Management of powdery mildew in field and greenhouse cucurbits

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Department of Employment,
Economic Development & Innovation

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This report summarises the results of a three-year study examining integrated management strategies for powdery mildew in field and greenhouse cucurbits. It is the final report for the project VG05054 "**Management of powdery mildew in field and greenhouse cucurbits"** outlining the work undertaken and the outcomes achieved for the Australian vegetable industry.

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Media Summary

Powdery mildew is caused by the fungus *Podosphaera xanthii* which is widespread in many cucurbit production districts. The disease can seriously affect the yields of cucurbit crops in different tropical and subtropical environments, where the crops are predominantly grown in Australia. Powdery mildew is an all-season disease and becomes a problem on plantings where no protective measures are used. It can be controlled with regular sulphur fungicide sprays. In farms where conditions favour the rapid establishment and spread of the disease, systemic fungicides can further enhance its control, but only if properly timed to commence with initial infections.

The project's focus was to investigate conditions that favour the development of powdery mildew epidemics in cucurbits which could be used as a guide to make spray decisions; investigate if resistance has developed to any of the fungicides being used for its control, and establish sustainable options to manage the disease.

Of the many zucchini varieties currently grown in Australia, *Crowbar, Amanda* and *Calida* were shown to have good levels of resistance to powdery mildew. *Calida* and *Crowbar* also showed multiple resistances to viruses. Among pumpkin cultivars, most of the "Jap" varieties as well as *Sampson* and *Early Jaragray* showed good powdery mildew resistance.

A number of alternate fungicide products were tested to determine their effectiveness in protecting against powdery mildew. Several of them proved to be good protectants and were shown to be effective in breaking the continuous use of the systemic fungicides. The integrated use of these products could result in prolonging the effectiveness of systemic fungicides, when used in a carefully planned resistance management program.

There have been some recent concerns of possible resistance to the current systemic fungicides registered for powdery mildew control on cucurbits. This study investigated and confirmed that resistance has indeed developed against some of these fungicides. New strategies are urgently needed to slow down the resistance breakdown process in areas where it is still not apparent.

Even though the project investigations were carried out mainly on pumpkins, zucchinis and squash, new strategies need to consider how to incorporate melons in the production system. This is because the same fungus attacks all cucurbit crops. Regulating production practices in some and not the others may not work in most production areas where all the cucurbit crops are grown. It will be necessary for melon growers, in the absence of an industry levy, to consider some form of a voluntary contribution, so that future follow-up studies could be carried out comprehensively on all the cucurbit crops.

Based largely on these studies, a set of guidelines were developed and distributed to cucurbit growers in different production regions and districts during industry presentation workshops that followed the conclusion of the project.

This project has established that disease resistant varieties to powdery mildew are available within the different cucurbit species and cultivars being planted in the different cucurbit production zones of Australia. They should be considered and incorporated as an integral part of any integrated management program of the disease. There is evidence that resistance has already developed against some of the systemic fungicides currently registered and recommended for use in managing powdery mildew on cucurbits. To limit the widespread development of resistances, more careful planning of spray programs is needed, taking into consideration all aspects of fungicide resistance management. Incorporating some of the softer fungicide options identified from research in such programs can be a useful way of managing the disease sustainably without risking the loss of systemic fungicides which are very effective when used correctly and in areas where resistance to them has not developed.

Technical Summary

Powdery mildew caused by the fungus *Podosphaera xanthii* (Castagne) is a very common disease on cucurbits in all production areas of Australia. The disease occurs on both greenhouse and field grown cucurbits. Crop losses due to the disease may be very severe when seasonal conditions favour its development and spread and when no effective management strategies are in place.

The disease has mostly been kept under regular check with the use of regular fungicide sprays including protectants and four systemic fungicides currently registered for use in controlling the disease in Australia. In more recent years, however, the disease intensity has been increasing in some regions, even with the repeated use of these fungicides. There has been concern that the pathogen may have developed resistance to the systemic fungicides and that more sustainable approaches may be needed to manage the disease in endemic areas.

The objective of this study was therefore to investigate if resistance to the systemic fungicides has developed and to collect epidemiological data that could be used to predict the occurrence of the disease so that fungicides sprays could be strategically used to limit the extent of resistance development. It was also the aim of the project to evaluate other options that could be integrated with judicious fungicide sprays in integrated disease management programs to more effectively manage the disease in a sustainable way.

A cross-sectional grower survey of the major cucurbit production regions, in the northern Queensland production regions of Australia, revealed that powdery mildew was indeed a major disease for which a substantial part of the crop production costs was devoted, mainly in continuous fungicide spray programs.

A series of field trials and experiments were initiated during the 2006 season and carried out over the 3 year study period to investigate other options that could be integrated with the seasonal sprays to cut back on the number of sprays without compromising on disease control. Studies were also conducted on a range of pathogen isolates from across the major production areas of Australia to determine pathogenicity shifts against the current systemic fungicides.

Extensive field screening of zucchini, squash and pumpkin cultivars identified many varieties with good levels of resistance to powdery mildew. These are suggested to be the preferred varieties in locations with highly favourable conditions for disease epidemics. From zucchini, the resistant selections included 3 varieties namely; *Amanda, Crowbar* and *Calida.* From pumpkins, most of the "Jap" varieties including 2 others; *Sampson* and *Early Jaragrey*, were selected as being resistant. Some zucchini varieties such as *Crowbar* and *Calida* exhibited multiple resistances to both prevailing viruses and powdery mildew.

From the isolate collection study undertaken, it was established that resistance had already developed to some of the systemic fungicides used for the management of powdery mildew. This was clearly the case in both the Bundaberg and Burdekin regions where samples were collected and characterised. Some farms had a disturbing finding of resistance having developed against all the four systemic fungicides in use, while in others one or a few had shown signs of resistance. These findings confirmed the worries of some of the growers, especially around the Bundaberg and Burdekin districts, who strongly suspected this to be the case, because of the lack of an effective response from multiple systemic fungicide sprays.

The confirmation of fungicide resistance in some of the farms is of major concern. The affected farmers will be advised to take additional measures to ensure that their future spray programs are stringent and based on recommended parameters and monitoring to ensure spray efficacy. Follow up additional screenings will be needed to identify new chemistry to replace the ineffective chemicals in use in some of these regions.

Epidemiology data was collected to help develop some disease predictive schedule and establish a forecasting system. These data were very inconsistent with observed disease trends and no definitive conclusions or recommendations could be made. The disease threshold of two percent infection (one leaf in fifty showing first signs of infection) as a guide to initiate the first systemic fungicide spray in a disease management programme was confirmed to be a useful guide and is being recommended for use in farms that use scouting services, to determine when sprays should be made.

Among the products evaluated for control of powdery mildew under field infection conditions, sulphur was still shown to be very effective as a protectant in slowing down the spread of the disease. The other softer options such as silicon, milk and foliar fertilizers such as Ecocarb were shown to play an effective role in integrated disease management programs but generally their effectiveness under high disease pressure was only enhanced when the spray period was shortened. The activator, Bion was quite effective in delaying disease initiation and spread, especially on pumpkins where it gave better control than the industry standards in most of the trials.

The alternatives to protectant fungicide were evaluated in integrated disease management trials with systemic fungicides, and shown to be effective in breaking the continuous use of the systemic fungicides sprays. If used in such programs, this should prolong the effectiveness of these systemics; especially in areas where resistance has not yet been detected and where carefully managed resistance management practices can be implemented.

This project established that genetic resistance, where available, should be the backbone of any integrated disease management program. Grower surveys have shown that they would readily select resistant varieties if readily available. Some cucurbit species and cultivars currently grown in Australia have good levels of resistance to powdery mildew. These should be identified in every production region and incorporated as an integral part of the sustainable management of powdery mildew in cucurbits.

Concerns expressed about fungicide resistance developing in populations of powdery mildew in some cucurbit production districts were confirmed. It is therefore important to identify and promote effective fungicide resistance management strategies to limit the development of fungicide resistance across the different cucurbit production regions and districts. Incorporating some of the fungicide alternatives identified from the research into powdery mildew management programs can be a useful way of managing the disease sustainably.

Chapter 1: General Introduction

Powdery mildew in cucurbits

Powdery mildew is a very common disease on cucurbits in all production areas in Australia and around the world. The disease occurs in cucurbits grown under both field and greenhouse conditions. Crop losses due to the disease may be very severe when conditions favour its development and spread. The disease is caused by the fungus *Podosphaera xanthii* previously known as *Sphaerotheca fuliginea.* This fungus consists of several races, with some attacking all cucurbits while others have a host range limited to only certain types of cucurbits.

Symptoms of powdery mildew

Symptoms of powdery mildew are often easier to identify than symptoms of any other disease, because powdery mildew forms obvious pads of whitish mycelium on upper and lower leaf surfaces, petioles, and stems of affected plants (Figures 1.1 - 1.5). They appear as a white powdery mass composed of fungal strands and countless numbers of spores on these affected surfaces. The powdery growth tends to develop first on older leaves, on shaded lower leaves and the under-surfaces of leaves. Under favourable environmental conditions the entire upper surfaces of older leaves becomes covered with the fungus (Hansen, 2000). Typically, symptoms begin to develop as plants start to produce fruit. Severely infected leaves loose their normal dark green colour, turn pale yellow, and then brown, and finally shrivel up and die, sometimes leaving cucurbit crops exposed to sunburn (Figures 1.6 - 1.8). Cucurbit fruits tend not to be directly attacked by the fungus. However, they may become malformed or sunburnt due to loss of foliage cover. Severe infections may cause the reduction in number and size of fruit (Hansen, 2000).

The powdery mildews are examples of a polycyclic or multi-cyclic group of pathogens which produce multiple new generations of spores during the growing season. They can cause disease over a wide range of environmental conditions. However, several environmental factors may directly affect the development of this disease on cucurbits; among them are: temperature, relative humidity and light. Temperature and humidity must be examined together since it is the water vapour pressure deficit that has the greatest effect on host-parasite interactions (Jarvis *et al.*, 2002). Like other powdery mildew fungi, *P. xanthii* is an obligate parasite and will grow and survive only on living plant tissue. In general, powdery mildews do not require moist conditions to establish and grow, and normally will do well even under warm and dry conditions. During periods of intensive dew on leaf surfaces, the severity of the disease is enhanced. However, excessive water on the leaf surface is often detrimental to the development of powdery mildew disease (Jarvis *et al.,* 2002). The pathogen can infect leaves under relatively dry conditions if the inoculum level is high enough, with spores from nearby infected plants. It can become a very severe disease when rainfall is low and conditions are dry. These are the types of conditions prevailing in the later part of the season in most cucurbit production districts.

Production of cucurbit crops in Australia occurs over a climatic variation ranging from latitudes 12^0S to 43^0S. Approximately 435,000 tonnes are produced from about 25,000 hectares and the value of the industry is estimated to be $330M. Cucurbit growing occurs in all states and major production locations are: the Burdekin region (north Queensland), Bundaberg and Lockyer Valley (SE Queensland), Murrumbidgee Irrigation Area (southern New South Wales) for field production (particularly melons and pumpkins) and outer Sydney metropolitan areas and outer Adelaide metropolitan areas for greenhouse cucumber production. All these regions to a certain degree have conditions favourable for the development of powdery mildew into epidemic proportions during the production season.

The major cucurbit crops and types produced are mainly melons (rockmelon, watermelon, honeydew), greenhouse cucumbers (Lebanese, continental), pumpkins (large grey, butternut, jap), gherkins (processing), zucchini and squash (Kelly, 2007).

Traditional methods of powdery mildew control in cucurbits

The repeated use of fungicide sprays has been the primary means of managing powdery mildew. The disease can be difficult to control once leaves become heavily infected. Preventative measures are therefore a necessity in the early stages of the disease initiation. Traditionally, frequent calendar-based sprays with different formulations of sulphur have provided adequate control under low infection conditions across cucurbit production regions of Australia (O'Brien *et al.,* 1988). However, under favourable environmental conditions for disease progress and crop development the use of fungicides with systemic or trans-laminar properties becomes the preferred option. In Australia, there are currently four of these type of fungicides registered for the control of powdery mildew in cucurbit crops (Table 1.1). Details of the other range of products available are on pages 63-66.

Table 1.1: Analysis of the curret systemic fungicides registered for cucurbit powdery mildew control in Australia

Product name	***Activity Group***	***Fungicide Class***	***Active Constituent***	***Group and other information***
Amistar	Quinone outside inhibitors (QoL)	Methoxy acrylate	azoxystrobin	K – translaminar activity
Bayfidan	DMI	Triazole	triadimenol	C – Broad spectrum
Nimrod	Hydoxy pyrimidine	Hydoxy-(2-amnio) pyrimidine	bupirimate	H – both eradicant and protectant
Spin Flo	Methyl Benzimidazole	Benzimidazole	carbendazim	A - Others as Bavistan

Emerging issues and the way forward

The repeated use of systemic fungicides has led to the development of resistant populations of powdery mildew fungi being reported in some areas in Australia resulting in reduced efficacy. Following regular consultative visits by researchers to growers' farms and industry meetings, there were demands from the industry for researchers to investigate and provide more sustainable guidelines for managing powdery mildew in cucurbit crops.

Support was obtained from industry by researchers to investigate if there were indeed fungicide resistance problems, identify alternate control options and establish more sustainable options for managing powdery mildew in cucurbit crops.

The objectives of the project proposal developed to address these issues were:

1. Understand grower perception on the importance and practices for managing powdery mildews on cucurbits.
2. Determine pathogen diversity by undertaking fungicide resistance evaluations
3. Undertake epidemiological studies to collect data for a possible disease forecasting system.
4. Evaluate different fungicide alternatives to control powdery mildew.
5. Assemble and evaluate integrated disease management strategies and compare their efficacy with existing strategies for managing the disease.

Symptoms of powdery mildew in Field Cucurbits

Figure 1.1: Severely infected button squash plant at start of flowering

Figure 1.2: Close-up of a severely infected leaf with powdery mildew spore coverage

Fig. 1.3: Discreet powdery mildew colonies on mature upper zucchini leaf surfaces at mid season

Fig. 1.4: Discreet powdery mildew colonies on mature lower zucchini leaf surfaces at mid season

Fig. 1.5: Severely infected leaves stems and petioles of zucchini in late season

Fig. 1.6: Severely infected whole zucchini plant at end of season


Fig. 1.7: Early pumpkin powdery mildew infection


Fig. 1.8: End of season powdery mildew infection of pumpkin

Chapter 2: Industry Survey

Introduction

A needs analysis grower survey was undertaken during the 2006 production season as part of the Silverleaf Whitefly project (VG05050). Questions on powdery mildew were included in the survey in the Burdekin, Gumlu and Bowen districts of North Queensland where most of the cucurbits in Queensland are produced, to get a growers' perception on issues of dealing with and managing powdery mildew, especially on the cucurbit crops.

Except for one telephone interview, all the interviews were conducted face to face by The Department of Primary Industries and Fisheries personnel, using a standardised questionnaire containing a mix of open and closed questions (See Appendix 1).

Methods

Note: *Three Ayr growers did not complete the powdery mildew section of the survey (2 eggfruit growers, 1 pumpkin/melon grower) so results are based on interviews with 5 Ayr, 3 Gumlu and 2 Bowen growers as well as 2 Ayr Agribusinesses and 1 Bowen Agribusiness, added during some follow up interviews in 2007.*

The following section summarises the findings of these industry surveys, especially as directly related to powdery mildew.

Results

1. Yield losses from powdery mildew

Growers were asked to estimate what percentage of yield was lost due to powdery mildew in the previous two years.

- For small cucurbits, growers ranked losses from less than 2% through to about 10% of yield lost in 2005, with around 5% being the most common response.
- Pumpkin yield losses were ranked more highly with the range extending from less than 2% to 20% or more yield loss for 2005, with the most common responses being around 5% and 20% or more.
- Two growers said that 2005 was better than the year before; five growers said it was the same and 4 growers said that this was worse than 2004.

2. Current powdery mildew management practices

Growers were asked to describe their current powdery mildew management programs or practices.

The following are the responses from the individual growers:

- *Pumpkin and chilli grower* - Consultant advises on which fungicides to use; Morestan, Dithane, Mancozeb, Ridomil are the main ones used.
- *Small cucurbits, pumpkin, chilli grower* - Amistar sprays at 3 to 4 leaf stage for powdery & downy mildew control; they are very happy with it. A number of different fungicides are used as the crops get older; Agrofos and Fungimil were mentioned; they try to rotate these.
- *Zucchini* - 10 to 15 g/L of dairy milk powder obtained in 20 kg bags, mainly used for powdery mildew control.
- *Pumpkin, cane* - Sulphur sprays are put on early, and then alternated with Nimrod and other systemics.
- *Pumpkin, watermelon*: Nimrod, Spinflo, Morestan, Bayfidan are used alternatively. Start with Morestan as an early (pre flowering), then alternate with systemics. No Morestan after flowering; from flowering spray weekly on watermelon, forthnightly on pumpkins; Lakeland Downs where farm is located is extremely bad for PM. They use a fungicide which is used on pineapples for controlling PM; Amistar is not really good and Nimrod is not as good as it used to be.
- *Pumpkin, watermelon, capsicum*: - Bayfidan and Nimrod mainly used; they access and use infopest CD for guidance.
- *Cucumber* - Morestan is used as a preventative; has also used Nimrod, Bayfidan; Uses Morestan to start when PM appears, then alternate with Rubigan and Bayfidan.
- *Chilli, eggfruit, pumpkin* – Bayfidan and Nimrod mainly used; Bayleton used occasionally; Sulphur and Morestan as a preventative then alternate with systemics; Morestan has become very expensive. Should be cheaper so that more could be used and reduce chances of resistance to systemics occurring.
- *Cucumber, pumpkin, rockmelon* - Dithane/Acrobat, then Nimrod and Bayfidan alternated weekly; Amistar sprayed twice if early problems with PM and then leave out Dithane.

- *Tomato*: Bayfidan mainly and a bit of Amistar, fair bit of Sulfur. It stinks and gets complaints from others, but used in most sprays.
- *The Ayr Agribusinesses* - mentioned Cabrio, Carbendazim, Rubigan, Nimrod, Thiovit, Morestan, Bayfidan as mainly chemicals sold to growers; Remarked that more registered products would improve the situation especially on capsicum, chilli and cucurbits.
- *The Bowen Agribusiness* - mentioned rotation of available groups and good application as the key to good powdery management.

It is worth noting that respondents only used chemical sprays applied, to describe their management program for powdery mildew. From the earlier results obtained during the 2004 surveys, this type of response was expected.

The next set of questions was actually designed to explore a more integrated approach to managing the disease. The lead in question:

"Is there anything else you do to manage powdery mildew problems?"

This question did not get much response but was followed with several questions to collect baseline data on practices/attitudes. Agribusiness responses are included in italics.

Do you get rid of old crop straight away?

- Yes (from 6 responses)
- Yes – This is very important
- Quickly - and if there is powdery around uses Gramoxone with Roundup
- Not quickly enough - admits he is a bit of a dirty farmer
- Not many do, but he does
- *Yes, if replanting but if not replanting then not all get rid of old crop*
- *Yes, majority do, similar to Silver Leaf Whitefly program*
- *This is crop dependent; we advise all to do this, perhaps 90% of cucurbit growers comply as crop is easy to remove. All implement until staff becomes a limitation especially once they get busy later in the season.*

Do you regularly calibrate your spray rig to improve coverage?

- Checked every 6 weeks
- Twice per season
- One to two times per year
- At least once per year
- Once per year
- Yes (3 responses)
- Yes, definitely
- Yes, helps workers with this
- *As necessary or needed*
- *Yes, as part of Freshcare, done annually*
- *Still some that could be better, computer electronics makes this easier*

Does powdery mildew influence your choice of variety?

- Thinks so; trying out now different varieties
- Not often
- No, probably not
- No, only grows Ken's special hybrid pumpkin; On Eldorado melon PM management is more difficult; reason why he stopped growing zucchinis
- Market dictates variety with white cues; with green slicing uses tolerant variety Coola
- Gourmet tomatoes more susceptible than older varieties
- No (x4)
- *Dictated by markets, would if they could, resistant varieties don't hold up as quick when sprayed once powdery mildew has taken hold.*
- *Yes, pumpkin only, will go for less susceptible varieties eg. Easier crop coverage*
- *Very variety dependent especially in pumpkin, some exotics very difficult and some last year (2006) very susceptible – ask seed companies these questions*

What is your approach to managing fungicide resistance?

- Don't use conventional fungicides
- Consultant advises on what fungicides to be used
- Try and rotate sprays

- Alternate chemical
- Alternate control
- Try to rotate chemicals
- Rotate chemicals but limited choice
- Only use chemicals when needed except for sulphur, used in most sprays like a protectant, and rotate fungicides
- He & most growers alternate fungicides but commented that it was mostly to see if they could find out one that worked well
- *Rotate chemicals, try not to overuse, not much to work with*
- *Won't do more than 2 curative sprays of one group, then go to different group*
- *Early detection, proactive action in disease control, when its seen its too late, good monitoring, application, rotation, farm planning and ICM*

3. How can powdery mildew management be improved?

As a lead in to this section, growers and agribusiness were asked:
Are you getting adequate control of powdery mildew?

The range of responses reflects the results to the earlier questions
Note again that agribusiness responses are in italics.

- Yes
- Yes, with Amistar - prior to it, this was a bigger problem
- Yes, most of the time
- Most of the time
- *Most of the time*
- Most to sometimes
- Sometimes (x2)
- Sometimes, depends on the weather
- Sometimes to No
- No
- *No*

We then asked a series of questions to find out what growers thought would help them improve their powdery mildew management. As the responses show, a greater choice of chemicals and better application were the most frequently mentioned as what growers and industry needs.

What do you think is essential for getting good control of powdery mildew?

- More info as new products are developed
- Weather conditions
- Routine sprays and weather conditions
- Get in early, rotate chemicals
- Good luck and spray coverage
- More systemics, more chemicals; Bayfidan works, Amistar doesn't give good result under adverse weather conditions

What would help you improve your management of powdery mildew?

- Other chemicals
- New products
- None of the chemicals seem as good as they used to be. Not sure why.
- Good coverage- need at least 600L/H; for many growers improve their crop hygiene, some more chemicals for rotation, depend too much on Nimrod
- Some better chemicals
- Encouragement to use preventatives ie. make these cheaper; more systemics
- Maybe varieties
- *One pager outlining a workable program for cucurbits, more products, Understanding of how to apply products, different mode of actions of different products*
- *Farm planning, need more products with different modes of action; some resellers recommending non-registered & off label products from West Australia, which is not effective as it puts off genuine companies from getting into the market*

Is there any other information or training needed or anything else you would like to learn about?

- No, gets what he wants from current info systems
- No
- No, what will that do?

- Seminars, newsletters - would rather seminar at night as he does all the work on his farm
- Anything new
- Better application methods
- Any advice
- *Don't wait until they get powdery; need preventatives, softer options; try not to use systemic fungicides in early part of crop*
  Pumpkin: resistant varieties don't hold up as quick when sprayed once powdery mildew has taken hold
  Increase water volumes for better coverage
  Systemic trickle applied fungicide eg would work with netting
  Looking forward to Chrys Akem at seminar - have not seen any information from project yet.

Discussions

Some conclusions and recommendations can be made from the results of these surveys

- There appears to be some considerable confusion among growers on the identification of powdery mildew and downy mildew and what fungicides control which mildew.
- Some growers are using unregistered products.
- There is a difference in the quality of advice coming through from the resellers

- Growers and agribusinesses are aware and generally practice quick removal of old crops to reduce inoculum loads in the farms

- Growers and agribusinesses seem to be aware of varietal susceptibility to powdery mildew as part of their decision making tools

- More education and general information is needed on the classification of chemical groupings, mode of action and resistance levels.

- There is generally still a very strong focus by growers and agribusinesses on chemical control as the main means of managing diseases.
- There appears to be very limited knowledge on the concept or integrated approach to to powdery mildew management.

- The survey results validate the key objectives of this project plus the need for considerable technology transfer and increased knowledge, especially for consultants and chemical resellers.

Chapter 3 – Epidemiology - Fungicide Resistance Testing

Introduction

In a broader sense, studies with the epidemiology of a disease allow us to understand how that particular disease is increasing and spreading in different populations. In powdery mildew this also helps us to explain why resistance against some fungicides easily develop and what can be done to guard against this and also how to prolong the life of available fungicides.

Fungicide resistance development is of concern to the growers when suddenly their regular sprays fail to achieve adequate disease control. It is also of concern to the chemical company that manufactures the fungicide because it means the chemical has to be withdrawn, at times without recovering the huge costs associated with its development.

In the next series of studies, we determined if resistance by the powdery mildew pathogen had already developed against the fungicides used. For this purpose, assays and bioassays were set up using cucumber seedlings of a variety known to be highly susceptible to powdery mildew. The glasshouse and field bioassays were undertaken to complement unsuccessful in-vitro studies (Fig 3.1) plagued with contamination issues, which had been undertaken to evaluate possible powdery mildew resistance against the available systemic fungicides, using isolates collected from a number of diverse environmental conditions.

Materials and Methods

A. Comparison of inoculation techniques

Determination of the most effective method to inoculate seedlings with powdery mildew was undertaken prior to the commencement of the trial. The aim of this was to endeavour and achieve uniformity of inoculum distribution of powdery mildew spores from infected leaves.

Seedlings of the cucumber variety, "Crystal Salad" obtained from South Pacific Seeds, were transplanted individually into 12 cm diameter, 10 cm high pots. Three pots were grouped together in a large saucer and a green garden stake placed in each pot. A large plastic bag was placed around the assembly to create a high humidity environment and prevent cross-contamination from other isolates. Then an inoculation method was performed on each of the three plants before the bag was gathered at the top, sealed with an elastic band and placed in an evaporatively-cooled glasshouse. The same inoculum source was used for the procedure.

The following techniques were evaluated in the trials:

1. *Spores in suspension*: lightly tap powdery mildew colony over a sterilised beaker containing distilled water and Tween 20. Gently swirl. Pour into atomiser and spray on leaves. Encourage rapid air-drying.
2. *Blowing*: hold a heavily infected leaf near the trial seedling leaves and blow across it towards the uninfected leaf.
3. *Wiping*: gently wipe an infected leaf across the surface of an uninfected leaf.
4. *Combined blowing and wiping*.
5. *Cotton ball rolling*: gently roll a wad of sterilized cotton over the surface of an infected leaf and then over the uninfected leaf.
6. *Suspended leaf*: suspend a heavily infected leaf inside the container.

The pots were bottom-watered (as germination of powdery mildew spores is reduced from free moisture on leaf surfaces for any extended length of time) via the saucer and observed daily for any infection.

B. Bundaberg Isolates Bioassay - June 2008

A cross-section of ten isolates samples of powdery mildew infected plant leaves collected from various crops and locations during a disease prevalence survey in the Bundaberg region during May 2008, was used (Table 3.1). Samples collected were placed in large paper bags, placed in an air-conditioned room and used two days later to inoculate Crystal Salad cucumber seedlings by gently rubbing leaves of the seedlings with the infected leaves.

A day prior to this the cucumber seedling test plants were sprayed with the following systemic fungicides: an azoxystrobin (Amistar^{R} 250 SC), a triadimenol (Bayfidan^{R}), a bupirimate (Nimrod^R) and a carbendazim (Spinflo^R) at 10 or 50 ppm active ingredient, to the point of run-off with a generic 500 mL hand-held atomiser. A control treatment using only water to spray the seedlings was also included.

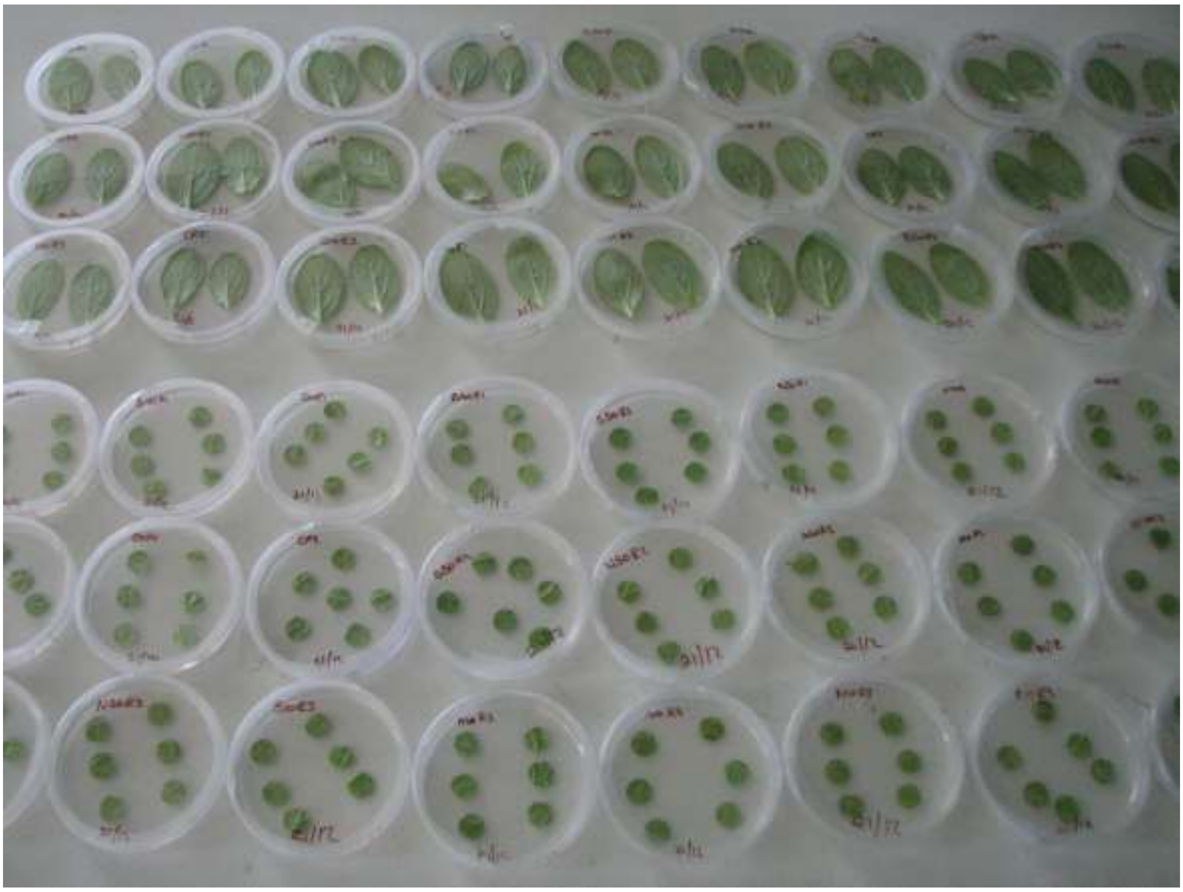


Fig 3.1: Laboratory in-vitro attempt to determine fungicide resistance

Table 3.1: Bundaberg Powdery mildew isolates details.

Isolate #	*Location*	*Crop*	*Available cultivation details*
Bb1	Moorland	Button squash	Unsprayed crop.
Bb2	Moorland	Button squash	Sprayed with different fungicides.
Bb3	Oakwood	Watermelon	Bravo^{R} and sulphur sprays.
Bb4	Igloos	Cucumber	Grown in igloos; trellised.
Bb5	Oakwood	Zucchini	Regal Black variety.
Bb6	Burnett Heads Rd	Zucchini	N/A
Bb7	Burnett Heads Rd	Pumpkin	N/A
Bb8	Elliott Heads	Pumpkin	Unsprayed; home garden.
Bb9	Elliott Heads	Pumpkin	Rubigan^{R} sprays.
Bb10	Dahl Rd	Pumpkin	Sprayed with various fungicides.

Fig 3.2: Seedlings with different fungicide treatments for isolate testing

Trays holding 45 native tubes containing SPS cucumber “Crystal Salad” variety seedlings at first true leaf stage were individually labelled with the fungicide treatment and concentration; for example Amistar^{R} dilute (Fig 3.2).

The seedlings were then removed from the other trays and sprayed with that fungicide at the specified dilution factor with a generic 500 mL hand-held atomiser. Trial design was a radomized complete block with each isolate grouping representing a complete block and the funigicide treatments randomized within the block. Each treatment was replicated 4 times.

Fig 3.3: Fungicide treated seedling block sprayed with a powdery mildew isolate

Empty trays were labelled with the isolate reference number (Fig 3.3). Four seedlings that had been sprayed with each fungicide at each concentration and 4 unsprayed controls were then randomly placed in each tray once their leaves had dried.

Trays were then placed inside large individual containers for 24 hours and then inoculated with the particular powdery mildew isolate. (e.g; Bb 9 = Bundaberg isolate # 9).

Fig 3.4: Hand inoculation of treated seedlings with isolates

Inoculating the cotyledons and young leaves of trial plants by first blowing, then wiping with collected isolates of cucurbit leaves heavily infected with powdery mildew (Fig 3.4) was the next step in the exercise.

Strict hygiene by operators is essential during these procedures (arms and hands washed between applications and new disposable gloves used) to reduce chances of isolate contaminations.

Fig 3.5: Containers with inoculated seedlings reared

Once all test plants were wiped with the appropriate powdery mildew isolate (Fig 3.5), containers were covered with heavy clear plastic held in place with elastic. They were then randomly placed on benches within an evaporative-cooled glasshouse (Fig 3.6).

Fig 3.6: Due to high humidity levels within the plastic containers, the heavy plastic was replaced with very fine insect netting.

Fig 3.7: Positioning of containers for side watering to establish infection

Each container of plants was watered individually with an equal volume of water by removing the cover and gently pouring along the sides of the container to reduce water splash on leaves (Fig 3.7).

Plants absorbed water from the bottom of the container.

Fig 3.8: Initial symptoms of powdery mildew infection colonies on leaf surfaces

Powdery mildew infection showed up on inoculated leaves of trial plants a few days after inoculation (Fig 3.8).

Note the scratch marks on the picture (Fig 3.8) from the wiping. This action may assist hyphal penetration of leaves.

Plants were rated for disease severity (% leaf area infected) seven days after inoculation, using the following scale:

0 = Nil, (no infection infection detected on the leaf surface)

1 = ≤ 10 (up to 10% of leaf surface area infected),

2 = 11-25 (11 to 25% of leaf surface area infected),

3 = 26-50 (26 to 50% of leaf surface area infected), and

4 = > 50% (greater than 50% of leaf surface area showing infection).

The data was analysed using Genstat to see if there were any significant differences among isolate treatments.

C. Burdekin Field Bioassay 2008

Seeds of the Congo zucchini variety (South Pacific Seeds), were sown into a sterilised potting mix (2 peat: 1 sand: 1 vermiculite No. 3). They were sown into individual native tubes and placed on benches surrounded by insect netting inside an evaporatively-cooled glasshouse. After emergence, seedlings were fertilized using Manutec "African Violet Food" (soluble) according to label rates. Plants of good vigour and uniform growth were transplanted into 12 cm diameter, 10 cm high black pots and fertilized again.

Pots were labelled and sprayed (using a domestic hand atomiser) with the 4 systemic fungicides; Amistar^{R}, Bayfidan^{R}, Nimrod^{R} and Spinflo^{R} (at half, full and double the recommended label rates), to give complete coverage of stems and leaves to the point of run-off. Plants were then left in the glasshouse for 24 hours to ensure uptake of fungicide.

Plants were grouped into complements of each of the four fungicides at the three different concentrations plus six control plants (not sprayed with any fungicide; 3 to be placed in the field and 3 to be left in the glasshouse), making 30 plants in total. Actively growing apical shoots were pinched off each plant; leaving two cotyledons and three true leaves.

One complement of plants (minus the glasshouse controls) was randomly placed in a commercial cucurbit crop at various Burdekin locations (Table 3.2) to trap aerial spores overnight. The following morning, the plants were retrieved from the fields and randomly placed on benches in the glasshouse, with plants from each locality grouped together. The glasshouse controls were randomly placed among each group. Each day the plants were bottom watered using a hand-held hose.

All plants were rated for disease severity after 11 days and again 4 days later. The rating scale used was a visual rating scale of 0 to 100% as explained for the Bundaburg isolate ratings.
The data was analysed using Genstat to see if there were any significant treatment differences.

Table 3.2: Sampling sites information in the Burdekin where test plants were exposed.

Site #	*Location*	*Crop*	*Details observed at placement*	*Sprays used at the site (from diary or from discussions)*
1	Millaroo	Jap pumpkin	Started picking; high infection.	Uses mainly Nimrod and SpinFlo with Bravo in alterations
2	Riverview, Payards Lagoon	Jap pumpkin	Picking completed; moderate infection.	No spray diary kept; mainly mancozeb and Bayfidan used
3	Clare	Watermelon	4 weeks off picking; low-moderate infection.	Amistar, Nimrod and Bayfidan used. No Spinflo
4	Rocky Ponds	Honeydew melon	Some harvested; high infection.	Has used all registered fungicides with no success; thinks Amistar is ineffective.
5	Guthalungra	Rockmelon	Low to moderate infection.	Amistar, Nimrod and Bayfidan used. No SpinFlo
6	Ayr	Butternut	Being harvested; moderate–high infection.	Amistar, Nimrod and Bayfidan used. No SpinFlo
7	Ayr Research Station (ARS)	Pumpkin	Harvest completed; moderate infection.	No spray was used on this planting

Results

A. Comparison of inoculation techniqies

Among the different inoculation techniques compared for efficacy in infection establishement, gently wiping the leaf surfaces with infected leaves was observed to be the most effective method of powdery mildew transfer from source to uninfected leaves. This technique was subsequently adopted and used in making all the inoculations of the test plants.

B. Bundaberg Isolates

The disease severity results for the first true leaves are summarised in *Table 3.3*. Similar results were recorded for cotyledons but are not listed here. There were different responses to the various fungicide treatments depending on where the isolate was collected from and whether or not a fungicide management programme was implemented at the location or farm.

Where the values are greater than or similar to the control, there is the likelihood that there was some level of resistance developed by the particular isolates to the test fungicides used. In situations, where there were no fungicide sprays (locations 1 and 8), the lack of powdery mildew growth shows that the isolates are still sensitive to the applied fungicides. At locations 1 and 2 (the same hobby farm) there was a button squash crop that had been sprayed and another section that had been left unsprayed. The isolate (isolate 2) collected from the sprayed portion of the crop, performed poorly to the test fungicides indicating that some level of resistance had developed. At location 4, good control was offered by Amistar^{R}, Nimrod^{R} and Spinflo^{R}, however Bayfidan^{R} performed poorly. At location 5, Bayfidan also performed poorly, while at locations 6 and 7, all the test fungicides performed poorly, indicating resistance problems. The isolate from location 8 was sensitive to all the fungicide treatments. Spores transferred from location 9 did not even infected the control plants, meaning they were probably not viable and so did not germinate. At location 10, while there was some level of control afforded by Amistar, Bayfidan and Nimrod, however, Spinflo, was ineffective, again suggesting resistance development at this location to Spinflo.

Table 3.3: Mean disease severity ratings on cucumber seedlings sprayed with fungicide concentrations for ten Bundaberg isolates of powdery mildew.

Mean Disease Severity (0-4)*	Bundaberg Isolates (Bp)									
Treatment (a.i)	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Amistar 10 ppm	0	0.8	0	0.8	1.3	1.3	1.5	0	0	0.3
Amistar 50 ppm	0	0.5	0	1.0	0.5	2.5	0.8	0	0	0
Bayfidan 10 ppm	0.5	1.8	1.0	1.0	0.8	1.8	3.3	0	0	0.3
Bayfidan 50 ppm	0	1.3	0	0.5	0.5	1.8	1.8	0	0	0.3
Nimrod 10 ppm	0.5	1.0	2.0	2.0	0.8	3.0	4.0	0	0	0
Nimrod 50 ppm	0	1.5	1.0	1.3	1.0	3.0	1.8	0	0	0.3
Spinflo 10 ppm	0	2.0	0	0.8	0.5	2.8	2.0	0.3	0	0
Spinflo 50 ppm	0.5	1.5	0.3	1.3	0.5	1.8	2.0	0.3	0	0.5
Control	0.75	0.75	2.0	1.75	0.5	0.5	0.5	0.75	0	0.5

**Rating was based on a disease severity scale of 0-4 as explained on page 31*

C. Burdekin area bioassays

The first signs of slight infections on the potted plants from different locations were observed on some plants just 7 days after field exposure. Two days later infections had become quite pronounced on some plants. Infected plants were removed and placed in an adjacent glasshouse to separate them from uninfected ones. The first signs of secondary infections from infected plants in the glasshouse were about 7 days later, when powdery mildew was first noticed on some leaves of the glasshouse controls.

Disease severity ratings on day 11 and 15 were summarised in Tables 3.4 and 3.5, respectively and the details are presented graphically in Figures 3.11 to 3.17. At all sites the level of disease increased over time as indicated in the graphs. At site 1 (Millaroo) the recorded level of disease was low, 7% and 10% for the Control for the first and second rating dates respectively. All the fungicide treatments showed less disease infection with no infection recorded for Amistar, indicating it was quite effective at this site.

At sites 2 and 7 where test plants were exposed in old pumpkin crops that had been harvested, there was little disease in any of the treatments, most likely due to the low level of inoculum. At site 2, even though there was no disease recorded even on the control plants, those treated with spinflo showed very high levels of infection. This can certainly not be attributed to resistance development because no spinflo sprays were made at this site. It is a site to be followed up in future, with a new crop, to ascertain the situation.

At site 3 (Clare) the level of disease in the controls was relatively high in comparison to all the fungicides which were considerably lower (Fig 3.13). Here the funigicides used still have some good effects at controlling the disease. Amistar here was doing better than all the others.

At site 4 (Rocky Ponds), high levels of disease were recorded for Amistar, Bayfidan, Nimrod and Spinflo treatments, which were not significantly different from the control treatment (Fig 3.14). The overall level of disease control at the site was poor as grower had used all these available options in different rotations, yet was not experiencing good control. Resistance to Amistar and to some extent Bayfidan is clearly evident at this ite.

At site 6 (Guthalungra) disease levels were quite high in the Control and Amistar treatments (Fig 3.15). Amistar is clearly not very effective at this site when compared with the other fungicides. Nimrod and Bayfidan, the other systemics used here, are still providing some control.

At site 6 (Ayr) the level of disease on the controls was relatively low and all the fungicides suppressed the disease, with the exception of Spinflo (Fig 3.16). Spinflo actually seemed to have stimulated infection as it had higher incidences than the control.

Figures 3.9 below shows an example of the screening set up in the glasshouse when the potted plants have been exposed and brought back to the glasshouse for evaluations. Fig 3.10 is a close up of infection for an unsprayed plant (or one with complete resistance to a fungicide).

Fig 3.9: An example of a greenhouse bioassay set up to screen for fungicide resistance

Fig 3.10: Close up infection on seedlings showing complete fungicide resistance

Table 3.4. Powdery mildew expression on zucchini seedlings with different fungicide treatments exposed to the disease in 7 commercial cucurbit crops – Rating 1 *(11 days after spray infection).*

Treatment*	Millaroo	Riverview	Clare	Rocky Ponds	Guthalungra	Ayr	ARS
Amistar 0.5*	1	0	2	43	15	1	0
Amistar 1*	0	0	1	36	31	0	0
Amistar 2*	2	0	1	37	20	0	0
Bayfidan 0.5	2	0	26	38	13	3	0
Bayfidan 1	5	0	7	33	14	1	0
Bayfidan 2	0	0	4	44	25	0	0
Nimrod 0.5	3	0	5	26	18	11	0
Nimrod 1	2	0	11	15	16	5	0
Nimrod 2	0.3	0	7	6	1	5	0
Spinflo 0.5	3	0	5	43	18	2	0
Spinflo 1	3	0	4	18	12	3	0
Spinflo 2	2	0	0	24	12	5	0
Control	7	2	29	40	41	11	1

Amistar 0.5*, 1* and 2* represent Amistar at half, full and double recommended label rates. Values are the means of all leaves on a plant for both replicates, to the nearest whole number. There were a maximum of four true leaves per plant.

*Table 3.5. **Powdery mildew expression on zucchini seedlings with different fungicide treatments exposed to the disease in 7 commercial cucurbit crops – Rating 2** (15 days after spray infection).*

Treatment* (a.i)	Millaroo	Riverview	Clare	Rocky Ponds	Guthalungra	Ayr	ARS
Amistar 0.5*	2	0	3	51	24	2	0
Amistar 1*	0	0	3	55	41	1	0
Amistar 2*	3	0	3	49	27	1	0
Bayfidan 0.5	27	0	31	54	29	5	0
Bayfidan 1	6	0	18	34	25	2	0
Bayfidan 2	0.1	0	13	41	47	3	0
Nimrod 0.5	6	0	16	46	24	15	0
Nimrod 1	3	0	26	23	26	15	0.3
Nimrod 2	0.3	0	19	16	4	7	0
Spinflo 0.5	6	0	7	55	50	7	0
Spinflo 1	3	0	9	32	30	5	0
Spinflo 2	1	0	5	35	26	14	0
Control	10	4	63	48	64	20	2

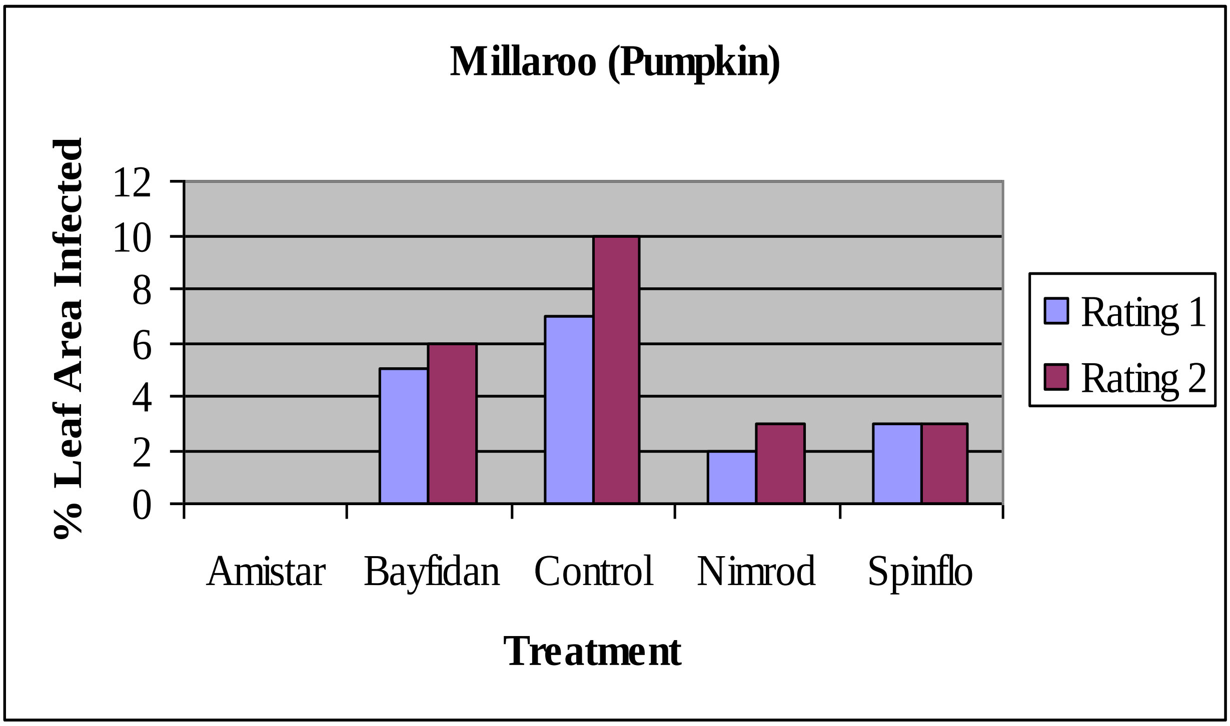


Fig 3. 11: Fungicide reactions to powdery mildew on pumpkins at Millaroo

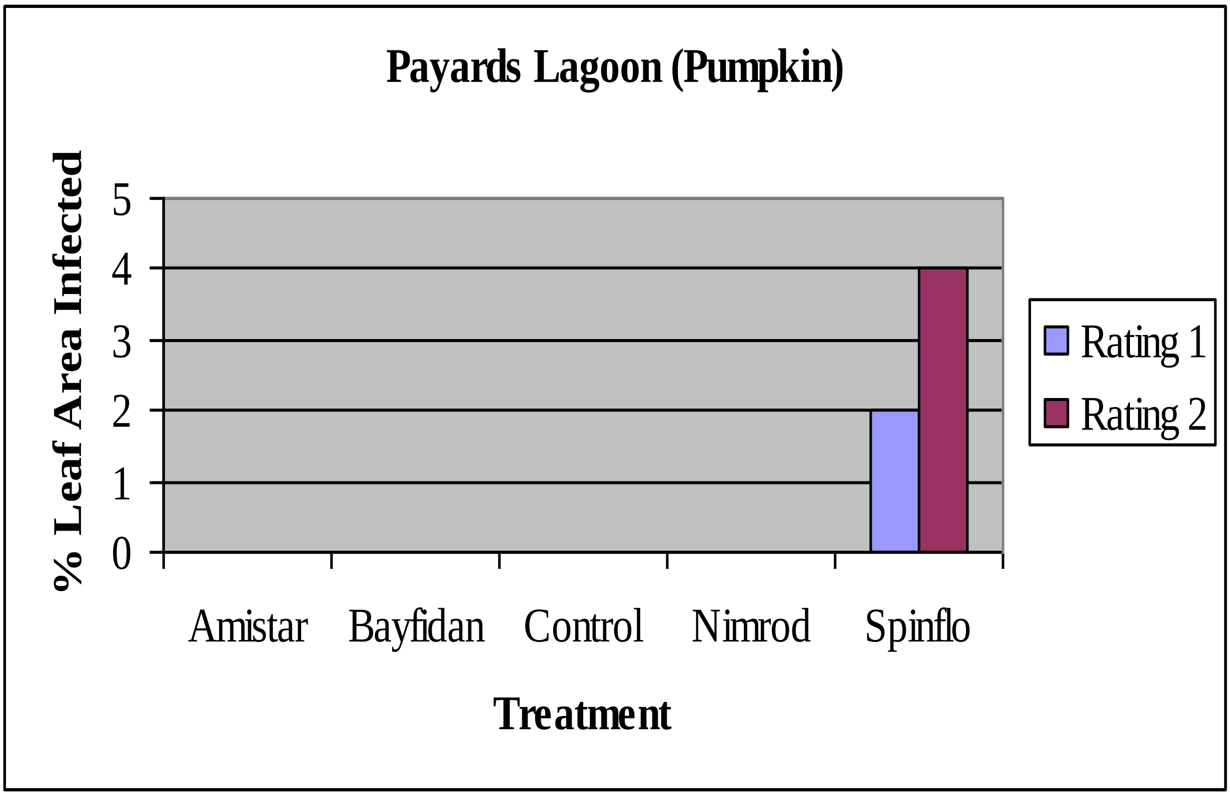


Fig 3. 12: Fungicide reactions to powdery mildew on pumpkins at Payards Lagoon.

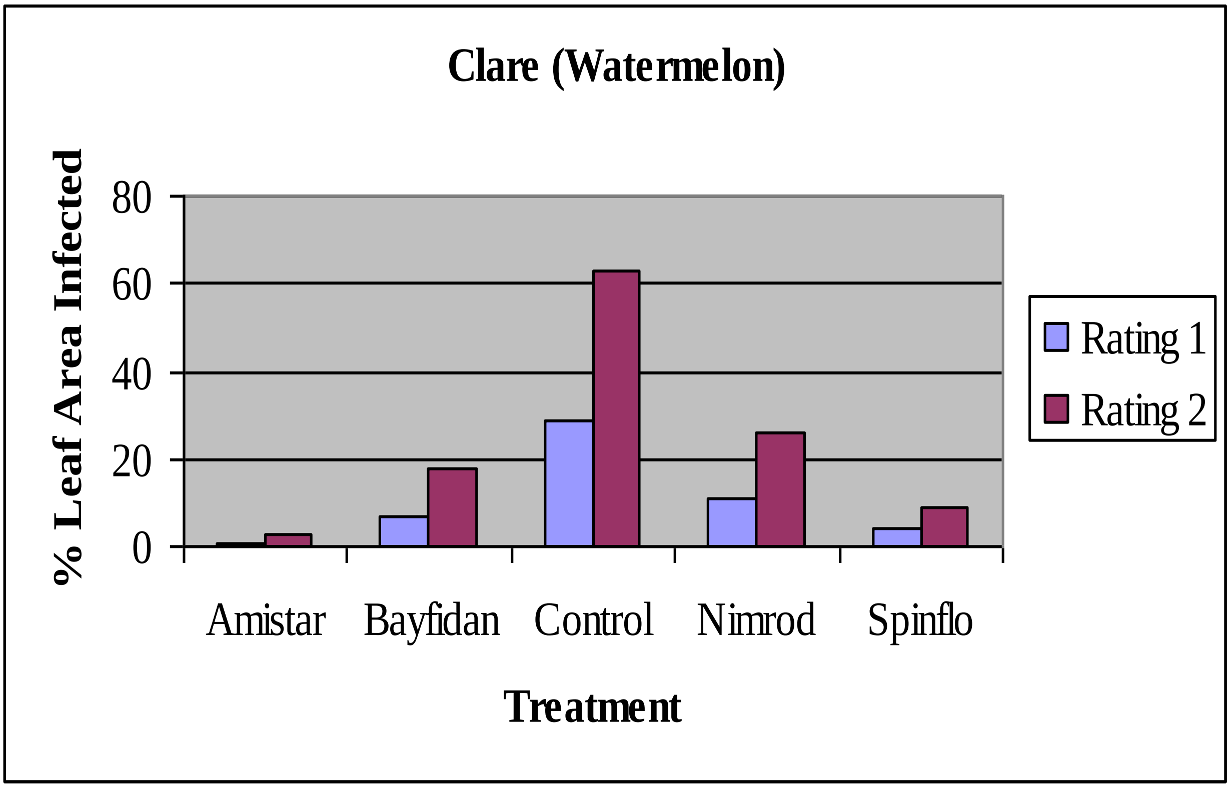


Fig 3.13: Fungicide reactions to Powdery mildew on watermelon at Clare.

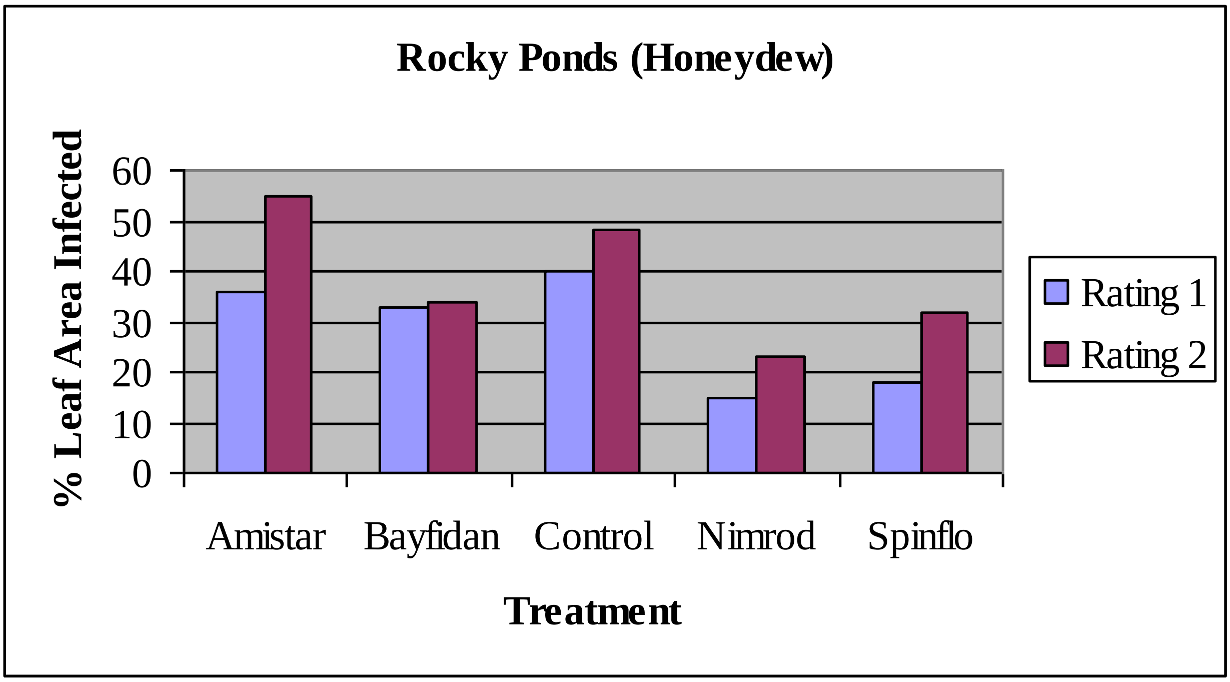


Fig 3.14: Fungicide reactions to Powdery mildew on Honeydew at Rocky Pond Farms.

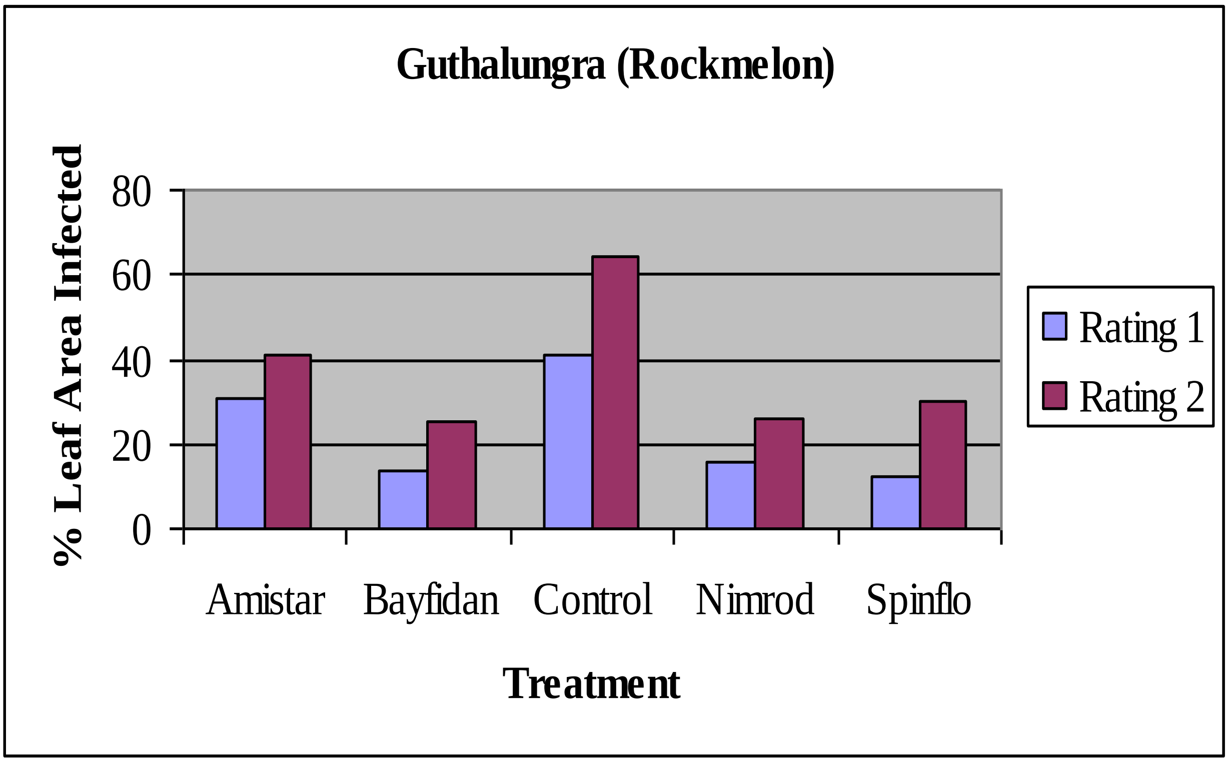


Fig 3.15: Fungicide reactions to powdery mildew on rockmelons at Guthalungra.

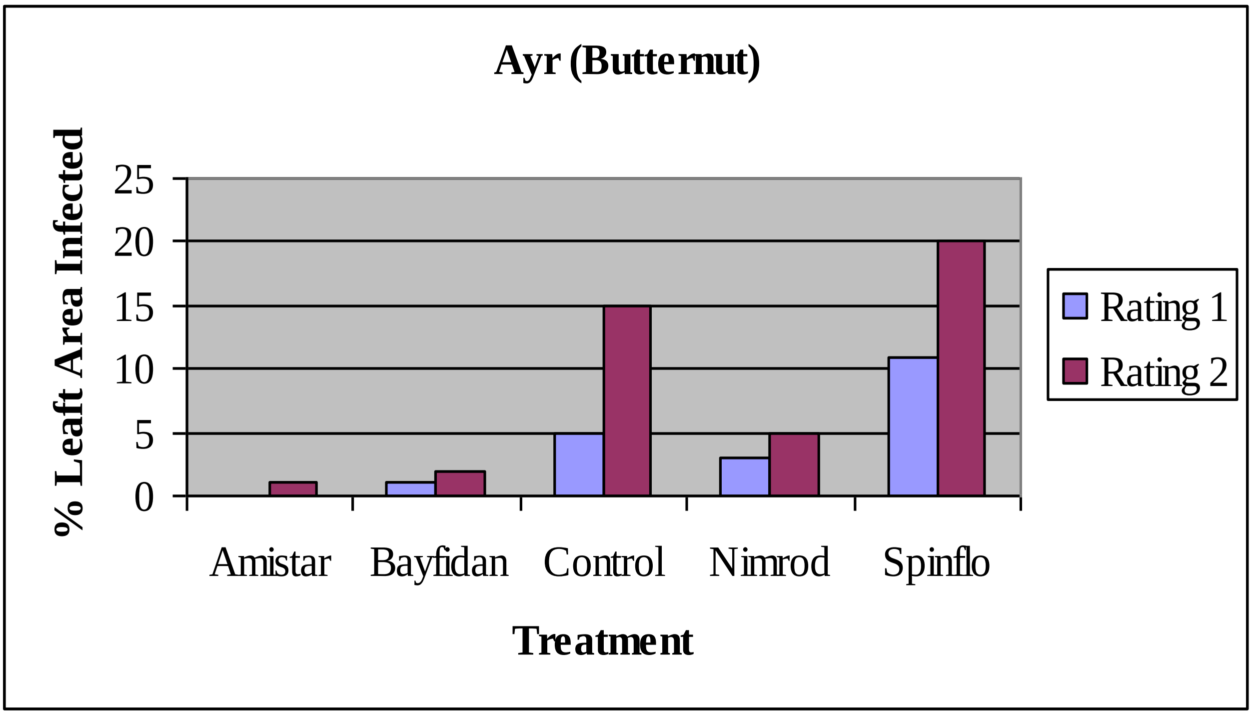


Fig 3.16: Fungicide reactions to powdery mildew on Butternut at Ayr.

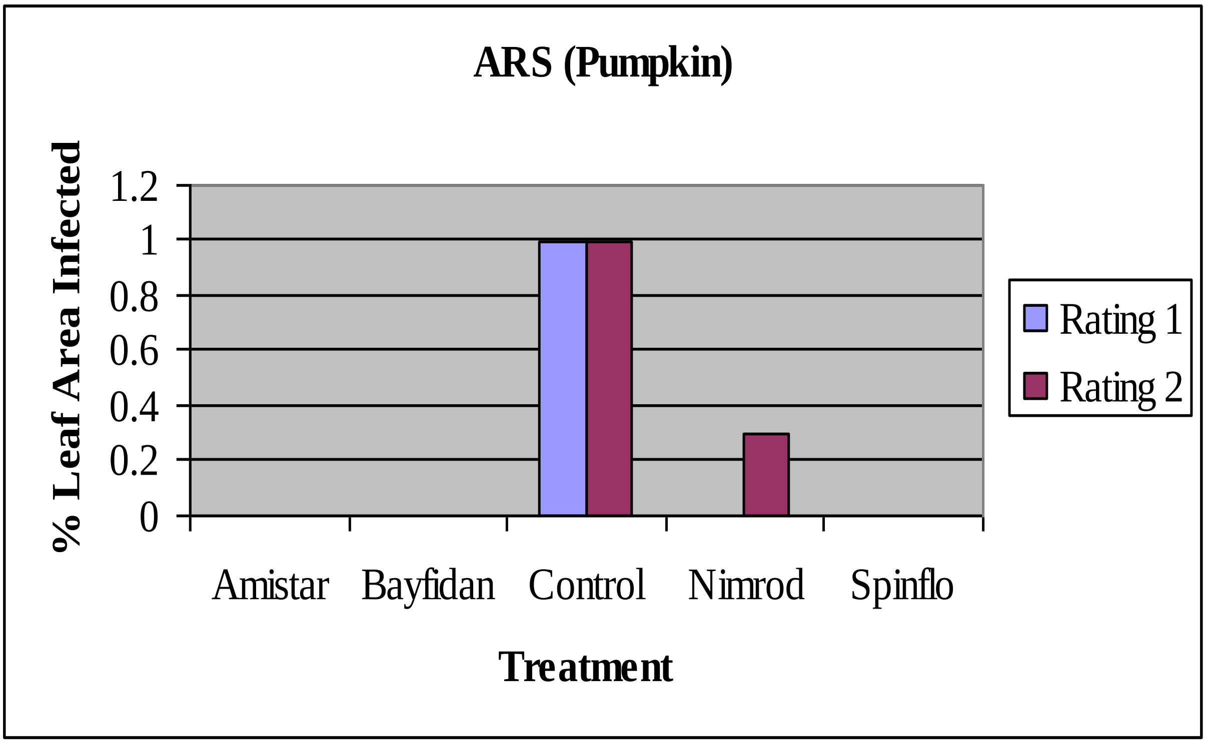


Fig 3.17: Fungicide reactions to powdery mildew on pumpkins at the Ayr Research Station.

Discussion

These results clearly show that there was reason to believe that there is a fungicide resistance problem in some of the farms in the Bundaberg region. This is clearly a cause for concern. This reinforces the need for continuing monitoring of isolate sensitivities to the registered systemic fungicides on an ongoing seasonal basis and to continue to promote resistance management strategies within the cucurbit industry. Because the Bundaberg isolates were collected during a snap survey, spray information on most of the locations was unavailable to be able to explain why resistances developed in some fields but not others. It is likely that where a particular fungicide was used heavily or frequently, resistance was likely to develop against that fungicide by pathogen populations in the particular field.

At location 4 in Bundaberg, for example, good control to powdery mildew was achieved with the use of Amistar^{R}, Nimrod^{R} and Spinflo^{R}, however Bayfidan^{R} performed poorly. It can only be suspected that this farm might have been a heavy Bayfidan user since spray records were not available to confirm this with some certainty.

The results of particular interest are the performance of the fungicide treatments (at the recommended label rate of application) compared to the Control treatment. If the disease severity ratings are similar to the Control then this is a good indication that the fungicide has been ineffective and the particular isolate may have developed some level of resistance. This seems to be the case at Rocky Ponds Farms in the Burdekin region and confirms concerns expressed by the grower for apparent failure of the fungicides under high disease pressure. At Guthalungra there was also high disease pressure and Amistar was the least effective of the fungicides, although there was some suppression of disease, but at varying levels.

Under favourable environmental conditions, as experienced during this experiment, the life cycle of powdery mildew on healthy plants, which were exposed overnight in cucurbit crops, was 7 days. With rubbing, this interval was as short as 5 days. This short interval and repeated cycles is characteristic of polycylic pathogens such as powdery and downy mildews. Having such a short lifecycle and repeated lifecycles during the life of a crop necessitates the need for a good monitoring and spray management programme to keep the disease in check.

Of the different methods of assessing the likelihood of development of resistant populations of powdery mildew, the whole plant bioassays were particularly useful. They are quick and give very conclusive results. While the artificial technique of rubbing to transfer spores was successful, this method is not uniform and is subject to operator bias, whereas field exposure of seedlings subjects plants to natural infection by prevalent field populations of the pathogen, and gives a better indication of what really happens in the field. The leaf disk technique is useful provided contamination from miscellaneous fungi, as reported by other researchers (O' Brien *et al* 1992 and McGrath 2001), is kept in check. The technique is also labour intensive.

Ongoing disease resistance testing using the whole plant bioassays and field exposure are planned for the future with sampling to occur early, mid and late season in the different cucurbit production districts so as to stay on top of things and offer timely advice to growers when shifts in pathogen populations are noticed, so that they can adjust their spray programs.

These studies clearly show that development of resistance in the different production areas of the Burdekin and Bundaberg is a cause for concern. The reported failures of systemic fungicides, especially during seasons when there is high disease pressure, resulting from favourable weather conditions and the repeated use of systemic fungicides, may be a combination of resistance development and/or poor spraying operations.

Good coverage of foliage is paramount with the use of protectant fungicides such as sulphur and Morestan, foliar fertilisers and plant activators such as Bion, which stimulate the plant's natural defence mechanism. This is of less importance with single-site fungicides because of their translaminar or systemic activity.

Chapter 4: Varietal screening for powdery mildew resistance

Introduction

The management of powdery mildew in most cucurbit fields in Australia is relying heavily on the use of fungicide sprays. While this approach is unsustainable, it is also clear that it is costly both in terms of added production costs and the price paid to the environment because of drifts and run-offs into streams and waterways. Despite these draw backs, things are not going to change in a hurry. Fungicide sprays will continue to play a critical role in powdery mildew disease management for sometime.

Other options are needed to complement the use of fungicides, which could hopefully lead to a reduction in the use of these fungicides without compromising on disease control. The selection of varieties with some levels of genetic resistance can play this role. It is an effective parameter in disease management in most countries where there are concerns of excess pesticide use and in small scale farming systems where the farmers cannot afford the use of excessive fungicides to control their diseases because of associated increase in production costs. This is an option that needs to be considered because of increasing environmental concerns from excess pesticides use.

Most Australian cucurbit crops are bred by established seed companies overseas. In most cases the varieties are subjected to screening tests for a number of diseases and only those found to have reasonable levels of resistance are released for cultivation. The only issue is that these new varieties are only screened for resistances to the prevailing pathogen populations in the countries where they are bred. When brought to Australia, there is always a risk of crop failure in a season where conditions favour disease development and the pathogen strains are more aggressive or different from those to which the cultivars were initially screened against. This phenomenon has occurred time and again where seed packages clearly labelled overseas as having resistance to some specific diseases are planted and soon experience epidemics from the same diseases for which the cultivars are supposed to be resistant.

Even though other options may be available to consider in disease management including the judicious use of fungicide sprays, the cheapest and most effective means for sustainable control of the disease is the use of resistant varieties (McGrath and

Zitter, 2000). Because many of the available varieties in Australia have been bred overseas and have not been exposed or screened for reaction to Australian pathogen strains or races, the objective of the next series of studies were mainly to evaluate commercial zucchini and pumpkin varieties for genetic resistance against powdery mildew populations under Australian field conditions.

Materials and Methods

1. 2006 Field Trials

Zucchini field screening trials were conducted at the Bowen Research Station of the Department of Primary Industries and Fisheries (DPI & F), north Queensland. Standard agronomic practices for irrigation, weed control and fertilization were implemented but no fungicides were applied to allow natural infection from powdery mildew. The different varieties evaluated were as follows: Crowbar (Syngenta), Hummer (SPS), Amanda (Clause), Calida (Clause), Congo (Seminis), and Regal Black (Lefroy Valley) (Fig 4.1). These were all appropriated randomised in using a randomised complete block design (RCBD) in replicated field blocks with 4 replications per variety.

Eleven other varieties (Table 4.1) were also included in the screening trial. However, because of insufficient seed these could not be adequately replicated for analysis. These 11 varieties were formed as guard rows for the main replicated trial.

Disease Assessments

Disease Severity

Disease severity was assessed on stems and leaves of four tagged data plants from within the middle of each plot (Fig 4.2). Powdery mildew disease severity from stem infection was rated on a 0-5 scale as follows:

0 = no disease infection detected on the stem,

1 = 1-10% infection on the stems,

2 = 11-25% infection on the stems,

3 = 26-50% infection,

4 = 51-75% infection and

5 = 76-100% infection on the stems.

Two leaves were sampled from each of the data plants per plot and given a percentage rating to the nearest 5%. The data leaves were sampled from within the lower third of the canopy with each leaf facing the intra-row (the leaf node was 2 nodes below the lowest previously harvested fruit).

Disease ratings for the other 11 none replicated varieties included, were done on similar scales as described above on leaves and stems of cultivars.

Fig 4.1: Screening of zucchini varieties for resistance to powdery mildew

Fig 4.2: Sources of resistance to powdery mildew in zucchinis

Table 4.1: Varieties, supplier and number of replicates for each variety

Variety	**Supplier**	**No. of Replicates**
1. Colombia	SPS	2
2. Gold Rush	Seminis	2
3. Regal Supreme	Henderson	2
4. 29417	Clause	1
5. 6071	Lefroy Valley	2
6. 6072	Lefroy Valley	2
7. 6073	Lefroy Valley	1
8. 6074	Lefroy Valley	2
9. 6075	Lefroy Valley	2
10. 6076	Lefroy Valley	2
11. Jaguar	Lefroy Valley	2

Yield Assessments

The effect of disease severity on yields was determined by harvesting fruits from tagged plants over a 40 day period at a 2-4 day interval. Marketable fruit numbers were recorded for all data plants.

2. 2007 Field Trials

Seventeen varieties were raised in a glasshouse and transplanted 2 weeks after sowing at the Ayr Research Station, Ayr, in north Queensland. Field plots, with eight plants per plot, were arranged in a randomized complete block design with four replications. Seedlings with three true leaves were transplanted into drip-irrigated (2 L/m row) raised beds covered with black polyethylene mulch. Bed rows were 1.52 m wide and plants were spaced at 55 cm within rows. Pre-plant fertilizer (N-P-K, 13-15-13 at 2 kg/100 m row) was applied in a band and incorporated. After flowering, fertilizers applied through drip irrigation included potassium nitrate (three applications at 0.6 kg/100 m of row). Plots were irrigated as needed, with water delivered once or twice a week for irrigation periods that ranged from 4 to 7 h. No fungicides or insecticides were applied. Weeds were removed manually with a chipping hoe. Fruit were harvested on a 3-day interval between 6-8 weeks. Weight and number of harvested fruits was recorded at each harvest date from three inner data plants. Disease assessments were made 5 weeks after transplanting. Each data plant was assigned a disease severity score for leaves and fruits as follows for viral diseases: 0; absence of infection, 1; mild viral infection with some leaves having vein clearing but fruits normal, 2; moderate viral infection (some leaves slightly distorted and some fruits slightly lumpy and distorted), 3; high infection (most leaves distorted and most fruits lumpy and distorted), 4; severe infection (most leaves severely distorted with small lumpy and severely distorted or no fruits). Leaves in the upper quarter of the canopy where symptoms were most noticeable were assessed. Leaf samples (one leaf per plant of the second youngest unfolded leaf) were tested by ELISA on 25 October using antibodies to papaya ingspot virus (PRSV), water melon mosaic virus (WMV) and zucchini yellow mosaic virus (ZYMV).

Table 4.2: Zucchini varieties tested, seed supply companies and general comments

Variety	Supplier	Comments
Quirinal	Seminis	Very mild
Paydirt	Syngenta	Mild leaf symptoms
Crowbar	Syngenta	Very mild
Calida	Clause	Symptoms on older leaves
CLX29881	Clause	Mild symptoms
ZU393	Syngenta	Fruit discoloured
CLX29442	Clause	Mild leaf infections (later stages infected)
Regal Black Improved	Seminis	Very poor fruitset
7709	Lefroy Valley	
Regal Black	Lefroy Valley	Poor fruitset (6 severe, immoderate)
Amanda	Clause	
Congo	Seminis	Very few fruit
6496	Lefroy Valley	
5191Y	Lefroy Valley	Very poor fruitset
Black Adder	Terranova	Very poor fruitset
Mamba	Terranova	Very poor fruitset
Caroline	South Pacific Seeds	

3. 2008 Pumpkin Field Trials at Bowen Research Station

Nine cultivars of different fruit types were evaluated for resistance to natural infection by powdery mildew in Bowen (Table 4.3). Field plots with six plants per plot were arranged in a randomized complete block design with four replications. Three week old seedlings with three unfolded leaves were transplanted on 19 June into drip-irrigated (2 L/m/h) raised beds covered with black polyethylene mulch. Double row beds with a width of 3.04 m were used. Plants were planted a metre apart within rows. Standard agronomic practices for irrigation, insects, weed control and fertilization were implemented but no fungicides were applied to allow natural infection from powdery mildew.

In each plot, disease severity was assessed on 8 leaves of 4 plants on 20, 27 August and 11 September. Two runner shoots were randomly selected in each plant and disease severity was assessed on the lower surfaces of the leaves located at leaf node number 8, counting from the youngest fully expanded leaf near the shoot tip. Each selected leaf was assigned a disease severity score based on the percentage of leaf surface covered with powdery mildew colonies. Weight and number of harvested fruits were recorded on 14 October. During the crop growing period, mean high and low temperatures (ºC) were 25.5/12.0 in June, 24.3/12.6 in July, 25.1/11.3 in August, 28.4/16.8 in September, and 30.3/19.9 in October, respectively. Rainfall (mm) was 0, 105, 0.4, 10.4, and 2.0 for the latter months, respectively.

Table 4.3: Pumpkin varieties evaluated and seed supply companies

Variety	Fruit Type	Supplier
1. Sampson	Grey	Terranova Seed
2. 183-6	Grey	SPS Seeds
3. 188-6	Grey	SPS Seeds
4. Early Jarragrey	Grey	Clause
5. Royal Grey	Grey	Clause
6. Kens Special 864	Japanese	SPS Seeds
7. Kens Special	Japanese	SPS Seeds
8. Dynamite	Japanese	Clause
9. TNT	Butternut	Clause

4. 2008 Zucchini Field Trials at Bowen Research Station

Thirteen varieties of zucchini were evaluated for resistance to powdery mildew under conditions of natural infection in Bowen (Table 4.4). No treatments were applied. Field plots were arranged in a RCBD comprised of 13 varieties and four replications.
The standard crop husbandry practices used for zucchini in earlier trials were implemented. Three week old seedlings with two to three unfolded true leaves were transplanted on 16 June. There were 10 plants per plot, with the inner five plants being used as data plants. Disease severity assessments (upper leaf surfaces from lower and upper canopy and stem) were carried out as previously. There were three disease ratings on 14, 21, 27 August, and 11 September. As disease on stems only becomes obvious later in the season, ratings were only made on the latter three dates.

For the disease severity data using Area Under Disease Progress Curve (AUDPC) was from ratings taken on 14, 27 August and 11 September (Table 4.8).

Table 4.4: Zucchini varieties evaluated at Bowen in 2008 and seed supply companies

Variety	**Supplier**
1. Calida	Clause
2. CLX29881	Clause
3. 582-6	SPS
4. Zest	Lefroy Valley
5. Amanda	Clause
6. Paydirt	Syngenta
7. Caroline	SPS
8. Crowbar	Syngenta
9. Houdini	Syngenta
10. Golden Rod	Clause
11. Congo	Seminis
12. 7708	Lefroy Valley
13. HMX5702	Clause

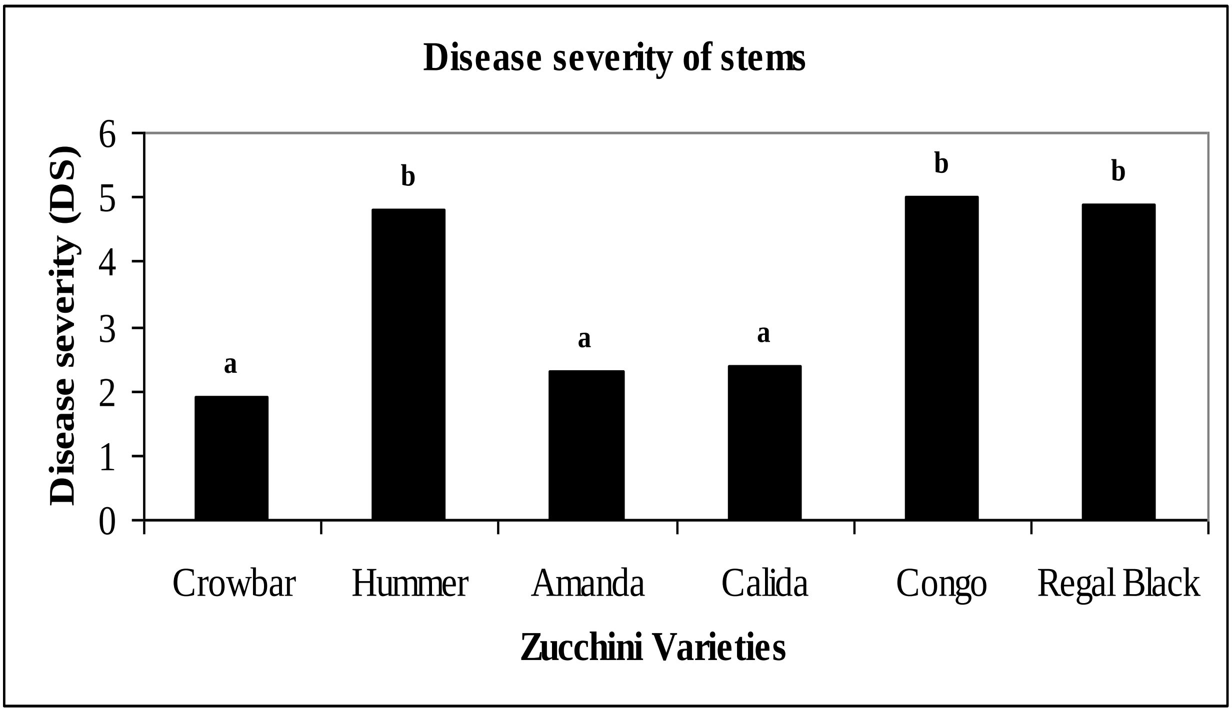
Results

2006 Field Trials

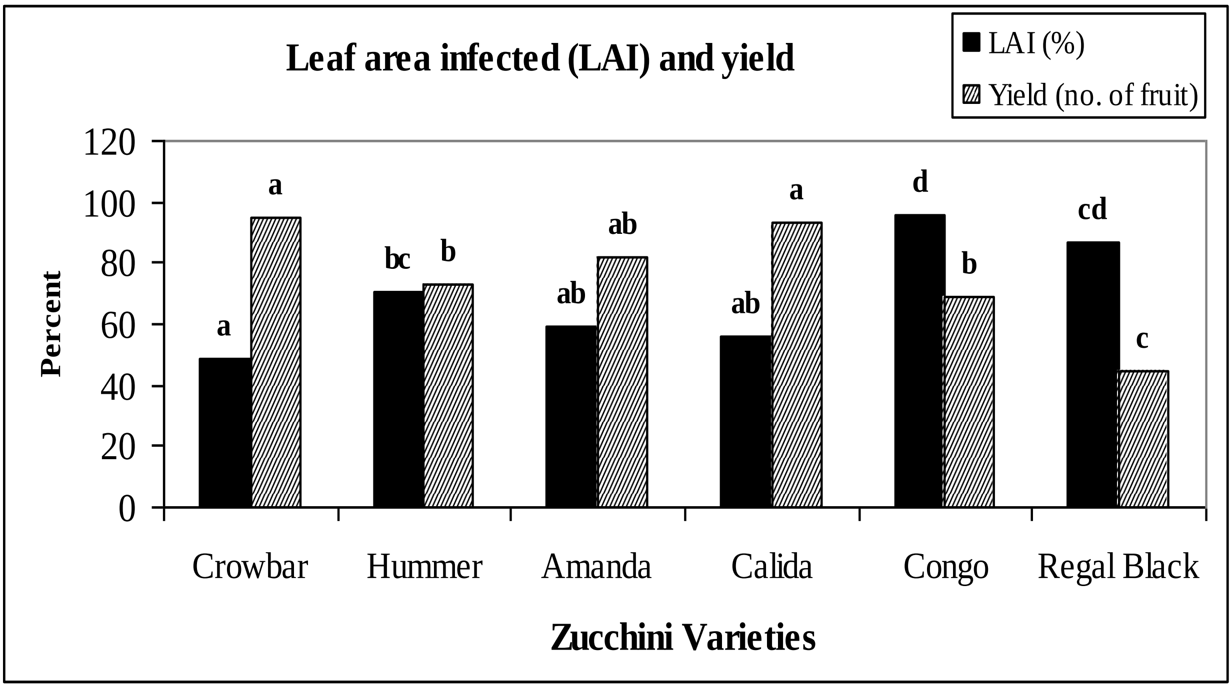
There were significant differences ($P<0.05$) in disease severity and yield among different varieties evaluated. Crowbar, Amanda and Calida had significantly less powdery mildew on stems (Fig. 4.4) and leaves and higher fruit yield (Fig. 4.5) compared to Congo, the industry standard. Hummer and Regal Black along with Congo were highly susceptible varieties to powdery mildew and yielded fewer fruit (Fig 4.3).

Fig 4.3: Susceptible zucchini cultivar with infection on leaves and stems

Fig 4.4: Resistant zucchini cultivar with little or no infection on leaves and stems



Treatment means with the same letter are not significantly different (P=0.05)
Fig. 4.5: Reaction of zucchini varieties to powdery mildew on stems.



Treatment means with same letter are not significantly different (P=0.05)

Fig. 4.6: Percent Leaf Area Infected (LAI) by powdery mildew and fruit yields of zucchini varieties.

There were large differences in the varietal expression of resistance among zucchini varieties tested for powdery mildew (Table 4.5) for each of the sampling dates. All the varieties showed high levels of disease on both surfaces of the leaves. There were some differences in the level of resistance to powdery mildew on the stems. Varieties 29417 and 6073 were resistant (Fig 4. 4) and 6074 and 6075 showed a moderate level of resistance, with all the other varieties being highly susceptible.

Table 4.5: Mean Disease Severity ratings for stems and leaves of zucchini varieties for two sampling dates.

Variety	**26/09/06**	**26/09/06**	**05/10/06**	**05/10/06**
	Stem (0-5)	**Stem (0-5)**	**Upper (%)**	**Lower (%)**
1. Colombia	5	5	100	92
2. Gold Rush	5	4.4	100	95
3. Regal Supreme	5	5	100	83
4. 29417	0	0	98	28
5. 6071	0.5	-	M	M
6. 6072	4.5	5	99	90
7. 6073	0	0	71	39
8. 6074	0.5	1.5	100	47
9. 6075	0.5	1.5	89	30
10. 6076	4.3	5	100	96
11. Jaguar	4.8	M	M	M

2007 Field Trials

There was a large variation in the inherent genetic resistance to virus infection of the varieties evaluated (Table 4.6). Quirinal, Paydirt, Crowbar and Calida showed low incidence of viruses and there was also low severity expressed on both fruit and leaves. They also performed better for yield parameters. Conversely, there were a few varieties, particularly Caroline, Congo, Regal Black, 5191Y, Black Adder and Mamba that performed very poorly with very high incidence and very severe disease which also resulted in poor yields. The other varieties showed intermediate levels of virus infection and fruit yield. WMV was not detected in any of the varieties sampled while 82 and 72% revealed the presence of PRSV and ZYMV, respectively. Both viruses were detected in 60% of the plants tested.

Table 4.6: Varietal reactions to viruses and their effects on leaves, fruit and yield

Variety	Disease Incidence* (%)	Disease Severity Fruit[z] (0-4)	Disease Severity Leaf (0-4)	Fruit yield (No./plant)	Fruit yield (g/plant)
Quirinal	11 a	0.3 ab	1.3 abc	3.8 a	206 a
Paydirt	21 a	0.0 a	0.9 ab	3.6 a	165 ab
Crowbar	23 ab	0.1 ab	0.8 a	3.8 a	146 ab
Calida	28 ab	0.9 abc	1.5 bcd	3.2 ab	155 ab
CLX29881	41 bc	1.4 bcd	2.1 de	3.1 ab	144 ab
ZU393	58 cd	2.4 def	2.0 de	2.8 ab	126 bc
CLX29442	59 cd	1.0 abc	2.0 de	3.6 a	143 b
Regal Black Improved	65 de	3.0 efg	4.0 f	2.1 bc	121 d
7709	68 de	1.9 cde	1.9 cde	2.4 ab	112 a
Regal Black	75 def	2.9 efg	4.0 f	1.9 bc	114 a
Amanda	81 ef	2.9 efg	2.3 e	2.7 ab	134 b
Congo	90 f	4.0 g	4.0 f	1.9 bc	57 cd
6496	90 f	2.9 efg	2.0 de	1.8 bc	158 a
5191Y	90 f	4.0 g	4.0 f	0.7 cd	142 ab
Black Adder	90 f	3.9 g	4.0 f	0.4 d	66 de
Mamba	90 f	4.0 g	4.0 f	2 bc	57 e
Caroline	90 f	3.5 fg	3.8 f	2.8 ab	63 de
***P*-value**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**

* Arc-sin transformation was used for percentage data prior to analysis. Back-transformed means are presented. Means followed by the same letter within a column are not significantly different from each other using Fisher's protected least significant (LSD) test ($P < 0.05$).

2008 Pumpkin Field Trials at Bowen Research Station

Powdery mildew was first observed on cotyledons and first true leaves in mid July. During August and September, disease severity was minimal on the upper leaf surfaces but increased on the lower leaf surfaces in all cultivars with the exception of the three Japanese fruit cultivars (Table 4.7). On 20 August, the greatest disease severity values among all cultivars were recorded in the grey fruit cultivars Royal Grey and 183-6 (29.7% and 25.8% respectively). As the season progressed the disease developed rapidly and differences in disease severity expression became more pronounced between varieties. On the final rating date in mid September, the three Japanese fruit cultivars recorded the lowest disease severity scores, showing good levels of resistance and were significantly better than all the other varieties. Varieties 183-6, Royal Grey and Dynamite showed high levels of disease (poor resistance) while Sampson, 188-6 and Early Jarragrey showed intermediate levels of disease. Yields in weight and number of fruit of Royal Grey and 183-6 were comparable to grey fruit cultivars Sampson and 188-6. Early Jarragrey had the lowest fruit yield in weight among the grey fruit cultivars. Among Japanese cultivars, fruit weights were not significantly different from each other (mean of 2.0 kg). Fruit quality (cosmetic appearance) was not affected by powdery mildew.

Table 4.7: Effect of powdery mildew severity on lower leaf surfaces and yield in pumpkins

Fruit types and Variety	**Disease Severity on lower leaves (% LAI)***		
	20 Aug	27 Aug	11 Sept
Grey fruit types			
Sampson	8.3 bc	6.5 abc	48.2 bc
183-6	25.8 d	33.3 d	73.6 c
188-6	9.2 bc	10.8 bc	55.9 bc
Early Jarragrey	9.2 bc	15.9 c	38.7 b
Royal Grey	29.7 d	42.2 d	71.7 c
Jap fruit types			
Kens Special 864	1.6 a	1.2 a	1.4 a
Kens Special	3.0 ab	1.1 a	2.0 a
Dynamite	4.6 abc	3.0 ab	4.1 a
Butternut fruit types			
TNT	10.4 c	16.3 bc	70.3 c
P-value	<0.001	<0.001	<0.001

* Arc-sin square root transformation was used for percentage data prior to analysis. Back-transformed means are presented. (% LAI = % leaf area infected).

2008 Zucchini Field Trials at Bowen Research Station

Disease traces were first noticed on some plants on 16th July. There were significant treatment differences for disease severity on leaves and stems as the severity intensity increased (Table 4.8).

Table 4.8: Effect of zucchini varieties on disease severity of leaves and stems at Bowen in 2008

Variety	Disease Severity on lower leaf surfaces (% LAI)*		
	14 Aug	27 Aug	11 Sep
1. Calida	12 ab	9 a	24 a
2. CLX29881	11 ab	10 ab	25 ab
3. 582-6	7 a	9 a	29 ab
4. Zest	13 b	13 abc	28 ab
5. Amanda	10 ab	22 abcd	30 ab
6. Paydirt	12 ab	24 abcd	32 abc
7. Caroline	15 b	24 abcd	42 abcd
8. Crowbar	13 b	26 bcd	49 cde
9. Houdini	16 bc	31 d	43 bcde
10. Golden Rod	21 cd	37 de	40 abcd
11. Congo	22 cd	27 cd	53 de
12. 7708	25 d	48 ef	61 e
13. HMX5702	32 e	62 f	57 de
P-value	<0.001	<0.001	<0.001

*%LAI = Percent leaf area affected
Arc-sin transformation was used for percentage data prior to analysis. Back-transformed means are presented. Means followed by the same letter within a column are not significantly different from each other using Fisher's protected least significant (LSD) test ($P < 0.05$).

Figure 4.7 shows the combined reactions of all the zucchini varieties screened as expressed on stems, upper and lower leaves of plants. By combining these reactions from the different plant parts, the highly resistant varieties such as Paydirt and Crowbar, stand out.

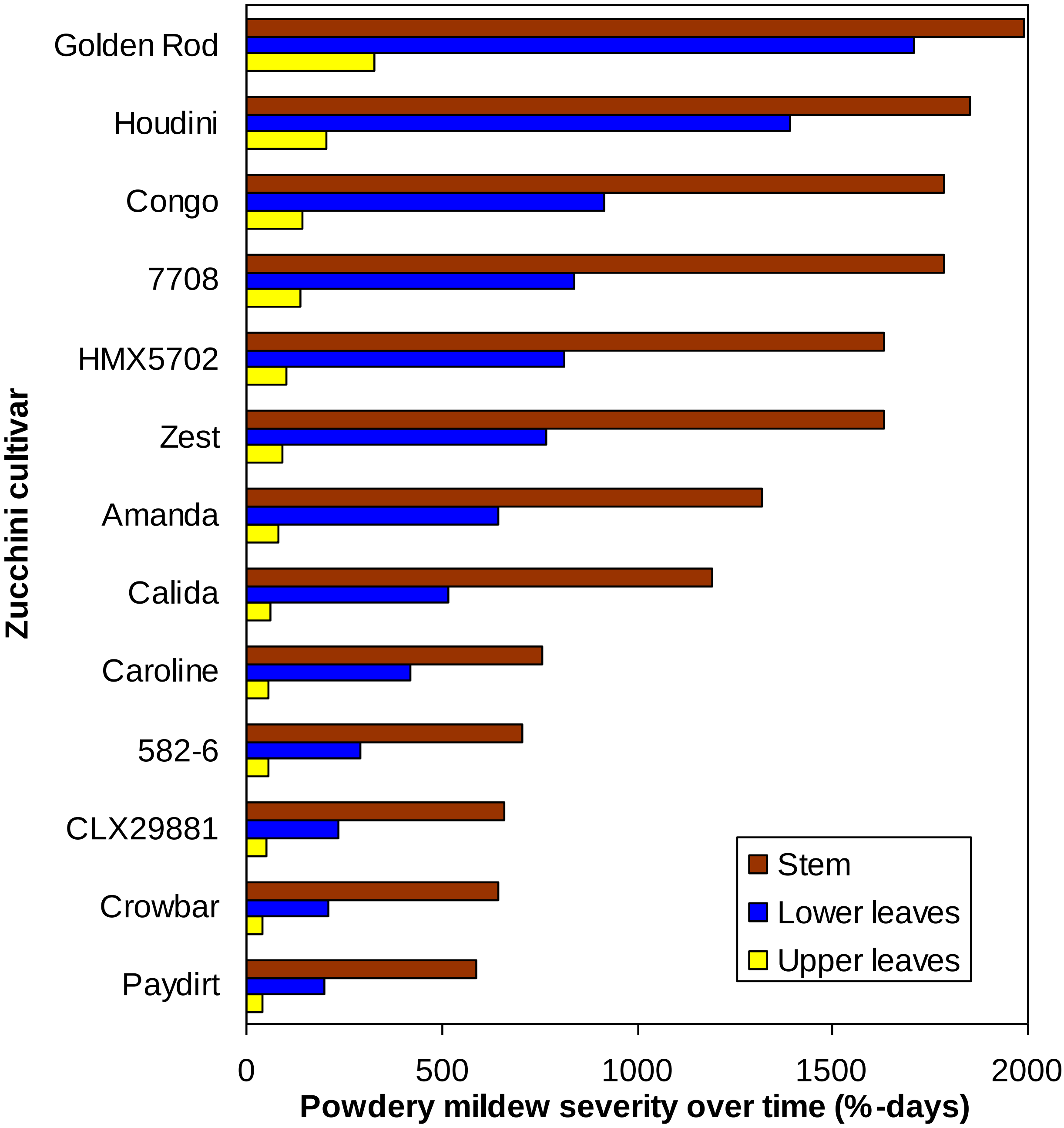


Fig 4.7: Combined expression of powdery mildew severity on different plant parts of zucchini varieties.

Discussion

These results demonstrate that variation in levels of resistance to powdery mildew do exist in the zucchini varieties evaluated. There was a significant positive correlation between reaction evaluations on stems and leaves ($r=0.81$, $P<0.001$), indicating that either parameter is sufficient to use in screening for resistance to powdery mildew on zucchinis. The levels of resistance identified in the varieties are sufficient to integrate them with other soft chemical options in an integrated management programme for powdery mildew for sustainable yields of zucchini. Zucchini varieties 29417 and 6073 showed strong resistance whereas 6074 and 6075 showed a moderate level of resistance against powdery mildew disease.

During 2007, field trials were initially meant to evaluate the natural resistance on a range of zucchini varieties against powdery mildew. Due to delayed sowing and high temperatures during the time of the trail under field conditions, viral diseases severely affected the plants and masked the symptoms of powdery mildew, particularly on the foliage. Therefore the results of 2007 field trials were consequently utilized to evaluate the resistance of zucchini varieties to various viral diseases such as watermelon mosaic virus (WMV), papaya ring-spot virus (PRSV) and zucchini yellow mosaic virus (ZYMV), which is commonly found on cucurbits grown in north Queensland. However varieties like Quirinal, Paydirt, Crowbar and Calida showed low incidence levels of above mentioned viral diseases. These varieties also exhibited the lowest infection levels on leaves, and had greater yields compared with other varieties tested. This confirmed their superiority both in terms of disease expression and yield potential.

Field variety trials conducted at Bowen Research Station for pumpkin and zucchini showed variable resistance against powdery mildew. Pumpkin varieties Kens special, Kens special 864 and Dynamite showed least disease incidence. Crowbar, Paydirt and CLX 29881 varieties of zucchini were least infected by the powdery mildew fungus on stem and upper or lower leaf surfaces compared with the other varieties.

From these studies, resistance to powdery mildew was shown to exist among current pumpkin and zucchini varieties available to growers in north Queensland and should be considered as a way of minimising the use of fungicide sprays to control powdery mildew. Appropriate sprays should be applied where tolerant varieties such as Congo are grown to reduce the pathogen population build up which could be transferred to less tolerant varieties in same locations.

In general, cultivars showing resistance to powdery mildew should be considered just as a parameter in the choice of options for the integrated management of powdery mildew on cucurbits. Other parameters to be considered should include fungicide alternatives and the application of different cultural management options in addition to timely sprays based on weather parameters.

Varietal resistance to powdery mildew is important as a disease management parameter. For the varieties to be readily selected and grown by famers, consumer preferences to the selected varieties must also be considered before they are recommeded for cultivation.

Chapter 5: Integrated Management of Powdery Mildew

Field Control Options

Introduction

Fungicides are currently the primary method of control of powdery mildew diseases in most crops including cucurbits, but the development of resistance to some fungicides by some of the pathogens which is increasing pre and postharvest losses to growers is a major concern. In addition, there is an increasing pressure from consumers to limit the use of synthetic fungicides used in vegetable and fruit production (Wilson and Wisneiwski, 1989). Chemical control is not always efficient and commercially acceptable resistant varieties of cucurbits are not readily available, even though using resistant cultivars would be the preferred option to limit fungicide applications. There is therefore a renewed interest in the development of alternative, environmentally-friendly methods of controlling fungal pathogens like powdery mildew which are widespread and have a large host range. The constant use of fungicides can also result in environmental contamination and selection of resistant populations of powdery mildew pathogens (O'Brien *et al.,* 1988; McGrath *et al.*, 1996). For these and other reasons, alternative control measures are needed.

Several alternatives to conventional fungicides have been evaluated for cucurbit powdery mildew control. Reuveni *et al.* (1995) verified that powdery mildew could be effectively controlled by a single spray of aqueous solutions containing various phosphates and potassium salts. The authors then concluded that phosphates and potassium are appropriate as foliar fertilizers with a potential added benefit of disease control. Pasini *et al.*, (1997), verified the effectiveness of JMS Stylet oil, canola oil and synertrol oils in satisfactorily controlling powdery mildew on roses. Marco *et al.*, (1994) described the suppression of powdery mildew on squash by applications of whitewash, clay and anti-transpirant material. Inorganic and organic products have all been reported to exhibit some form of induced or activated resistance as well as fungicidal properties against a range of powdery mildew pathogens on different field and horticultural crops.

Most of the above alternatives to fungicides work either as protectants or by inducing the plants natural defence resistance mechanisms to the pathogens, known as systemic acquired resistance (SAR). Resistance can thus be systematically induced in plants lacking the gene for resistance, by inoculating with non-pathogens, or by treatment with activators (Reuveni *et al.,* 1998). Foliar treatments with mono-potassium phosphate may simultaneously protect against pathogens and provide nutrients as has been demonstrated by the use of potassium mono-phosphate (Reuveni and Reuveni, 1997).

The aim of this section of the research was to evaluate some of these activators and compare their performance with that of synthetic fungicides in controlling powdery mildew on cucurbits under field conditions.

Products evaluated

During the 2006 to 2008 cropping seasons, the following activators and fungicides were evaluated for their efficacy in controlling powdery mildew under field infection conditions at the DPI&F Research Stations at Ayr and Bowen.

Activators

- ***Bion***

  This is a widely tested activator that has been shown to induce disease resistance in a number of crops (Matheron, 2002; Cole, 1999). It is an analogue of salicylic acid and is effective against a range of pathogens including ones that cause powdery mildew on a number of crops. It has however not been evaluated for its performance against powdery mildew on cucurbits.

- ***Cow Milk***

  Both liquid and powdered formulations of milk have been evaluated. In several studies in Brazil, milk was reported to have both resistance-inducing as well as fungicidal properties against powdery mildew. Weekly applications of milk concentrations from 10% to 50% proved to be more effective than weekly applications of fenarimol and benomyl in the control of powdery mildew in zucchini under controlled conditions (Bettiol, 1999). Other studies have also suggested that the powdered formulation would work just as well in appropriate dilutions. A powdered milk formulation, (Denkovit[R]), has been used successfully by a large local zucchini grower in the Burdekin and is used also by organic growers. Scientists working on powdery mildew in grapevines in South Australia found that milk and whey were just as effective, or better, than conventional fungicides. Salts in milk and whey produced oxygen radicals in natural light and damaged spores within 24 h of treatment (Crisp *et al.,* 2006). Powdered milk (45 g/L of water) also gave effective control of powdery mildew in grapevines in South Australia. Pittaway (2003) proposed that regular sprays of milk would favour the growth of naturally occurring yeast populations on leaves which antagonise the developing powdery mildew fungi.

In these series of field trials the powdered formulation of milk (generic household brand) at the 10% dilution rate was used.

- ***EcoCarb***

Ecocarb is classed as a plant bio-stimulant with activated potassium bicarbonate (Reuveni *et al.,* 1995). It has been reported to be effective in suppressing the infection of a wide range of fungi including powdery mildew on a range of crops. Its exact mode of action is still unclear, but has been suggested to include changes in pH of leaf surfaces to a more alkaline nature making the environment less suitable for fungal spore germination. The cell walls of germinating spores are also damaged. It has been shown to be the most suitable and recommended for use to control powdery mildew and other diseases in organic cropping systems. It currently is registered in Australia for the control of powdery mildew on grapes and roses while national registration is pending for its use in cucurbits (this followed research conducted by DPI&F on behalf of Organic Crop Protectants here in Ayr during 2006 and 2007 seasons). For fungicide resistance management it is classed as a Group Y fungicide.

- ***Silicon***

Silicon is available in different formulations, especially in soluble forms. It has been reported to work by promoting a plant's own natural defence mechanisms (Belanger *et al.,* 1995). It has also been shown to work by creating cell wall physical defence barriers against infections (Zhang *et al.,* 1997). Additional studies overseas showed it to be effective against powdery mildew on cucurbits and other vegetable crops. Foliar sprays of silicon have also been shown to reduce aphid populations in field crops. A soluble formulation, Stand CSP (calcium silicate, phosphorous acid and potassium hyroxide) and was obtained from the agrochemical company Agrochem and used in the evaluations.

- ***Synertrol Horti Oil***

This product was obtained from Organic Crop Protectants, the same company that manufactures and distributes EcoCarb. This product has been registered for use singly or in combination with EcoCarb for the control of powdery mildew for a number of crops in organic cropping systems.

- ***Messenger***

This product is an activator which uses harp-N-Tek, Eden's proprietary harpin protein technology. It has been shown to enhance a plant's natural defence mechanisms and growth systems against diseases, insects and environmental stresses. It degrades rapidly after application and leaves no detectable residue, which gives it a high degree of environmental safety.

Protectant or Contact Fungicides

These are fungicides that generally have multi-site activity against the biochemical pathways in the various pathogens they control, however because they lack systemic or translaminar activity, are applied to crops to protect them prior to infection. Subsequent growth is not protected by these fungicides.

- ***Sulphur***

This is the most widely used conventional fungicide for the control of powdery mildew on different crops including cucurbits (Baker, 1989). It belongs to the inorganic chemical group of Y fungicides. Several formulations are commercially available. Label recommendations caution its use in rockmelons and cucumbers when temperatures exceed 24^0 C as leaf scorching may occur. Sulphur is also a micro insecticide and miticide. While it kills few beneficial insects, it can devastate predatory mite populations, triggering a secondary outbreak of harmful mites and other pests. Thus it should be used only as necessary. It was mainly included in these evaluations to compare its current efficacy against that of the activators.

- ***Morestan***

Morestan belongs to the quinoxaline chemical group of X fungicides (unspecified mode of action). It is registered for control of powdery mildew and mites in cucurbits. It ia a non-systemic fungicide with protectant and eradicant mode of action. Label recommendations are that wetting agents not be used or mixing with strong alkaline materials such as Bordeaux mixture. It should not be applied within 2 weeks before or 3 weeks after an oil spray and spraying should be avoided if temperatures are likely to exceed 30^0 C as it accentuates sunburn and blemishes on fruit.

Systemic/Translaminar Fungicides

There are four groups of fungicides that are currently registered for control of powdery mildew in cucurbits in Australia. These are Amistar, Bayfidan, various carbendazim formulations and Nimrod.

- ***Amistar 250 EC (azoxystrobin)***

Amistar is registered in Australia for the control of powdery mildew and gummy stem in cucurbits and a range of other diseases in fruit and vegetable crops. It is a member of the strobilurin group of fungicides and for fungicide resistance management is a Group K fungicide. Label recommendations are that it be applied as a protectant and not as a curative fungicide at 7 to 14 day intervals from soon after transplanting and continuing up to fruit maturity. The shorter application is to be used under humid conditions which favour powdery mildew, downy mildew and gummy stem infection and where there is rapid vegetative growth during the early part of the crop cycle. No more than 1/3 of the total fungicide sprays or ≤4 sprays per crop is recommended.

- ***Bayfidan (triadimenol)***

Bayfidan is registered in Australia for control of powdery mildew in cucurbits, grapevines and papaws. It is a broad-spectrum, systemic, foliar fungicide belonging to the DMI group of fungicides and for resistance management is classed as a Group C fungicide.

- ***Carbendazim formulations***

There are various registered fungicides belonging to this group, however either Spin Flo or Bavistin were used in these trials. They are broad-spectrum, systemic fungicides registered for the control of powdery mildew in cucurbits and other crops. They belong to the benzimidazole fungicides and for resiatnce management are classed as a Group A fungicide.

- ***Nimrod (bupirimate)***

Nimrod is a systemic fungicide with protective and curative action for the control of powdery mildew in a range of fruit and vegetable crops, including cucurbits. It has a special minor use APVMA permit for powdery mildew control in bitter melon, cucumber, gherkin, pumpkin, squash, watermelons and zucchini. It is a hydroxyl-pyrimidine fungicide and for resistance management is classed as a Group H fungicide.

Note: For more detailed information on resistance management among fungicide groupings, see DPI &F Note; Fungicide resistance: threats and strategies (Broadly, R. 2006)

Aims and Objectives

The specific objectives of these series of field trials from 2006 to 2008 were to:

1. Evaluate the efficacy of alternative products, namely powdered milk, Bion, Messenger, Ecocarb and silicon (as Stand CSP) in the management of powdery mildew on zucchini, button squash and pumpkin.
2. Compare the efficacy of these treatments to registered fungicides, alone or in combination, and an untreated control.
3. Evaluate the effect of all these treatments on yield parameters (where applicable).

Material and Methods

Experimental Sites and Designs

Field trials were conducted at Ayr (19.62^0 S, 147.38^0 E) and Bowen (20.04^0 S, 148.11^0 E) Research Stations of the Queensland Department of Primary Industries and Fisheries in north Queensland. Standard agronomic practices for irrigation, weed control and fertilizer application were implemented throughout the duration of the trials at both sites.

Disease Assessments

Disease Severity

Disease severity was assessed on stems and leaves of five randomly tagged data plants within each plot. Powdery mildew severity for stem infection was rated on a 0-5 scale as follows:

0 = no disease infection detected on the stem,

1 = 1-10% infection on the stems,

2 = 11-25% infection on the stems,

3 = 26-50% infection,

4 = 51-75% infection and

5 = 76-100% infection on the stems.

This was mainly from stems in the lower third of the canopy. Percent leaf area infected (%LAI) was estimated to the nearest 5% on two to four leaves per plant from actively growing leaves from the lower third of the canopy of the crops for both upper and lower surfaces.

Yield Assessments

Fruit were harvested on a 2 to 3 day interval at Ayr while at Bowen it was harvested once weekly. At each harvest the number and weights of marketable fruit from 5 data plants for each plot were recorded.

Statistical Analyses

All data collected was analysed using the Genstat statistical programme. All analyses were two-way Analysis of Variance (ANOVA). Fisher's Least significant differences (LSD) test was used to make the appropriate pairwise comparisons of treatment means.

2006 Field Trials

Ayr Research Station

Zucchini Trial

A Randomised Complete Block Design (RCBD) comprised of 10 treatments with five reps was used. Rows were 60 m long and individual plots were 10 m with a one metre inter-plot spacing. A powdery mildew susceptible variety of zucchini, Congo (Seminis), was direct seeded into single raised beds covered with black mulch and drip-irrigated at 2 L/m/h on 10 July 2006. Bed rows were 1.52 m wide and plants were 55 cm apart within rows.

Treatments

Treatment applications for the Ayr trial are summarised in Table 5.1.

Each spray treatment was applied using a motorised knapsack backsprayer with hollow cones to give good coverage of data plants (Fig 5.1).

Figure 5.1: Application of spray treatments using a motorised knapsack sprayer

Table 5.1: Treatments and application rates for the Ayr trial, 2006

Treatment Number	Product	Application Rate/10 L
1	Bion	2 g
2	Silicon as Stand CSP	33 mL
3	Powdered milk	100 g
4	Sulphur	37.5 g
5	EcoCarb	40 g
6	Messenger	1 pkt
7	Control (Water)	10 L
8	Ecocarb + Synertrol Oil	40 g & 20 mL
9	Industry Standard 1	Various
	Sulphur/Carbendazim*/Sulphur	5 mL*
10	Industry Standard 2	Various
	Sulphur/Bayfidan#/Sulphur	4 mL#

* Bavistin was the carbendazim formulation used.

Treatments were applied on three separate occasions, namely, 20 and 28 September and 10 October.

Fruit was harvested from the plots at six different harvests, namely, 13, 15, 18, 20, 22 and 25 September. Fruit were collected from 5 tagged data plants from within each plot and the number and total weight of fruit recorded (Table 2).

Bowen Research Station

Zucchini Trial

A RCBD comprised of 6 treatments and 4 reps was used. Congo was also used at this site. Seed was sown into Speedling® trays on 11 July 2006 and transplanted on 3 August 2006.

Treatments

Treatment applications for Bowen trials are summarised in Table 5.**2**. Each spray treatment was applied using the same motorised knapsack sprayer for Ayr trials.

Table 5.2: Treatments and application rates for Bowen trial in 2006

Treatment Number	Product	Application Rate/10 L
1	Unsprayed Control	
2	Powdered milk	100 g
3	Silicon as Stand CSP	100 mL
4	Sulphur	35 g
5	Morestan	3 g
6	Industry standard	
	1. Bayfidan (B)	4 mL
	2. Nimrod (N)	6 mL
	3. Morestan (M)	3 g
	4. Bayfidan (B)	4 mL
	5. Nimrod (N)	6 mL
	6. Morestan (M)	3 mL

Treatment applications were made on the following dates: 15, 21, 28 September, 13, 19 October and 1 November.

The plots were rated twice for disease throughout the trial, on 19 and 26 September respectively and disease severity recorded for leaves and stems.

Harvesting of the plots commenced on 5 August and took place at two to four day intervals over 40 days. The final harvest was on 9 September. At each harvest the number of marketable fruit that were at average marketable size was recorded.

2007 Field Trials

The same integrated disease management treatments were evaluated on zucchini and button squash at Ayr and on pumpkin at Bowen which were used earlier in this study (Table 5.3).

Ayr Research Station (Zucchini and Button squash)

Seed of zucchini (Congo) and button squash (SPS variety "Sunburst") were sown into seedling trays on 25 June and transplanted into the field on 13 July after a few days of hardening in full-sun. Plots were 60 m long (black plastic and trickle irrigated) and the standard 55 cm plant spacing was used for both crops.

Disease severity was recorded on 4 leaves (upper and lower leaf surfaces) on 3 data plants from each plot on 5 sampling dates (3, 10, 20, 31 August and 4 September) using the same procedure in 2006. In addition an overall plot rating was assigned as there were notable visual differences between treatments.

Fruit were harvested 3 times a week (Monday, Wednesday and Friday) from 15 and 17 August to 31 August, for zucchini and button squash, respectively.

Bowen Research Station (Pumpkin)

Butternut Large (SPS) were sowed into Speedling® trays on 18 June and raised in an evaporatively-cooled glasshouse at Ayr, were 'hardened off' in full-sun from 9 July, before being transplanted at Bowen on 12 July and irrigated immediately to minimize transplant shock.

A RCBD of 8 treatments and 4 reps was used. Rows were 60 m long and each rep was comprised of 2 rows widths. Each treatment plot was 7 m long, comprised of 8 plants spaced at 1 m within rows and a 1 m space separating plots.

Four and later 3 data plants from the middle of each plot were used as data plants for disease assessments. Four leaves per plant from lower third of canopy were sampled and rated for disease severity on lower leaf surfaces.

There were a total of five spray treatments (Table 5.3) applied by a motorised knapsack sprayer on 5, 23 August and 6, 17, 26 September 2007, with the first spray was applied at first sign of powdery mildew infection.

Table 5.3: Treatment schedule for spray programme in zucchini and button squash at Ayr and pumpkin at Bowen in 2007

Ayr Zucchini & Button squash	**Spray 1**	**Spray 2**	**Spray 3**	**Spray 4**	**Spray 5**
Treatment	03 Aug	10 Aug	20 Aug	31 Aug	04 Sep
1	Bion	Bion	Bion	Bion	Bion
2	Silicon	Silicon	Silicon	Silicon	Silicon
3	Milk	Milk	Milk	Milk	Milk
4	Sulphur	Sluphur	Sulphur	Sulphur	Sulphur
5	Ecocarb	Ecocarb	Ecocarb	Ecocarb	Ecocarb
6	Control	Control	Control	Control	Control
7	Sulphur	Carbendazim	Sulphur	Carbendazim	Sulphur
8	Sulphur	Bayfidan	Sulphur	Bayfidan	Sulphur

Bowen Pumpkin	**Spray 1**	**Spray 2**	**Spray 3**	**Spray 4**	**Spray 5**
Treatment	05 Aug	23 Aug	06 Sep	17 Sep	26 Sep
1	Bion	Bion	Bion	Bion	Bion
2	Silicon	Silicon	Silicon	Silicon	Silicon
3	Milk	Milk	Milk	Milk	Milk
4	Sulphur	Sluphur	Sulphur	Sulphur	Sulphur
5	Ecocarb	Ecocarb	Ecocarb	Ecocarb	Ecocarb
6	Control	Control	Control	Control	Control
7	Sulphur	Carbendazim	Sulphur	Carbendazim	Sulphur
8	Sulphur	Bayfidan	Sulphur	Bayfidan	Sulphur

2008 Field Trials

There were two field trials of zucchini at Ayr to determine if there were any differences in the level of powdery mildew from an early (April) and late season (mid June/early July) planting. However, the first planting was later abandoned as there was a severe outbreak of downy mildew. Despite removing all infected lower leaves to reduce inoculum, the downy mildew had effectively colonised the foliage, preventing any powdery mildew infection. A zucchini crop was also established in Bowen and the same IDM treatments were evaluated at both locations.

Ayr Research Station (Zucchini planting 1)

Congo seed was sown into Speedling® trays on 14 April 2008 and transplanted into field plots on 30 April. A RCBD comprised of 8 treatments and 4 reps (10 plants/plot) was established. Standard crop husbandry practices were implemented as in previous years. Downy mildew became established with the cool, dewy mornings experienced.

On 13 June the older, infected leaves from the lower part of the canopy were removed to reduce the spread of downy mildew but this was unsuccessful and prevented any powdery mildew occurring by the time harvesting had commenced. Further data could not be collected from this trial because of the downy mildew infection.

(Zucchini planting 2)

Congo seeds were sown into Speedling® trays (50:50 peat/vermiculite) on 16 June and seedlings transplanted into the field on 1 July.

For the Bowen trial seeds were sown on 2 June and seedlings transplanted into the field on 20 June.

A RCBD comprised of 8 treatments and 4 reps was used at both locations.

Plots were 5 m long with a 1 m gap between plots within a row. There were ten plants spaced at 55 cm in each treatment plot. Initial sprays were applied once disease was first detected and on a weekly to fortnightly basis thereafter (Tables 5.4 and 5.5). Five data plants per treatment plot were used for disease and yield assessments. Fruit were harvested from 30 July to 8 September at Ayr and from 11 to 27 August at Bowen.

Table 5.4: Treatments and application dates on zucchini at Ayr 2008

Trt No.	Spray 1	Spray 2	Spray 3	Spray 4	Spray 5
1	Sulphur	Nimrod		Sulphur	Nimrod
2	Silicon	Silicon	Silicon	Silicon	Silicon
3	Powdered Milk	Powdered Milk	Powdered Milk	Powdered Milk	Powdered Milk
4	Sulphur	Sulphur	Sulphur	Sulphur	Sulphur
5	Ecocarb	Ecocarb	Ecocarb	Ecocarb	Ecocarb
6	Water	Water	Water	Water	Water
7	Sulphur	Bavistin/ Carbendazim		Sulphur	Amistar
8	Sulphur	Bayfidan		Sulphur	Bayfidan
Date sprayed	28/07/08	04/08/08	11/08/08	26/08/08	02/09/08
Days from 1st spray	0	6	13	38	44

Table 5.5: Treatments and application dates on zucchini at Bowen 2008

Trt No.	Spray 1	Spray 2	Spray 3	Spray 4	Spray 5	Spray 6	Spray 7
1	Sulphur	Nimrod		Sulphur	Nimrod		Sulphur
2	Silicon	Silicon	Silicon	Silicon	Silicon	Silicon	Silicon
3	Powdered Milk	Powdered Milk	Powdered Milk	Powdered Milk	Powdered Milk	Powdered Milk	Powdered Milk
4	Sulphur	Sulphur	Sulphur	Sulphur	Sulphur	Sulphur	Sulphur
5	Ecocarb	Ecocarb	Ecocarb	Ecocarb	Ecocarb	Ecocarb	Ecocarb
6	Water	Water	Water	Water	Water	Water	Water
7	Sulphur	Bavistin/ Carbendazim		Sulphur	Amistar		Sulphur
8	Sulphur	Bayfidan		Sulphur	Bayfidan		Sulphur
Date sprayed	11/07/08	17/07/08	Missed (Rain)	30/07/08	7/08/08	14/08/08	21/08/08
Days from 1st spray	0	6	-	19	26	33	40

Results

Ayr, 2006

Disease was first noted on the crop on 20 September in the form of small discrete colonies of powdery mildew. Subsequently, the first spray treatments were applied as the disease threshold of 2% incidence of sampled plants had been reached. At the three sampling dates the mean disease severity was very low (<5%) for all treatments and there were no significant differences. There were also no significant treatment effects on yield parameters (fruit weight or fruit number), as summarised in Table 6.

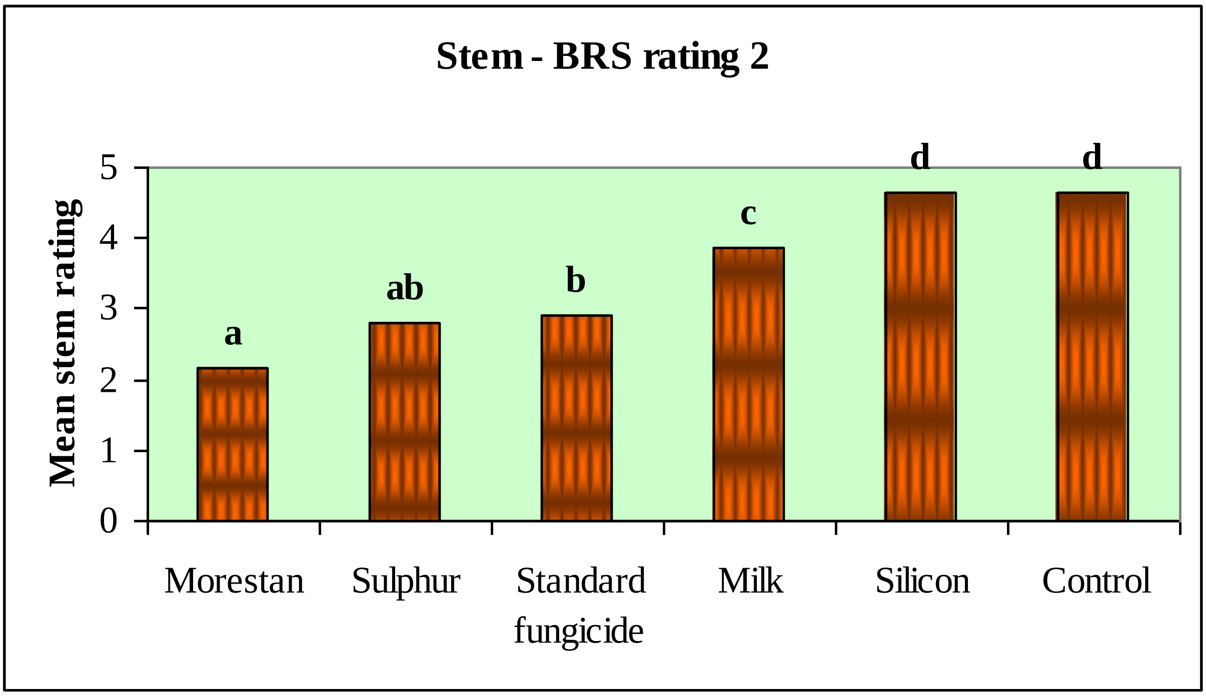
Bowen, 2006

There were no treatment effects on the level of disease on stems (P=0.173) or leaves (P=0.812) for the first disease rating date (19/09/06). On the second assessment date (26/09/06) there were significant treatments differences (P<0.001) for disease severity on stems (Figure 5.2). All the fungicide treatments had less disease than the fungicide alternative treatments and the Unsprayed control. The silicon treatment was no better than the Unsprayed control treatment. However, the milk treatment did have a suppressive effect and was better than both these treatments.

There was a significant treatment effect on mean disease severity of leaves (P< 0.001) in rating two at Bowen (Figure 5.3), with all the fungicides being better than the fungicide alternative treatments and the Unsprayed control. The milk and silicon treatments were ineffective, being no better than the Unsprayed control (Figure 5.3 and Table 5.4).

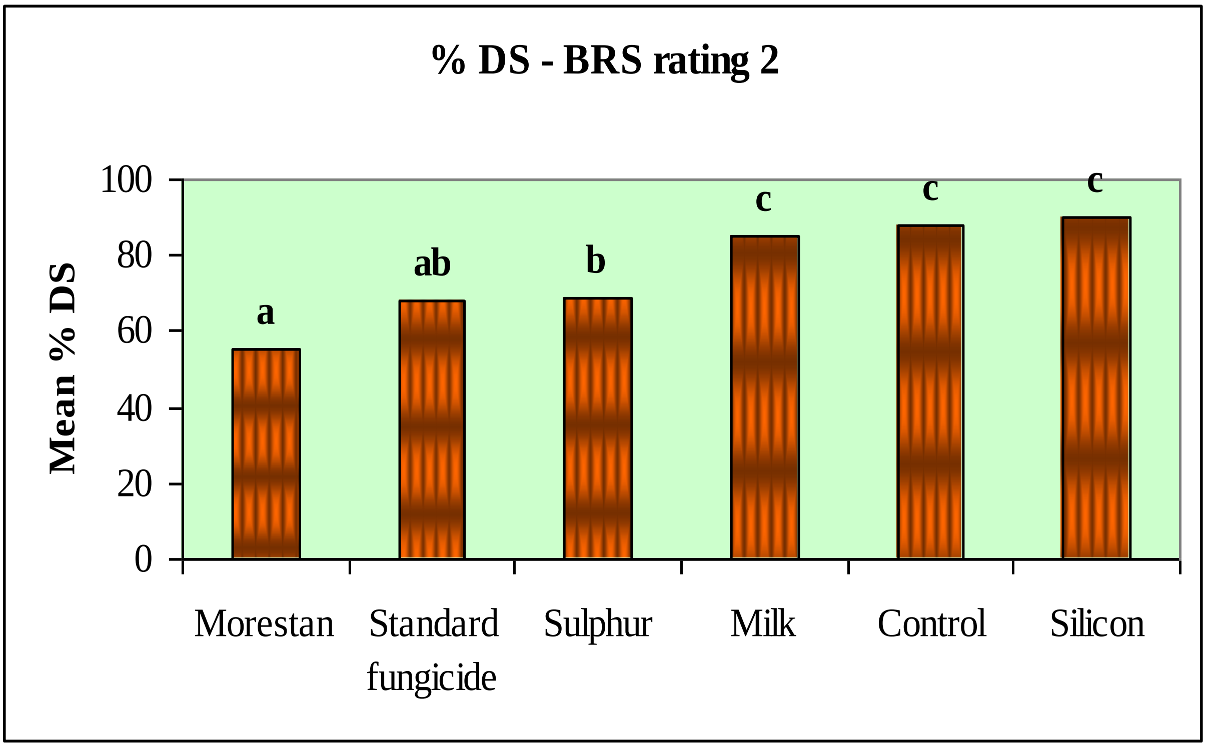
Table 5.6: Effect of treatments on yield in zucchini at Ayr 2006

Treatment	**Fruit Weight (kg)/plot**	**Mean Fruit Number**
1. Bion (x3)	33.3	6.6
2. Silicon as Stand CSP (x3)	31.5	6.1
3. Powdered milk (x3)	33.3	5.9
4. Sulphur (x3)	31.0	6.2
5. EcoCarb (x3)	29.3	5.7
6. Messenger (x3)	32.9	5.3
7. Control (Water) (x3)	36.4	7.2
8. Ecocarb + Synertrol Oil (x3)	40.4	6.6
9. Industry Standard 1	41.9	7.2
(Sulphur/Carbendazim/Sulphur)		
10. Industry Standard 2	31.5	5.6
(Sulphur/Bayfidan/Sulphur)		
LSD (P>0.05)	P=0.979	P=0.830



(Treatments with the same letter are not significantly different at the P = 0.05 level)

Figure 5.2: Effect of treatments on mean disease severity of stems (0-5) at Bowen- 2006



(Treatments with the same letter are not significantly different at the P= 0.05 level)

Figure 5.3: Effect of treatments on mean % disease severity of leaves at Bowen -2006.

DS = Disease Severity

There was no significant (P = 0.391) treatment effect on the number of marketable fruit produced (Table 5.7).

Table 5.7: Disease severity of stems (0-5) and fruit number of zucchini at Bowen - 2006

Treatment	**Disease Severity of Stem (0-5)**	**Mean Disease Severity (%) of leaves**	**Fruit Number**
1. Unsprayed Control	4.650 d	88 c	60
2. Powdered milk (x6)	3.850 c	85 c	68
3. Silicon (x6)	4.550 d	90 c	64
4. Sulphur (x6)	2.800 b	69 b	57
5. Morestan (x6)	2.150 a	56 a	64
6. Industry Standard (B, N, M, B, N, M)	2.900 b	68 ab	61
LSD (P<0.05)	0.7342	13.4	(P=0.391)

(Treatments with the same letter are not significantly different at the P=0.05 level).

Ayr, 2007

There were low levels of powdery mildew on zucchini at Ayr. For the first four rating dates there were no significant treatment differences for disease severity. On the final rating date there were no treatment differences (P=0.148) for disease severity on the upper leaves, however there were significant treatment differences (P=0.07) on the lower leaves (Table 8). All the fungicide treatments were better than the silicon treatment (Treatment 2), but were no better than any of the other treatments. The plot ratings show that were significant treatment differences (P<0.001) with the all the fungicide treatments and milk performing better than all the other treatments which were no worse than the Untreated Control.

Table 5.8: The effect of treatments on disease and yield parameters in zucchini at Ayr in 2007

Treatments	**Disease Severity**			**Mean Yield (kg/plot)**	**Mean Fruit No.**
	Leaves Upper (%LAI)	**Leaves Lower (%LAI)**	**Mean Plot Ratings**		
1. Bion	3.1	8.7 ab	51 b	3.843	36
2. Silicon	14.0	21.9 c	65 b	3.540	34
3. Powdered Milk	0.9	11.5 abc	20 a	5.266	40
4. Sulphur	0	1.4 a	8 a	4.135	36
5. Ecocarb	5.4	17.3 bc	50 b	4.270	38
6. Untreated Control	6.2	12.0 abc	56 b	3.906	37
7. S*/C*/S/C/S	0.2	4.1 a	10 a	4.234	38
8. S/B*/S/B/S	0.2	2.7 a	6 a	4.601	41
LSD (P<0.05)	P=0.148	11.0	18.3	P=0.479	P=0.90

*S=Sulphur, B= Bayfidan, C= Carbendazim.

(Treatments with the same letter are not significantly different at the P=0.05 level).

There were no significant treatment differences for yield, expressed as fruit weight (P=0.479) or fruit numbers (P=0.900).

Button squash 2007

The level of disease severity showed a gradual increase over time. There were no treatment differences for the first four sampling dates, and differences only became significant at the final assessment date (Table 9), similar to the results for zucchinis.

All the treatments were better than the Untreated Control but were no different to each other for disease severity ratings of the upper leaf surfaces.

Table 5.9: The effect of treatments on disease and yield parameters in button squash at Ayr in 2007

Treatments	Mean Upper (%LAI)	Mean Plot Ratings (%)	Mean Plot Yield (kg)	Mean Fruit Number
1. Bion (x5)	16.2 b	34 b	1.7	19
2. Silicon (x5)	17.2 b	53 c	2.1	29
3. Powdered Milk (x5)	6.9 ab	35 b	2.50	26
4. Sulphur (x5)	0.6 a	14 a	2.0	23
5. Ecocarb (x5)	11.5 ab	35 b	1.9	25
6. Untreated Control	40.3 c	72 d	1.5	19
7. S*/C*/S/C/S	7.8 ab	13 a	2.3	27
8. S/B*/S/B/S	2.9 a	11 a	2.0	23
LSD (P<0.05)	11.84	14.27		
Fpr	P<0.001	P<0.001	P=0.805	P=0.430

*S=Sulphur, B= Bayfidan, C= Carbendazim.

(Treatments with the same letter are not significantly different at the P=0.05 level).

The final disease severity assessments showed that there were significant treatment differences with all treatments being better than the untreated control for both disease severity of leaves and plot ratings. For disease severity on upper leaf surfaces, the Sulphur (Treatment 4) and Industry standard (Treatment 8) were better than Bion (Treatment 1) and Silicon (Treatment 2). Powdered milk, Sulphur, and Industry standard with carbendazim (Treatment 7), Ecocarb, Bion and Silicon treatments were no different to each other. For the overall plot rating the treatment differences are more clearly demarked, such that: Treatments 8, 7 and 4 were better than Treatments 1, 3 and 5, which in turn were better than Treatment 2 and all treatments were superior to the Untreated control for suppression of powdery mildew.
Similar to zucchini there were no treatment differences for yield parameters.

There were no treatment differences for disease severity which was relatively low throughout the growing season season (Table 5.10).

Table 5.10: The effect of treatments on disease severity of leaves in pumpkin at Bowen in 2007

Treatments	**Disease Severity Lower Leaves (%LAI)**
1. Bion (x5)	6.7
2. Silicon (x5)	28.0
3. Powdered Milk (x5)	33.9
4. Sulphur (x5)	21.4
5. Ecocarb (x5)	32.3
6. Untreated Control	37.1
7. S/C/S/C/S	20.4
8. S/B/S/B/S	24.5
LSD (P>0.05)	P=0.114

Ayr, 2008

Powdery mildew was first observed on zucchini plants in Ayr on 26 July and first sprays were applied immediately after rating data plants on 28 July. Subsequently, weekly disease assessments were made. Powdery mildew infection was relatively low throughout the growing season of the crop (Figure 5.4), with downy mildew being more of a problem. As there were few sporulating lesions of the upper surfaces of data leaves, ratings were made primarily on the lower leaf surfaces for the third to sixth rating dates. Throughout the entire period there were no significant differences between treatments for disease severity on leaves (Table 5.11). However, on the final assessment date (8 September) there were significant treatment differences for disease which appeared on stems (Table 5.12), with all treatments being better than the Untreated Control which demonstrates that these treatments had a suppressive effect on disease development.

Table 5.11: The effect of treatments on disease severity of leaves (% Lower Leaf Area) in zucchini at Ayr in 2008

	Rating date					
Treatment	28/07/2008	4/08/2008	18/08/2008	25/08/2008	2/09/2008	8/09/2008
1	0.17	0.00	0.00	0.00	0.50	0.71
2	0.21	0.00	0.00	0.13	0.42	0.83
3	0.42	0.08	0.04	0.04	0.46	0.71
4	0.29	0.04	0.13	0.13	0.75	0.67
5	0.33	0.00	0.04	0.13	0.63	0.54
6	0.21	0.04	0.00	0.13	0.75	0.88
7	0.38	0.08	0.04	0.04	0.75	1.00
8	0.21	0.00	0.17	0.04	0.58	0.75
P value	0.294	0.692	0.058	0.478	0.205	0.654

Table 12: The effect of treatments on mean disease severity of stems (0-5) in zucchini at Ayr in 2008

	Rating date	
Treatment	***2/09/2008***	***8/09/2008***
S/B/S/B/S	0.58	0.00 **a**
Sulphur (x5	1.00	0.00 **a**
Powdered Milk (x5)	0.25	0.08 **a**
Bion (x5)	0.50	0.08 **a**
S/C/S/C/S	0.58	0.25 **a**
Silicon (x5)	0.25	0.33 **a**
Ecocarb (x5	1.00	0.42 **a**
Untreated Control	1.00	1.17 **b**
P value	0.816	0.001
LSD(P<0.05)	n/a	0.4803

Treatment means with the same letter are not significantly different at the P=0.05 level

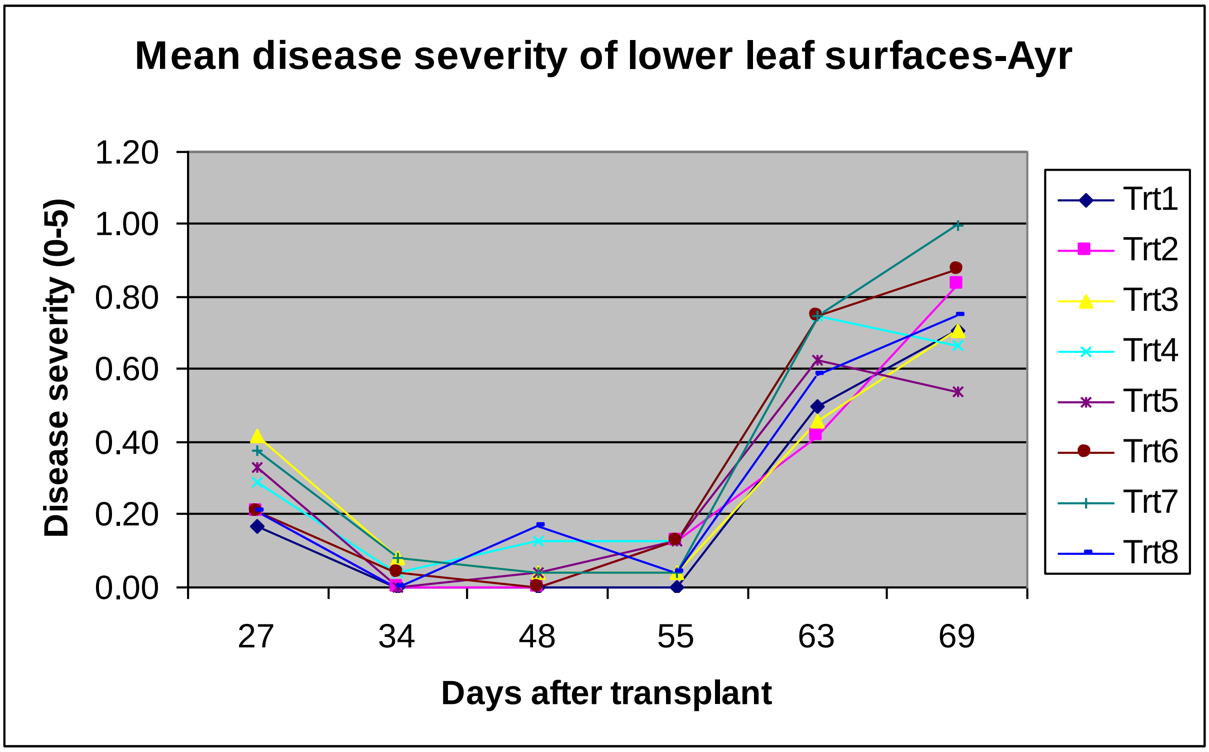


Figure 5.4: Effect of treatments on disease severity of leaves in zucchini in Ayr, 2008

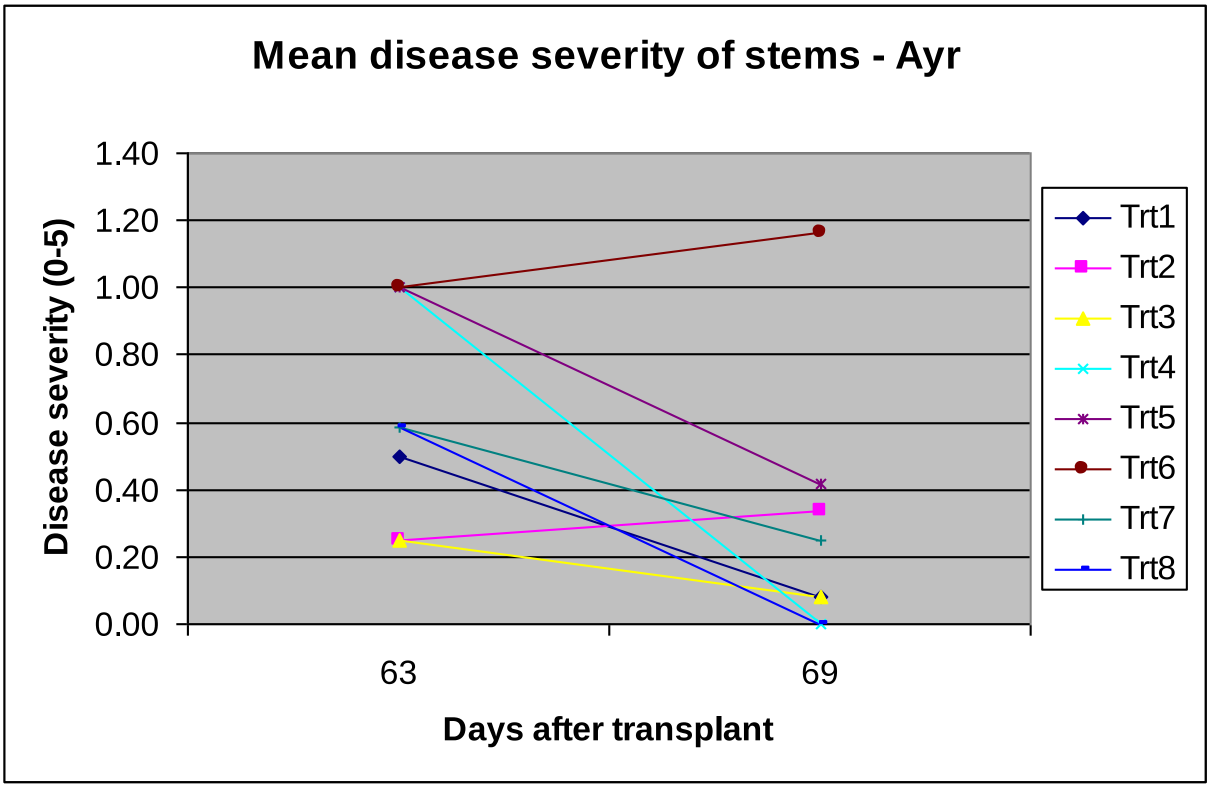


Figure 5.5: Effect of treatments on disease severity of stems in zucchini in Ayr in 2008

There were no significant treatment differences for yield parameters (Table 5.13).

Table 5.13: Effect of treatments on yield in zucchini at Ayr in 2008

Treatment	Fruit weight (kg/plot)	Fruit No	Mean Fruit Weight (g)
1. Sulphur/Nimrod	10.26	63	164
2. Silicon	9.23	59	156
3. Powdered Milk	9.33	61	163
4. Sulphur	10.14	60	167
5. Ecocarb	9.09	59	154
6. Untreated control	9.57	59	162
7. Sulphur/Amistar	10.16	62	165
8. Sulphur/Bayfidan	11.90	69	173
P>0.05	P=0.316	P=0.618	P=0.442

Bowen

Powdery mildew was first observed on zucchini plants in Bowen on 11 July and first sprays were applied on the same day immediately after rating data plants. Subsequently, weekly disease assessments were made. Tables 5.14 and 5.15 show the effects of the different treatments on the progression of powdery mildew on upper and lower leaves, respectively, over the different rating perods.

Table 5.14: The effect of treatments on disease severity of leaves (% LAI upper surfaces) in zucchini at Bowen in 2008

	Rating date			
Treatment	17/07/2008	30/07/2008	6/08/2008	20/08/2008
Sulphur/Bayfidan	0.03 **a**	0.00 **a**	0.25	0.29 **a**
Sulphur/Amistar	0.09 **a**	0.21 **ab**	0.29	0.29 **a**
Sulphur/Nimrod	0.34 **c**	0.00 **a**	0.25	0.92 **ab**
Sulphur	0.06 **a**	0.00 **a**	0.13	0.96 **ab**
Untreated control	0.13 **ab**	0.75 **c**	0.54	2.04 **bc**
Powdered Milk	0.03 **a**	0.29 **abc**	0.17	2.17 **bc**
Ecocarb	0.03 **a**	0.58 **bc**	0.46	2.46 **bc**
Silicon	0.31 **bc**	0.46 **abc**	0.58	2.96 **c**
P value	0.024	0.022	0.273	0.013
LSD	0.2166	0.4848	n/a	1.6280

Treatment means with the same letter are not significantly different at the P=0.05 level

Table 5.15: The effect of treatments on disease severity of leaves (% LAI lower surfaces) in zucchini at Bowen in 2008

	Rating date						
Treatment	17/07/2008	30/07/2008		6/08/2008	20/08/2008		
Sulphur/Bayfidan	0.66	0.17	**a**	1.04	1.46	**a**	
Sulphur/Amistar	0.84	0.88	**bc**	1.46	1.54	**a**	
Sulphur/Nimrod	0.72	0.88	**bc**	0.88	1.79	**a**	
Sulphur	0.56	0.79	**b**	1.29	2.29	**ab**	
Powdered Milk	0.88	1.21	**bc**	1.38	2.79	**bc**	
Untreated control	0.88	0.96	**bc**	1.46	3.08	**bc**	
Ecocarb	0.94	1.13	**bc**	0.79	3.08	**bc**	
Silicon	0.81	1.25	**c**	1.46	3.25	**c**	
P value	0.242	0.001		0.189	<0.001		
LSD	n/a	0.4390		n/a	0.8664		

Table 5.16: Mean disease severity of stems in zucchini in Bowen in 2008

	Rating date									
Treatment	6/08/2008		20/08/2008		27/08/2008		11/09/2008*		11/9/2008	
Sulphur	0.09	**a**	0.42	**a**	0.50	**a**	1.69	**a**	0.2043	**a**
Sulphur/Bayfidan	0.33	**a**	0.58	**a**	1.17	**ab**	2.06	**ab**	0.3066	**ab**
Sulphur/Nimrod	0.11	**a**	0.42	**a**	1.33	**b**	2.69	**ab**	0.422	**bc**
Sulphur/Amistar	0.33	**a**	0.67	**a**	2.17	**c**	2.69	**ab**	0.4233	**bc**
Powdered Milk	0.67	**ab**	2.33	**b**	3.33	**d**	3.19	**c**	0.4995	**c**
Silicon	1.78	**c**	3.92	**c**	5.00	**e**	4.31	**d**	0.6342	**d**
Ecocarb	1.22	**bc**	3.00	**bc**	4.42	**e**	4.75	**d**	0.6761	**d**
Untreated control	1.42	**c**	4.00	**c**	5.00	**e**	4.75	**d**	0.6747	**d**
P value	0.002		<0.001		<0.001		n/a		<0.001	
LSD (P<0.05)	0.8066		1.1560		0.7247		n/a		0.1207	

Table 5.16 shows the effect of the different treatments on the mean progression of powdery mildew disease severity on stems, rated during the production period.

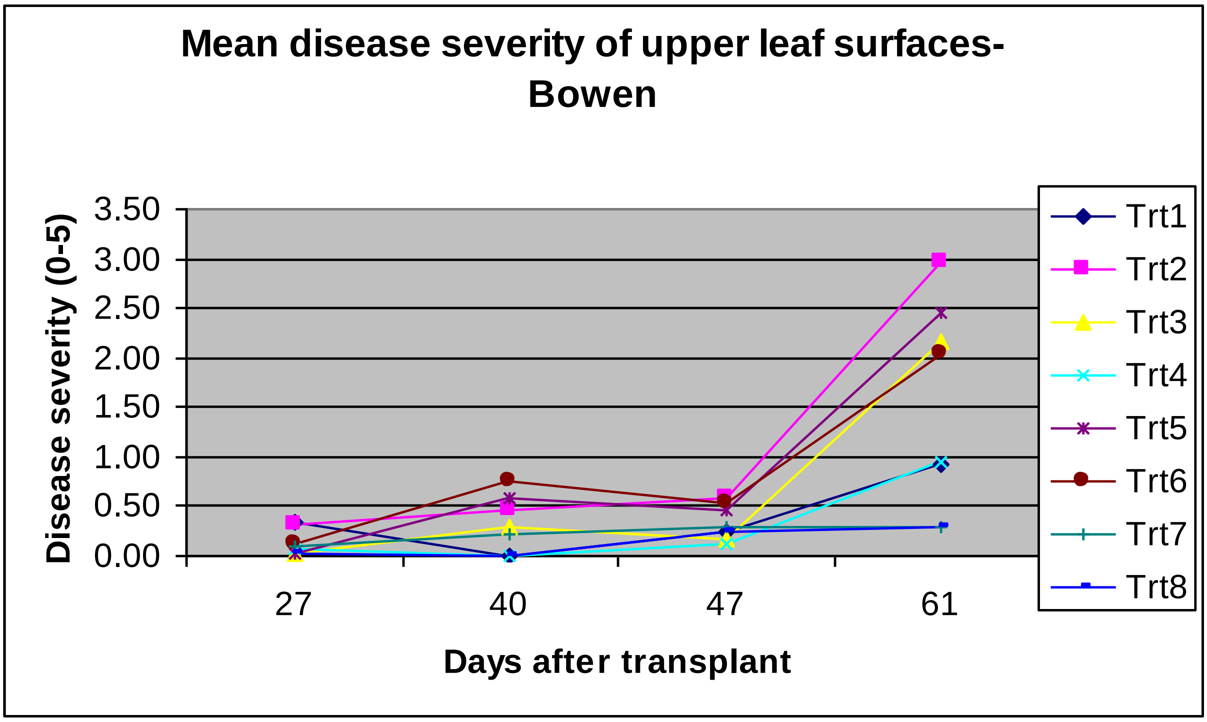


Figure 5.6: Effect of treatments on disease severity of leaves (upper surfaces) in zucchini in Bowen in 2008

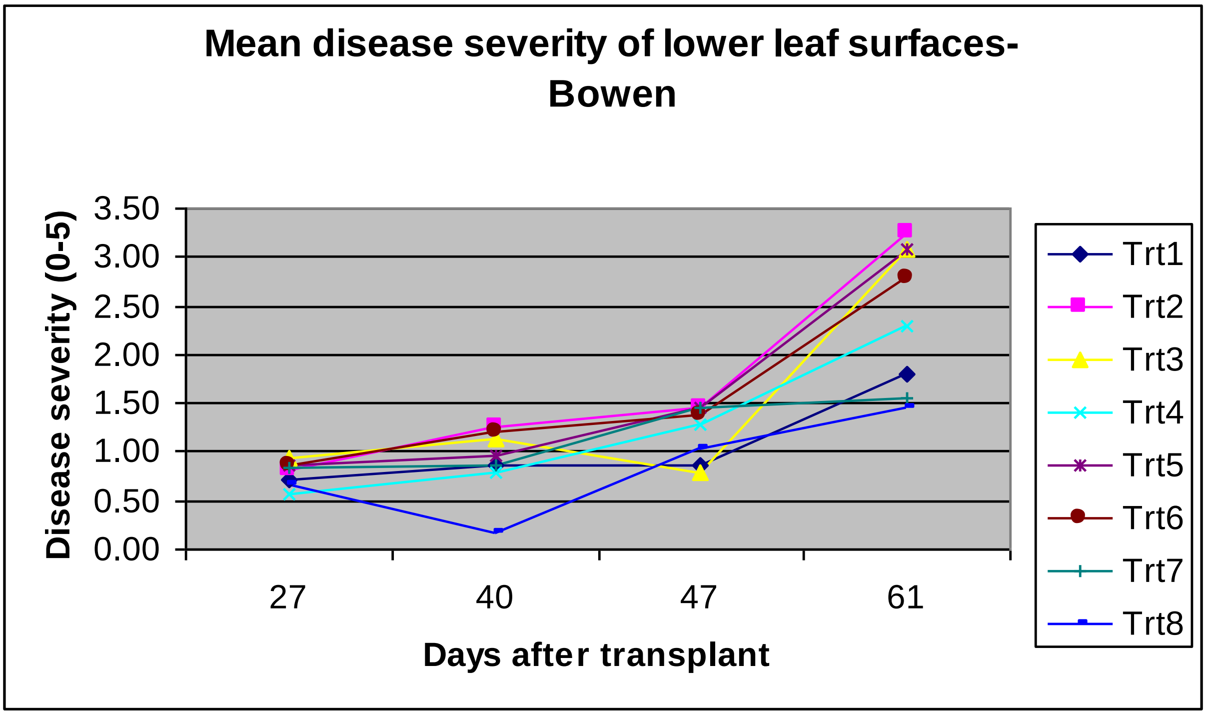


Figure 5.7: Effect of treatments on disease severity of leaves (lower surfaces) in zucchini in Bowen in 2008

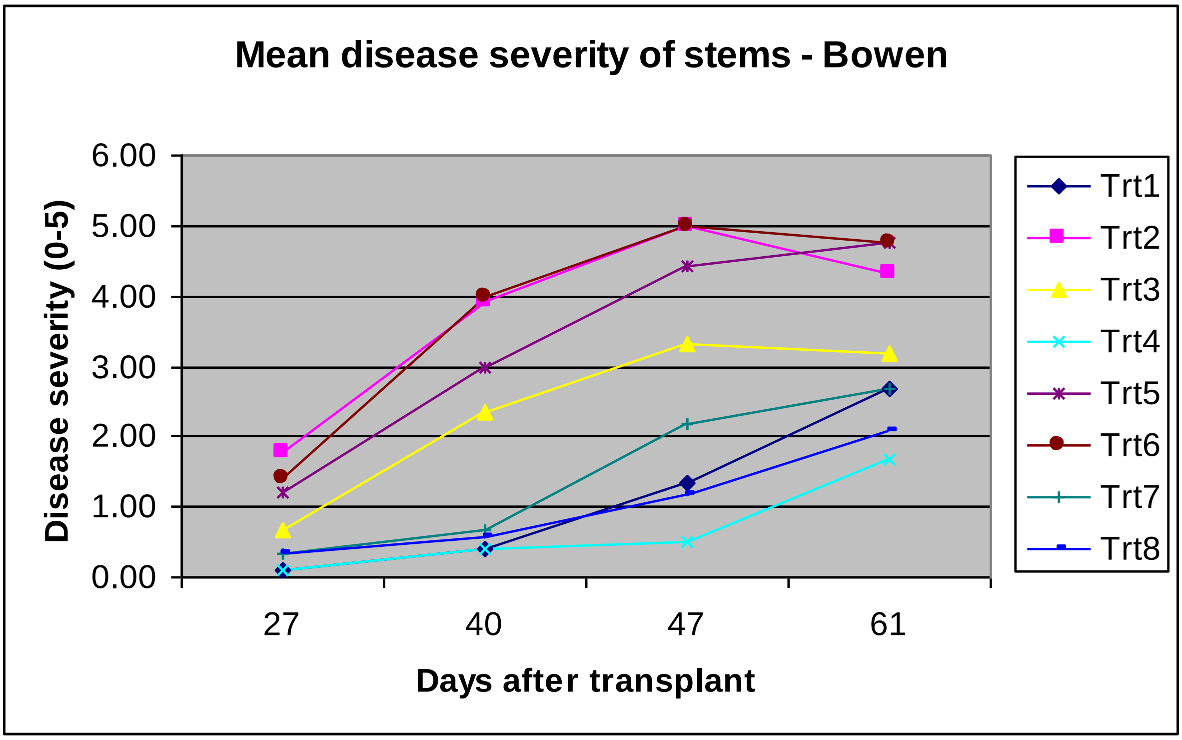


Figure 5.8: Effect of treatments on disease severity of stems in zucchini in Bowen in 2008

The disease severity data showed that there is a gradual increase in disease in the early ages of crop development (11 or 17 July to 6 August) with a sharp increase later in the season (20 August). Heavy rain on 24 July would also have been detrimental by washing spores off leaf surfaces. There were significant treatment differences for rating dates 17, 30 July and 20 August for both upper and lower leaf surfaces. The lower leaf surfaces being more sheltered showed higher disease as would be expected. There we no significant treatment differences for 6 August. The records for disease severity of stems show a similar stepwise increase over time which is typical of polycyclic disease such as powdery mildew (Figures 5.6 and 5.7).

*Those treatments containing a systemic fungicide, i.e. treatments 7, 8 and 1 were superior to all the other treatments except Treatment 4, in suppressing disease on lower leaf surfaces.

Fruit were harvested weekly from July 24 to 27 August (24, 30 July, 6, 12, 20 and 27 August). As would be expected with this less frequent harvesting schedule the average fruit weight was more than those harvested on a 2 to 3 day schedule at Ayr, being 264 g and 163g, respectively.

Discussion

Ayr Research Station, 2006

Zucchini Trial

The trial at Ayr was discontinued because of low powdery mildew severity and severe virus infection late in the season, which had masked powdery mildew. Fruit were severely distorted from the virus infection and would not have been marketable. It was clear from this trial that to extend cucurbit planting late into the season, an adequate insecticidal spray program for the protection and management of viruses is critical.

Bowen Research Station, 2006

All the fungicide treatments had a suppressive effect on powdery mildew disease, as did powdered milk, but to a lesser degree. The silicon treatment was not effective. This may suggest that silicon sprays may not be effective on the cucurbit powdery mildew pathogens strains at this location as it has been reported to be effective against powdery mildew on cucurbits elsewhere.

The disease severity on cucurbit leaves at the final rating was quite high for all the treatments. Even though the fungicide treatments were better than the fungicide alternatives used, this did not result in significant differences in number of marketable fruit that were harvested from the trials. The trials also clearly demonstrates that since Congo is a variety that is highly susceptible to powdery mildew, it can and should be classified as a tolerant variety because it can withstand high disease pressure without much effect on fruit yield.

In other cucurbits, particularly melons and cucumbers, this may not be the case where severe infection levels would lead to a drastic loss of photosynthetic capacity through premature leaf fall. This in turn would lead to yield decline from sunburn and poor fruit quality from which fruit fail to develop completely. Those that develop would either have low brix or poor taste. Additionally, because the time from flowering to fruit maturity is much less in the zucchini crop, fruit yield and quality do not appear to be adversely affected by powdery mildew coming in when the fruit has set. The same cannot be said for the adverse effects of viruses, especially ZYMV and PRSV, which immediately result in unmarketable fruits from the distortion and deformation caused by severe viral infections.

Similar to the zucchini trials in 2006 and 2007 at both Ayr and Bowen there was no apparent detrimental effects of powdery mildew on yield or fruit quality of button squash in 2007. Virus infection became noticeable towards the end of the season but did not appear to have any detrimental effects on fruit quality.

During the early stages of disease development where inoculum loads are lower, fungicide alternatives generally performed just as effectively as the fungicide treatments.

General Discussion

Conducting field trials at two different locations where there are distinct micro-climate was extremely helpful in understanding how powdery mildew develops under these different environmental conditions. This may be related to and affect the management decisions that need to be made for the disease control at each location. Using a commercial zucchini variety such as Congo which is highly susceptible to powdery mildew makes more sense, as any treatments which performs under conditions of high disease pressure, is likely to be even more effective in commercial varieties which are known to have some levels of resistance to powdery mildew bred into them.

Conditions at the Bowen location were definitely more favourable to powdery mildew development with higher levels of severity being recorded over the three seasons. Being more exposed to wind meant that the likelihood of moisture from heavy dews remaining on plants for extended periods was not a significant factor in inhibiting powdery mildew development. This was not the case with the Ayr location which was more protected by wind breaks from nearby trees and established guard rows of sweet corn. This also meant that heavy dew persisted until mid-morning, especially in the early planting in 2008 season. Thus it was not surprising that downy mildew became the more predominant disease on zucchini at the Ayr location, during the 2008 season.

The fungicide alternatives; dilute powdered milk, silicon, Ecocarb and Bion do have some positive effect on the suppression of powdery mildew during the early stages of crop development, especially prior to fruiting when the canopy area is much less, and under conditions of low disease pressure with low inoculum loads. Being protectants, these alternatives rely on good spray coverage of the plant surfaces to protect such surfaces from infection. Unfortunately, emerging tissue subsequent to spray application is not protected. This is where the systemic fungicides can be used to maximum effect because of their systemic or trans-laminar activity.

Sulphur was shown in all the trials to be consistently effective in suppressing powdery development as a protectant. This had been demonstrated by other researches here in Australia (O'Brien *et al,* 1994) and in the USA (McGrath, 2001), on various cucurbit crops. It is particularly useful as a fungicide with a multisite mode of action. Thus the likelihood of the development of isolates building up resistance to it is much less than the case with systemics with single-site activity against the fungus. More frequent sprays of sulphur and good coverage are particularly important to maintain good disease control compared to a spray program that incorporates sulphur, and other fungicides alternatives and systemic fungicides.

The alternation of systemic fungicides from different chemicals groups is paramount to minimize the likelihood of the development of resistant strains of powdery mildew. Of the cucurbit crops tested over the three year period at the two locations, there consistently was no yield decline from even the untreated controls which would suggest that the varieties tested can withstand quite high levels of infection and thus can be classified as tolerant varieties. If they are indeed all tolerant varieties, then the preferred option would be to use the more environmentally-friendly alternatives and multisite protectant fungicides in a spray programme, in preference to the costly, environment damaging single-site fungicides which are more likely to experience resistance problems from their repeated use.

Timing of first fungicides applications is also critical to obtain good management of the disease. A powdery mildew disease threshold of 2% based on the detection of a single infected leaf out of 50 scouted has been demonstrated as the best guide to commence systemic fungicide applications in a spray program (McGrath, 2001). At such an early intervention, other fungicide alternatives in the program would be effective at keeping the disease spread under acceptable management levels throughout the season.

Viruses can cause severe production losses, especially in late plantings in North Queensland as insect activity from aphids and whiteflies, increases. It is therefore imperative to have a good pest management programme in place for such late planted crops. Another important management decision is to select varieties that have some levels of resistance to the common viruses, ZYMV and PRSV, prevalent in the fields at such periods. Data collected from some of the trials in the project indicated that there are some cucurbit varieties with multiple disease resistance to powdery mildew and viruses. These should be used for late plantings.

The results on the impact of diseases on fruit yield, where no apparent yield losses were detected, begins to put to question the need for such high levels of disease control. There may be some impact on the productive life of the plant, but if some slight suppression of the disease can take place in early plant growth, a more moderate management strategy may be more economical as opposed to the apparent current vigorous fungicide programs in most farms with limited economic benefit to the producers.

Chapter 6: General Discussion

I. Summary of key project findings:

- Powdery mildew is endemic in most of the cucurbit production districts of north Queensland, especially the Burdekin district and the Bundaberg region. This is not a new observation as it has been known to be in these regions and all other cucurbit production regions for a long time. What was of interest in the grower survey was to find out how different growers are dealing with the disease in their different cucurbit crops.

- Pathogen resistance to some of the key systemic fungicides used in the regions was confirmed from isolates collected from various cucurbit crops, especially from the Burdekin and Bundaberg regions. There is an urgent need to find suitable replacements, especially in the Gumlu area where there was massive crop failure in a number of farms because of lack of a response from the fungicides to control the disease towards the end of the 2008 season.

- Zucchini yellow mosaic virus (ZYMV) and papaya ring spot virus (PRSV) can be a serious problem on zucchini late in the season, if insect vectors have not been well managed. At such periods in the production season, more attention should be given to the management of the associated insect vectors. In tropical environments temperatures tend to rise above the optimum levels for powdery mildew infection towards the end of the season and the viruses become the major issues and should receive adequate attention.

- Powdery mildew is currently controlled primarily with fungicides and is likely to continue to be the case in the future. There is a need for more sustainable strategies to deal with the disease, without compromising the environment and without unduly increasing production costs as is the case at the moment, with many calendar-based routine spray programs.

- Fungicide alternatives such as powdered milk, silicon, Bion, potassium bicarbonate (Ecocarb) evaluated in this project could be used interchangeably with sulfur as protectants early in the season when disease pressure is low. If opted for later in the season, especially in organic production systems or where systemic fungicides have become ineffective, then the interval between successive sprays should be reduced to get better results.

- Sulphur sprays on their own performed just as good as an integrated spray programme where systemics and protectants were used in alternation. Sulphur is recommended later in the season if disease pressure is high, to reduce the likelihood of resistance developing. It should not be used in combination with oils when these are used in an insect management program because phytotoxicity has been shown to develop in some pathosystems with such a combination.

- There are varieties of zucchini and pumpkin that showed relatively better levels of resistance to powdery mildew and should be seriously considered when deciding on a variety to be used by growers. This will ensure less fungicidal inputs as the genetic resistance would make a substantial contribution to the overall disease management. This is what is and should be considered as part of any integrated crop management program. However, consumer acceptance of the varieties is also critical in this decision process and should be considered.

- Using a disease threshold level of 2% incidence (one out of 50 leaves sampled from scouting in a crop) as an index to schedule first systemic sprays could lead to less overall sprays being used to control the disease in the field. Crop consultants should be encouraged to adopt and use this recommendation for a reduction in seasonal sprays without compromising crop yields.

- Zucchini cultivars can generally withstand high levels of disease pressure without apparent loss in yield. Most of them are therefore tolerant to powdery mildew and routine seasonal fungicide sprays may not really be necessary unless in conditions where infection sets in early in the growing season. Even then, a well planned spray program based on initial threshold levels will keep the disease under control.

- Pumpkin crops on the other hand are generally very tolerant to powdery mildew infections. Spray programs should be initiated with appropriate scouting and the underlying decisions must be based on disease threshold levels including other general environmental conditions that favour the spread of disease in affected farms.

- While strip cropping of many cucurbit crops is essential to maintain continuous market supply of the produce, it is critical to be planned in such a way that old crop debris from completed strips are destroyed as soon as completed, or else they could become reservoirs for powdery mildew inoculum and also a source of virus spread to newly established strips. This fact has also been demonstrated from the studies undertaken.

- There are differences in environmental conditions between various cucurbit production regions and districts. This should be taken into consideration each time recommendations are made. For example, vegetable production areas between Bowen and Ayr where most of the research was undertaken, powdery mildew was more severe in Bowen in all seasonal trials where it is generally windy and drier, whereas other comparable diseases like downy mildew were more prevalent in Ayr with less wind but often heavier morning dews. Such favourable climatic conditions for disease development should be taken into account when adopting strip cropping and also in integrated crop management practices, when these are implemented in the districts.

- Ongoing monitoring for resistance is a priority in the near future. It is important to preserve the useful life of systemic fungicides that are currently registered by continuing to implement resistance management strategies, such as using sytemics on a needs basis only and the alternation of fungicides from the different chemical groups.

- Integrated crop management strategies, such as regular monitoring for disease and spraying only when needed rather than on a calendar basis, selection of varieties with good resistance characteristics, substituting protectant fungicides with foliar fertilizers such as silicon, potassium bicarbonates, etc., plant activators and powdered milk, in addition to regular maintenance of spray equipment and destroying crop residues once a crop has been fully harvested, can all have a positive effect on managing powdery mildew in cucurbit crops.

II. Management guidelines for powdery mildew on cucurbits:

1. Use resistant cultivars that have good marketable fruit traits as the first preferred option. With late plantings it is important to select varieties with good resistance to the main viruses, particularly papaya ringspot virus (PRSV) and zucchini yellow mosaic virus (ZYMV) both of which predominate in many production fields and environments. A good insecticide programme is also essential to minimise the adverse effects of such viruses.

2. Early plantings in North Queensland are more likely to experience downy mildew infections when there are heavy dews and morning fogs. These should be anticipated and strategies put in place to minimise the effects.

3. Fungicide alternatives such as powdered milk, silicon and potassium bicarbonate work well when applied early in the season as protectants and when the disease pressure is still low. They could be used as a substitute for either sulphur or Morestan. However, their efficacy may be reduced when disease pressure becomes high. A shorter spray interval later in the season is recommended under such high disease pressure.

4. Good spray coverage of both upper and lower leaf surfaces is crucial for better results. Should there be situations where only protectants are used, for example, as part of an organic programme, then the interval for sprays could be reduced from weekly to 5 days and applied when disease pressure is high.

5. Crop scouting using a disease threshold of 2% (i.e., one in every fifty plant leaves sampled that shows first signs of disease, such as discrete fluffy powdery mildew colonies, should be the basis for the first spray of systemic fungicides in a good powdery mildew management guide.

6. Alternation of single-site activity fungicides from different chemical groups is a must, and so is the need to alternate with protectants. Later in the season it is advisable to use protectants as part of an overall disease resistance management strategy to preserve the effective life of systemic fungicides.

7. Time plantings to avoid periods of known high disease pressure, especially in late plantings.

8. Where there are a number of sequential plantings in a cropping season, it is important to immediately remove and destroy crop debris which can become a reservoir of spores for subsequent plantings and also a source for virus infection and spread thereafter.

9. As part of an Integrated Crop Management programme, fungicide inputs should be reduced and only used when necessary, avoiding calendar sprays which may be unnecessary. This will ensure sustainable management of powdery mildew in cucurbits. The guiding motto here should be: Use as minimal inputs as possible but as much as needed to give best results.

III. Specific recommendations for future work:

1. The project findings have demonstrated the role genetic resistance can play in powdery mildew disease management. It would be good to include this

parameter in any future integrated disease management research, especially on powdery mildew disease management.

2. Fungicide resistance has been shown to be an issue in some of the cucurbit production areas of central and north Queensland that were surveyed or monitored. It would be useful to monitor and document how widespread the problem is, by extending the surveys and monitoring to all cucurbit production regions of Australia.

3. A comprehensive grower brochure outlining in very simple steps procedures or guidelines guidelines to follow in spray applications in other to minimize the development of fungicide resistance would be very useful.

Chapter 7: Technology Transfer

Industry Field Days and Workshops

Project Field Days

There was a Field Day held at the Bowen trial site in mid-June 2006, which was organised by Clause, the seed company that supplied most of the entries in the zucchini variety screening for resistance to powdery mildew. This was attended by 5 Clause seed company staff, including the area research and development manager, 6 DPI&F personnel (4 from the Bowen Station and 2 from Ayr Station) and 8 local cucurbit growers, maninly from the Bowen production district.

In early October 2007 the Ayr DPI&F staff organised a Field Day at the trial site in Ayr. Five key cucurbit growers from the Burdekin area, 3 seed representativess and staff from Syngenta (2 officers) and Clause (1 officer) as well as local 5 DPI& F staff showcased the 17 varieties that were being tested for sensitivity to powdery mildew as well as viruses that predominated at the time.

Project Workshops

During the off-season, Project Workshops were held at Bowen, Gumlu and Ayr in mid March/early April 2007, 2008 and 2009 to present the key findings from the previous season's trials. These were well attended by local growers and agrochemical representatives and local consultants. Attendance records for the 2008 project workshop showed that there were 15 in attendance at Bowen workshop, including 7 district consultants and 3 growers; 7 in Gumlu including 2 growers and 2 consultants and 24 in Ayr, including 12 growers and 5 consultants. The rest of the attendees at each location were DPI&F staff.

At the upcoming workshops in 2009 a copy of the Brochure ***"Guidelines for Sustainable Management of Powdery mildew in Cucurbits",*** an output of the project**,** will be given to each attendee and will be in demand by local agrochemical resellers.

Conference Presentations

Australasian Plant Pathology Conference, Adelaide, September 2007

The Project Leader (Dr Chrys Akem) presented a research paper from the project results titled *"Powdery mildew resistance in zucchini varieties",* during this conference.

Media Report

Dr Gerry MacManus, the Project Pathologist was interviewed by ABC local radio in June 2006, following a ***Media Release*** by QDPI&F highlighting the new research project.

The QDPI&F Media Release was also featured in the local ***Burdekin Grower,*** a section in the two local newspapers ***The*** **Advocate** (Ayr) and **The Observer** (Home Hill).

Other Reports

A feature article was written for Vegetables Australia towards the end of 2008. It has been published with title: "***Milk cucurbit protection for all it's worth***" *Vegetables Australia* Volume 4.6, May/June 2009; page 24.

A poster summarising some of the project findings has been produced for presentation during the Australian Hydroponic and Greenhouse Association Conference schedule to hold in Sydney in mid July 2009.

Two technical articles (Appendix 2 and 3) outlining project results were produced and accepted for publication in *Pest Disease Management Reports*, a publication of the American Phytopathological Society. The reports were:

1. ***Virus resistance evaluation of zucchini varieties, 2007*** – *Plant Disease Management Reports 3: V019*
2. ***Powdery mildew resistant evaluation, Bowen, Australia, 2008*** - *Plant Disease Management Reports 3: V020.*

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I would like to extend my sincere thanks to the project team members for their support. In particular, I would like to mention Ross Wright here, who started off with the project and decided to avail himself to a well deserved early voluntary retirement at the end of the first year of the project. The other members of the team who continued with the work were: Gerry MacManus, Paula Boccalatte and Zoe Disher. Kerry-Lee Stockdale joined the project mid way. Then in the last season of the project, Elio Jovicich and Dalvinder Lakhesar also joined the team and contributed towards the project activities. The hard work of the entire Tropath Team in different ways and their dedication to the success of the project cannot go unnoticed. Ross Wright again needs to be singled out (shown in photo below) and appreciated for the collaborative skills he displayed in coordinating the varietal zucchini trials from the different seed companies for resistance evaluation in the project. One of the company representative even decided to declare that the trials were established by him just to gain some recognition from his superiors; something Ross never stopped joking about.

Other colleagues who played significant roles in the success of the project though not directly in the project team are Sue Heisswolf who together with Ross included a section on grower perspectives on powdery mildew on cucurbits to her Western Flower Trip Grower survey.

Considerable in-kind contributions were provided by various seed and chemical companies. We thank representatives of:
- Clause
- Lefroy Valley
- Seminis
- South Pacific Seeds
- Syngenta
- Terranova

for providing the seed that was used in the resistance screening trials.

We would also like to thank the following chemical companies for making in-kind contributions with the different products that were evaluated for their efficacy in controlling powdery mildew on cucurbits: Agrochem for the provision of liquid silicon, Organic Crop Protectants for EcoCarb and Synetrol Oil, and Syngenta for Bion.

We thank cucurbit growers who provided ready collaboration by allowing us into their fields to collect samples, attending organised field days, and making time to participate in project workshops. Particular appreciation is extended to the Chapman Brothers in Gumlu in whose fields some resistance testing bioassays were carried out after they experienced an outbreak of powdery mildew on their late melon crops.

Lastly, but certainly not he least, our appreciation goes to Horticulture Australia Limited (HAL) and the Queensland Department of Primary Industries and Fisheries (DPI&F) for providing needed funding for this project.

Ross Wright – Examining his screening trial at Bowen Research Station

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Appendices

Appendix 1: Powdery Mildew Section of 2006 Needs analysis for WFT project (VG05050)

Grower survey form

Identification of Issues and Needs; Collection of Baseline Evaluation Data

Name	Phone
Business	Fax
Address	Mobile
	Email
District	Consultant?

Question 1.

Main crops grown	Area grown	Main pest problems? What time of year?

Question 2. What practices are you currently using to manage these pest problems?

Crop/pest	Managing with….

Question 3. Where do you get the most useful information for managing pests?
Rate in order of importance

Part A: Focusing on Western Flower Thrips (WFT) Questions….

Part B: Focusing on Powdery mildew Questions

Question 4. What percentage of yield do you estimate to be lost due to powdery mildew in the previous two years our farm?

Which crops, and the estimated % per year?

Question 5. How are you currently managing powdery mildew problems?
Note also main fungicides used and their effectiveness

Question 6. Is there anything else you do to manage powdery mildew problems?
Note the practices and attitudes from the response

Question 6. Do you think you are getting adequate control of powdery mildew?

***If** YES*

What do you think is essential for getting good control?

Are there any other suggestions you could make for further improving powdery mildew management?

***If** NO*

What are some of the main problems?

What would help you to improve powdery mildew management on your farm?

Question 7. What do you think is essential to get good control of powdery mildew?

Question 8. Do you get rid of old crops straight away?
Question is to see if grower understands the role of old crops in disease spread

Question 9. Do you regularly calibrate your spray rig to improve coverage?

Question 10. Would you be willing to try out any new methods of controlling powdery mildew?

Question 11. What would help you improve your powdery mildew management?

Question 12. Does powdery mildew influence your choice of variety?

Question 13. What is your approach to managing fungicide resistance?

Question 14. Is there any other information or training needed or anything else you would like to learn about?

Question 15. Would you be interested in attending any Field days, Workshops or Seminars on powdery mildew management on cucurbits? ***Mention newsletter***

Field days Workshops Seminars	If **NO**, any suggestions on alternatives?
Best location	

Best day of week	
Best time of day	
Preferred length	

Thank you for your time in completing this survey
Your answers will help us develop better ways of managing powdery mildew and getting this information out to you

Appendices 2- 3: Plant Disease Management Reports from the Project

PUMPKIN (*Cucurbita pepo*) Powdery mildew; *Podosphaera xanthii*

E. Jovicich, C. Akem and G. MacManus
Department of Primary Industries & Fisheries; Horticulture and Forestry Sciences; ARS, PO Box 15, Ayr, QLD 4807, Australia

Appendix 2: Powdery mildew resistant pumpkin cultivar evaluation, Bowen, 2008.

The main objective of this study was to evaluate the resistance to powdery mildew of a range of pumpkin cultivars available and grown across tropical locations in north Queensland, Australia. Nine cultivars of different fruit types were evaluated for resistance to natural infection by powdery mildew in Bowen (Long. 148º 11' 42", Lat. 20º 0' 38"). In a Don sandy clay loam soil, field plots with six plants per plot were arranged in a randomized complete block design with four replications. Three week old seedlings with three unfolded leaves were transplanted on 19 June into drip-irrigated (2 L/m/h) raised beds covered with black polyethylene mulch. Bed rows were 3.04 m from each other and plants were 1.0 m apart within bed rows. Pre-plant fertilizer (N-P-K, 13-15-13 at 4 kg/100 m row) was applied in two bands of the planting beds. After flowering, fertilizers applied through drip irrigation included potassium nitrate (three applications at 0.6 kg/100 m of row) alternated weekly with calcium nitrate (two applications at 0.5 kg/100 m of row), and one final application of potassium sulphate (0.2 kg/100 m of row). Plots were irrigated as needed, with water delivered two to three times per week for irrigation periods that ranged from 2 to 4 h. No fungicides were applied. Weeds were managed with Roundup (7 mL/L), applied as a directed shielded spray in the area between plots during the early part of the season, and with manual cultivation in the later part of the season. Insecticide Confidor Guard, (a.i. imidacloprid; 14 mL/100 m of row) was drip-injected once after transplanting for controlling whitefly [*Bemisia* spp. (Hemiptera: Aleyrodidae)] and cotton aphid [*Aphis gossypii* Glover (Homoptera: Aphididae)]. In each plot, disease severity was assessed on 8 leaves of four plants on 20 Aug, 27 Aug and 11 Sep. Two runner shoots were randomly selected in each plant and disease severity was assessed on the lower surfaces of the leaves located at leaf node number 8, counting from the youngest fully expanded leaf near the shoot tip. Each selected leaf was assigned a disease severity score based on the percentage of leaf surface covered with powdery mildew colonies. Weight and number of harvested fruits were recorded on 14 Oct. During the crop growing period, mean high and low temperatures (ºC) were 25.5/12.0 in June, 24.3/12.6 in July, 25.1/11.3 in Aug, 28.4/16.8 in Sep, and 30.3/19.9 in Oct, respectively. Rainfall (mm) was 0, 105, 0.4, 10.4, and 2.0 for the latter months, respectively.

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

Japanese cultivars, fruit weights were not significantly different from each other (average 2.0 kg). Fruit quality (cosmetic appearance of fruit) was not affected by powdery mildew.

		Powdery mildew severity[z]						
		Percentage of area covered on lower leaf surface (%)[y]			AUDPC[w]	Fruit yield[z, x]		
Cultivar	Fruit type	20-Aug	27-Aug	11-Sept	(%-days)	(kg/fruit)	(No.×1000/ha)	(t/ha)
Sampson	Grey	8.3 bc	6.5bcd	48.2ab	462 c	4.8 b	6.7 cd	32.3ab
183-6	Grey	25.8 a	33.3 a	73.6 a	1009 a	4.8 b	7.4 bc	36.1 a
188-6	Grey	9.2 bc	10.8 bc	55.9ab	570 bc	6.2 a	5.2 d	32.3ab
Early Jarragrey	Grey	9.2 bc	15.9 b	38.7 b	497 bc	3.8 c	6.2 cd	22.7 c
Royal Grey	Grey	29.7 a	42.2 a	71.7 a	1106 a	3.2 d	9.6 a	30.5 b
Kens Special 864	Japanese	1.6 d	1.2 d	1.4 c	29 d	1.9 e	10.9 a	21.1 c
Kens Special	Japanese	3.0 cd	1.1 d	2.0 c	38 d	2.0 e	9.9 a	20.3 c
Dynamite	Japanese	4.6bcd	3.0 cd	4.1 c	80 d	2.1 e	9.4 ab	19.9 c
TNT	Butternut	10.4 b	16.3 b	70.3 a	743 b	1.3 f	9.1 ab	11.7 d
P-value		<.001	<.001	<.001	<.001	<.001	<.001	<.00

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

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

[w] Area under disease progress curve (AUDPC) calculated for disease severity assessed 20 Aug, 27 Aug, and 11 Sep.

[x] Yield per ha calculated for a full area cropped (3,290 plants/ha) with no drive ways.

Appendix 3: Virus resistance evaluation of zucchini varieties, 2007.

ZUCCHINI (*Cucurbita pepo*) Viruses (Water melon mosaic, papaya ringspot, zucchini yellow mosaic)

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The objective of this study was to evaluate the resistance of zucchini varieties to various viruses, namely, watermelon mosaic virus (WMV), papaya ring-spot virus (PRSV) and zucchini yellow mosaic virus (ZYMV) which are commonly found on cucurbits grown in north Queensland, Australia. Seventeen varieties were raised in a glasshouse and transplanted on 6 Aug, into a dark clay loam soil in Ayr (19.62^0 S, 147.38^0 E), 2 wks after sowing. Field plots with eight plants per plot, were arranged in a randomized complete block design with four replications. Seedlings with three true leaves were transplanted into drip-irrigated (2 L/m/h) raised beds covered with black polyethylene mulch. Bed rows were 1.52 m wide and plants were 55cm apart within rows. Pre-plant fertilizer (N-P-K, 13-15-13 at 2 kg/100 m row) was applied in a band and incorporated. After flowering, fertilizers applied through drip irrigation included potassium nitrate (three applications at 0.6 kg/100 m of row). Plots were irrigated as needed, with water delivered once or twice a week for irrigation periods that ranged from 4 to 7 h. No fungicides or insecticides were applied. Weeds were removed manually with a chipping hoe. Fruit were harvested on a 3 day interval from 21 Sep to 19 Oct. Weight and number of harvested fruits was recorded at each harvest date from three inner data plants. Disease assessments were made on 17 Oct. Each data plant was assigned a disease severity score for leaves and fruits as follows: (0=absence of infection; 1=mild, some leaves having vein clearing; fruits normal; 2= moderate, some leaves slightly distorted; some fruits slightly lumpy and distorted; 3=high, most leaves distorted; most fruits lumpy and distorted; 4= severe: most leaves severely distorted with small, lumpy and severely distorted fruits or no fruits at all. Leaves in the upper quarter of the canopy where symptoms were most noticeable were assessed. Leaf samples (one leaf per plant of the second youngest unfolded leaf) were tested by ELISA on 25 Oct using antibodies to PRSV, WMV and ZYMV.

There was a large variation in the inherent genetic resistance to virus infection of the varieties evaluated. Quirinal, Paydirt, Crowbar and Calida showed low incidence of viruses and there was also low severity expressed on both fruit and leaves. They also performed better for yield parameters. Conversely, there were a few varieties, particularly Caroline, Congo, Regal Black, 5191Y, Black Adder and Mamba that performed very poorly with very high incidence and very severe disease which also resulted in poor yields. The other varieties showed intermediate levels of virus infection and fruit yield. WMV was not detected in any of the varieties sampled while 82 and 72% revealed the presence of PRSV and ZYMV, respectively. Both viruses were detected in 60% of the plants tested.

	Disease Incidence**	Disease Severity Fruit*	Disease Severity Leaf*	Fruit yield*	
Variety	(%)	(0-4)	(0-4)	(No./plant)	(g/plant)
Quirina.	11 a	0.3 ab	1.3 abc	3.8 a	206 a
Paydirt.	21 a	0 a	0.9 ab	3.6 a	165 ab
Crowbar	23 ab	0.1 ab	0.8 a	3.8 a	146 ab
Calida	28 ab	0.9 abc	1.5 bcd	3.2 ab	155 ab
CLX29881.	41 bc	1.4 bcd	2.1 de	3.1 ab	144 ab
ZU393	58 cd	2.4 def	2 de	2.8 ab	126 bc
CLX29442	59 cd	1 abc	2 de	3.6 a	143 b
Regal Black Improved.	65 de	3 efg	4 f	2.1 bc	121 d
7709.	68 de	1.9 cde	1.9 cde	2.4 ab	112 a
Regal Black.	75 def	2.9 efg	4 f	1.9 bc	114 a
Amanda.	81 ef	2.9 efg	2.3 e	2.7 ab	134 b
Congo.	90 f	4 g	4 f	1.9 bc	57 cd
6496.	90 f	2.9 efg	2 de	1.8 bc	158 a
5191Y	90 f	4 g	4 f	0.7 cd	142 ab
Black Adder..	90 f	3.9 g	4 f	0.4 d	66 ab
Mamba..	90 f	4 g	4 f	2 bc	57 c
Caroline	90 f	3.5 fg	3.8 f	2.8 ab	63 de
P-value	<.001	<.001	<.001	<.001	<.001

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

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

Appendix 4: Grower Brochure.

VG05054: Management of powdery mildew in field and greenhouse cucurbits.

The Problem

For some time now, conventional fungicides have not been giving adequate control to powdery mildew (*Podosphaera xanthii*) on cucurbits, suggesting that resistance by the fungi has developed or is developing. Alternative treatments and strategies to minimise the use of systemic fungicides, and therefore the threat of resistance were investigated in this project.

The Disease

Powdery mildew is a major disease of cucurbits grown under field and glasshouse conditions in Australia. The disease is caused by the fungus (*Podosphaera xanthii*), previously known as *Sphaerotheca fuliginea*. The fungus is an obligate parasite and will only survive on living plants. It produces multiple generations in a cropping season and under favourable conditions spreads rapidly, reproducing every 5-7 days. Powdery mildew requires warm, dry conditions to spread. Prolonged, heavy dews retard its spread and favour the spread of downy mildew. Spores are spread primarily by wind. Lack of response to sprays can result from a number of things. Among these are: poor spray coverage, bad timing and the development of resistance by the fungus to the fungicides being used.

Symptoms

Distinctive whitish fungal colonies occur on both upper and lower surfaces of older leaves and later in the season on the stems and petioles in the lower canopy.

Close-up of a severely infected leaf with powdery mildew spore coverage

What was done:

1. Test the resistance of isolates from some major cucurbit growing areas of Central (Bundaberg) and Northern (Burdekin) Queensland, to the main systemic fungicides (Amistar, Bayfidan, Spin Flo and Nimrod) currently in use'
2. Study weather parameters and establish a spray threshold-based system to determine the time of first fungicide applications,
3. Evaluate alternative control strategies to fungicides, such as cultivar resistance and the use of non-synthetic products, as part of an integrated crop management strategy.

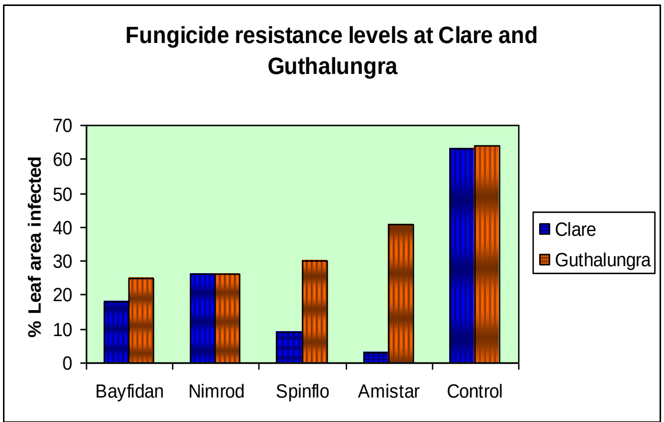
Application of fungicide alternative treatments to zucchini using a motorized backpack.

How it was done:

A series of field trials were undertaken during the 3-year duration of the project. These included: 1) Screening pathogen isolates from different cucurbit crops and locations, for resistance development; 2) Evaluating the effectiveness of alternatives to fungicides in spray programmes; 3) Studying the development of the disease to determine spray timings and 4) Testing cucurbit varieties for natural resistance to powdery mildew.

What we found

There were clear indications that fungicide resistance was a problem on some farms in both the Bundaberg and Burdekin regions. This is cause for concern and will need to be followed up to see how the widespread occurrence of the problem could be limited. Powdery mildew isolates that were exposed to systemic fungicides showed varying levels of resistance (see graph).



Fungicide resistance levels at two locations in the Burdekin. The greater the leaf area infected, the lower the effect of the fungicide. Control = no fungicide applied

Seasonal monitoring of isolate sensitivities is being implemented in north Queensland to better understand the extent of the problem and advice growers on how to limit its widespread.

Fungicide alternatives such as powdered milk, silicon, Bion, potassium bicarbonate (EcoCarb) have been shown to be suitable replacements or complements to sulphur at the start of the season, when disease pressure is still low. Their early use can delay or limit the use of systemic fungicides without compromising on production.

In terms of crop monitoring, a disease threshold of 2% was found to be useful in determining the timing of the first systemic spray. Using this threshold guide could lead to a reduction in fungicide use over the season, thereby saving production costs. To implement this threshold, the first fungicide application is made when one leaf in fifty is showing symptoms of powdery mildew infection.

There were differences in the natural resistance to powdery mildew among the cucurbits. For zucchini, good varieties that are commercially available were Amanda, Calida and Crowbar. Congo, though highly susceptible can tolerate high levels of infection without yield decline. For pumpkin, varieties showing high levels of resistance were most of the Jap varieties as well as Sampson and Early Jarragray.

A susceptible cultivar (left) of zucchini showing infection on the stem and leaves compared to a resistant cultivar (right)

Key recommendations for integrated management of powdery mildew on cucurbits:

1. Start with resistant cultivars that have good marketable fruit traits.
2. Fungicide alternatives such as milk, silicon and potassium bicarbonate work well early in the season as protectants, when disease pressure is still low.
3. Limit spray applications to only when weather parameters favour disease development. Unnecessary calendar-based sprays should be avoided.
4. Crop scouting using a disease threshold of 2% (one in every fifty plants showing first signs of disease) is a good time for the first systemic spray.
5. Try to alternate multisite fungicides (systemics) from different chemical groups with the different protectants.
6. In situations where only protectants are used, such as part of an organic programme, spray intervals should be reduced from weekly to 5 days when disease pressure is high.
7. Time plantings to avoid periods of known high disease pressure, especially in late plantings when the spore populations are high.
8. Under high disease pressure conditions, especially late in the season, systemic fungicides should be avoided and only protectants should be used to minimise the likelihood of resistance developing.
9. Good spray coverage is essential, so ensure that both upper and lower surfaces are targeted. To achieve this, regular calibration of sprayers is essential.
10. Remove crop debris from previous plantings to reduce fungal spores as part of a cultural disease management strategy.