Figure 51 Fruit developing from cucumber flowers inoculated with Botrytis grey mould at 14°C six days after inoculation (left), eight days after inoculation (centre) and 12 days after inoculation (right)**

**Figure 52 Fruit developing from cucumber flowers inoculated with Botrytis grey mould at 22°C 14 days after inoculation (left) and fruit with dry end symptom after incubation for 6 days in high humidity (right)**

Flower stage trials

Trials were conducted to examine the susceptibility of cucumber flowers over time. After being open for three days flowers started to wilt and die as fruit began to fill.

*Materials and methods*

Cucumber seedlings were raised as previously described. As flowering occurred, plants were sorted into four different flowering stages, unopened, open one day, open two days, open three days, with 10 plants per stage and then inoculated with a spore suspension of Botrytis grey mould with $10^5$ spores/mL as previously described. Fruit were assessed seven and 14 days after inoculation using the severity rating (see General Materials and Methods). Data were analysed using ANOVA (Statistix 8).

*Results and Discussion*

Infection seven days after inoculation was very low so only 14 day results are presented. Infection on fruit from flowers inoculated when unopened was significantly less infected than fruit from flowers inoculated at the other three stages (Figure 53). Subsequent trials requiring inoculation of cucumber flowers commenced when flowers were at the F1 stage and flowers were never inoculated later than the F3 stage.

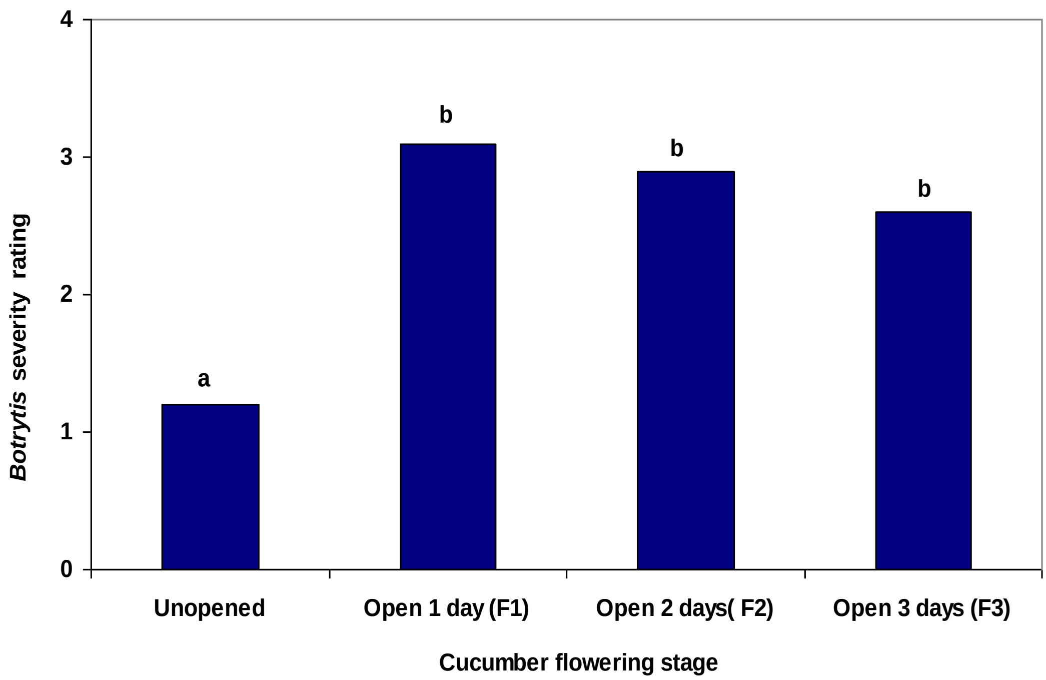



**Figure 53 Severity of Botrytis grey mould infection in cucumber 14 days after flowers inoculated at different stages and incubated at 14°C.** Botrytis grey mould rating scale: 0=no disease; 1=watery area starting to develop; 2=watery area clearly visible, progressing up fruit; 3=sporulation; 4=majority of fruit sporulating.

Concentration of spore solutions for trials with biological products

Biological agents are often not effective at high disease pressure and the spore concentrations that are used to trial fungicides may be too high to effectively evaluate the biological control agents (Metcalf, personal communication). A trial was conducted to determine if lower spore concentrations would produce disease symptoms on cucumber fruit.

*Materials and methods*

Cucumber seedlings variety Mascot with one flower at the F2 stage were inoculated as previously described with a *B.cinerea* spore suspension of either $10^1$, $10^3$ or $10^5$ spores/mL or water using six plants per treatment and approximately 0.5mL per flower. Fruit were assessed seven and 14 days after inoculation for symptoms of Botrytis grey mould. Data was analysed with ANOVA and LSD ($p<0.05$) (Statistix 8).

*Results and Discussion*

Botrytis grey mould symptoms on fruit developed at the higher spore concentrations but there was no significant difference between $10^3$ and $10^5$ spores/mL (Figure 54). The flowers inoculated with spore suspensions of $10^1$ spores/mL did not develop disease on the fruit. A concentration of $10^3$ spores/mL was selected to use in trials with biological agents because it produced consistent infection but was not an unrealistic inoculum load for biological products to be effective against.

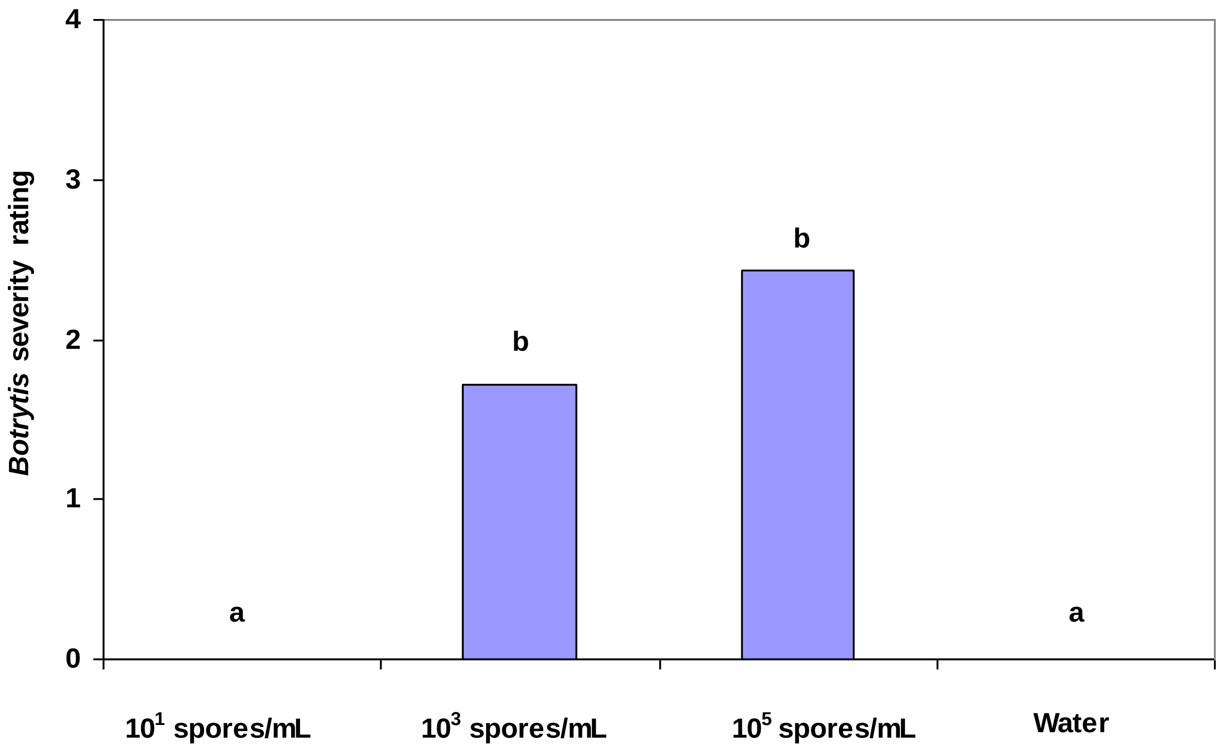



**Figure 54 Severity of Botrytis grey mould in cucumber fruit 14 days after flowers inoculated with spore solutions of different concentration and incubated at 14°C.**
Botrytis grey mould rating scale: 0=no disease; 1=watery area starting to develop; 2=watery area clearly visible, progressing up fruit; 3=sporulation; 4=majority of fruit sporulating

Fungicides

Five fungicides with potential support for registration by the relevant agrochemical companies were evaluated. Some were identified in the pesticide gap analysis conducted as part of HAL project MT 07029.

*Materials and Methods*

Seedlings were raised as previously described. When all plants had at least one flower at the F1 stage, plants were sprayed with one of five fungicides or water only with 10 plants per treatment (Table 13) and incubated in a controlled environment room (Figure 55) with a mean temperature of 14°C and mean relative humidity of 83%.

**Table 13 Fungicides evaluated for efficacy against Botrytis grey mould in cucumber fruit in controlled environment room**

| Product | Active ingredient | Rate |
|---|---|---|
| Filan® | 500g/kg boscalid | 1.2g/L |
| DC086 (Bayer Crop Science) | Confidential | 0.25mL/L |
| Colliss® | 200g/L boscalid<br>100g/L kresoxim-methyl | 0.5mL/L |
| Teldor® 500 SC | 500g/L fenhexamid | 1mL/L |
| Switch® | 375g/kg cyprodinil<br>250g/kg fludioxinil | 1g/L |

One day after treatment, all plants were inoculated as previously described with *B.cinerea* at $10^3$ spores/mL.

In the second trial 14 plants were sprayed with one of the same 6 treatments and then for each treatment seven plants were inoculated with *B.cinerea* one day after treatment and another seven were inoculated two days after treatment. Botrytis grey mould infection was rated seven and 14 days after inoculation using the rating scale previously described.

*Results and discussion*

In the first trial, all fungicides except Teldor® controlled Botrytis grey mould fruit infection up to 14 days after inoculation. The severity of infection in the Teldor® treatment was very low (Figure 56). In the second trial fruit from plants treated with Colliss® and Teldor® were infected when flowers were inoculated with *B.cinerea* one day after fungicide application and plants treated with Filan®, DC086® and Switch® had no infection (Figure 57). There was no infection in any of the treatments with flowers inoculated with *B.cinerea* two days after fungicide application however infection in the control was very low so conclusions cannot be drawn on the efficacy of the fungicides in this part of the trial.

**Figure 55 Fungicide trials for Botrytis grey mould on cucumbers in controlled environment room at 14°C (left) and example of infected fruit (right)**

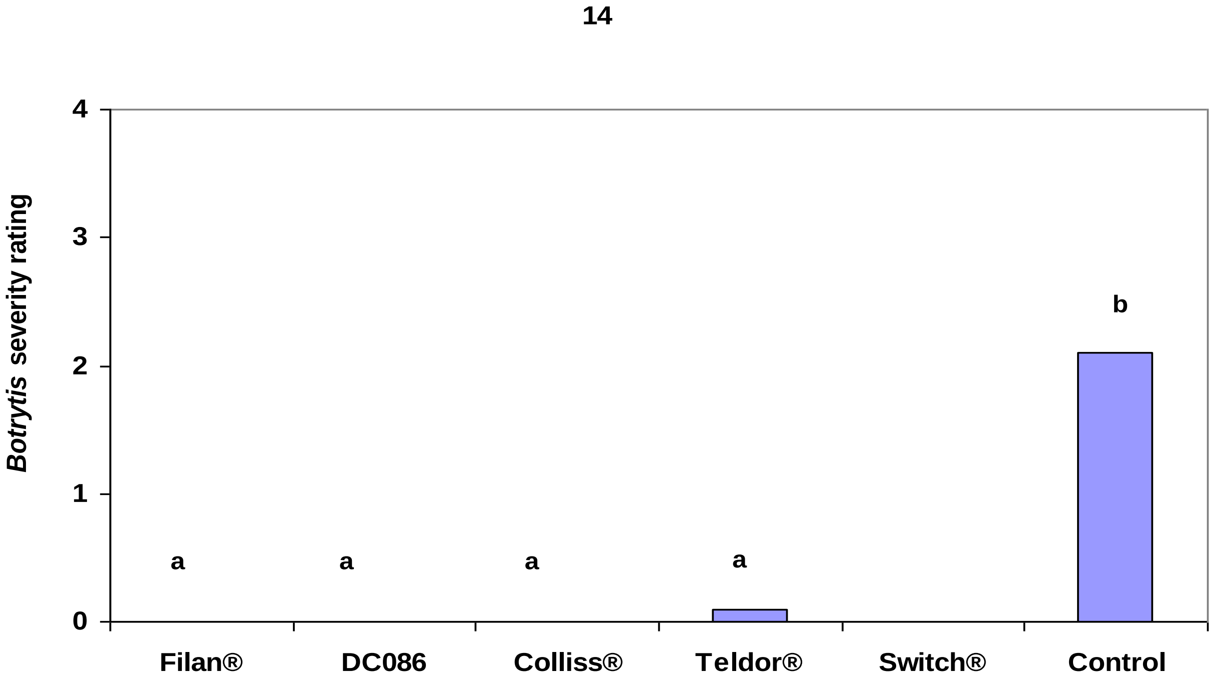



**Figure 56 Severity of Botrytis grey mould on cucumber fruit after flowers were treated with various fungicides before inoculation with *Botrytis cinerea*.** Botrytis grey mould rating scale: 0=no disease; 1=watery area starting to develop; 2=watery area clearly visible, progressing up fruit; 3=sporulation; 4=majority of fruit sporulating. Treatments with same letter are not significantly different from one another ($p<0.05$).

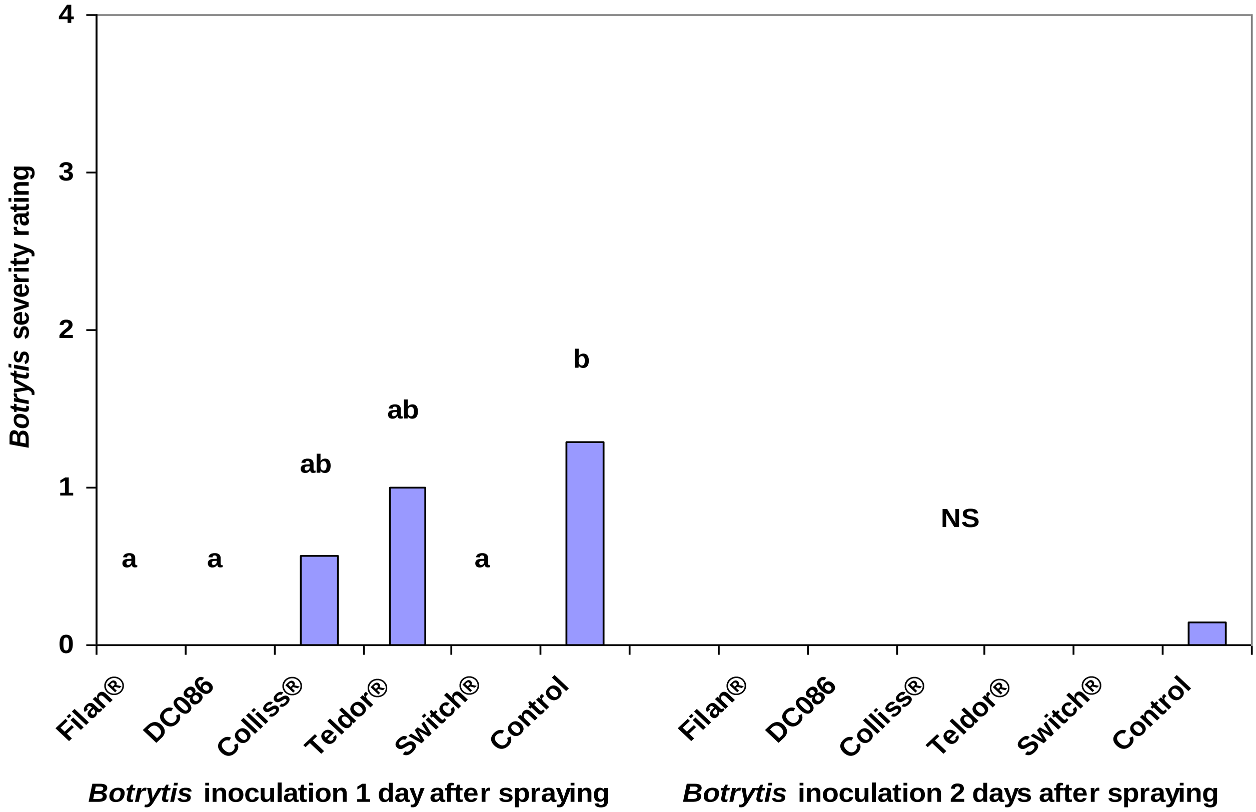



**Figure 57 Severity of Botrytis grey mould on cucumber fruit after flowers were treated with various fungicides then inoculated with *Botrytis cinerea* 1 and 2 days later.** Botrytis grey mould rating scale: 0=no disease; 1=watery area starting to develop; 2=watery area clearly visible, progressing up fruit; 3=sporulation; 4=majority of fruit sporulating. Treatments with the same letter are not significantly different from one another (P=0.05). NS = no significant differences between treatments.

Alternative products

Discussions with greenhouse growers revealed some growers were using alternative products to manage Botrytis grey mould with some success. Fungicides for Botrytis grey mould are most effective if used as protectants and alternative products like sanitisers are primarily protectants and can destroy spores of pathogens and reduce inoculum loads. The eradicant and protectant efficacy of four alternative products and an aerosol fungicide were evaluated in this trial.

*Materials and methods*

Seedlings were grown as previously described. When all plants had at least one flower at the F1 stage, plants were sprayed with one of 5 treatments or water only with 10 plants per treatment (Table 14).

**Table 14 Alternative products evaluated for efficacy against Botrytis grey mould in cucumber in controlled environment room, Waite 2009**

| Product | Active ingredient | Rate of product |
|---|---|---|
| Path X™ | 120g/L didecyldimethyl-ammonium chloride | 1mL/L |
| Silmatrix™ | 29% potassium silicate | 7.5mL/L |
| Scomrid | Imazalil | Pre-prepared aerosol |
| Eco Protector™ | 20% fatty acids as potassium salts | 20mL/L |
| Ecocarb® +<br>Synertrol® HortiOil | 940g/kg potassium bicarbonate<br>905g/L emulsifiable botanical oil | 4g/L<br>2.5mL/L |

In the protectant trials plants were sprayed with the treatment and then one day later inoculated with Botrytis grey mould. In eradicant trials plants were inoculated with Botrytis grey mould and then one day later sprayed with the treatments. Botrytis grey mould on the fruit was assessed seven and 14 days after inoculation using the rating previously described.

*Results and discussion*

In the protectant trial all treatments had fruit were infected with Botrytis grey mould, however while not statistically significant infection was numerically less than the control (Figure 58). In the eradicant trials (no data shown) no disease developed in the control plants so conclusions cannot be drawn about the efficacy of treatments. Flowers sprayed with the Scomrid aerosol were dead one day after treatment, before inoculation was conducted.

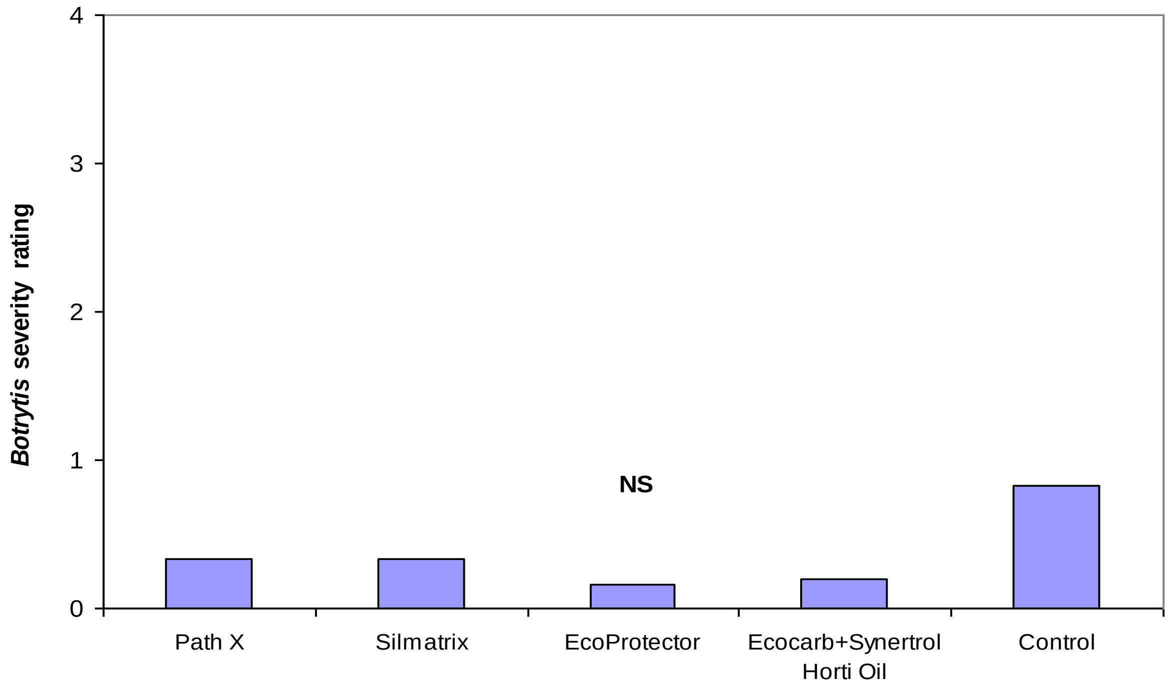



**Figure 58 Severity of Botrytis grey mould on cucumber fruit after flowers were treated with various alternative products then inoculated with *Botrytis cinerea* 1 day later.**
Botrytis grey mould rating scale: 0=no disease; 1=watery area starting to develop; 2=watery area clearly visible, progressing up fruit; 3=sporulation; 4=majority of fruit sporulating. NS = no significant difference between treatments ($p<0.05$).

Biologicals

Biological products such as beneficial fungi and bacteria are used by some growers to improve root growth and plant health, particularly during times of high temperature stress. These products may also have a role in management of foliar diseases like Botrytis grey mould. Commercial formulations of beneficial bacteria and fungi are available overseas that are not currently registered in Australia and several new strains are being developed for use in other crops in Australia that require testing.

*Bacteria*

Three bacterial products were evaluated for efficacy against Botrytis grey mould, one that is commercially available and two formulations of another bacterial product produced by Becker Underwood (Table 15).

*Materials and methods*

Seedlings were grown as previously described. When all plants had at least one flower at the F1 stage 14 plants were sprayed with one of 3 treatments, mixed with water, or water only (Table 15).

**Table 15 Bacterial products evaluated for efficacy against Botrytis grey mould in cucumber in controlled environment room, Waite 2010**

| Product | Active ingredient | Rate |
|---|---|---|
| Serenade Max$^{TM}$ | 14.6% QST713 strain of dried *Bacillus subtilis* | 6g/L |
| BU EXP-1360 | Experimental | 10g/L |
| BU EXP-1430 | Experimental | 25mL/L |

Seven plants from each treatment were inoculated one day after treatment and the remaining seven inoculated two days after treatment. Botrytis grey mould on fruit was assessed seven and 14 days after inoculation using a rating scale (General Materials and Methods). The entire trial was repeated due to variability in infection.

*Results and discussion*

Botrytis grey mould infection was inconsistent in the two trials due to contamination in the inoculum, however all controls had infected fruit (Figure 59; Figure 60). In the first trial flowers treated with Serenade Max$^{TM}$ produced fruit infected with Botrytis grey mould for both inoculation days. In the second trial there was no fruit infection from the flowers treated with Serenade Max$^{TM}$. Results for BU EXP-1430 were also variable with a lower infection rating in the second trial than the first. BU EXP-1360 was variable when Botrytis grey mould inoculation occurred one day after the bacteria was applied, but was consistently zero when inoculation occurred two days after bacterial spray. Although some bacterial products were effective against infection, there is evidence of the inherent variability of biological products for control of diseases like Botrytis grey mould.

Although the flower stage trials indicated there was no statistically significant difference between infection in flowers inoculated at F2 and F3 stages, the lower fruit infection in the controls where flowers were inoculated 2 days after spraying may indicate the potential for reduced infection at this flowering stage.

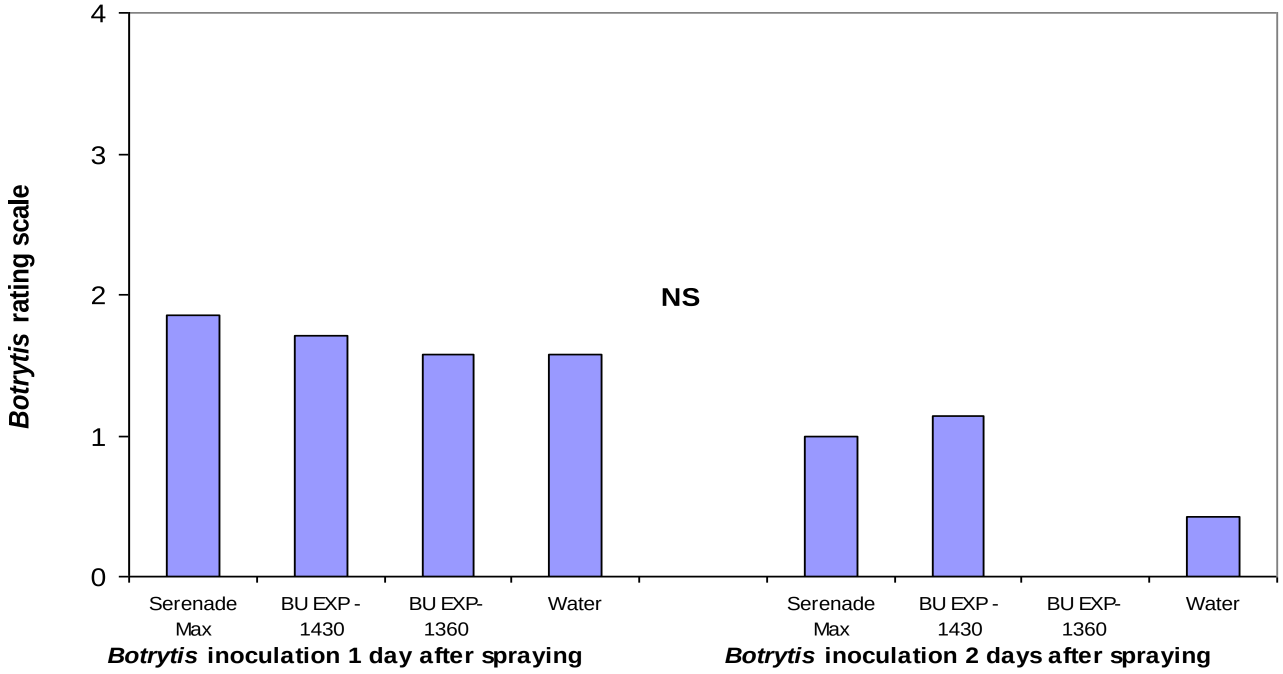



**Figure 59 Severity of Botrytis grey mould on cucumber fruit after flowers were treated with various bacterial products before inoculation with *Botrytis cinerea*.** Botrytis grey mould rating scale: 0=no disease; 1=watery area starting to develop; 2=watery area clearly visible, progressing up fruit; 3=sporulation; 4=majority of fruit sporulating. NS = no significant difference between treatments ($p<0.05$).

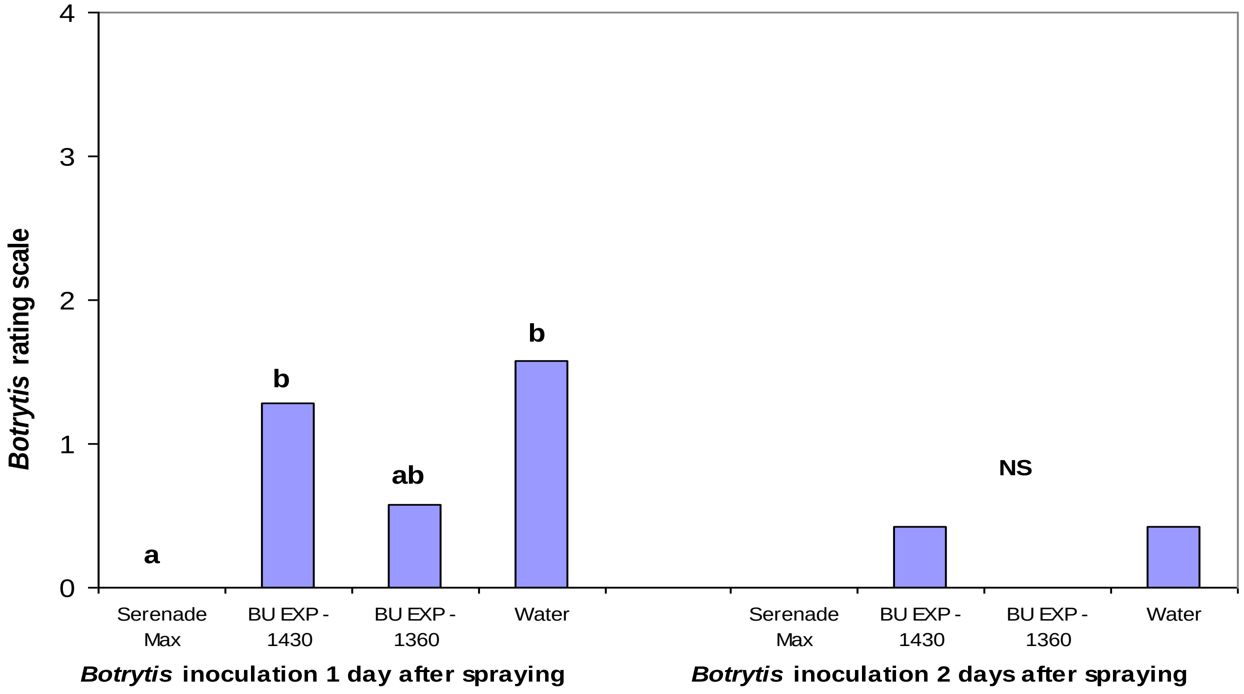



**Figure 60 Severity of Botrytis grey mould on cucumber fruit after flowers were treated with various bacterial products before inoculation with *Botrytis cinerea*.** Botrytis grey mould rating scale: 0=no disease; 1=watery area starting to develop; 2=watery area clearly visible, progressing up fruit; 3=sporulation; 4=majority of fruit sporulating. Treatments with the same letter are not significantly different from one another ($p<0.05$). NS = no significant difference between treatments ($p<0.05$).

*Trichoderma*

Six *Trichoderma* isolates from Biocontrol Australia were evaluated for control of Botrytis grey mould. One isolate (Td67) was a commercial formulation undergoing registration with the APVMA for management of Botrytis grey mould in grapes. The remaining isolates were experimental formulations. Sentinel®, a commercially available isolate of *Trichoderma atroviride* LC52 for control of Botrytis grey mould in tomatoes in New Zealand was also trialled. Some early trials with Trichoderma were inoculated with spore suspensions with $10^5$ spores/mL. These trials were conducted prior to spore concentration trials that determined lower inoculum concentrations that would still produce consistent infection.

*Materials and methods*

In all trials seedlings were raised as previously described. All treatments were applied with a hand-held sprayer.

Trial 1

When all plants had at least one flower at the F1 stage 20 plants were randomly assigned to one of three treatments:

1. *Trichoderma koningii* Td67 1.67g/L
2. *Trichoderma koningii* Td22 1.67g/L
3. Water

Ten plants in each treatment were inoculated as previously described with *B.cinerea* using a spore suspension of $10^5$ spores/mL one day after treatment and the remaining ten were inoculated two days after treatment.

Trial 2

When all plants had at least one flower at the F1 stage 16 plants were randomly assigned to one of six treatments:

1. *Trichoderma* spp. isolate Td67 1.67g/L
2. *Trichoderma* spp. isolate Td74 1.67g/L
3. *Trichoderma* spp. isolate Td75 1.67g/L
4. *Trichoderma* spp. isolate Td84 1.67g/L
5. *Trichoderma* spp. isolate Td89 1.67g/L
6. Water

Eight plants in each treatment were inoculated as previously described with a *B.cinerea* spore suspension with $10^3$ spores/mL one day after treatment with *Trichoderma* and the remaining ten were inoculated two days after treatment. This entire trial was repeated due to lack of infection in the first trial.

In each trial disease on fruit was assessed seven and 14 days after inoculation as previously described using the Botrytis grey mould rating scale (see General Materials & Methods).

Trial 3

Eighteen seedlings were randomly assigned to one of three treatments:

1. Sentinel® 0.4g/L
2. Sentinel® 0.8g/L
3. Water

Nine plants in each treatment were inoculated as previously described with *B.cinerea* using a spore suspension of $10^5$ spores/mL one day after treatment and the remaining ten were inoculated two days after treatment. The entire trial was repeated to examine the consistency of the results. The higher spore solution concentration was used because these early trials were conducted before the spore concentration trial.

*Results and discussion*

Trial 1

None of the *Trichoderma* isolates prevented Botrytis grey mould on the flowers and development of fruit symptoms. (Figure 61).

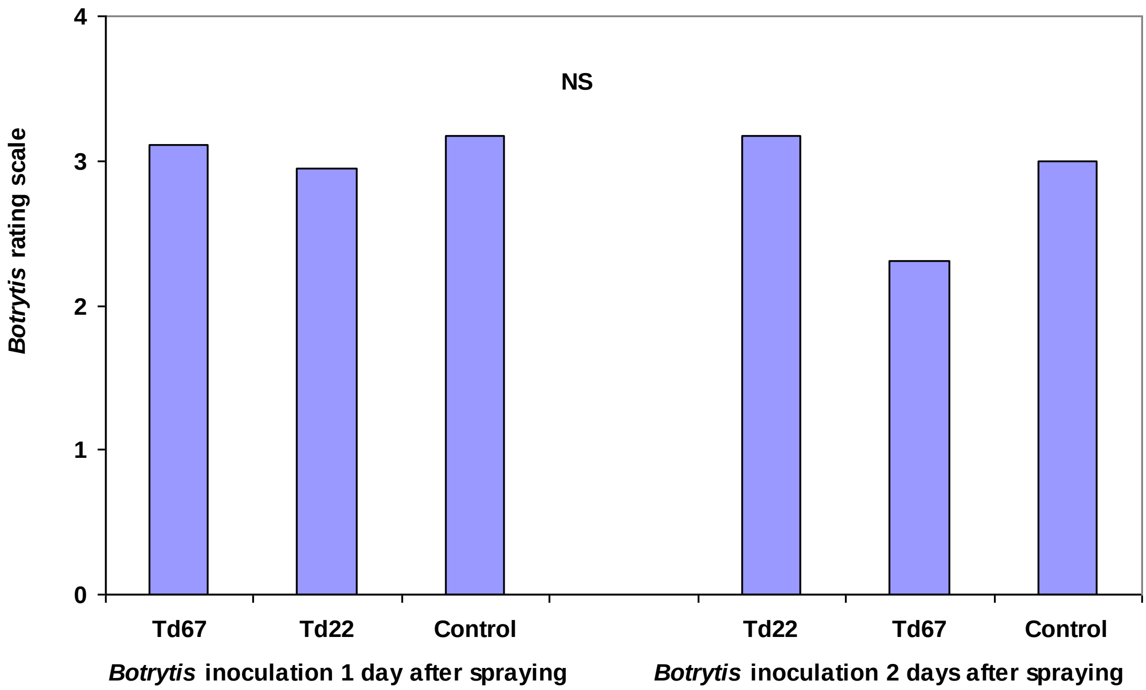



**Figure 61 Trichoderma isolates trialled against cucumber Botrytis grey mould in controlled environment room, Waite 2009.** Botrytis grey mould rating scale: 0=no disease; 1=watery area starting to develop; 2=watery area clearly visible, progressing up fruit; 3=sporulation; 4=majority of fruit sporulating

Trial 2

Despite this trial being repeated, Botrytis grey mould did not develop in any treatments or the controls so the isolates were not able to be successfully evaluated in the second trial (data not shown).

Trial 3

There were high levels of Botrytis grey mould on fruit in all treatments where flowers were treated with Sentinel® in both trials (Figure 62; Figure 63).

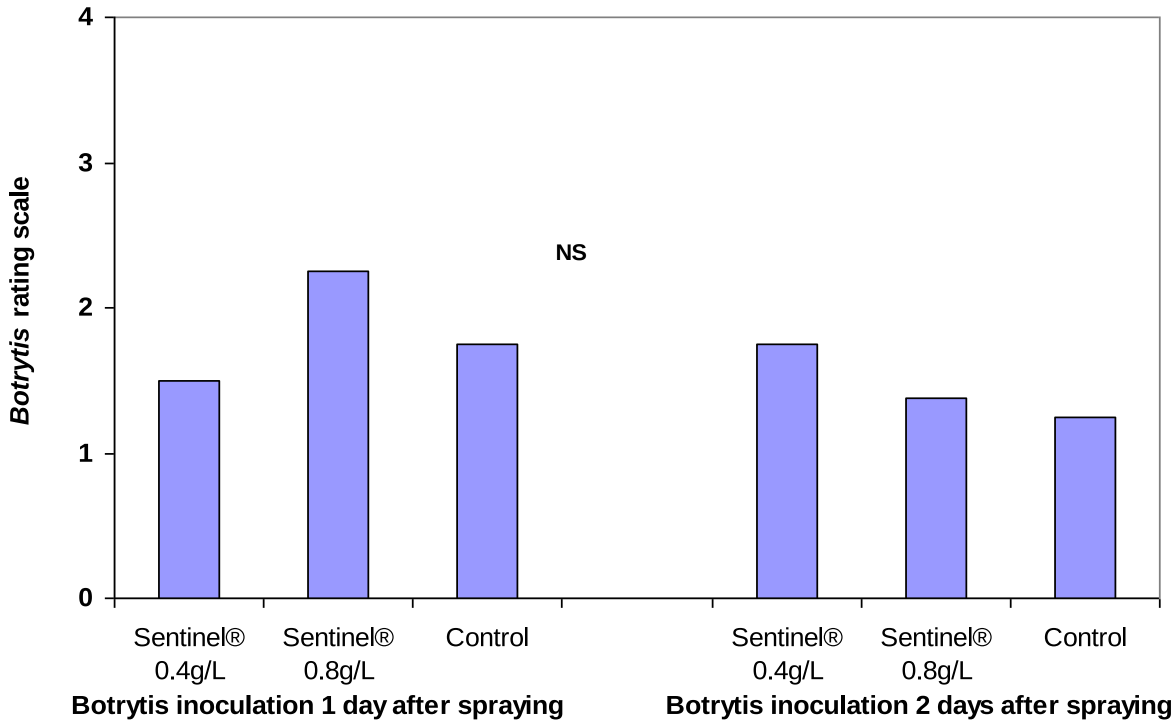



**Figure 62 Severity of Botrytis grey mould on cucumbers treated with two rates of Sentinel and inoculated with *Botrytis cinerea* 1 or 2 days later.** Botrytis grey mould rating scale: 0=no disease; 1=watery area starting to develop; 2=watery area clearly visible, progressing up fruit; 3=sporulation; 4=majority of fruit sporulating. NS = no significant difference between treatments ($p<0.05$).

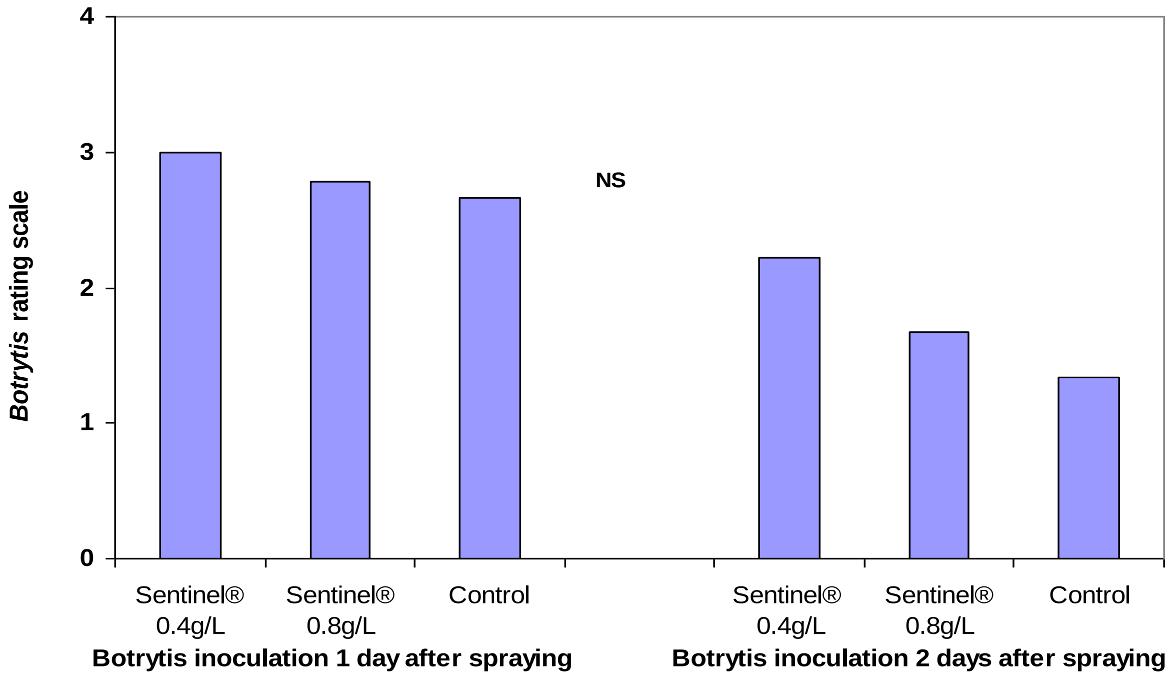



**Figure 63 Severity of Botrytis grey mould on cucumbers treated with two rates of Sentinel and inoculated with *Botrytis cinerea* 1 or 2 days later.** Botrytis grey mould rating scale: 0=no disease; 1=watery area starting to develop; 2=watery area clearly visible, progressing up fruit; 3=sporulation; 4=majority of fruit sporulating. NS = no significant difference between treatments ($p<0.05$).

*In vitro studies*

The *Trichoderma* isolates evaluated did not prevent infection under the trial conditions which were favourable to the development of Botrytis grey mould. Therefore the isolates were examined *in vitro* to compare the relative temperatures for optimum growth and inhibition of *Botrytis cinerea* by the *Trichoderma* isolates.

*Materials and methods*

Isolates of the *Trichoderma* biological agents and *B.cinerea* were grown on PDA. After 14 days, when all cultures were sporulating, a 4mm plug of each *Trichoderma* was placed on one side of a plate of PDA and a plug of *B.cinerea* of the same size placed on the other side. Six replicates of each plate were prepared, three were incubated at 15°C and three at 22°C. Control plates had a plug of *B.cinerea* placed on either side of the plate to check the natural growth. Two measurements of colony diameter taken perpendicular to each other were recorded each day for up to 3 days after plating.

*Results and Discussion*

Growth of *Trichoderma* isolates at 22°C was more rapid than at 15°C and 3 days after plating individual isolates were difficult to distinguish (Figure 64), so data for 2 days is presented. Colony diameter of all *Trichoderma* isolates was less at 15°C than at 22°C and for *B.cinerea* was more at 14°C than at 22°C (Figure 65; Figure 66). This indicates that the *Trichoderma* isolates were less suited to the 15°C conditions than the *B.cinerea*. Of the *Trichoderma* isolates evaluated Td75 performed best at 15°C and perhaps warrants further investigation.

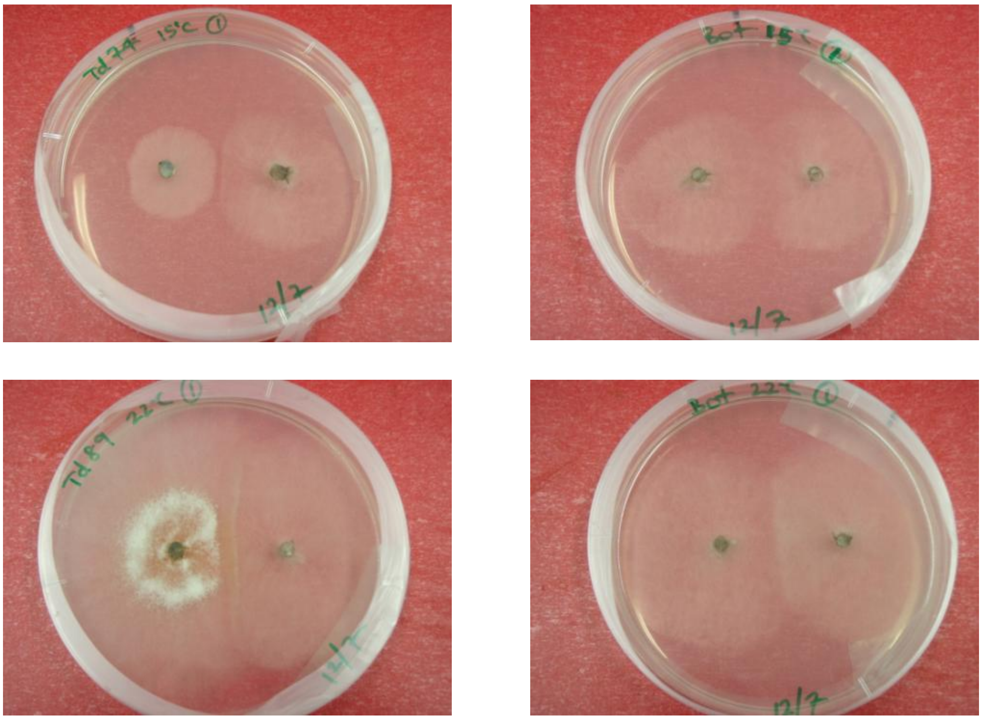



**Figure 64 *In vitro* trials for *Trichoderma* isolates, *Botrytis cinerea* is on the right of the plate and Trichoderma isolates on left. Td74 vs Botrytis grey mould at 14°C (top left), Td 89 vs Botrytis grey mould at 22°C (bottom left), Botrytis grey mould vs Botrytis grey mould at 14°C (top right) and 22°C (bottom right)**

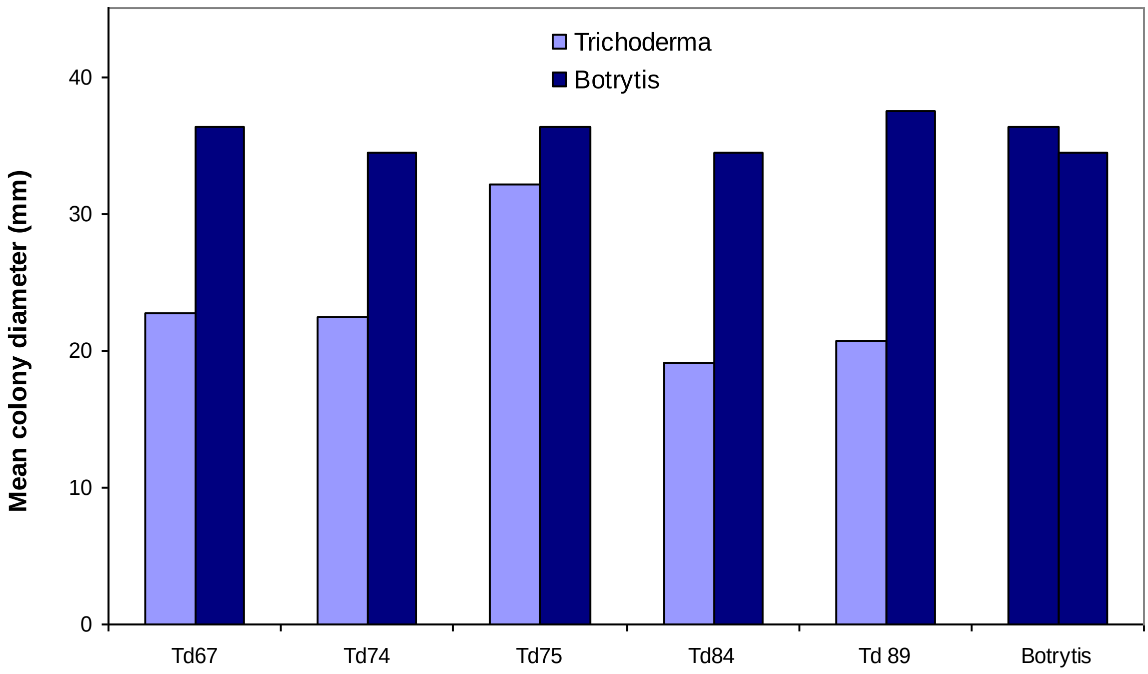



**Figure 65 Mean colony diameter of *Trichoderma* isolates versus Botrytis grey mould on potato dextrose agar after 3 days at 14°C**

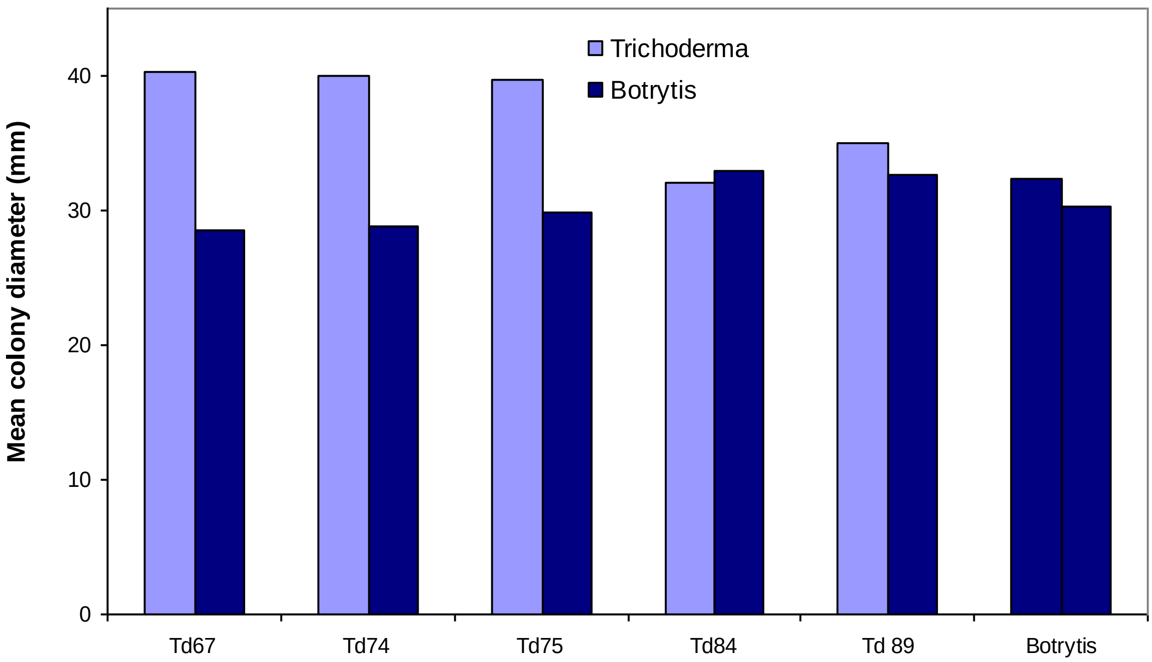



**Figure 66 Mean colony diameter of *Trichoderma* isolates versus Botrytis grey mould on potato dextrose agar after 2 days at 22°C**

### 4.7.6. Conclusions

Of the fungicides that showed efficacy against Botrytis grey mould both Colliss® and the coded product DC086 warrant further investigation and would be supported for greenhouse use by the chemical companies. Delays in the development of a reliable protocol to evaluate Botrytis infection and fruit rot in the research greenhouse meant that field trials were unable to be completed for these products. Switch® was highly effective, however the permit for this product has now expired. Teldor® will not be supported for greenhouse use.

None of the alternative products were effective when used as protectants. Alternative products may be effective as eradicants but as there was a lack of infection in the controls of these trials further work is needed to determine their effectiveness.

In the bacteria trials only one formulation of one isolate, BU EXP 1360 produced a consistent and favourable result and further trials are necessary for this product.

None of the *Trichoderma* isolates prevented Botrytis grey mould infection in flowers and the subsequent rot of the fruit. More testing is required for these isolates as there was a high degree of variability in infection combined with the inherent variability of biological products. Unlike fungicides biological products are living organisms and rely on conditions being right for growth. *In vitro* studies indicated temperature could play a major role in the effectiveness of *Trichoderma* and an isolate that is effective below 15°C is needed. *Trichoderma* products like Sentinel® are used commercially overseas for control of Botrytis grey mould in tomatoes and although studies in the controlled environment room were variable, research into the efficacy and application timing of these products in commercial greenhouses is still warranted.

The majority of the biological products trialled produced inconsistent results. Biological products need to be reliable if growers are to use them in a commercial situation. Growers are unlikely to rely on products that don’t produce consistent results. There is also a need for more work with biological products that can perform effectively in the temperature and humidity range that favours development of Botrytis grey mould. Even if biological products are only moderately effective, if they are somewhat persistent they can reduce the number of other sprays required and form a valuable part of an integrated management program.

Trials demonstrated the differing susceptibility of flower stages to infection by Botrytis grey mould. In a commercial crop, cucumber flowers are constantly being produced and an individual plant will have many flowers at different stages and different levels of susceptibility to infection. Products with good protectant/systemic activity are likely to be the most effective for preventing flower infection.

## 4.8. Variety Trials

Resistant varieties can be a valuable part of an integrated disease management program. Seed companies make claims about the resistance of different varieties to foliar diseases but growers often have little idea what that means for their crop. Growers are also unsure of how much yield loss is caused by infection with powdery mildew. These trials aim to evaluate cucumber and capsicum varieties for susceptibility to powdery mildew and Botrytis grey mould and to examine the effects of diseases on yield.

### 4.8.1. Powdery mildew on cucumber

Fourteen Lebanese and seven continental cucumber varieties, including those commonly grown in Australia were evaluated for susceptibility to powdery mildew in the research greenhouse.

*Lebanese varieties*

Deltastar, Khassib, Mascot, Montana and Nurin - Rijk Zwaan
Austin, Cobra, Eskimo, Panama and Sultan - South Pacific Seeds
Green Star, Ilas, Olympos and Robin - Syngenta Seeds.

*Continental varieties*

Celsius, Prevelli and Palermo - Syngenta Seeds
Reko and Vancouver - South Pacific Seeds
Zakros - Seminis Seeds
Myrthos - Rijk Zwaan

Materials and Methods

Ten seeds of each cucumber variety were planted into 200mm pots filled with coco-peat mix. When plants were two weeks old five plants of each variety were inoculated as previously described with a spore suspension of $10^5$ spores/mL powdery mildew (Figure 68). The remaining five plants were not inoculated. As powdery mildew spreads freely within the greenhouse control plants were sprayed up to five times during trials, at 7-14 day intervals during trials with Ecocarb 4g/L+Synertrol Horti Oil 2mL/L to keep them free of powdery mildew. This product was chosen because it has low volatility and low toxicity to the beneficial organisms that were being used for management of insect pests in the greenhouse. Plants were tied to 1m stakes as required and pruned to one main stem by removing lateral shoots and tendrils. Severity of powdery mildew on all leaves was assessed weekly from the day of inoculation using a rating scale previously described, and a mean for each plant and disease progress curves calculated. Fruit were harvested as they reached marketable size, number and weight recorded and data analysed with ANOVA (Statistix 8).

Results and Discussion

All Lebanese and continental cucumber varieties were susceptible to powdery mildew. Most varieties showed a similar progression of disease but there were some differences that could potentially be exploited by greenhouse growers to reduce losses caused by powdery mildew. Panama and Myrthos developed less disease late in the crop (Figure 67b and e.) and Palermo had a delay in the onset of disease (Figure 67d.). As powdery mildew has the capacity to shorten the life of cucumber crops, having less disease late in the crop could be useful as growers may be able to sustain a crop for several more weeks than with other varieties.

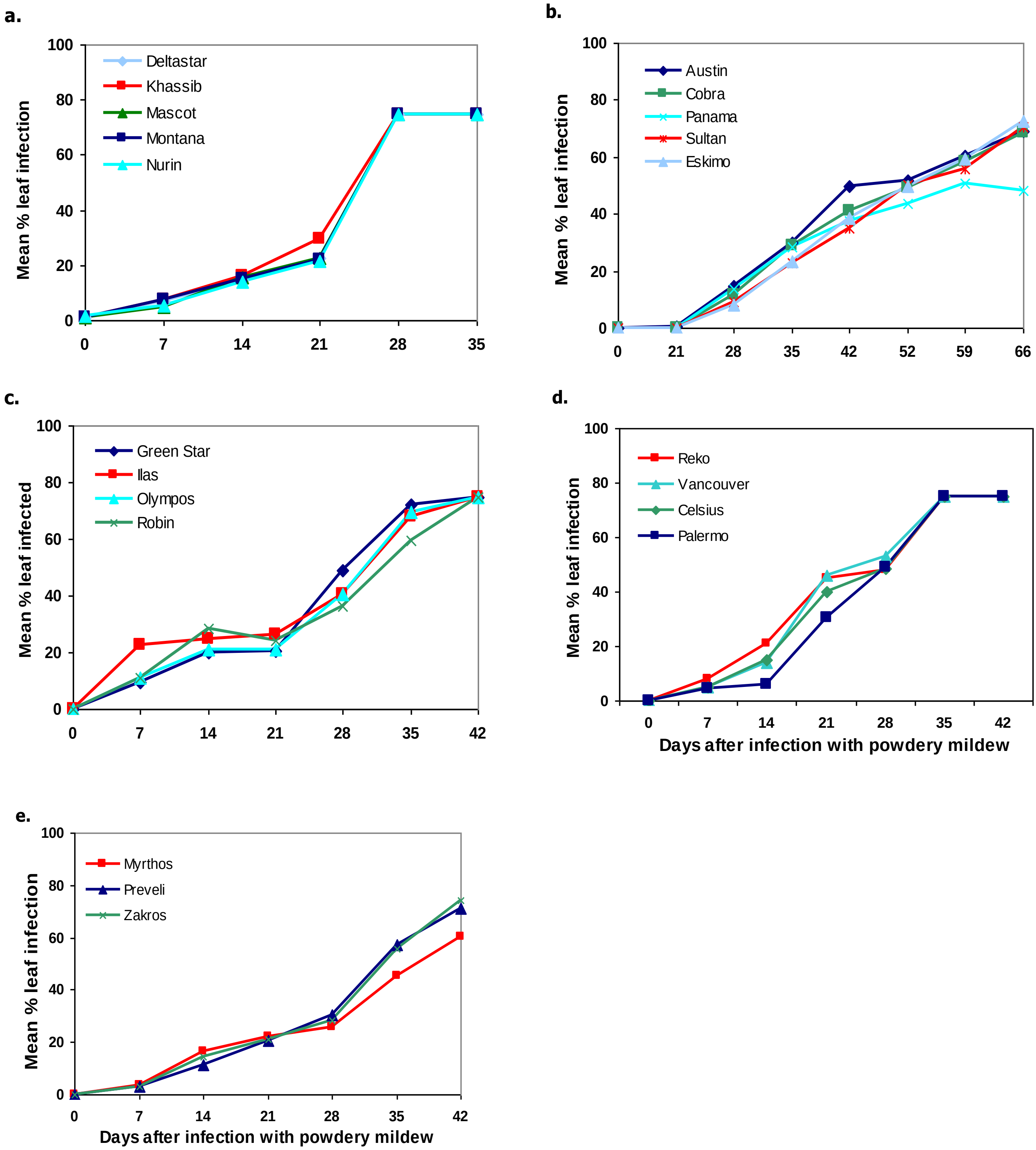



**Figure 67 a. Disease progression curves for cucumber variety trials a. Trial 1 Lebanese varieties; b. Trial 2 Lebanese varieties; c. Trial 3 Lebanese varieties; d. Trial 4 and e. Trial 5 Continental varieties**

**Figure 68 Cucumber variety trials 14 days (left) and 35 days after inoculation with powdery mildew**

A delay in the onset of disease compared to other varieties, even if it is only a day or two may give a grower the time needed to implement management strategies to restrict the spread of powdery mildew. Several varieties had less than 30% powdery mildew up to 21 days after inoculation and could give growers a chance to prune leaves or apply a spray (Figure 67a, c and e). Varieties with a faster disease onset do not provide that chance. The sooner that management strategies are implemented around the onset of disease the more effective the strategies will be. In favourable conditions powdery mildew can progress rapidly from one spot on a leaf to a full blown epidemic that cannot be brought under control by any means.

In Trial 1 only the variety had a significant affect on total fruit weight so weights from inoculated and control plants were combined. Mascot and Nurin yielded significantly less than the other varieties (Figure 69). Overall each of these varieties yielded well despite infection with powdery mildew.

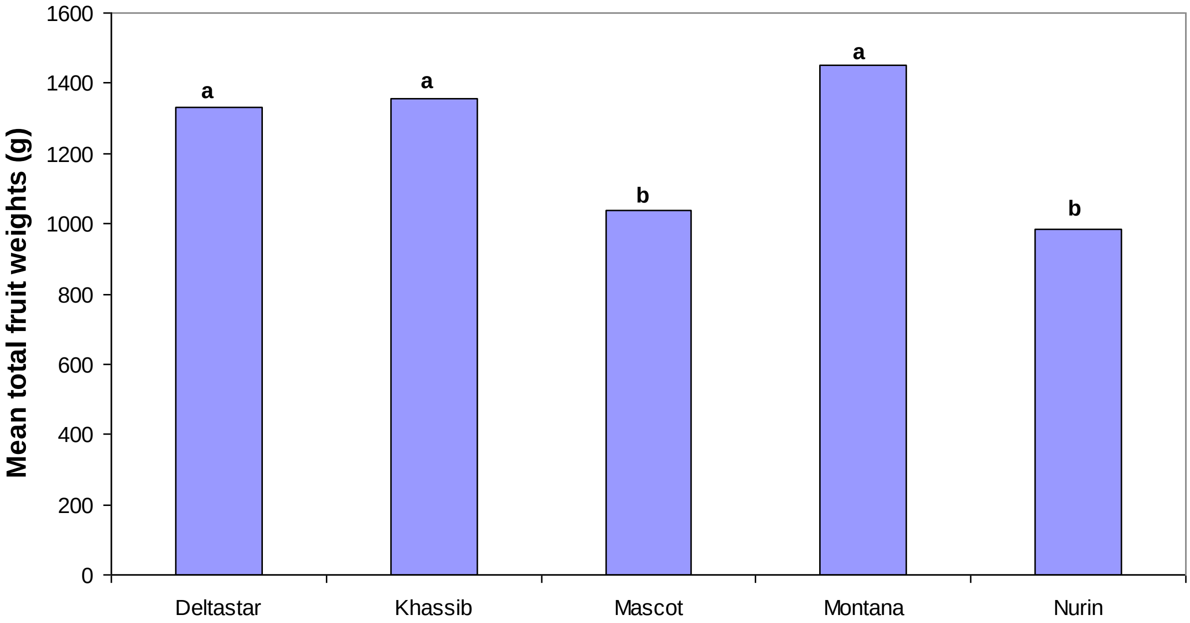



**Figure 69 Mean total fruit weight (grams) of cucumber varieties inoculated with powdery mildew.** Treatments with same letter not significantly different from one another ($p<0.05$).

In Trial 2, the interaction between treatment and variety was significant with all varieties except Austin yielding less when inoculated with powdery mildew (Figure 70). In Trial 3, the interaction was also significant with GreenStar and Ilas having significantly higher fruit weights when not inoculated with powdery mildew (Figure 71).

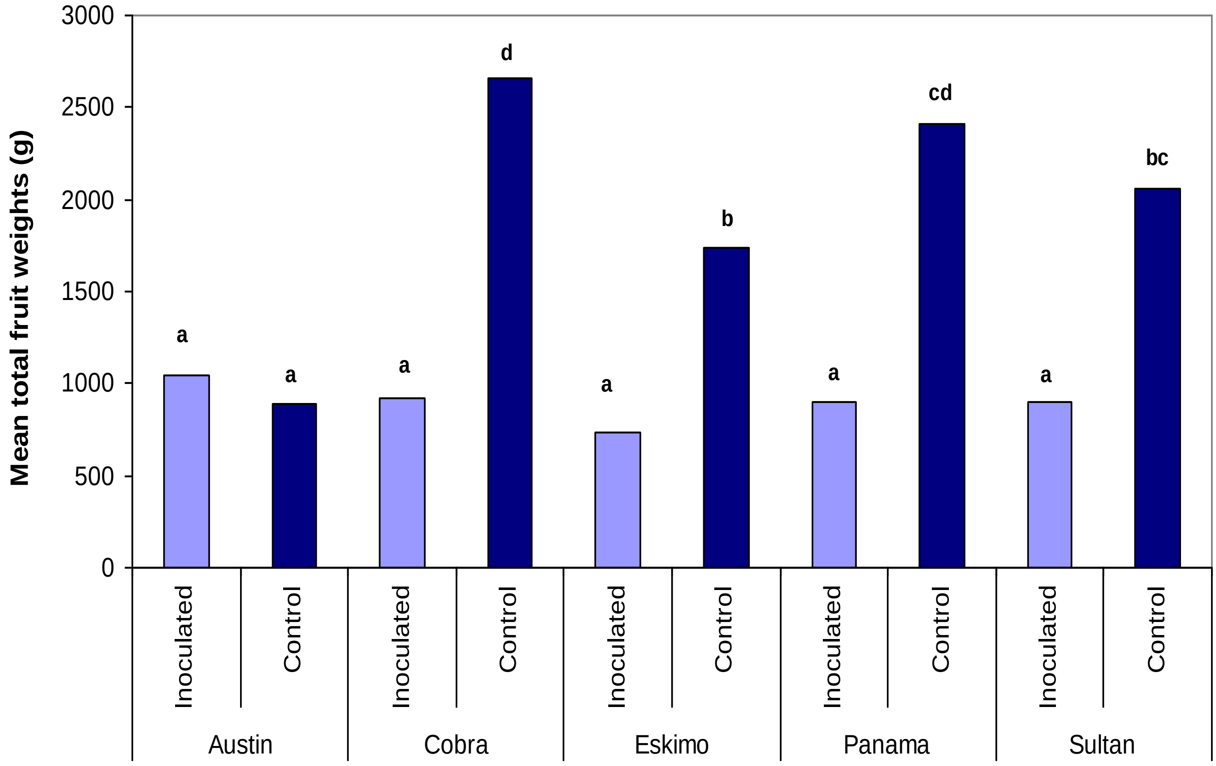



**Figure 70 Mean total fruit weight (grams) of cucumber varieties inoculated with powdery mildew.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

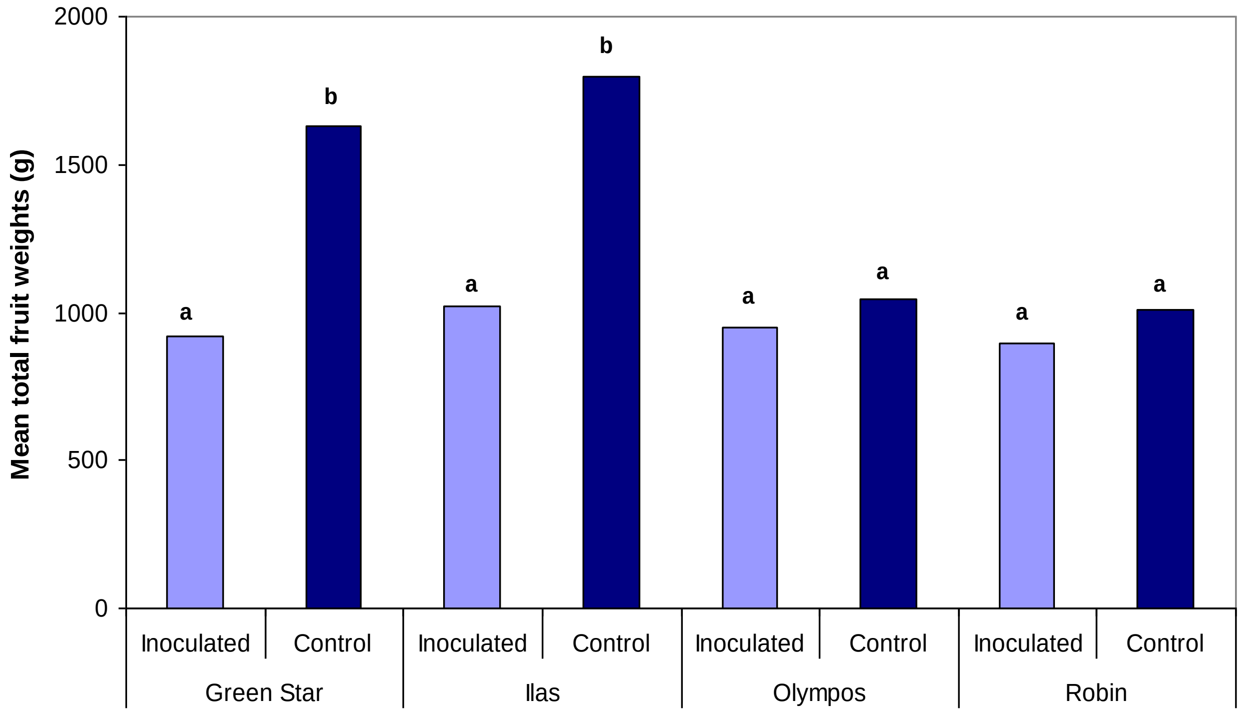



**Figure 71 Mean total fruit weight (grams) of cucumber varieties inoculated with powdery mildew.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

In Trial 4, the interaction between variety and treatment was significant. Mean total fruit weight was lower in all varieties inoculated with powdery mildew except Vancouver. Differences were only significant for Celsius (Figure 72). Inoculated plants of Vancouver had significantly higher fruit weights than control plants as only one control plant produced fruit of a marketable size during the trial. The reason for this difference was not clear but it possible that this was a slower maturing variety and plants did not have enough time to mature fruit within the scope of the trial.

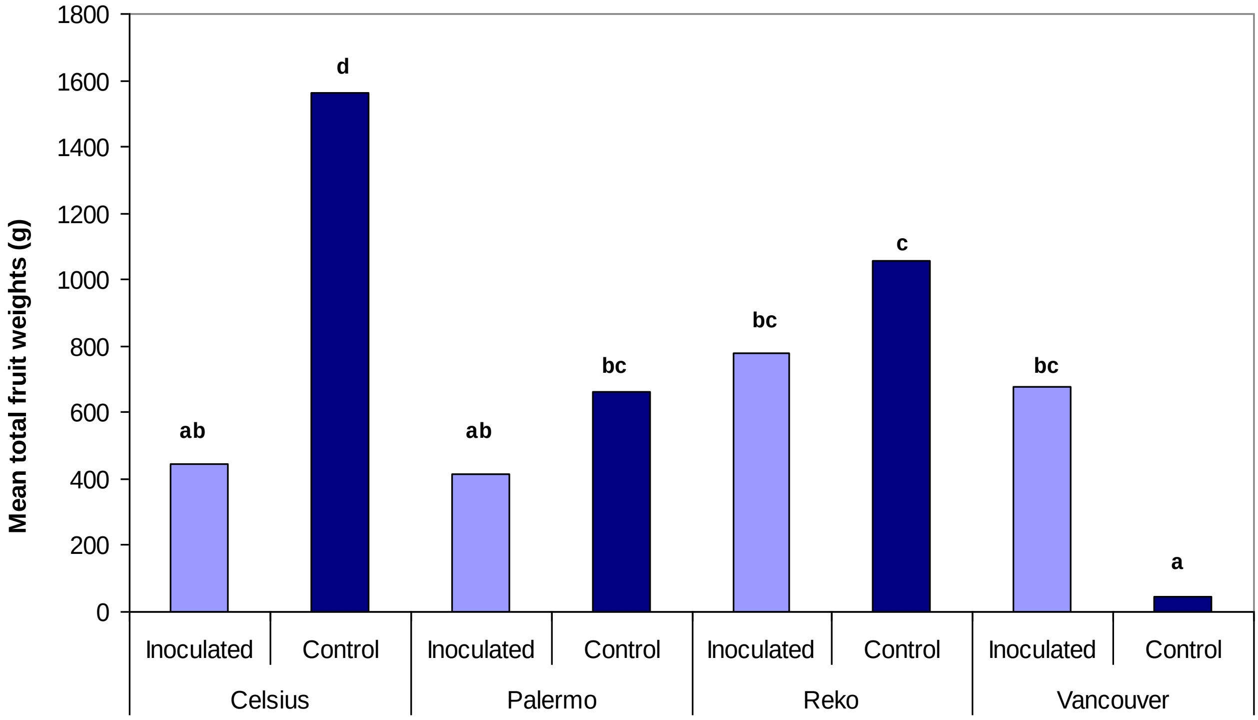



**Figure 72 Mean total fruit weight (grams) of cucumber varieties inoculated with powdery mildew.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

In Trial 5, both the variety and the treatment significantly affected fruit weight and data for variety and treatment were pooled. Myrthos had the highest fruit weights (Figure 73). Control plants yielded significantly less than inoculated plants (Figure 74). Many of the control plants only produced one fruit of marketable size during the course of the trial, however this does not explain the differences between control and inoculated plants.

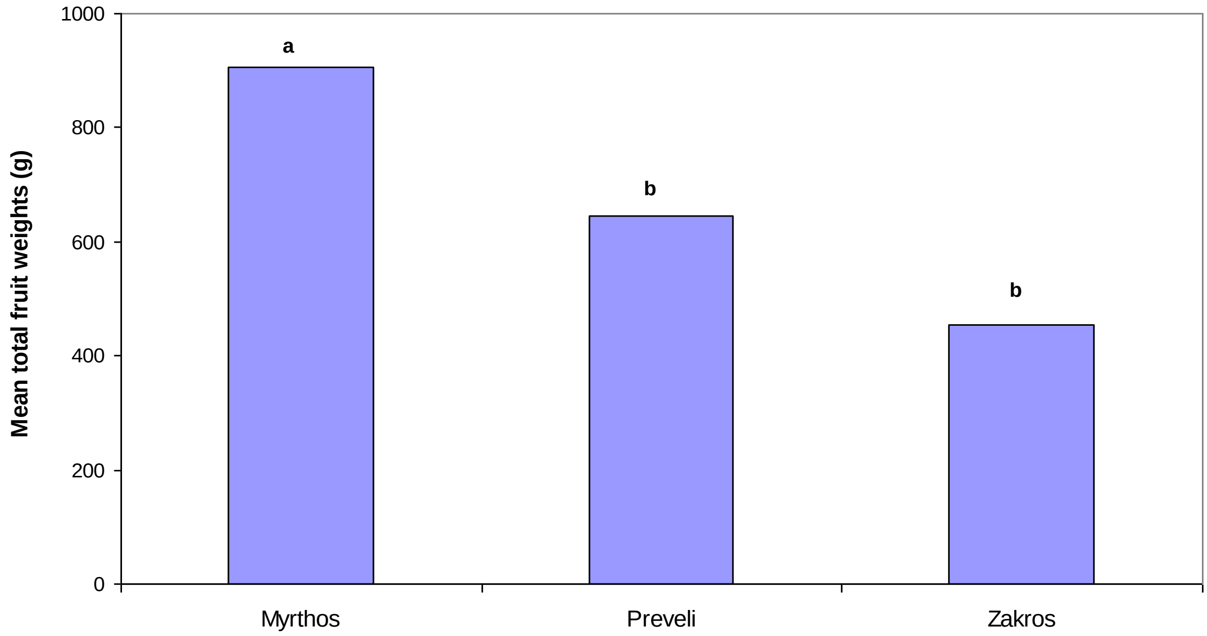



**Figure 73 Mean total fruit weight (grams) of cucumber varieties inoculated with powdery mildew in research greenhouse.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

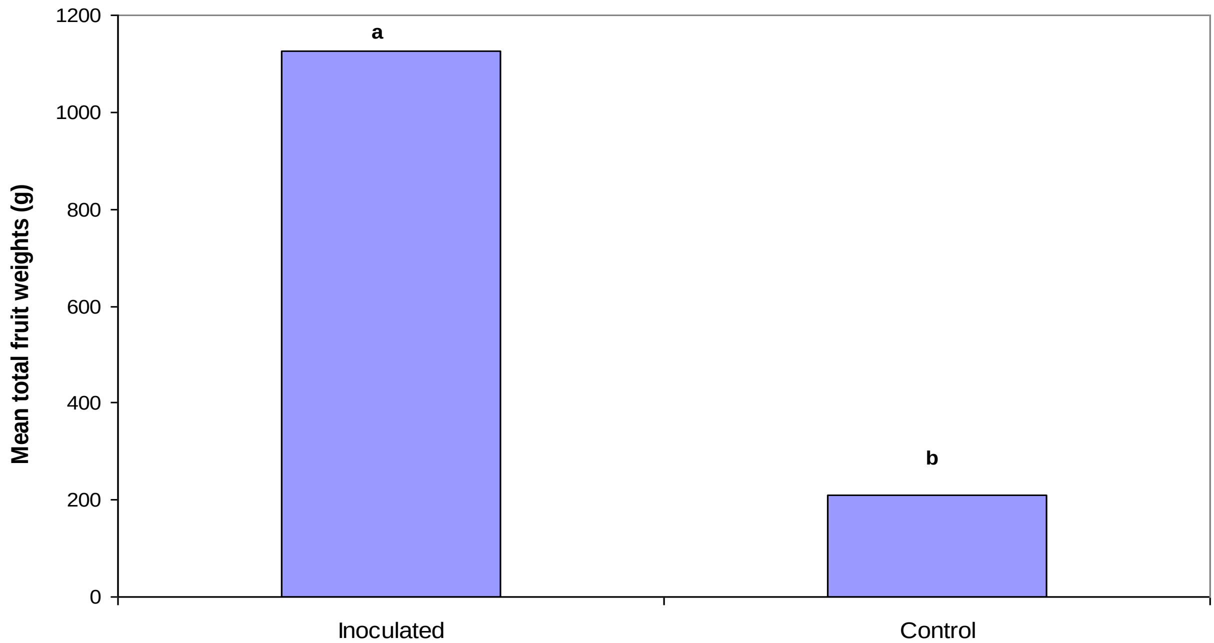



**Figure 74 Mean total fruit weight (grams) of cucumbers inoculated with powdery mildew in research greenhouse.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

### 4.8.2. Powdery mildew on capsicum

Five capsicum varieties including those commonly grown were evaluated to determine susceptibility to powdery mildew.

Capsicum varieties

Biela, Raptor and Remy – Syngenta Seeds
Kapto and Combat – South Pacific Seeds

Materials and Methods

Ten seeds of each capsicum variety were planted into 200mm pots filled with coco-peat potting mix (Figure 75). When plants were 13 weeks old, five plants of each variety were inoculated as previously described with a spore suspension of powdery mildew $10^5$ spores/mL. The remaining five plants were not inoculated. As powdery mildew spreads freely within the greenhouse control plants were sprayed up to five times during trials, at 14-28 day intervals during trials with Ecocarb® 4g/L+Synertrol® Horti Oil 2mL/L. Plants were tied to 1m stakes as required and pruned to two main stems by removing lateral shoots. Severity of powdery mildew on all leaves was assessed using a rating scale (see General Materials and Methods) weekly from the day of inoculation and a mean and disease progression curves calculated for each variety. Leaf drop was recorded for each plant. Fruit were harvested as they reached maturity and the number and weight of fruit recorded (Figure 75). Data were analysed with two-way ANOVA (Statistix 8).

Results and Discussion

All varieties tested were susceptible to powdery mildew and disease progression was similar for all varieties up until Day 28 (Figure 76). From Day 35 the percentage leaf infection in Combat and Biela appeared to decrease but leaf drop data shows that Combat and Biela had a higher percentage of leaf drop after Day 21 than the other varieties. The decrease in leaf infection seen in Combat, Biela and Kapto is due to severely infected leaves dropping from the plant and the new growth only having a low level of powdery mildew infection (Figure 77). Leaf drop not only reduces the photosynthetic capacity of the plant but also exposes fruit to sunscald so it is an advantage if plants infected with powdery mildew retain as many leaves as possible. Remy was severely infected with powdery mildew throughout the trial but dropped very few leaves making it less susceptible to the effects of powdery mildew overall. Israeli researchers also noted a reduction in powdery mildew severity due to leaf drop in capsicum varieties. Differences were also found in the number of leaves shed by different varieties (Elad 2007).

**Figure 75 Capsicum variety trials for powdery mildew in research greenhouse**

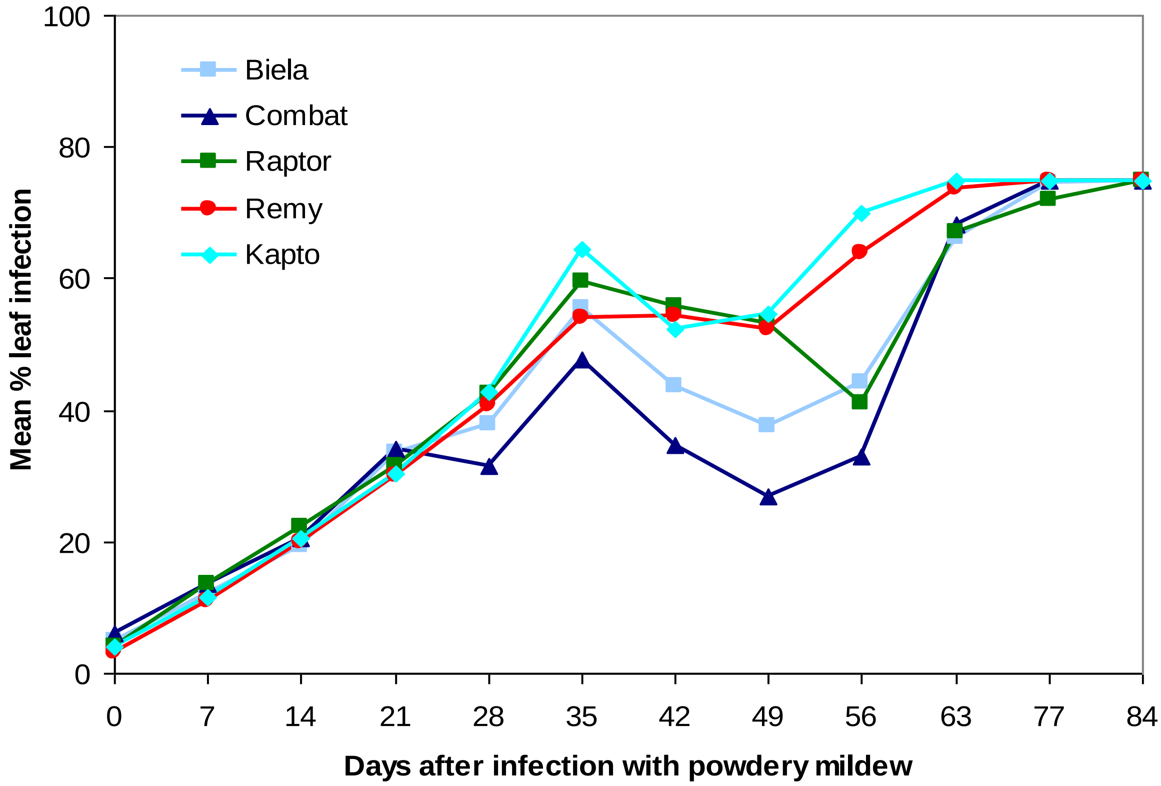



**Figure 76 Development of powdery mildew in capsicum varieties inoculated with powdery mildew in the research greenhouse**

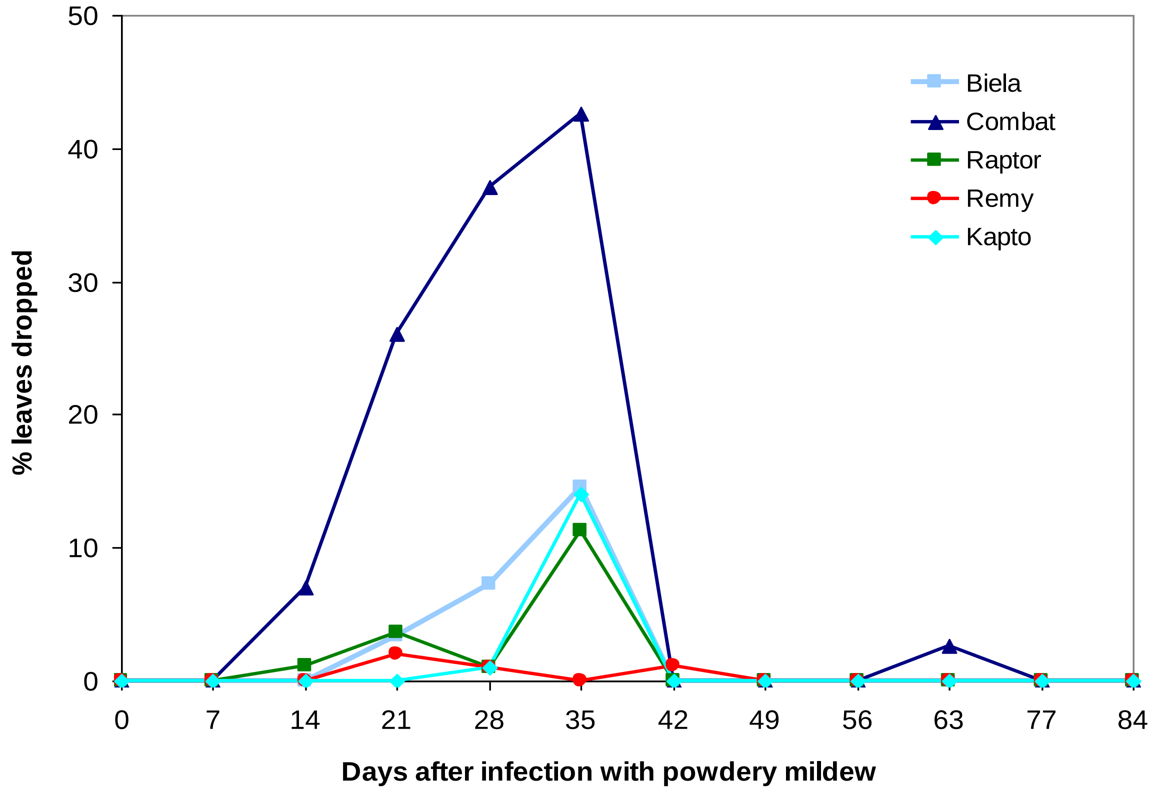



**Figure 77 Defoliation in capsicum varieties inoculated with powdery mildew in research greenhouse**

Plants inoculated with powdery mildew had significantly lower total fruit weight than the control plants that were not inoculated (Figure 78). Variety did not have a significant effect on the total weight of marketable fruit. Although Biela and Combat dropped more leaves than the other varieties, yields were not significantly different from the varieties that retained more leaves.

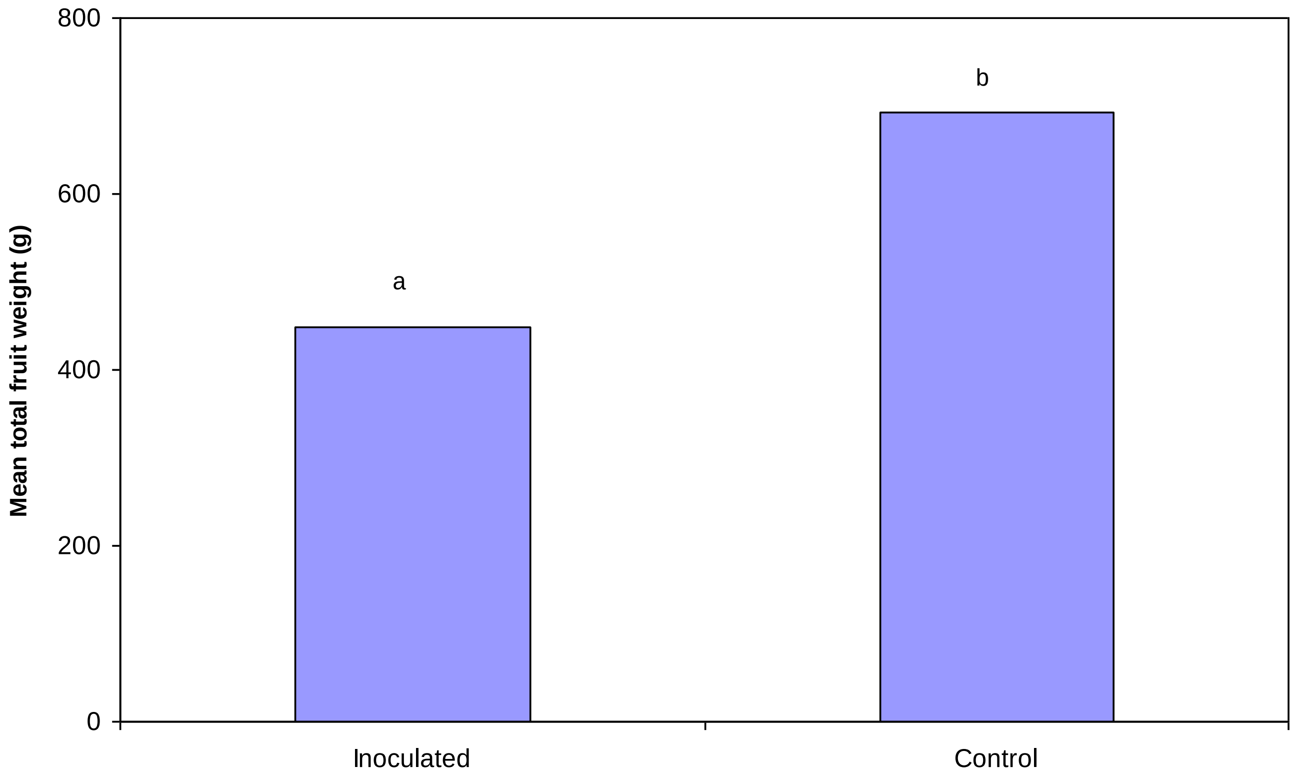



**Figure 78 Mean total fruit weights (grams) for capsicum inoculated with powdery mildew in research greenhouse, Waite 2009.** Treatments with the same letter are not significantly different from one another ($p<0.05$).

### 4.8.3. Botrytis grey mould on cucumber

Growers try to manipulate the climate, particularly reducing humidity and increasing temperature, to make the greenhouse less favourable to Botrytis grey mould. Trials examining infection with Botrytis grey mould at different temperatures indicated that Botrytis grey mould could infect plants at 22°C but infection was more consistent at 14°C (see ‘Screening products for Botrytis grey mould’). Those trials were conducted on only one variety, Mascot which was suited to cooler conditions. Six Lebanese cucumber varieties were evaluated for susceptibility to development of Botrytis grey mould under two different temperature and humidity regimes.

*Lebanese varieties*

Mascot and Montana – Rijk Zwaan
Green Star, Ilas, Olympos and Robin - Syngenta Seeds.

Materials and methods

Twenty plants of each Lebanese cucumber variety were planted into 0.9L plastic pots (Masrac), tied to 300mm stakes as required and growing tips removed when plants reached the top of the stake. When all plants of a variety had at least one flower at the F1 stage 10 plants were inoculated as previously described with a spore suspension of *B.cinerea* with $10^5$ spores/mL and 10 were sprayed with water only. Five plants of each variety were moved to a controlled environment room with a constant temperature of 14°C and mean relative humidity of 83% and five plants were kept in a greenhouse with mean temperature of 22°C and mean relative humidity of 53%. Varieties were inoculated on different dates because they flowered at different times. Fruit were assessed seven and 14 days after inoculation and mean Botrytis grey mould symptoms rated. Disease progression curves were calculated for each variety at each temperature and humidity regime.

Results and Discussion

At 14°C the most susceptible varieties were Montana and Olympos and the least susceptible variety was Mascot (Figure 79). At 22°C the most susceptible variety was again Montana. Although the level of infection was very low for all varieties any infection of flowers which results in fruit rot will cause yield loss (Figure 80). As in pilot trials conducted for Botrytis grey mould screening trials, symptoms of infection in plants at 22°C were different to symptoms at 14°C and disease severity was also lower at 22°C (Figure 81; Figure 82). At 22°C infected fruit developed a dry patch on the flower end which did not sporulate. When the fruit with this symptom were incubated at high humidity the presence of Botrytis grey mould was confirmed. Regardless of sporulation the patches would likely prevent the fruit from developing properly or render the fruit unmarketable, causing yield loss. No claims are made by seed companies regarding varietal resistance to Botrytis grey mould and any differences seen may be a reflection of the climate to which the variety is most suited rather than differing susceptibility to disease.

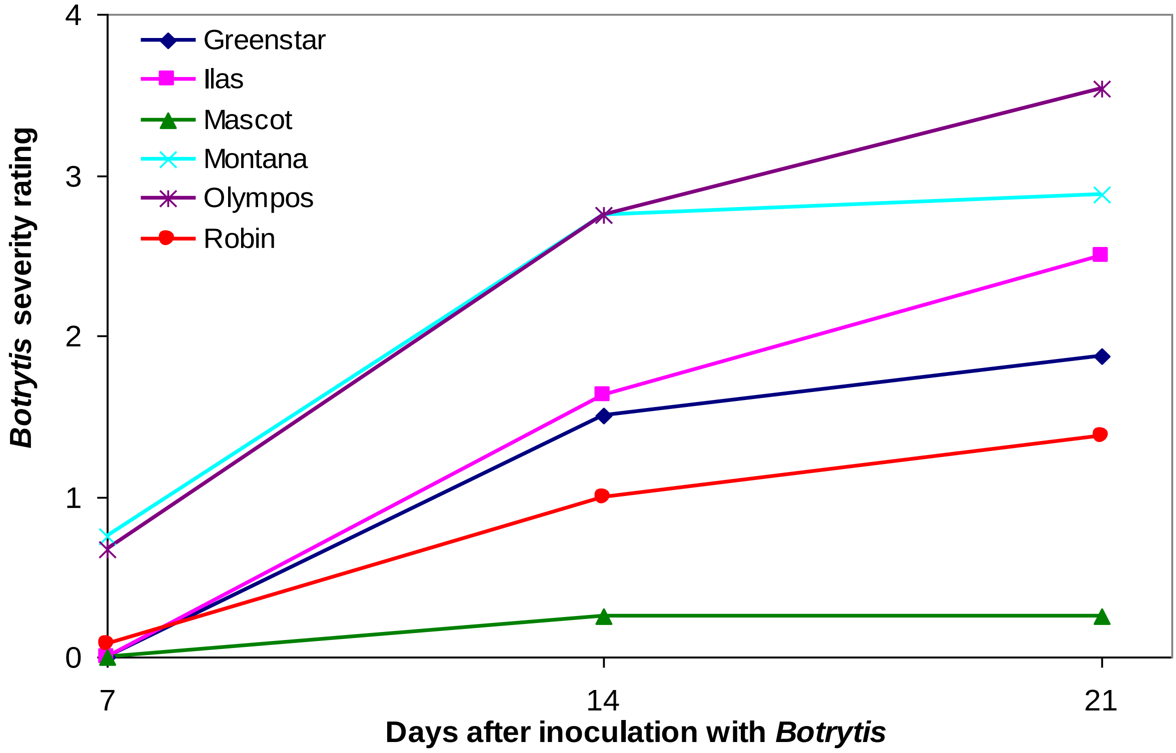



**Figure 79 Disease progress curves for Lebanese cucumber varieties inoculated with Botrytis grey mould in research greenhouse at 14°C**

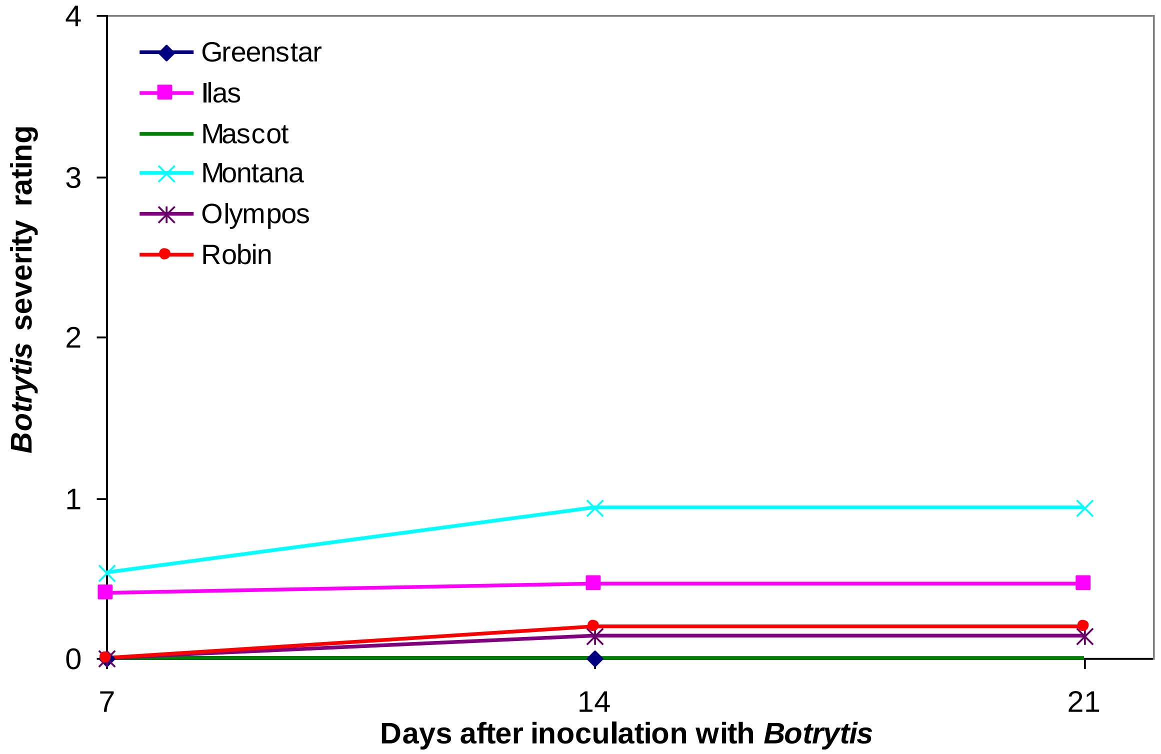



**Figure 80 Disease progress curves for Lebanese cucumber varieties inoculated with Botrytis grey mould in research greenhouse at 22°C**

**Figure 81 Fruit of Lebanese cucumber variety Montana 21 days after inoculation of flower with Botrytis grey mould at 14°C**

**Figure 82 Fruit of Lebanese cucumber variety Montana with dry patch on blossom end 16 days after inoculation of flower with Botrytis grey mould at 22°C**

### 4.8.4. Botrytis grey mould on capsicum

Three capsicum varieties Biela, Raptor and Remy from Syngenta Seeds were evaluated for susceptibility to *Botrytis cinerea*.

Materials and methods

Fourteen seeds of each variety were planted into cocopeat potting mix in 200mL pots and tied to 1m stakes as required, pruned to 2 main stems. When all plants of a variety had flowers either full size but not open, beginning to open, or fully open, the flowers on seven plants of each variety were inoculate as previously described with a spore suspension of *B.cinerea* $10^5$ spores/mL and moved into a controlled environment room with a mean temperature of 14°C and mean relative humidity of 83%. Fruit from inoculated flowers were examined 7 and 14 days after inoculation and mean Botrytis grey mould per plant rated.

Results and Discussion

Of the three varieties trialled, Biela, Remy and Raptor, only two flowers on two separate plants of the Raptor variety developed into fruit infection which was not sufficient to accurately evaluate varietal susceptibility. No claims are made by seed companies regarding resistance to Botrytis grey mould in capsicum varieties.

### 4.8.5. Conclusions

De Ruiter seeds and Rijk Zwaan, the breeders of Lebanese cucumber varieties Mascot, Montana, Khassib and Deltastar claim these varieties have a “high level of partial resistance to powdery mildew”, a claim which means little to a grower. Although there were slight differences between varieties in these trials, the majority of the varieties were highly susceptible to powdery mildew and developed severe infections. The varieties may have shown reduced susceptibility with lower inoculum levels, however in greenhouse environments the levels of natural inoculum can be as high as that used in these experiments.

Differences observed in varieties need to be interpreted in the context of the climatic conditions to which varieties are best suited. For example, Mascot is one of the standard varieties planted on the NAP for winter conditions, so plants in Botrytis grey mould variety trials would have been more suited to the cool conditions under which the trial was conducted. Montana is best suited to spring, summer and autumn crops, and would have been under significant stress at 14°C and potentially more susceptible to disease. The lower rate of infection in Mascot is an important result as it is the variety that is most likely to be growing when conditions in the field are conducive to Botrytis grey mould.

Trials with cucumbers showed some varietal differences in susceptibility to powdery mildew and Botrytis grey mould that could potentially be exploited as part of integrated management programs for these diseases. Use of less susceptible varieties cannot be relied upon solely and will be most effective when used as part of an integrated management program.

Establishing the damage relationship, i.e. the amount of yield loss that results from different levels of disease, was not examined in this project as it requires the establishment of epidemics of different sizes which was outside the scope of this project However, research into the relationships could be of benefit to the industry as growers would understand as what point yield loss begins to occur. The damage relationship has been established for cucumber powdery mildew by Dutch researchers but only for the Dutch high tech greenhouses (Dik 1999). The research showed that as the severity of cucumber powdery mildew increased, yield decreased, and the damage relationship was consistent across various seasons and cultivars. However, the point at which yield was reduced and the cost of spraying versus the cost of yield loss was not reported.

Damage relationships for capsicum powdery mildew have not been determined (Elad 2007). Research from Israel with capsicum powdery mildew showed that disease significantly reduced yield with severe epidemics. If night temperatures in the greenhouse were low, as it is at certain times of the year in unheated greenhouses in Australia, then powdery mildew could also reduce quality (Elad et. al., 2007). The relationship between disease and yield may actually vary throughout the season in non climate controlled protected cropping and so economic losses may also be variable. The researchers suggested that late season disease is unlikely to cause yield losses and fungicide applications late in the season were unlikely to give any benefit (Elad et. al., 2007), but no cost-benefit analyses were actually shown to support that suggestion.

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## 6. Technology Transfer

Research findings contained in this report have been presented to industry by one on one contact with growers, at grower workshops and information sessions and through factsheets and newsletters. Factsheets and newsletters have been translated into Vietnamese as required. Seminars and poster presentations have also been made at industry and scientific conferences in Australia.

**Newsletters/Factsheets:**

- Foliar Diseases in Greenhouse Vegetables Issue 1 March 2007
- Foliar Diseases in Greenhouse Vegetables Issue 2 December 2008
- Greenhouse vegetable foliar diseases identification, December 2008
- Foliar Diseases in Greenhouse Vegetables Issue 3 January 2010

**Industry publications:**

- Article in SA Grower 'Team seeks to deliver on true grower needs', July 2006
- Article in HAL Vegetable industry annual report 2007/08
- Article in PIRSA Primetime 'My research', Autumn 2010

**Newspaper articles**

- Article in The Advertiser (Adelaide) 'Working to keep our vegies free of disease', March 2010
- Article in The Advertiser (Adelaide), August 2010

**Conference proceedings/posters:**

- Poster: K.L. Ferguson, B.H. Hall and T.J. Wicks (2007) Foliar diseases in protected crops. In 'Proceedings of the 16th Biennial APPS conference, Adelaide, p 200.

- Poster: K.L. Ferguson and B.H. Hall (2009) Sustainable integrated control of foliar diseases in greenhouse vegetables, AUSVEG Annual conference, Melbourne 2009

- Invited speaker at the Australian Hydroponic and Greenhouse industry conference, 'Managing leaf diseases in your crop', Sydney NSW, July 2009

- Oral presentation: K.L. Ferguson, B.H. Hall and T.J. Wicks (2009) Evaluation of spray programs for powdery mildew management in greenhouse cucumbers. In: 'Proceedings of the 17th Australasian Plant Pathology Conference, Newcastle, p 89

**Grower information sessions/workshops :**

- Presentation to grower group at "Protected cropping strategic plan meeting", Virginia, South Australia, August 2006
- Grower workshop with Len Tesoriero from NSW DPI, Virginia South Australia, October 2007
- Grower field day with NSW DPI, Sydney Basin NSW, May 2008

**Scientific seminar:**

- 'Foliar diseases in protected greenhouse vegetables'. SARDI Horticulture seminar series, Plant Research Centre, September 2007

**Other presentations:**

- Presentation of research at ‘Green and Groovy’ event held by PIRSA/SARDI highlighting research focussing on sustainability, October 2008
- Presentation to group of high school science teachers as part of GrowSmart field day held at Virginia, South Australia by PIRSA

**Presentations at HAL/Industry meetings**

HAL Greenhouse meeting, July 2006

# 7. Main outcomes

## 7.1. Recommendations – scientific and industry

To sustainably manage foliar diseases in greenhouse vegetable crops growers must take an integrated approach. The strategies that are applicable to the main foliar diseases are outlined below.

### 7.1.1. Powdery mildew

- Check for disease one to two times a week on the lower leaves of cucumber and capsicum crops
- Remove infected leaves from the greenhouse when first detected and apply a protectant spray
- Grow less susceptible varieties
- Experiment with the use of alternative products alone to see if desired levels of control can be achieved in certain crops e.g. short term crops
- Incorporate alternative products into fungicide spray programs to reduce fungicide resistance potential

### 7.1.2. Botrytis grey mould

- Scout the whole plant regularly for Botrytis grey mould as favourable conditions are approaching (late autumn), checking stems, flowers and leaves
- Ensure protectant sprays are applied
- Remove infected plants entirely, ensuring no part of the stem remains that could harbour infection
- Consider heating the greenhouse overnight in cooler periods to increase temperatures and decrease humidity

For all foliar diseases growers must:

- Get accurate diagnosis of diseases including information on the source, cycle and spread so they can understand which management strategies will be effective.
- Protect the use of the available fungicides by understanding fungicide activity groups and resistance management strategies as set out by CropLife Australia.
- Use new fungicides approved for the greenhouse industry with care and following recommendations.
- Seeking training and advice in fungicide selection and spray timing.
- Follow strict greenhouse hygiene as outlined in 'Keep it clean. Reducing costs and losses in the management of pests and diseases in the greenhouse' produced by NSW Department of Primary Industries (Badgery-Parker 2009).

## 7.2. Recommendations – further work

Further research is needed into:

- Establishing damage relationships for powdery mildew in cucumber and capsicum for lower technology greenhouses to determine if growers can cease fungicide use when it is not economical justified.
- Sanitisers like PathX™ and alternative products like Silmatrix™ to evaluate crop and human safety, effects on beneficial organisms and determine residue limits
- Sourcing efficacy data for new fungicides so that registration can be sought in the greenhouse industry.
- Improved spray application technology in low-medium technology greenhouses to improve conditions for workers and coverage of plants.

## 8. Acknowledgements

We wish to acknowledge and thank the greenhouse growers who participated in the surveys as part of this project and who provided access to greenhouses for disease surveys, climate data logging and trials. A special thank you to Andrew and Zurriyet Braham, Rudy and Veda Kotoric, Bill and Emmanuel Cafcakis and Mr Phan Le for providing access to their properties and invaluable chats about disease and production issues.

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We gratefully acknowledge the funding from the Vegetable Industry Levy and the Commonwealth of Australia through Horticulture Australia Limited.

# 9. Appendix

## Grower survey

ID #

**GREENHOUSE SURVEY**

**GROWER'S DETAILS**

**Name:** ____________________

**Address:** ____________________

____________________

**Home:** ____________ **Mobile:** ____________

**Date of survey:** ____________

**CROP DETAILS**

**Which crops do you grow? Which Varieties?**

| Cucumber ☐ | Capsicum ☐ | Eggplant ☐ | Tomato ☐ | Other ☐ |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

W= Winter; S=Summer

**HOUSE TYPE**

**What type of greenhouses do you have?**

Glass ☐ Plastic ☐ Shadecloth ☐

## GREENHOUSE DIMENSIONS

(complete for each greenhouse type on front)

**Plastic** **Glass** **Shadecloth**

| Number of houses | Height (m to gutter) | Width (m) | Area ($m^2$) |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

## GREENHOUSE DETAILS

**What ventilation does house have?**

Side/End ☐ Roof ☐ Doors ☐
Fans ☐ Other ☐ None ☐

**Do you monitor the climate?**

Temp ☐ Humidity ☐ Light ☐ No ☐

**Do you alter the climate?**

Heating ☐ Cooling ☐
Misters ☐ No ☐

**What is the watering system?**

Drip ☐ Sprinkler ☐ Flood ☐ Overhead ☐

**What is the growth media?**

In ground ☐
Hydro ☐
- Peat ☐
- Rockwool ☐
- Soil mix ☐
- Other ☐

## CROP ROTATION

**What is your usual crop rotation?**

## PLANT SPACING

**What plant spacing do you use (no./$m^2$)?**

Cucumber________ Capsicum________
Eggplant________ Tomato________

## SOIL TREATMENTS

**Do you use compost?**

Jeffries ☐ Make own ☐
Peats ☐ Beta-gro ☐
Other ☐
No ☐ (Go to fumigation question)

**How often do you use compost?**

Before every crop ☐ Once/year ☐
As required ☐ Other ☐

**Do you fumigate?**

Telone C35 ☐ Basimid ☐
Met Sod ☐ Other ☐
No ☐ (Go to nutrient testing)

**How often do you fumigate?**

Before every crop ☐ Once/year ☐
Every 2 years ☐ Every 3 years ☐
As required ☐ Other ☐

## NUTRIENT TESTING

Capsicum Cucumber Tomato Eggplant

**Do you do soil tests for nutrients before planting?**

Before each crop ☐ Once/year ☐ As required ☐ Other ☐ No ☐

**Do you do leaf tests for nutrients?**

Regular ☐ If problem ☐ Other ☐ Fruit set ☐ No ☐

## FERTILISER REGIME

(Complete separate sheets if fertiliser or watering regimes are different for each crop)

| Type (Base, Fertigation, Foliar) | Fertiliser | kg/house or kg/m² | Frequency |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
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| | | | |
| | | | |

## WATERING REGIME

| Time of Year | Minutes or hours/house | L/hour through irrigation | Time of Day | Frequency |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

W= Winter; S=Summer

**How do you decide when to water?**

Soil probe ☐ Regular program ☐ Automated ☐ Dig down ☐
Weather ☐

## FOLIAR DISEASES and FUNGICIDE APPLICATION

(Complete for each crop, in each type of house and rate each disease)

0=no problem
1=slight
2=moderate
3=bad
4=really bad

**Capsicum** **Cucumber** **Tomato** **Eggplant**

**Disease** ____________ **Plastic** ☐ **Glass** ☐ **Shade** ☐

**Fungicides Used**

| Fungicide | Wetter | Rate[1] | Rate of water[2] | Frequency |
| --- | --- | --- | --- | --- |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Disease** ____________ **Plastic** ☐ **Glass** ☐ **Shade** ☐

**Fungicides Used**

| Fungicide | Wetter | Rate[1] | Rate of water[2] | Frequency |
| --- | --- | --- | --- | --- |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Disease** ____________ **Plastic** ☐ **Glass** ☐ **Shade** ☐

**Fungicides Used**

| Fungicide | Wetter | Rate[1] | Rate of water[2] | Frequency |
| --- | --- | --- | --- | --- |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

[1](mLs, L or g/100L) [2](L/house or L/ha)

Powdery mildew; Downy mildew; Botrytis; *Sclerotinia*; TSWV, Leaf Spot

## CULTURAL CONTROLS - FOLIAR

**Do you use any strategies other than fungicides to manage foliar diseases?**

Sanitation ☐ Resistant cultivars ☐
Pruning lower leaves ☐ Venting ☐
Other ☐ No ☐

## BIOLOGICAL CONTROLS - FOLIAR

**Do you use biological controls for foliar diseases?**

*Trichoderma* ☐ Would like to try ☐
Other ☐ Trying this year ☐
No ☐ (Go to Cultural Controls)

## FOR MAIN FOLIAR DISEASES

**Do you know where the disease comes from?**

Crop residue ☐ Weeds ☐
Soil ☐ Wind ☐
Neighbours ☐ Insects ☐
Other ☐ No ☐

**Do you know what the favourable conditions are for the disease?**

High humidity ☐ Over-crowding ☐
Free water ☐ Moderate temp ☐
Other ☐ No ☐

**Do you know how disease is spread?**

Wind ☐ Workers/equipment ☐
Water splash ☐ Plant-Plant contact ☐
Other ☐ No ☐

## FOR MAIN FOLIAR DISEASES

**Have you ever had any diseases you couldn't identify?**

Cucumber ☐ Capsicum ☐
Tomato ☐ Eggplant ☐
No ☐ (Go to Spray Decisions)

**Did you get help to identify the disease?**

Consultant ☐ Re-seller ☐
Neighbour ☐ VHC ☐
Government ☐ Other ☐
No ☐

## SPRAY DECISIONS

**How do you decide when to spray?**

Regular program ☐ Monitoring ☐
Weather ☐ Preventative ☐
Other ☐

**How do you decide what to spray?**

Re-seller advice ☐ Cheapest ☐
Whatever in shed ☐ Consultant ☐
Resistance Management Program ☐
Other ☐ WHP ☐

## FUNGICIDE RESISTANCE

**Have you ever thought you had resistance to fungicides?**

**Yes** ☐

Which fungicide/disease?

**No** ☐

## SOIL DISEASES

**Do you have soil diseases?**

Cucumber ☐ Capsicum ☐
Tomato ☐ Eggplant ☐
(If any diseases complete following page)
No ☐ (Go to Cultural Controls – Soil)

## SOIL DISEASES

(Complete for each crop, in each type of house and rate each disease)

0=no problem
1=slight
2=moderate
3=bad
4=really bad

**Capsicum** **Cucumber** **Tomato** **Eggplant**

| Disease | Plastic | Glass | Shade |
|---|---|---|---|
| ______________ | ☐ | ☐ | ☐ |
| ______________ | ☐ | ☐ | ☐ |
| ______________ | ☐ | ☐ | ☐ |

**Capsicum** **Cucumber** **Tomato** **Eggplant**

| Disease | Plastic | Glass | Shade |
|---|---|---|---|
| ______________ | ☐ | ☐ | ☐ |
| ______________ | ☐ | ☐ | ☐ |
| ______________ | ☐ | ☐ | ☐ |

**Capsicum** **Cucumber** **Tomato** **Eggplant**

| Disease | Plastic | Glass | Shade |
|---|---|---|---|
| ______________ | ☐ | ☐ | ☐ |
| ______________ | ☐ | ☐ | ☐ |
| ______________ | ☐ | ☐ | ☐ |

Damping off; Root Rot, *Pythium, Fusarium, Phytophthora, Rhizoctonia*

## CULTURAL CONTROLS – SOIL

**Do you use any strategies other than fungicides or fumigation to prevent soil diseases?**

- Sanitation ☐
- Solarisation ☐
- Steaming ☐
- Resistant cultivars ☐
- Resistant rootstocks ☐
- Crop Rotation ☐
- Other ☐
- No ☐

## BIOLOGICAL CONTROLS - SOIL

**Do you use biological controls for soil diseases?**

| | | | |
|---|---|---|---|
| *Trichoderma* | ☐ | Would like to try | ☐ |
| Other | ☐ | Trying this year | ☐ |
| No | ☐ | (Go to Cultural Controls) | |

## FOR FOLIAR & SOIL DISEASES

**Do you think you could improve your disease management?**

**Yes** ☐

**What would help?**

- Bigger range of fungicides ☐
- Training in:
  - how to spray ☐
  - when to spray ☐
  - what to use ☐
  - recognising diseases ☐
- Diagnostic support ☐
- Alternatives to fungicides ☐
- Other ☐

**No** ☐

## FOR FOLIAR & SOIL DISEASES

**Is it getting harder to manage diseases?**

**Yes** ☐

**Why is it getting harder?**

- Increased production ☐
- Resistance/over-use ☐
- Not enough fungicides registered ☐
- New diseases ☐
- No diagnostic support ☐
- No advice ☐
- Other ☐

**No** ☐

**Estimated loss due to diseases (%)**

## OTHER COMMENTS

## INSECT PESTS and INSECTICIDE APPLICATION

(Complete for each crop, in each type of house and rate each insect pest)

**Capsicum** **Cucumber** **Tomato** **Eggplant**

0=no problem
1=slight
2=moderate
3=bad
4=really bad

**Insect** ____________ **Plastic** ☐ **Glass** ☐ **Shade** ☐

**Insecticides Used**

| Insecticide | Wetter | Rate[1] | Rate of water[2] | Frequency |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Insect** ____________ **Plastic** ☐ **Glass** ☐ **Shade** ☐

**Insecticides Used**

| Insecticide | Wetter | Rate[1] | Rate of water[2] | Frequency |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Insect** ____________ **Plastic** ☐ **Glass** ☐ **Shade** ☐

**Insecticides Used**

| Insecticide | Wetter | Rate[1] | Rate of water[2] | Frequency |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Thrips, Aphids, Mites, Whiteflies, Fungus gnats
[1](mLs or L/100L) [2](L/house or L/ha)

## FOR MAIN INSECT PESTS

**Do you know how insects come into crop & where from?**

Crop residue ☐ Weeds ☐
Soil ☐ Wind ☐
Neighbours ☐ Vents/Doors ☐
Other ☐ No ☐

**Do you know the favourable conditions for insects?**

Low Humidity ☐ Moderate temp ☐
Free water (fungus gnat larvae) ☐
Other ☐ No ☐

**Do you know which insects can carry diseases?**

Thrips ☐ Aphids ☐
WF ☐ Other ☐
No ☐

**Have you ever had any insects you couldn't identify?**

Cucumber ☐ Capsicum ☐
Tomato ☐ Eggplant ☐
No ☐ (Go to Spray Decisions)

**Did you get help to identify the insect?**

Consultant ☐ Re-seller ☐
Neighbour ☐ VHC ☐
Government ☐ Other ☐
No ☐

## SPRAY DECISIONS

**How do you decide when to spray?**

Regular program ☐ Monitoring ☐
Weather ☐ Other ☐

**How do you decide what to spray?**

Re-seller advice ☐ Cheapest ☐
Whatever in shed ☐ Consultant ☐
Resistance Management Program ☐
Other ☐

## INSECTICIDE RESISTANCE

**Have you every thought had resistance to insecticides?**

**Yes** ☐

Which insecticide/insect?

**No** ☐

## BIOLOGICAL CONTROLS - INSECT

**Do you use biological controls in your greenhouses?**

Aphid wasps ☐ Whitefly wasps ☐
Predator mites ☐ Would like to try ☐
Other ☐ Trying this year ☐
No ☐ (Go to Cultural Controls)

**Do you use IPM?**

| Always | Try to | This year | No |
|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ |

## CULTURAL CONTROLS - INSECT

**Do you use any strategies other than insecticides or biological control to manage insect pests?**

Sanitation ☐ Double Doors ☐
Insect Mesh ☐ Resistant cultivars ☐
Other ☐ No ☐

## FOR INSECT PESTS

**Do you think you could improve your insect pest management?**

**Yes** ☐

**What would help?**

Bigger range of insecticides ☐

Training in: how to spray ☐
when to spray ☐
what to use ☐
recognising pests ☐

Diagnostic support ☐

Alternatives to insecticides ☐

Other ☐

**No** ☐

**Is it getting harder to manage insects?**

**Yes** ☐

**Why is it getting harder?**

Increased production ☐

Resistance/over-use ☐

Not enough insecticides registered ☐

New pests ☐

No diagnostic support ☐

No advice ☐

Limited income ☐

Other ☐

**No** ☐

**Estimated loss due to insects (%)**

## MONITORING

**Do you regularly monitor for pests or diseases?**

Daily ☐ Weekly ☐ Fortnightly ☐

Often as possible ☐ Other ☐

No ☐ (Go to Pesticide Application)

**Who does the monitoring?**

Grower ☐ Sticky Traps ☐

Consultant ☐ Workers ☐

## PESTICIDE APPLICATION

**What equipment do you use to apply pesticides?**

Hand Spray ☐ Other ☐

Knapsack ☐

**How do you determine your spray volumes?**

To run-off ☐ L/ha ☐

Other ☐

**Do you calibrate your spray equipment?**

Yes ☐ How often?__________

No ☐

Change Jets ☐ How often?__________

**Do you mix fungicides and insecticides?**

Never ☐ Usually ☐

Sometimes ☐ Only if compatible ☐

## GREENHOUSE HYGIENE

### How do you dispose of old crops?

**CAPSICUM**

Plough in ☐ Manure/Compost ☐
Burn ☐ Recycling service ☐
Rubbish Pile ☐ Other ☐

**CUCUMBER**

Plough in ☐ Manure/Compost ☐
Burn ☐ Recycling service ☐
Rubbish Pile ☐ Other ☐

**TOMATO**

Plough in ☐ Manure/Compost ☐
Burn ☐ Recycling service ☐
Rubbish Pile ☐ Other ☐

**EGGPLANT**

Plough in ☐ Manure/Compost ☐
Burn ☐ Recycling service ☐
Rubbish Pile ☐ Other ☐

### Do you control weeds outside your greenhouses?

Spray ☐ Mulch/gravel ☐ Slash ☐
Clean-up program ☐ No ☐

### Do you use footbaths?

Always ☐ Only if problem ☐
No ☐

## GREENHOUSE HYGIENE

### Do you clean and sanitise your pruning and harvesting equipment?

Sporekill ☐ Bleach ☐
Wipe ☐ Other ☐
No ☐ (Go to info sources)

### How often do you clean/sanitise equipment?

Every use ☐ Weekly ☐
As required ☐ Other ☐

## INFORMATION SOURCES

### Where do you currently get your pest and disease information?

Re-seller ☐ Consultant ☐
Neighbour ☐ Good F & V ☐
The Grower ☐ Government ☐
VHC ☐ Researchers ☐
Other ☐

### How do you most like to get your pest and disease information?

Field days ☐ Workshops ☐
Fact sheets ☐ Consultant ☐
Neighbours ☐ TV/radio ☐
IDO ☐ Publications ☐
One on one ☐ Other ☐

## ANY OTHER GROWER COMMENTS

## MY NOTES

## VAN INTERPRETED

Yes ☐ No ☐

**Results from tomato growers**

**Number of each greenhouse type, technology level and production systems surveyed growing tomatoes in each region**

| Region[1] | Low tech | | | | High tech |
|---|---|---|---|---|---|
| | Plastic | | Glass | Shade | Plastic |
| | Soil | Hydro | Soil | Soil | Hydro |
| **NAP** | 2 | 0 | 2 | 1 | 3 |
| **MB** | 0 | 0 | 5 | 0 | 0 |
| **SB** | 0 | 1 | 0 | 0 | 2 |
| **Totals** | 2 | 1 | 7 | 1 | 5 |

[1] NAP = Northern Adelaide Plains; MB = Murray Bridge; SB = Sydney Basin

## Greenhouse technology level as defined by (Badgery-Parker and James 2010)

### Classifying greenhouses

Greenhouses are a technology based investment. The higher the level of technology used, the greater potential for achieving tightly controlled growing conditions. This capacity to tightly control the conditions in which the crop is grown is strongly related to the health and productivity of the crop. The following three categories of greenhouse have been defined to assist people in selecting the most appropriate investment for their needs and budget.

### Low technology greenhouses

A significant proportion of the industry in Australia currently uses low technology structures. These greenhouses are less than 3 metres in total height. Tunnel houses, or "igloos", are the most common type. They do not have vertical walls. They have poor ventilation. This type of structure is relatively inexpensive and easy to erect. Little or no automation is used.

While this sort of structure provides basic advantages over field production, crop potential is still limited by the growing environment and crop management is relatively difficult. Low level greenhouses generally result in a suboptimal growing environment which restricts yields and does little to reduce the incidence of pests and diseases. Pest and disease control, as a result, is normally structured around a chemical spray program.

Low technology greenhouses have significant production and environmental limitations, but they offer a cost effective entry to the industry.

### Medium technology greenhouses

Medium level greenhouses are typically characterised by vertical walls more than 2m but less than 4 metres tall and a total height usually less than 5.5 metres. They may have roof or side wall ventilation or both. Medium level greenhouses are usually clad with either single or double skin plastic film or glass and use varying degrees of automation.

Medium level greenhouses offer a compromise between cost and productivity and represent a reasonable economic and environmental basis for the industry. Production in medium level greenhouses can be more efficient than field production. Hydroponic systems increase the efficiency of water use. There is greater opportunity to use non-chemical pest and disease management strategies but overall the full potential of greenhouse horticulture is difficult to attain.

**High technology greenhouses**

High level greenhouses have a wall height of at least 4 metres, with the roof peak being up to 8 metres above ground level. These structures offer superior crop and environmental performance. High technology structures will have roof ventilation and may also have side wall vents. Cladding may be plastic film (single or double), polycarbonate sheeting or glass. Environmental controls are almost always automated. These structures offer enormous opportunities for economic and environmental sustainability. Use of pesticides can be significantly reduced. High technology structures provide a generally impressive sight and, internationally, are increasingly being involved in agribusiness opportunities.

Although these greenhouses are capital intensive, they offer a highly productive, environmentally sustainable opportunity for an advanced fresh produce industry. Investment decisions should, wherever possible, look to install high technology greenhouses.

# Foliar Diseases in Greenhouse Vegetables

**Issue 1** **March 2007**

**A new research project examining foliar diseases in greenhouse vegetables commenced in June 2006. The project is funded by the protected cropping industry and the Commonwealth government through Horticulture Australia Limited and runs until May 2009.**

## Aims of Project

- Determine the main disease problems in greenhouse cucumber, capsicum and eggplant crops
- Identify the current strategies used for disease management
- Examine the environmental conditions most suitable for disease development
- Determine areas in which disease management can be improved
- Evaluate alternative fungicides, environmental controls and resistant varieties
- Develop integrated management programs for foliar diseases

Growers in the Northern Adelaide Plains, Murray Bridge and Sydney Basin were surveyed from July to December 2006 to determine their main foliar disease problems and current management strategies. A total of 78 crops were surveyed comprising cucumbers, capsicums, eggplants and tomatoes. This newsletter outlines the results of the survey and the future work that is planned as part of this research project.

## Foliar Diseases

**Powdery Mildew**

- Most common disease in all crops surveyed
- 100% of cucumber, 85% of capsicum and 87% of tomato crops affected
- Disease most severe in cucumbers

**Powdery mildew on cucumber (above) and capsicum (right)**

**Downy Mildew**

- 55% of cucumber crops affected, not as serious as powdery mildew

**Downy mildew on cucumber**

**Grey mould (*Botrytis*)**

- 23% of capsicum crops affected, moderate problem
- 36% of tomato and 10% of cucumber crops affected, only slight problem
- Big problem in winter
- 16% of growers do not grow over winter to avoid disease

**Bacterial (Black) Spot**

- 13% of tomato crops affected, moderate problem
- 8% of capsicum crops affected, only a slight problem

## Disease Management

Most growers surveyed use several different methods to manage foliar diseases.

**Fungicides**

- Main method of management for majority of foliar diseases
- When disease pressure high or conditions are favourable for disease growers may spray every 7-10 days
- Some growers relying on one fungicide only
- Lack of fungicides registered for greenhouse restricts choice
- 20% of growers selecting inappropriate fungicides e.g. Bravo and Ridomil do not work against powdery mildew

**Cultural Methods**

- Venting greenhouses to reduce humidity
- Pruning lower leaves to increase airflow around plants and remove diseased material
- Disposal of prunings and crop residues
- Growing of disease resistant varieties

**Disease Management Getting Harder**

Nearly half of the growers surveyed said it was getting harder to manage diseases because of:

- Over-use and mis-use of fungicides
- Increased disease pressure
- Increased production
- Constant workload associated with spraying fungicides.

# Foliar Diseases in Greenhouse Vegetables

**Issue 1** **March 2007**

### Improving Disease Management

Half of all growers surveyed thought they could improve their disease management with:

- Access to a bigger range of fungicides from different groups
- Training in which fungicides to use and spray timing.

### Fungicide Resistance

There is an extremely high risk of developing resistance to many of the fungicides currently used in greenhouses because:

- Disease pressure is often high
- Many growers using only one fungicide or fungicides from the same group
- Over-use of fungicides.

Cucurbit (cucumber) powdery mildew readily develops resistance to fungicides from a range of different groups.

- 7% of growers in the survey thought they had experienced fungicide resistance
- Lack of chemicals registered for greenhouses restricts fungicide choice

### Managing resistance

Until permits are obtained for alternative fungicides there are several practices commonly used to manage resistance.

- Do not continually spray with the same fungicide
- Rotate fungicides from different groups, not just those with different product names or different active ingredients
- Spray early in disease development

A complete list of fungicide groups and more information on managing fungicide resistance can be found at www.croplifeaustralia.org.au under the Stewardship menu.

- Only 35% of growers surveyed said they consider resistance management when making fungicide choices

### Greenhouse Hygiene

Many fungi that cause diseases survive between crops on crop debris and on weeds inside and outside greenhouses. Cleanliness of properties was a major concern for many growers in the survey.

- Old crops left inside houses for prolonged periods
- Crop debris, weeds and rubbish outside houses
- Many growers are not doing as much as they could to keep their properties clean
- Disposal of diseased material and removal of weeds is a critical part of a disease management program

**Prunings can harbour disease and re-infect crops**

**Datalogger in cucumber crop**

### Environmental monitoring

- Dataloggers recording temperature and relative humidity set-up in 5 commercial greenhouses
- Fortnightly assessments of disease levels

### Future Work

**Trials for alternative fungicides**

- Fungicides from different groups and biological controls will be screened in the research glasshouse
- Products showing promise will be trialled in commercial greenhouses
- Initial trials with powdery mildew in cucumbers and capsicums
- Trials with *Botrytis* and downy mildew when diseases appear later in year

**Environmental manipulation**

- Determine conditions that are favourable for disease outbreaks
- Help growers make better decisions about venting houses to prevent disease

**Disease workshops**

Regular workshops on diseases will be run for growers by SARDI and the Virginia Horticulture Centre. The workshops will cover:

- Disease diagnosis
- Spray timing
- Resistance management
- Greenhouse hygiene.

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We would like to acknowledge funding from the Vegetable Industry and the Commonwealth Government through Horticulture Australia

# Foliar Diseases in Greenhouse Vegetables

**Issue 2** **December 2008**

**This newsletter is an update on the research project aimed at improving the sustainability of foliar disease management in greenhouse vegetables. The project commenced in June 2006 and is funded by the Vegetable Levy and the Commonwealth Government through Horticulture Australia Limited.**

Issue 1 was sent out in March 2007 and outlined the aims of this project and the outcomes of the grower survey conducted in the initial stages of the project. Copies of Issue 1 are available on request.

The main outcomes of the research so far are:

- Powdery mildew occurs all year and is not managed effectively by humidity control
- Botrytis grey mould, Sclerotinia rot and downy mildew all require high humidity, occur more in winter and spring, and can be reduced by effective humidity control
- Venting is an effective way of managing humidity and can minimise some diseases
- Fungicide trials on cucumber powdery mildew show that early control is best, which minimises build up of the fungus. Once the mildew infection is severe, fungicides are ineffective.

### Foliar Diseases

Some foliar diseases are a problem all year round. Other diseases are only a problem at certain times of the year because they rely on specific climatic conditions such as high humidity to infect plants and grow. Correct disease identification is crucial to ensure that you are choosing the right management strategies for a disease. For example some growers still confuse powdery mildew with downy mildew, which could lead to choosing an inappropriate management strategy such as an ineffective fungicide.

The symptoms of the main foliar diseases seen in this project and the conditions that favour them can be found in the 'Greenhouse Vegetable Foliar Disease Identification' factsheet sent out with this issue.

### Greenhouse Climate and Disease

Temperature, relative humidity and the incidence and severity of foliar diseases has been recorded at 4 commercial greenhouse properties over the last 2 years. This data is being collected so we can look at how the greenhouse climate affects different diseases. This could help growers manipulate their greenhouse climate to help minimise the risk of disease.

- Powdery mildew does not need high humidity → can infect plants and grow at 0-100% relative humidity
- Reducing the humidity in the greenhouse is unlikely to be effective for minimising powdery mildew infection
- *Botrytis*, downy mildew and *Sclerotinia* need high humidity (>90%) → mainly found in winter and spring
- Reducing the humidity in the greenhouse will help to minimise infection → could mean don't have to spray



**Greenhouse venting – end doors only (left), ends up and roof vents (centre), sides up (right)**

**Reducing Greenhouse Humidity**

The easiest way to reduce humidity in the greenhouse is by venting. The type and number of vents in a greenhouse will affect the amount that humidity can actually be reduced. Some greenhouses only have very limited venting.

- In some greenhouses even when all vents are open humidity still very high (>90%)
- In other greenhouses ventilation more effective → humidity does not stay above 90% for prolonged periods
- For some growers may be worth investigating more effective ventilation

**Alternative Fungicides & Spray Programs**

Eighteen products have been assessed in greenhouse screening trials against cucumber powdery mildew. The trials included fungicides from 5 different resistance management groups as well as 'soft' products like oils and plant health products.

- Several products very effective against powdery mildew but relevant chemical company unwilling to support an application for a permit for greenhouse use
- Some products effective against powdery mildew but caused phytotoxicity → not suitable for use
- All results showed powdery mildew must be controlled early otherwise you cannot restrict the disease
- Soft options may have to be sprayed more often than fungicides to be effective
- Results from screening trials used by reviewers at SARDI when advising on APVMA permit applications for S.A.
- Spray programs being developed using fungicides only, 'soft' products only or fungicide and 'soft' in combination
- Spray programs will be trialled in commercial greenhouses in coming months

One of the reasons that some chemical companies are reluctant to support permits or registration for their products to be used on greenhouse crops is that the greenhouse industry has a reputation for use and abuse of pesticides. Your spray program needs to incorporate fungicides from different activity groups to reduce the risk of fungicide resistance. YOU CANNOT RELY ON ONE FUNGICIDE ONLY!

**Integrated Disease Management**

There is much more you can do to manage foliar diseases than just relying on fungicide sprays. Integrated disease management combines different strategies into a program to manage diseases in a sustainable way.

- Where possible change the climate in the greenhouse to make the environment less favourable for diseases
- Use spray programs that rotate fungicides from different activity groups
- Plant varieties that are less susceptible to disease
- Keep greenhouse free of plant debris that can harbour disease
- Maintain a zone around greenhouses free of weeds and rubbish

**In the next issue**

- Results from spray program trials
- Results from variety trials

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# Foliar Diseases in Greenhouse Vegetables

**Issue 3** **January 2010**

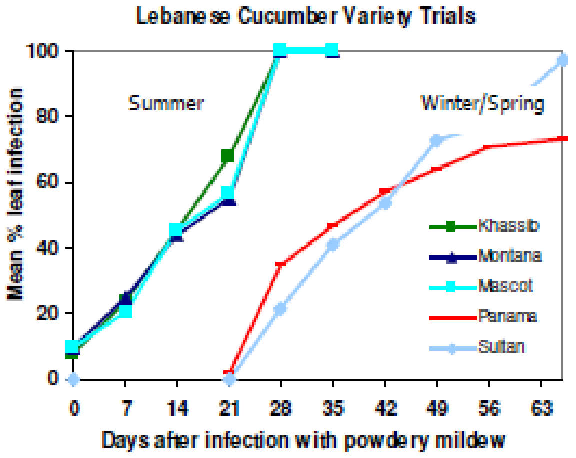
**This newsletter is an update on the research project aimed at improving the sustainability of foliar disease management in greenhouse vegetables. The project commenced in June 2006 and will conclude in July 2010 and is funded by the Vegetable Levy and the Commonwealth Government through Horticulture Australia Limited. Copies of Issue 1 (March 2007) and Issue 2 (December 2008) available on request.**

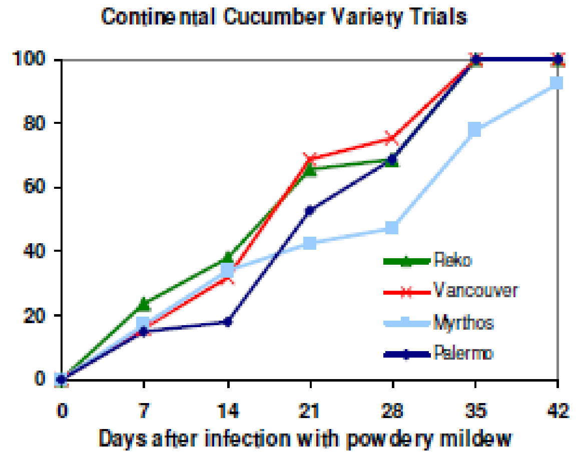
**In this issue:** Variety Trials for Cucumber and Capsicum Powdery Mildew

## Cucumber Varieties

Fourteen Lebanese and seven continental varieties were evaluated for resistance to powdery mildew. Results showed;

- All varieties were susceptible
- Disease progressed more rapidly in summer
- Some varieties had less disease later (e.g. Panama and Myrthos)
- Some varieties showed a delay in the onset of powdery mildew (e.g. Palermo)




Implications for management:

→ Start management early, especially in summer

→ Varieties with delayed disease onset could give you time to spray while infection is still low

→ Less susceptible varieties could allow production to be extended by 2 or 3 weeks

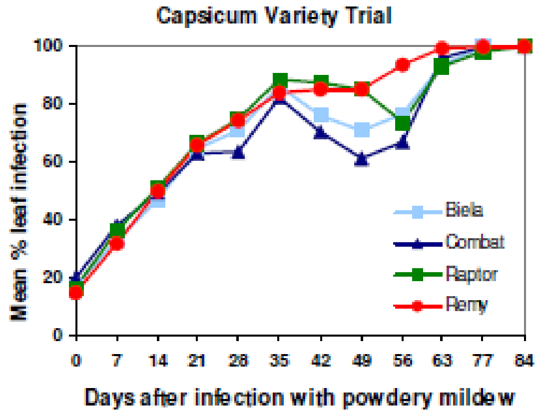
## Capsicum Varieties

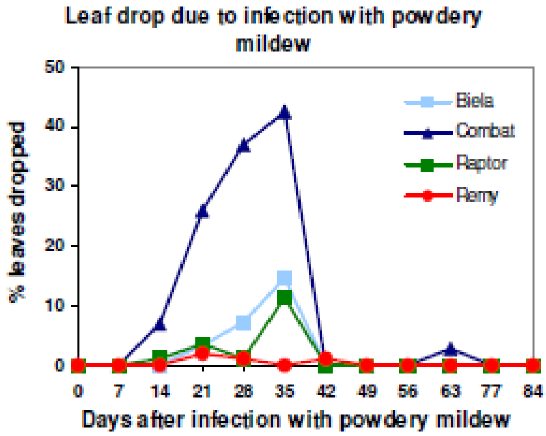
Results from 4 capsicum varieties are shown (right)

- All varieties were susceptible
- Disease developments was similar in all varieties up to Day 28
- Infection decreased in Biela and Combat due to drop of severely infected leaves (below right)
- Remy had severe infection but didn't drop leaves

Implications for management:

Using varieties that don't drop leaves provides protection for fruit from sunscald and maintains photosynthetic ability




**CONCLUSIONS**

**Varietal selection can help manage powdery mildew on cucumbers and capsicums by:**

- **Delaying the onset of disease**
- **Having less disease, particularly late in the crop**
- **Retaining leaves during severe infections**

**Less susceptible varieties will not halt the spread of powdery mildew completely and must be used as part of an integrated management program**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**In the next issue May 2010:**
Spray program trials for powdery mildew


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# Identification of Greenhouse Vegetable Foliar Diseases

## Powdery mildew

- Problem in greenhouse vegetables the whole year
- Favours temperatures around 20-25°C
- Does not need high humidity to establish or grow
- Usually appears on the oldest leaves first

- In cucumber white powdery growth appears on top and bottom of the leaves

- In capsicum the white powdery growth usually begins on the bottom of leaves (left)
- Yellow lesions can often be seen on top of infected capsicum leaves (right) that should not be confused with downy mildew
- Powdery mildew will also grow on top of capsicum leaves

- There are several different species of powdery mildew
- The powdery mildew that infects cucumbers is different to the one that infects capsicums and eggplants

**Do not confuse powdery mildew with downy mildew!!!**

## Downy mildew

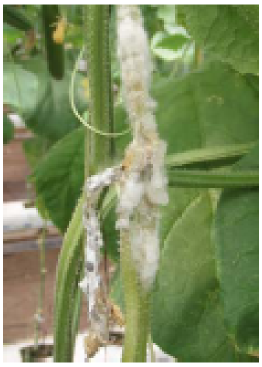
- Needs high humidity and temperatures around 20-25°C
- Usually seen in spring
- Yellow lesions appear first on older leaves
- Lesions are characteristically bordered by leaf veins so appear very angular
- Produces greyish fluff on undersides of lesions only
- Only infects cucumber – not known on capsicum

- Leaves infected with powdery or downy mildew will usually wither and die, leaving fruit exposed to sunscald
- Mildew does not infect the fruit directly
- Severe infections will shorten the life of the crop and reduce yield

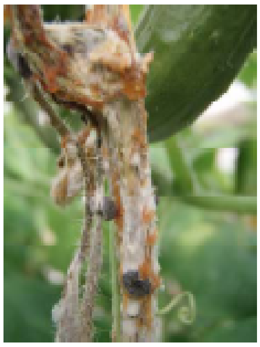
## *Botrytis* (Grey mould)

- *Botrytis* needs high humidity to develop and favours mild temperatures around 18-24°C
- Growth is grey and fluffy
- Infects through flowers and causes flower or fruit rot (left) or through pruning wounds and causes a stem rot that can kill plants (right)
- It is usually seen during the winter and spring months

## *Sclerotinia*



- Cool-mild temperatures and high humidity favour *Sclerotinia*
- It is usually seen during winter and early spring
- Growth is white and fluffy
- *Sclerotinia* forms characteristic survival structures that look like mouse droppings (right)
- It causes fruit rot or stem rot that can kill plants (left)



**Make sure you know what disease you are trying to control!**
- Correct disease identification is crucial to effective management of a disease
- If you aren't sure then find out

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# Foliar Diseases in Greenhouse Vegetables

Issue 4 August 2010

**This newsletter is an update on the research project aimed at improving the sustainability of foliar disease management in greenhouse vegetables. The project commenced in June 2006 and has now concluded and was funded by the Vegetable Levy and the Commonwealth Government through Horticulture Australia Limited.**

## Spray trials for powdery mildew on cucumbers

### Fungicides

- 10 fungicides trialled that are used for powdery mildew in other crops or overseas
- Nufarm has several fungicides they are interested in registering in greenhouses and trials will be conducted by SARDI in coming months
- Some effective fungicides not supported by chemical companies for use in greenhouses:
  - high risk of developing resistance
  - greenhouse industry has reputation for 'use and abuse of pesticides'

### Alternative products

**3 sprays at fortnightly intervals beginning at first sign of disease**

- Path X™ highly effective but **not registered as foliar spray on food crops** → registration needs research into residue limits, crop and human safety data
- Ecocarb®+Synertrol® Horti Oil → effective, permit for use until September 2012
- Silmatrix™ → effective, not registered in Australia
- XPress®+Sett Enhanced™ → not effective alone but may work as part of program

### Spray programs

- Fungicide programs trialled in research greenhouse – best results with protectant sprays like Morestan® or Bayfidan® before disease develops or as soon as disease detected
- If sprays are well timed and have good coverage, 14 day spray intervals may be adequate
- Trials in commercial greenhouse – programs of alternative products alone were more effective than programs that had Amistar® early

# Foliar Diseases in Greenhouse Vegetables

Issue 4 August 2010

**There's more to disease management than just spraying**
**Integrating strategies is the most effective and sustainable way to control disease**

## Powdery mildew

- Check regularly for on the lower leaves of cucumber and capsicum crops and being management at the first sign of disease
- Remove infected leaves from the greenhouse when first detected and apply a protectant spray
- Grow less susceptible varieties
- Experiment with the using a program of alternative products
- Incorporate alternative products into spray programs to reduce fungicide resistance risk

TO BE EFFECTIVE SPRAYS MUST START BEFORE OR AS SOON AS DISEASE IS DETECTED

DON'T LET POWDERY MILDEW GET ESTABLISHED!

## Use fungicides responsibly

- Check for registered and permitted fungicides at www.apvma.gov.au
- Check for resistance management strategies at www.croplifeaustralia.org.au
- Alternate fungicides from as many different groups as possible – Check number or letter next to 'Group' on the label
- Don't use fungicides from Group 3 (C) or 11 (K) if there is already a lot of disease – won't be effective and greatly increases the chance of developing fungicide resistance

USE NEWLY APPROVED FUNGICIDES WITH CARE AND FOLLOW RECOMMENDATIONS

ONLY RESPONSIBLE FUNGICIDE USE WILL CHANGE THE REPUTATION OF YOUR INDUSTRY

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# Foliar Diseases in Greenhouse Vegetables

**Issue 5** **August 2010**

**This newsletter is an update on the research project aimed at improving the sustainability of foliar disease management in greenhouse vegetables. The project commenced in June 2006 and has now concluded and was funded by the Vegetable Levy and the Commonwealth Government through Horticulture Australia Limited.**

## Screening products for *Botrytis* on cucumbers

### Fungicides

- 4 fungicides evaluated that are used for *Botrytis* in other crops or overseas
- New products from Nufarm and Bayer effective and may be supported for greenhouse use by chemical companies
- Further trials are needed to evaluate efficacy and establish residue limits

### Alternative products

- Ecocarb®+Synertrol® Horti Oil and EcoProtector™ were somewhat effective when sprayed one day before plants were inoculated with *Botrytis*
- A bacteria showed some promise and further trials are needed
- *Trichoderma* needs more trials done to find isolates that grow at the lower temperatures that favour *Botrytis*

### Spray Programs

- Protecting flowers and stem wounds is key
- Spray early to stop disease from establishing
- Alternate fungicides from as many different activity groups as possible – Check number or letter next to 'Group' on label

# Foliar Diseases in Greenhouse Vegetables

Issue 5 August 2010

**There's more to disease management than just spraying**
**Integrating strategies is the most effective and sustainable way to control disease**

## *Botrytis*

- Scout regularly for *Botrytis* as favourable conditions are approaching (late autumn/winter) checking stems, flowers and leaves
- Remove infected plants from greenhouse entirely, ensuring no part of the stem remains that could harbour infection
- Spray protectants when conditions are favourable and try alternative products
- If economically viable, consider heating the greenhouse overnight in cooler periods to increase temperatures and decrease humidity

## Use fungicides responsibly

- Check registered and permitted fungicides at www.apvma.gov.au
- Protect the use of the registered fungicides by understanding fungicide activity groups and resistance management strategies (www.croplifeaustralia.org.au)
- Use new fungicides approved for the greenhouse industry with care and follow recommendations

**ONLY RESPONSIBLE FUNGICIDE USE WILL CHANGE THE REPUTATION OF YOUR INDUSTRY**

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# Foliar diseases in protected crops

K.L. Ferguson, B.H. Hall and T.J. Wicks
South Australian Research and Development Institute (SARDI), GPO Box 397, Adelaide SA 5001.

Protected cropping (greenhouse) growers were surveyed to identify the main foliar diseases affecting their crops and the current management strategies used, to determine how disease management can be made more sustainable.

## METHODS

Thirty-one growers were surveyed in the Adelaide Plains (SA), five in Murray Bridge (SA) and seven in the Sydney Basin (NSW). The survey covered greenhouse type, crops grown, incidence and severity of diseases and disease management strategies, knowledge of disease cycles and favourable conditions for disease development. A total of 78 crops were surveyed comprising cucumbers, capsicums, eggplants and tomatoes.


Powdery mildew on cucumber


Downy mildew on cucumber


Prunung debris between rows


Soil-grown capsicums

## RESULTS

### Foliar Diseases

- Powdery mildew most common foliar disease in all crops
- Downy mildew in 60% of cucumber crops, not as severe as powdery mildew
- Botrytis not major problem, probably due to unseasonably dry weather in previous season

### Fungicides

- Growers often spray every 7-10 days when disease pressure high
- Lack of registered fungicides severely restricts options for resistance management
- Disease management made more difficult by over-use and mis-use of fungicides
- 50% of growers thought they could improve their disease management with access to a wider range of fungicides and with training in fungicide selection and spray timing

### Cultural Management Methods

- All growers vent houses to reduce humidity and help prevent disease
- 77% of growers prune lower leaves to increase airflow and remove diseased material from plants
- Not all growers clear prunings from house which can provide inoculum source for re-infection of crop
- Sanitation on neighbouring properties was major concern for many growers

### Soil vs Hydroponics

- Hydroponic growers in the Sydney Basin reported less disease problems than soil growers in South Australia
- Extra investment in hydroponic compared to soil-grown crops may result in extra vigilance by growers
- Growers in Sydney Basin had good understanding of sanitation and hygiene


Botrytis on cucumber


Powdery mildew on capsicum


Buffer zone around greenhouses


Hydroponic cucumbers

## CONCLUSION

Lack of registered fungicides was identified as one of the major threats to sustainability of the industry. There is a need to educate growers on how to integrate sustainable disease management practices into their existing systems.

**Acknowledgment**
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