Development of guidelines for sustainable management of powdery mildew in capsicums

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Development of Guidelines for Sustainable Management of Powdery Mildew in Capsicums.

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This report summarises the results of a three-year study examining options for the control of powdery mildew on capsicums and developing guidelines for the sustainable management of the disease. It is the final report for the project VG03029 ***"Development of Guidelines for Sustainable Management of Powdery mildew in Capsicums"*** outlining the work undertaken and the outcomes achieved for the Capsicum industry.

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Horticulture Australia Limited
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Media Summary

The latest research conducted in this project has identified some sustainable ways to protect the capsicum industry, worth almost $80 million a year, from powdery mildew.

Powdery mildew is caused by the fungus *Leveillula taurica* and can seriously affect capsicum production in tropical and subtropical environments, where the crop is predominantly grown. It is often a late-season disease and becomes a problem on plantings that are late or where no protective measures are used. Powdery mildew is often controlled with sulphur-based fungicides. Unfortunately, these fungicides seem to be inadequate when faced with epidemic proportions of the disease. There is a real need for the industry to have better, more sustainable ways of managing powdery mildew, and this was the aim of this project.

Field trials established that there had not been shifts in pathogen populations in recent years to warrant sudden epidemics, so epidemics like the one in 2000–01 was likely the result of particularly favourable weather conditions for the disease.

The project also investigated the level of resistance to the disease in current varieties and in germplasm from another breeding capsicum project. Of the six current varieties being grown in Australia, Toledo and Ingot had some resistance to powdery mildew. Some of the germplasm from the breeding project was also found to have multiple resistances to viruses and powdery mildew.

A number of products were tested to determine their usefulness to protect against powdery mildew. Several of the products proved to be good protectants and were shown to be effective in breaking the continuous use of the systemic fungicides, prolonging their effectiveness when used in a carefully managed resistance management program.

Based largely on the results from this project, a set of guidelines has been produced for distribution to growers and other capsicum industry stakeholders that will help them sustainably manage powdery mildew on capsicums in areas where the disease is a serious threat to either fruit yield or fruit quality during the production season.

Technical Summary

Powdery mildew caused by the fungus *Leveillula taurica* (Lev.) G. Arnaud), can be a serious disease of capsicums in the tropical and subtropical environments of Australia where the crop is largely grown. It is often a late-season disease and becomes a problem on late plantings or in plantings for which no protective measures for its control are being implemented. Protectant fungicides, especially sulphur in different formulations, have often been relied on for the control of the disease. In recent years, however, the disease intensity has increased, necessitating the need and use of more sustainable methods of managing the disease in endemic areas. The objective of this study was to quantify the prevalence of the disease across production zones in a typical production season, investigate other options that could be used for its control and evaluate some of these options in integrated disease management programs in order to establish guidelines for the sustainable management of the disease.

The study was necessitated by the apparent inadequacy of sulphur compounds as protectants to protect capsicums against the disease epidemics when higher than usual epidemics were recorded across the different production districts of Queensland during the 2000/2001 cropping season. Other systemic fungicides that had been shown to be effective against *L. taurica* and related powdery mildew-causing pathogens were quickly evaluated for efficacy and temporal registration for use under emergency and minor permits in subsequent year. It was then the focus of this project to evaluate and identify more sustainable methods for the management of the disease.

Since the identification and approval of emergency or minor permits for the use of some systemic fungicides to control the disease, an epidemic has not been reported in recent years, except in farms where the timing was off mark and the spray coverage was not adequate to protect the plants during optimal conditions for disease initiation and spread. A series of field trials and experiments were however initiated during the 2004 season and carried out over the 3 year study period to investigate possible options available for the disease control so as to establish some guidelines for growers to manage the disease more sustainably. This started with field surveys to determine if there had been shifts in pathogen populations in recent years to warrant sudden epidemics. It was established that this was not the case and 2000/2001 season might have just produced more favourable conditions for the disease initiation and spread. Extensive screening of germplasm being produced in a breeding project for resistance to the tospoviruses, another serious disease of capsicums, was undertaken in an effort to identify possible sources of multiple disease resistance in capsicums. The screening also included the currently available varieties used by growers across the production zones for which their reactions to the disease under Australian conditions have not been established. Germplasm was identified with multiple resistances to both tospovirus and powdery mildew and is being advanced under the tospovirus resistance breeding project. Of the six currently available varieties being grown in Australia, 2 (Toledo and Ingot) were identified to have some resistance, while 2 others (Tycoon and Aries) were considered very susceptible.

Among the products evaluated for control of powdery mildew under field infection conditions, silicon was shown to be effective both as an activator and a cell wall enhancing product whose use in the early stages of crop growth and at fruit set could offer extra protection from powdery mildew infections. Other products also shown to offer some efficacy were foliar fertilizers, such as mono potassium phosphate (EcoCarb) which as foliar spray applications suppressed the development of powdery mildew on capsicums. Milk in powdered form and at low concentrations was also shown to be effective in suppressing powdery mildew on capsicums, confirming earlier reports of its effectiveness against powdery mildew on cucurbits. These protectants and activators could substitute sulphur in integrated management programs in which sulphur has been routinely rotated with the systemic fungicides.

The protectants identified were evaluated in integrated disease management trials with systemic fungicides and shown to be effective in breaking the continuous use of the systemics and thereby prolonging their effectiveness through a carefully managed resistance management program.

Based largely on these studies, a set of guidelines has been produced for distribution to growers and other capsicum industry stakeholders that could be used for sustainably managing powdery mildew on capsicums in areas where the disease is a serious threat to either fruit yield or fruit quality during the production season.

Chapter 1: General Introduction

Powdery mildew on capsicums

Powdery mildew is a very common disease on capsicums in the tropical and sub-tropical environments of north Queensland where most of the Australian capsicums are produced. The disease is caused by the fungus *Leveillula taurica* (Lev.) G. Arnaud). It is the same fungus that has been found to predominantly cause powdery mildew on tomatoes in the tomato production regions of north Queensland. Its other hosts are eggplant and probably some weeds.

The powdery mildews are a group of pathogens that can cause disease over a wide range of environmental conditions. However, several environmental factors may directly affect the development of this disease on capsicums; among them, temperature, relative humidity and light. Temperature and humidity must be examined together since it is the water vapour pressure deficit (VPD) that has the greatest effect on host-parasite interactions (Jarvis *et al*., 2002). Like other powdery mildew fungi, *L. taurica* 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 production districts of North Queensland.

Powdery mildew infection symptoms usually first appear as white, powdery spots that may form on both surfaces of leaves on vegetable plants (Fig 1.1) and often leads to extensive defoliation (Fig 1.2). Hence the descriptive name, powdery mildew. On capsicums, detection of initial powdery mildew infection can be a bit difficult because initial powdery symptoms are not readily visible since they form on the underside of the leaf and soon turn from white to brown blotches. These initial underside infection symptoms are often followed by diffuse yellow rounded spots on the upper surface of the leaf (Fig 1.3).

The spots are indefinite and vary a great deal in size. They may coalesce to cover a large proportion of the total leaf area. Heavily infected leaves gradually turn yellow, curl off, die and then fall off the plant exposing the developing fruit to sunburn damage (Fig1.4).

The effect of powdery mildew on capsicum yields is often indirect. The disease does not usually directly affect the number of fruits on plants except in late plantings when pathogen populations are already established in the field, or the weight of the fruits formed. Infection greatly affects the quality of developing fruits when they become exposed to sun scalding because of the extensive defoliation that often follows heavy infections. Yields in a field can be greatly reduced when infection goes unchecked because most of he fruits will not be marketable.

Unlike powdery mildew pathogens on other vegetable crops such as zucchini, *L. taurica* does not usually infect capsicum stems or fruits or grow on the surface of the fruit. Infection usually starts and concentrates on the leaves and often progresses from the older to the younger leaves. Leaves of both seedlings and mature plants may be infected depending on time of season, availability of inoculum and conditions of exposure.

Traditional methods of control

Powdery mildew can be difficult to control once leaves become heavily infected. Therefore preventive measures are a necessity in the early stages of the disease initiation. Traditionally, frequent and calendar-based sprays with different formulations of sulphur have provided adequate control under low infection conditions across capsicum production regions. This was all that was needed and used to control the disease in all the capsicum production regions of Queensland and other regions of Australia where the crop is grown, until the 2000/2001 production season.

The 2000/2001 cropping season came with highly favourable conditions for the initiation and spread of powdery mildew on capsicums. These included unusually mild winters followed by generally dry and warm conditions across the production zones. This resulted in early initiation and fast spread of the disease across farms. Usual frequent sprays with sulphur failed to give adequate control in many districts. The growers were becoming desperate as volumes of fruit were unmarketable because of their poor quality due to sunburn from exposure after extensive defoliation.

Initially, it was unclear why there was this sudden change in the epidemic of the disease across the regions. There was also a suspicion that there might have been a shift or change in the pathogen populations resulting in more virulent strains of *L. taurica* that could not be adequately controlled with the usual regular sulphur sprays.

The industry immediately wanted something done to ensure that such devastating conditions did not repeat. Researchers were requested to investigate possible changed conditions that brought about such epidemics and to identify more sustainable methods of controlling the disease. As a short term measure, evaluations were carried out to identify a systemic fungicide that could be used in conjunction with sulphur sprays for the immediate remedy of the situation. Bayfidan, a systemic fungicide that had been tested and registered for use in controlling powdery mildew on tomatoes also caused by *L. taurica*, became the immediate candidate fungicide for capsicums. An application for an emergency permit to use Bayfidan to control powdery mildew on capsicums was made to the Australian Plant and Veterinary Medicine Authority (APVMA) in 2001. Following some unfortunate delays, the application was finally approved and an emergency use permit was issued during the 2002 cropping season and has since been renewed. The incorporation and use of Bayfidan in rotations with sulphur sprays in field control programs resulted in adequate control of powdery mildew on capsicums from and during the 2002 and 2003 cropping seasons. There was therefore some short-term relief with the problem but growers were still anxious to have more long term solutions and more sustainable ways of managing the disease.

During regular consultative visits by researchers to grower farms and industry meetings, there were demands from the industry for researchers to investigate and provide more sustainable guidelines at managing powdery mildew so as to avoid future epidemics on the crop like the one that occurred during the 2000/2001 production season.

Arising issues and the way forward

An evaluation on the use pattern of Bayfidan during the 2002/2003 cropping season raised concerns that there was a risk of early resistance development to the fungicide by the powdery mildew fungus, if recommended frequencies and rates were not strictly adhered to. The growing concerns about resistance developing on Bayfidan sooner than expected, led to another emergency permit application to APVMA for the approval for temporal registration of another systemic fungicide, Nimrod, from a different chemical group, to compliment Bayfidan in managing powdery mildew on capsicums at the start of the 2005 season. Nimrod had been established to be effective against powdery mildew on cucurbits, to which a full registration had been obtained. Even thought both systemic fungicides (Bayfidan and Nimrod) were recommended in sequential spray rotations with sulphur sprays, their availability and use was temporal and there was still a need for more sustainable guidelines to use them in rotation or in combination with other control options.

The need to investigate other options for the disease management that could be incorporated to break the fungicide spray cycle was heightened. Support was obtained from industry by researchers to develop and submit a proposal application seeking industry funds to investigate and establish guidelines at managing the disease. This industry funded project application was approved to investigate these alternate control options and to establish more sustainable options at managing powdery mildew on capsicums starting during the cropping season of 2004.

Fig 1.1: Powdery mildew infection symptoms on undersurface of chili leaves

Fig 1.2: Extensive defoliation of chilli plants from heavy powdery infection

Fig 1.3: Initial yellow blotches from powdery mildew infection on capsicum upper leaf surface

Fig 1.4: Fruit exposure and sun scalding after foliar defoliation from powdery mildew

Chapter 2: Field Surveys

Introduction

Powdery mildew is currently considered a production constraint on capsicums in all capsicum production regions of Australia. Economic losses are expected when the disease is not adequately controlled. Prior to the 2000/2001 cropping season when the first serious epidemic of the disease was observed across many of the capsicum-production zones of Australia, the disease was generally classified as a minor problem on capsicums. Frequent seasonal spray applications with sulphur fungicides in different formulations were providing adequate control of the minor disease.

The situation dramatically changed that season when environmental conditions favoured the initiation and rapid spread of the disease resulting in sudden epidemics, and the disease became a major production problem. When that epidemic set in, there was anxiety among growers who did not understand what was going on and were anxious to adopt any new control strategy that could provide them with more sustainable ways of managing the disease.

Largely lacking was any form of quantitative data to support the prevalence of the disease across the capsicum production zones. To fill this void and to understand the extent of the distribution and seasonal prevalence and intensity of the disease on capsicums in the main production regions, field surveys were planned as part of the activities of the integrated management of the crop, to be carried out in the main capsicum production regions during the 2004 production season. Also of importance was the need to collect infected samples during the surveys that could be used to study the epidemiology of the disease under controlled conditions and determine if there had been changes in the pathogen population to result in these sudden epidemics.

Materials and Methods

In order to ensure that the planned survey adequately covered all the areas in which additional information was needed, a detailed questionnaire was prepared ***(See***

Appendix A) and used to collect the relevant information from growers from each farm visited during the survey. It included specific information on current observed prevalent diseases in each orchard visited and their methods of control. The survey questionnaire also covered some needs analysis issues for the growers.

Four production districts, decided mainly by the perceived intensity of the disease in these districts from the 2000/2001 season observations and reports, were earmarked for the survey. These were: the Burdekin, Gumlu, Bowen and Bundaberg growing districts. These districts were considered representative enough to give a good picture of the current situation across the production zones of Queensland. The choice was later narrowed down from the four that were initially earmarked for the activity to the first three from North Queensland, where most of the Capsicums in Queensland, and indeed Australia are produced. The planned Bundaberg district surveys were cancelled because of seasonal scheduling conflicts.

To carry out the surveys, personal visits were made by project personnel to each of selected and representative farms based on previous collaborative links, location access, and direct request to the grower to permit entry into the farm among other factors. In the Burdekin area, the target was to visit the 3 main capsicum production farms and others as identified; in Gumlu target was set to include the farm groups that currently own and operate the North Queensland Fruit and Vegetable Packing shed, while at Bowen the target was to visit as many farms as known, especially those that interact frequently with the Department of Primary Industries and Fisheries (DPI&F) Centre for Dry Tropics Research in Bowen.

During the actual survey, visits were made to each of the selected farms and started with an interview of the grower. In an informal chat format, the necessary information sought on the questionnaire was collected. One officer carried out the discussion with the grower while another recorded the responses on the prepared questionnaire sheet. This was then followed by farm visit walks to evaluate for general disease occurrence, especially powdery mildew, and to assess the stage of the crop, the varieties grown as well as other agronomic practices in place, so as to try and understand how these factors could be influencing the diseases distribution and spread. In each farm surveyed, only the crop strips in the productive phase (flowering to maturity) were closely examined for prevalence of powdery mildew and other capsicum diseases.

All the responses collected were summarised into tables for further analysis of the current powdery mildew as well as other disease situations across the 3 districts surveyed.

Results

Final analysis of the survey sheets showed that the activity ended up covering 31 farms in the north Queensland region; (16 from Gumlu, 10 from Bowen and 5 from the Burdekin districts). The farms in these districts ranged in size from 5 hectares to over 200 hectares. The farms covered are estimated to represent more than 70% of the capsicum production volume of the whole of the north Queensland region.

Tables 1.1-1.3 summarises the levels of powdery mildew in each farm visited, and also lists other diseases that were detected in the farm at the time of the survey. The tables also include other farm parameters collected such as growth stage, farm size and varieties grown.

Table 2.1: Burdekin District Farms Surveyed

Farm #	***Growth stage of crop***	***Farm Size (ha)***	***Variety***	***Powdery mildew DS***	***Other diseases observed***
1	Fruiting	< 200 ha	Various	1.5	Bacterial spot, severe tospovirus, Mosaic
2	Fruiting	5 ha	Merlin	trace	tospovirus
3	Fruiting	25 ha	Merlin	2.0	Mosaic virus, *S. rolfsii*
4	Near maturity	10 ha	Warlock	2.5	Tospovirus, root rot
5	Flowering and fruiting	15 ha	Aries & Merlin	2.5	Foliar blight, brown spots, Bacterial spot
6	Fruiting	5 ha	Merlin	trace	tospovirus

Table 2.2: Gumlu District Farms Surveyed

Farm #	***Growth stage of crop***	***Farm Size (ha)***	***Variety***	***Powdery mildew DS***	***Other diseases observed***
1	maturity	< 50	Merlin	Trace (>1)	B. spot, viruses
2	near maturity	5	chillis	2.5	Bacterial spot
3	maturity	10	Merlin	3.5	Stem wilt
4	flowering	8	Warlock	2.5	Bacterial spot
5	Fruiting	25	Warlock & Merlin, chillis	Chillis – 2.5 Others- trace	Bacterial spot; viruses
6	fruiting	15	Warlock	1.0	Bacterial spot
7	fruiting	10	Warlock	1.5	Bacterial spot, viruses, S. wilt
8	Flowering and fruiting	20	various	2.0	Severe tospovirus, bacterial spot
9	fruiting	15	Merlin	trace	Bacterial spot
10	fruiting	5	chillis	2.5	Severe tospovirus
11	fruiting	10	chillis	2.0	viruses
12	Near maturity	12	Merlin	2.0	wilt
13	maturity	30	Aries	3.0	viruses
14	flowering	8	Warlock	2.5	none
15	Near maturity	15	Merlin	1.5	none
16	fruiting	10	Merlin	trace	viruses

Table 2.3: Bowen District Farms Surveyed

Farm #	Growth stage of crop	Farm Size (ha)	Variety	Powdery mildew DS	Other diseases observed
1	Flowering & Fruiting	25	various	trace	Bacterial spot
2	fruiting	15	Merlin	2.0	viruses
3	Near maturity	12	Warlock	1.5	Wilt, viruses
4	flowering	10	Merlin	trace	none
5	maturity	8	Warlock	2.0	viruses
6	Flowering & fruiting	20	various	trace	none
7	Near maturity	10	Merlin	trace	none
8	fruiting	15	Merlin & Warlock	1.5	Viruses, bacterial spot
9	flowering	10	Warlock	trace	none
10	fruiting	15	Merlin	trace	viruses

Discussion

From the surveys, the following issues were established from discussions with the growers:

- Powdery mildew is a major disease of concern on capsicums in nearly all the farms visited in the north Queensland region. Even when not readily detected during the survey visit, it was either because of a good management program in place or the early growth stage of the crop.
- The other very important diseases receiving attention or needing one are respectively, the capsicum tospoviruses and the Bacterial leaf spot.
- Growers who consider Bacterial spot to be an important disease include frequent copper sprays in their general disease management spray programs, especially during early crop establishment.
- Merlin was the widely grown cultivar in most farms visited. This was followed by Warlock in popularity. Main reason for cultivar choice was fruit shape and preference directives from the market outlets. Some growers revealed that the only cultivar they have purposely stayed away from because of shape and also apparent higher powdery mildew infection was Aries.
- All growers visited are relying mainly on the use of fungicide sprays to control powdery mildew. Some follow a routine spray schedule, while a majority depend on advice and recommendations from regional crop monitors and consultants.
- More than 75% of the farms visited hire the services of a crop consultant of some sort during the production season and rely on advice from this consultant to apply pesticides including fungicides to manage powdery mildew on capsicums. Those that do not use these services were more likely to follow some sort of a calendar-based spray program, often not dependent on any particular factor to decide when the next spray should go in.
- Sulphur and Bayfidan were currently the main fungicides in use. Overall, there was some satisfaction with the controls received from Bayfidan, depending on timing of application and levels of infection.
- Nimrod had just received emergency permit approval for use on capsicums before the survey was conducted but was not found in any spray program

during the survey. Many were not aware that it had received approval for use on capsicums.

- Concerns were expressed by some growers on the future when the emergency permit on Bayfidan runs out, especially in the absence of another registered fungicide and also no apparent moves to get the fungicide fully registered. They learnt of Nimrod recent approval in response to this concern.
- All growers visited, welcomed the objectives of the current project when briefed, and also expressed readiness to participate in any future planned project activity or workshops in order to be updated on the project findings.
- The activity of screening current available cultivars as well as breeding germplasm to identify sources of resistance to the disease for use in future integrated management programs was particularly welcome, as all the cultivars in use were developed overseas and had not been screened for reaction to the local pathogen populations of the disease.
- Growers also welcomed the idea of identifying and evaluating other soft or more sustainable products that could be used in rotations with fungicides in a more sustainable and integrated management program.

From the surveys it can be concluded that powdery mildew is still the most prevalent disease of capsicum in the different production zones of north Queensland even though its intensity varies from season to season depending on weather factors and from farm to farm largely depending on the general farm management practices in place. Growers are currently getting better powdery mildew control now than before, with the use of sulphur sprays in rotations with Bayfidan sprays, a situation that was different before the 2000 season disease epidemic. Growers surveyed were also keen to adopt any additional strategies that could result in more sustainable management of the disease into the future.

Some growers were conscious that it takes more than just fungicide sprays to manage diseases, revealing that a good balance fertilizer program has made a difference in their disease management efforts.

Chapter 3: Epidemiological Studies

Introduction

As an obligate parasite unable to achieve substantial growth and sporulation on growth media, the powdery mildew fungi present a challenge to those studying their biology and epidemiology. Since samples of the fungi must be maintained only on living plant tissue, preservation techniques must be established to do so without lose to virulence. To study their reactions on plants under controlled conditions, the stored isolates must be inoculated unto the study plants. This also calls for appropriate inoculation techniques to ensure success in the establishment of the disease from inoculated preserved material.

Until recently, the only way to conserve powdery mildew fungi was to propagate them on a susceptible host and to transfer them periodically to fresh plant material. This can be achieved easily with potted plants grown in the greenhouse (Reeser *et al.*, 1983). The need to sometimes work with pure and characterised isolates can complicate matters, as it requires the protection of plants from potential contamination by airborne spores of unknown isolates at all times before and after inoculation with a known powdery mildew isolate. This has been achieved by different containment procedures such as using mildew-free greenhouse compartments or growth cabinets to grow and incubate the plants (Ohtsuka *et al.,* 1991; Cohen *et al.,* 1993). Miniaturizing the preservation of powdery mildew isolates has also been achieved with the use of detached plant organs such as leaves (Molot *et al.*, 1987) or cotyledons (Reifschneider *et al.*, 1985), maintained in jars or petri dishes.

Basic methods for epidemiological studies of powdery mildew on other crops and pathosystems were first reviewed to ensure that these could be applied to situations with powdery mildew on capsicums. Of particular importance was the establishment and preservation of isolates and inoculation methods to re-establish them when needed to carry out trials with the powdery mildew pathogen on capsicums.

Materials and Methods

Inoculation of isolates

During the field surveys for prevalence of powdery mildew on capsicums in the main production districts of north Queensland, several samples of infected leaves were collected and brought back to the laboratory for further characterisation studies. This needed to be preserved until when needed for experimentation. Different inoculation and preservation techniques were investigated.

The inoculation techniques investigated from infected leaves collected for transfer unto preserved leaves were:

- Direct leaf-to-leaf contact by pressing the diseased sample against the surface of the healthy leaf to be inoculated;
- Using a small paintbrush to rub gently on the infected leaf and transfer the inoculum unto fresh leaves;
- Placing infected potted plants among healthy ones on a greenhouse bench and determining the infection rate of the surrounding plants;
- Using spore suspension sprays after washing infected leaves in water, and spraying unto healthy plants, and
- Using a spore suspension from infected leaves in water, with a Tween-20 amendment added to the solution.

Following inoculation with these techniques, the inoculated plants were monitored for infection over a period of time to determine the most efficient method that could be adopted for future use.

Preservation of isolates

After successfully re-establishing the isolates collected first on potted healthy plants in the enclosed greenhouse boxes, the next task was to establish or identify the best preservative technique that could be used to keep the isolates collected.

A number of techniques reviewed in powdery mildew literature were investigated. These included:

- Storage of isolates on detached leaves in large petri dishes lined with moistened filter paper;
- Storage on small inoculated potted plants placed inside enclosed boxes to reduce outside contaminations from aerial spores, and
- Placement of inoculated potted plants in growth chambers to regulate temperature and humidity so that growth could be maintained over a long period of time.

The length of isolate maintenance in each of the methods above was noted to decide on the most efficient to be used in preserving isolates for future use.

Possible shifts in pathogen populations

A total of 10 pathogen isolates collected during the survey were used to investigate possible pathogen shifts to the prevailing fungicides. To undertake this, the collected isolates were transferred and maintained on potted plants, which were either sprayed with sulphur or Bayfidan. Others were first sprayed with sulphur then followed by Bayfidan sprays.

The fungicide-sprayed plants were placed in polyethylene enclosures for 24 hours. They were then counter-sprayed with the different isolates of powdery mildew and kept for a further 7- 10 days in the enclosed chambers. Each plant was carefully examined for the presence of infection and given a general rating based on the intensity of the infection.

Results

Inoculation and preservation of isolates

Direct leaf-to-leaf contact of infected plants with healthy plants resulted in the quickest expression of powdery mildew symptoms. Minute yellow blotches were detected on the upper surface of inoculated leaves within 5 days following inoculations. This was closely followed by the paintbrush rub technique with infection symptoms appearing 7 days following inoculations. Infection on the leaves was a bit more profuse than on the leaf-to-leaf method. The least suitable method was with plants sprayed with spore suspensions of powdery mildew in water. Infection could not be detected even after 14 days of observation under good disease development conditions in either water suspensions alone or suspensions amended with low doses of Tween-20 (Table 3.1).

The best conditions for preservation of inoculum were on potted plants. Inoculation by leaf-to-leaf contact and placement on enclosures on greenhouse benches as well as in growth chambers both preserved infected plants for a considerable period of time.

Possible shifts in pathogen populations

All potted capsicum plants sprayed with Bayfidan alone and counter inoculated with different isolates of powdery mildew recorded no infection traces. This suggested that there had actually been no shift in pathogen populations from the use of the Bayfidan sprays. There was however traces of infection from some potted plants initially sprayed only with sulphur and then counter-inoculated with sprays of the powdery mildew isolates. This was not surprising or unexpected as sulphur sprays are non-systemic and serve mainly as contact protectants. In their physical absence, spore germination and infection from the pathogen was still possible. In pots first sprayed with sulphur, followed by Bayfidan sprays before inoculated sprays with powdery mildew isolates, there was no observed infection in any of the potted plants. This again may be explained by the systemic activity of the Bayfidan that protected the potted plants from infection once the fungicide established within the plant and protected it from infection.

Table: 3.1 Effect of inoculation techniques on powdery mildew initiation and spread

Inoculation Technique	**Days to first symptoms**	**Disease Severity (0-5) on day 14**
Direct leaf-to-leaf contact	5	3 (intermediate)
Paintbrush rubbing	7	3.5 (intermediate)
Placement on tables	14	1.5 (traces)
Spore suspension sprays	na	0
Spore suspension + Tween	na	0

Discussion

The lack of infection with spore suspensions in water confirms earlier reports on the unreliability of this method of inoculation. There have been early reports on the deleterious effect of water on spore germination and viability of a number of powdery mildew pathogens (Corner, 1935). Despite these reported limitations of water as an inoculum carrier, there are also reports of successful inoculations for a variety of powdery mildew species including *L. taurica* (Diop-Bruckler, 1987). It is thus clear that the deleterious effects of water on conidia of powdery mildew have remained a disputed subject. Some studies have even suggested that the longer the spores are stored in water, the better the rate of infection.

Studies conducted on amendments to improve the infection efficiency of spore suspensions in water have shown that Tween-20 and 80 did not interfere but had a positive effect at low doses on spore germination and infection efficiency (Reeser *et al.*, 1983). In our own study the addition of Tween-20 to spore suspensions in water failed to improve the infection efficacy of water for *L. taurica*. This may suggest that this amendment could be effective on some powdery mildew fungi but not others. The reason for these apparent differences is not clear.

Observations were made for a period of 4 weeks on the preservation studies and the infections on the potted plants were maintained during this period. No quantitative assessments were made since the purpose of the exercise was mainly to identify a suitable method that could be used in future epidemiological studies to preserve isolates over a reasonable period of time. The growth chamber preservation was also better as it gave the additional ability to adjust and maintain environmental growing conditions at a minimum, preventing rapid plant growth and maturity as was the case in the box enclosures in the greenhouse where flowering and fruiting were initiated by the 4th week of their placement.

To overcome the technical challenges attached to the study of obligate parasites such as powdery mildew of capsicums, researchers have devised or adapted a wide variety of methods for the culture and preservation of isolates. It is clearly not possible to readily single out a particular method as the most appropriate in all cases. Each researcher will have to continue to rely on different methodological strategies depending on the particular host/mildew systems and the domain under study.

From the current epidemiological studies focusing on inoculation and preservation techniques as well as possible pathogen shifts on powdery mildew on capsicums, the following was achieved:

- Inoculation techniques on potted plants in glasshouse conditions were established.

- It was established that there has been no apparent shift in pathogen populations from the use of either sulphur, Bayfidan or both fungicides in rotations.

- If there is no consistent control of the disease with spray applications of these fungicides, especially with Bayfidan, it is more likely due to the timing of the spray applications and the rates of application or any other related spray factor than possible changes in the pathogen populations.

- As an obligate parasite, the inoculum of powdery mildew can only be maintained on plant tissue (Reeser *et al.*, 1983). Accordingly, necessary protocol was developed to maintain the inoculum on greenhouse-grown and growth chamber potted plants.

- Growth chamber temperatures where the inoculated plants were preserved was regulated to stay within limits of 25-30 C, being the optimum temperature for infection of the pathogen (Goldberg, 2003). The relative humidity on the enclosure on greenhouse benches was also regulated at above 80% by enclosing potted plants in insulated boxes for infection initiation.

Chapter 4: Screening for Resistance to Powdery mildew

Introduction

Leveillula taurica, the fungus that attacks different capsicum species has been associated with several host plant species including tomatoes (*Lycopersicum esculentum*). Capsicums have been described as the most susceptible solanaceous host crop for this mildew (Dixon, 1978). In several places, the sweet pepper crop is particularly susceptible with the diseased plants giving lower yields and fruit quality as well as a reduced harvesting period. Direct losses result from fruit sunburn while indirect losses include a rise in production costs because of the need for frequent fungicide sprays to protect the crop.

Initially only a minor disease on capsicums in most of the world, the disease has been increasing in intensity and is now the most important disease of the crop. Increased importance of the pathogen worldwide could be related to the expansion of irrigated agriculture in dry regions and dry seasons, the prevalence of successive monoculture croppings and the consequent establishment of an environment favourable for the disease spread. Gradual selection of strains more aggressive to cultivated crops has also been postulated (Palti, 1988). Increased prevalence and severity of the disease indicates that routine control practices are now mandatory for capsicum production if crop quality is to be sustained. Chemical control is limited by the semi-endoparasitic nature of this mildew, but sources of resistance to the pathogen have been reported in the capsicum germplasm (Souza and Café-Filno, 2003).

Cultivating plants with genetic resistance to powdery mildew is the best method of growing disease-free capsicum crops. Consequently, an appropriate selection of resistant cultivars is the simplest way to deal with the disease infections. Previous studies on the distribution of resistance among different capsicums varieties in India revealed that about 6% of the germplasm was resistant or moderately resistant to powdery mildew (Ullasa *et al.*, 1981). Other studies identified other sources of resistance apparently controlled by a complex of genes (Shifriss *et al*., 1992).

Despite all these reported studies on the reaction of the disease to different capsicum germplasm, information on the reaction of commercial capsicum cultivars to powdery mildew is rather scarce. This project activity reports on the reaction of capsicum cultivars currently grown in the different production districts of Australia, as well as a selection of breeding lines, to the disease under field natural conditions. The studies were carried out over a 2-year period at the Bowen Research Station of the Queensland Department of Primary Industries and Fisheries in the first year and at the Ayr and Bowen Research Stations in the second year.

Materials and Methods

2004 Field assessments of capsicum varieties and breeding lines

Material screened

During the 2004 cropping season, 29 capsicum and chilli varieties were evaluated for resistance to powdery mildew under field natural infection conditions. The 29 entries consisted of 18 cultivated entries of both capsicums and chillis and 11 breeding lines (Table 4.1). All the entries were supplied by commercial seed companies and were made up of mostly the cultivars grown across different capsicum production districts of Australia at the time of evaluations as well as breeding lines still being evaluated across locations for yield parameters and adaptations to the different environments where the crop is grown.

Disease Assessments

Disease incidence

The incidence of powdery mildew on the entries was assessed first at the fruiting stage and again at near crop maturity. The two assessments were about 4 weeks apart. In the first assessment, disease incidence was recorded by visually estimating the number of infected plants per plot. In the second assessment, this was modified to focus mainly on assessing 50 randomly collected leaves from each plot, making sure they were all collected from the mid portion of the plants, avoiding the very old and most young leaves. The leaves were placed in plastic bags and taken to the laboratory where they were visually inspected for symptoms of powdery mildew infection.

Table 4.1: Cultivars and breeding lines screened for resistance to powdery mildew Bowen 2004

Cultivars	Breeding lines
Warlock	Sweet CPS 1443
Merlin	Sweet CPS 1976
Aries	Sweet CPS 1408
Tycoon	Sweet CPS 1972
Toledo	CPS 1127
Santino	Sweet CPS 1128 P
Ingot	Seln 5-1
Eshet	Seln 7-1
Sweet Red Stone	Seln 13-2
Sweet Sienor	Seln 23-2
Sweet Resisto	Seln 28-3
Sweet Rubit	
Sweet Lisa	
Sweet El Charro	
Sweet Golden Sun	
Sweet Denver	
Sweet Paz	
Sweet Cleor	

Disease severity

The severity of powdery mildew infection for each plot was determined in the field by visual assessment just before infected plants were assessed in the first assessment and just before the leaves were collected for disease incidence assessments in the second.

The rating scale for disease severity used was:

0 = no infection

1 = trace infection

2 = light infection with no observed defoliation

3 = moderate infection with some slight defoliation

4 = severe infection with high defoliation

5 = Very severe infection with massive defoliation

Percent diseased leaf area

Ten randomly selected infected leaves from the disease incidence assessments were further assessed to determine the area of infection on the leaf surface. A percent score was recorded for each leaf representing the approximate area of sporulation coverage on the infected leaf as a percent disease leaf area and used as another parameter to differentiate entry reactions to powdery mildew.

Percent canopy retention

Towards the end of the season, each plot was scored for percent canopy based on the visual estimated rate of leaf retention on the plants as compared to what had defoliated because of powdery mildew infection. This was an indirect way of accounting for defoliation since it was difficult to estimate defoliation on each plot because of the massive defoliations in some of the more susceptible lines.

Statistical analysis

All data collected from the plots for disease incidence and severity scores as well as percent leaf area infected and canopy retention, were statistically analysed using the Genstat statistical packages. All analyses were One-way ANOVAs in the randomised block design in which the trials were carried out.

2005 Field assessments of capsicum varieties and breeding lines

Material screened

A total of 12 cultivars obtained from commercial seed company vendors and 9 breeding lines obtained from the DPI&F plant breeder, were divide into Series A and B and planted at the DPI&F Research Stations at Ayr and Bowen. The division into series A and B depended on the readiness of the seedlings for transplanting with the series B plantings going in one week earlier than the series A selections in Ayr, while the B selections at Bowen were planted about 2 weeks before the A series (Tables 4.2 and 4.3). The commercial varieties were those largely grown in most of the capsicum-production districts of central and north Queensland. The choice of breeding lines to screen in the trial was based on the desire to identify multiple disease resistance as these lines were also being evaluated fro resistance against tospoviruses in a concurrent industry breeding project. The number of entries planted at each trial site depended largely on seed availability, especially of the breeding lines seed which was rather limited.

Seeds of each entry were pre-germinated in seedling containers over a period of 6 weeks (Fig 4.1). The seedlings were then transplanted to plastic covered rows, each

50m in length. The experiments were established in a randomised block design with three replications for each entry. Each replication consisted of a plot with approximately 20 plants. Each plot size was 3m by 1 m at Ayr and 6 m by 0.5 m at Bowen. Each row at Ayr had 2 plants while at Bowen the plantings were only in single row.

Twenty entries were planted and evaluated at the Ayr site (Table 4.2) while 27 entries were established and evaluated at the Bowen site (Table 4.3).

At each location normal agronomic practices as per industry standard, of fertilizer application and periodic trickler irrigation as well as weed management was implemented.

Table 4.2: Capsicum varieties and breeding lines screened at Ayr Research Station 2005

Series A (planted 18/7/05)	**Series B** (planted 26/7/05)
BC2 22112 x 23-2(Maz)	Tycoon
BC1 23-2(Maz)	Aries
BC2 Mer x 7-1(Mer)	Toledo
BC2 Mer x 17-5(Mer)	Warlock
BC1 7-1(mer)	Merlin
Hercules	Flame
Paz	Birdseye
Dracula	CLPX1408
Ingot	CLPX1720
	CLPX1483
	Lipari

Table 4.3: Capsicum varieties and breeding lines screened at Ayr Research Station 2005

Series B (planted 12/7/06)	**Series A** (planted 25/7/05)
BC2 22112 x 23-2(Maz)	Tycoon
BC1 30-4(Maz)	Aries
BC2 16134 x 23-2(Maz)	Toledo
BC1 7-1(Maz)	Warlock
BC1 5-1(Maz)	Merlin
BC1 23-2(Maz)	Flame
BC2 21814 x 7-1(Mer)	Birdseye
BC1 17-5(Mer) 59	Zoom
BC2 Mer x 7-1(Mer)	CLPX1408
BC2 Mer x 17-5(Mer)	CLPX1720
BC1 7-1(Mer)	CLPX1483
Hercules	Lipari
Paz	
Dracula	
Ingot	
Warlock	

Disease Assessment

Disease incidence

The incidence of powdery mildew on the entries was assessed at the same times for all the entries at each station regardless of the time of planting. This was about 8 weeks from the first planting at each site when fruits were near-maturity.

Disease incidence was assessed on each plot by randomly collecting 50 leaves from the plants in the plot (Fig4.2), taking them to the laboratory and visually inspecting for symptoms of powdery mildew infection.

Disease severity

The severity of powdery mildew infection for each plot was determined in the field by visual assessment just before the leaves were collected for disease incidence assessments. A score was assigned for disease severity on each plot based on the following scale:

0 = no infection

1 = very light infection

2 = light infection

3 = moderate infection

4 = severe infection

5 = extremely severe infection

Statistical analysis

As in 2004, all data collected from the plots from disease incidence and severity scores were statistically analysed using the Genstat statistical packages. All analyses were One-way ANOVAs in the randomised block design in which the trials were carried out.

Results

2004 Assessments

In the 2004 season, the first disease assessment data collected soon after fruit set did not show any significant differences among the entries as the disease pressure was still quite low in the season. This data was therefore not used to make the reaction comparisons. The results presented here for 2004 only reflect disease assessment data from the second ratings near crop maturity.

1. Disease incidence and disease severity

There was a significant ($P < 0.001$) varietal effect with Disease Incidence as reflected by the percentage of leaves with symptoms of infection by powdery mildew (Table 4.4).

There was also a significant ($p < 0.001$) varietal effect with Disease Severity as assessed and rated within the field plots (Table 4.4).

2. Canopy retention and leaf area infection

There was a significant ($P < 0.001$) varietal effect on the percentage of canopy retained after infection by powdery mildew on the different entries (Table 4.5).
There was also a significant ($P < 0.01$) varietal effect on the % leaf area of infected leaves from the different entries (Table 4.5).

2005 Assessments

Disease incidence

Generally there was a higher pressure of powdery mildew at the Bowen site when compared to the Ayr site during the 2005 season. The pressure at both locations was enough to differentiate between reactions of the entries to the disease.

Bowen Site

At Bowen, there was a significant ($P < 0.001$) varietal effect on the number of leaves with powdery mildew symptoms in the series 'A' plants (as well as series B plants ($P<0.007$) (Table 4.6).

Ayr Site

At the Ayr site there was no significant variety effect on the number of infected leaves in the series A plants, but there was a significant ($P< 0.047$) varietal effect with the series B plants (Table 4.7).

Disease Severity

Visual observation of the plots showed that there was a higher disease pressure at the Bowen site when compared to the Ayr site, to be able to differentiate entry response based on plot disease severity ratings.

Bowen Site

There was a significant variety effect on the mean plot disease severity rating for both the series A ($P<0.045$) and B ($P< 0.001$) plantings (Table 4.8).

Ayr Site

At the Ayr site, there was a significant variety effect on the mean plot rating for the series A plants ($p = 0.002$) but there was no significant variety effect on the mean plot rating in the series B plants ($p = 0.151$) (Table 4.9).

From the 2 year study over the 2 locations, the combined data from the 6 popular or widely cultivated varieties were classified for reaction to powdery mildew (Table 4.10).

Table 4.4: Incidence and severity of powdery mildew on capsicum varieties under natural field infection conditions - 2004.

Variety	Mean Disease Incidence (DI)*	Variety	Mean Disease Severity (DS)**
Seln 7-1	36.67 **a**	Toledo	1.33 **a**
Toledo	44.67 **ab**	Seln 7-1	1.67 **ab**
Ingot	50.67 **abc**	Seln 28-3	1.67 **ab**
Sweet Golden Sun	52.00 **bcd**	Seln 23-2	1.67 **ab**
Seln 28-3	56.67 **bcde**	Ingot	1.67 **ab**
Seln 23-2	60.67 **cdef**	CPS 1127	1.67 **ab**
Sweet Resisto	63.33 **cdefg**	Sweet CPS 1443	1.83 **abc**
Seln 13-2	63.33 **cdefg**	Seln 5-1	1.83 **abc**
Sweet Red Stone	64.00 **cdefgh**	Seln 13-2	1.83 **abc**
Warlock	65.33 **cdefghi**	Sweet Resisto	2.00 **bcd**
Merlin	65.33 **cdefghi**	Sweet CPS 1972	2.00 **bcd**
Sweet Cleor	66.67 **defghi**	Warlock	2.17 **bcde**
CPS 1127	66.67 **defghi**	Sweet Red Stone	2.17 **bcde**
Sweet Paz	67.33 **efghi**	Sweet Golden Sun	2.17 **bcde**
Sweet Lisa	67.33 **efghi**	Sweet El Charro	2.17 **bcde**
Sweet Denver	67.33 **efghi**	Sweet CPS 1976	2.17 **bcde**
Sweet CPS 1443	68.00 **efghij**	Santino	2.17 **bcde**
Sweet Rubit	70.67 **efghijk**	Sweet Rubit	2.33 **cdef**
Sweet CPS 1408	70.67 **efghijk**	Sweet Lisa	2.33 **cdef**
Sweet El Charro	72.00 **fghijk**	Sweet Denver	2.33 **cdef**
Seln 5-1	72.00 **fghijk**	Sweet CPS 1408	2.33 **cdef**
Eshet	78.00 **ghijk**	Sweet Sienor	2.50 **def**
Sweet Sienor	78.67 **hijk**	Sweet Paz	2.50 **def**
Sweet CPS 1972	78.67 **hijk**	Sweet CPS 1128 P	2.50 **def**
Tycoon	79.33 **ijk**	Merlin	2.50 **def**
Aries	80.00 **ijk**	Tycoon	2.67 **efg**
Sweet CPS 1976	80.00 **ijk**	Sweet Cleor	2.83 **fg**
Sweet CPS 1128 P	83.00 **jk**	Eshet	3.17 **g**
Santino	84.00 **k**	Aries	3.17 **g**
LSD	**15.09**	**LSD**	**0.643**

Note: Means with same subscript are not significantly different at P = 0.050 level.

* Disease incidence determined from the % of infected leaves out of 50 collected from each plot.
** Disease severity scale of 0-5 where: 0= no infection and 5= very severe infection with massive defoliation.

Table 4.5 Percent canopy retention and percent leaf area infected by powdery mildew in capsicum cultivars and genotypes under field infection conditions - 2004.

Variety /genotype	**% Canopy Retention***	**Variety/genotype**	**% infected leaf area**
Seln 7-1	81.67 **a**	Seln 13-2	5.00 **a**
Sweet CPS 1128 P	81.67 **a**	Seln 7-1	6.00 **ab**
Seln 28-3	68.33 **ab**	Toledo	7.00 **abc**
Seln 5-1	65.00 **bc**	Ingot	7.17 **abcd**
Sweet Golden Sun	65.00 **bc**	Seln 23-2	8.17 **abcde**
Ingot	58.33 **bcd**	Sweet Lisa	8.83 **abcdef**
Seln 23-2	56.67 **bcde**	Seln 28-3	9.00 **abcdef**
Sweet Paz	56.67 **bcde**	Sweet Paz	9.00 **abcdef**
CPS 1127	55.00 **bcdef**	Sweet Sienor	9.33 **abcdefg**
Sweet Lisa	55.00 **bcdef**	CPS 1127	10.37 **bcdefgh**
Sweet CPS 1408	53.33 **bcdefg**	Sweet CPS 1443	10.50 **bcdefgh**
Sweet Denver	53.33 **bcdefg**	Seln 5-1	10.83 **cdefgh**
Sweet El Charro	53.33 **bcdefg**	Sweet CPS 1972	11.33 **cdefghi**
Seln 13-2	51.67 **cdefg**	Sweet Resisto	11.67 **defghi**
Sweet Resisto	48.33 **defg**	Sweet Cleor	12.00 **efghi**
Sweet CPS 1976	46.67 **defgh**	Sweet Rubit	12.50 **efghi**
Warlock	43.33 **defghi**	Warlock	12.50 **efghi**
Merlin	41.67 **efghij**	Sweet CPS 1976	12.83 **fghi**
Sweet CPS 1972	41.67 **efghij**	Eshet	12.83 **fghi**
Sweet Sienor	41.67 **efghij**	Sweet Red Stone	13.00 **fghi**
Toledo	41.67 **efghij**	Sweet Denver	13.67 **ghij**
Aries	40.00 **fghijk**	Santino	14.50 **hij**
Sweet CPS 1443	40.00 **fghijk**	Sweet CPS 1408	14.67 **hij**
Sweet Red Stone	38.33 **ghijk**	Merlin	15.50 **ijk**
Eshet	31.67 **hijk**	Sweet El Charro	17.67 **jk**
Sweet Rubit	30.00 **ijk**	Sweet Golden Sun	17.83 **jk**
Sweet Cleor	26.67 **jkl**	Tycoon	18.17 **jk**
Santino	25.00 **kl**	Sweet CPS 1128 P	18.17 **jk**
Tycoon	13.33 **l**	Aries	19.67 **k**
LSD	**16.53**	**LSD**	**4.518**

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

* Obtained by scoring each plot towards end of season for the percentage of foliage hanging on the plants as compared to amount defoliated and dropped to the ground.
** Obtained by estimating the % leaf area with visible infection symptoms of powdery mildew from 10 randomly infected leaves of each lot.

Table 4.6: Incidence of powdery mildew on capsicum entries - Bowen

Series "A" plants		Series "B" plants	
Variety or B. line	**Mean Disease* incidence**	**Variety or line**	**Mean disease incidence**
Birdseye	44.00 **a**	BC1 7-1(Maz)	40.00 **a**
LIPARI	39.67 **ab**	BC1 7-1(Mer)	37.33 **ab**
CLXP1408	39.33 **ab**	Paz	37.00 **ab**
Zoom	35.67 **bc**	BC1 17-5(Mer) 59	36.67 **ab**
CLXP1483	34.67 **bc**	BC2 22112 x 23-2(Maz)	36.00 **ab**
Aries	33.67 **bc**	BC1 5-1(Maz)	35.00 **ab**
Tycoon	33.33 **bc**	BC1 23-2(Maz)	35.00 **ab**
Toledo	32.00 **c**	BC2 Mer x 7-1(Mer)	33.33 **abc**
Warlock	32.00 **c**	BC2 Mer x 17-5(Mer)	33.00 **abc**
Merlin	31.67 **c**	BC1 30-4(Maz)	33.00 **abc**
CLXP172	30.67 **c**	BC2 16134 x 23-2(Maz)	32.67 **abc**
Flame	13.67 **d**	Hercules	29.00 **bcd**
LSD	**7.16**	Dracula	24.33 **cd**
		Ingot	19.67 **d**
		BC2 21814 x 7-1(Mer)	19.33 **d**
		LSD	**7.12**

Varieties with the same letter are not significantly different
* Disease incidence determined from the % of infected leaves out of 50 collected from each plot.

Table 4.7: Incidence of powdery mildew on capsicum entries in series 'B' - Ayr.

Variety or genotype	**Mean # Infected**
Hercules	17.67 **a**
Dracula	17.00 **a**
Ingot	15.00 **ab**
BC2 Mer x 7-1(Mer)	14.67 **ab**
Paz	12.67 **abc**
BC2 22112 x 23-2(Maz)	9.33 **bc**
BC1 23-2(Maz)	9.33 **bc**
BC2 Mer x 17-5(Mer)	8.67 **bc**
BC1 7-1(Mer)	7.33 **c**
LSD	**7.118**

Treatments with the same letter are not significantly different.

Tables 4.8: Disease severity of powdery mildew entries - Bowen

Series "A" plants		Series "B" plants	
Variety or genotype	**Mean plot disease severity***	**Variety or breeding line**	**Mean plot disease severity**
Zoom	3.33 **a**	BC1 7-1(Maz)	3.83 **a**
Birdseye	3.17 **ab**	BC1 7-1(Mer)	3.50 **ab**
CLXP1720	3.00 **abc**	BC1 30-4(Maz)	3.33 **abc**
CLXP1483	2.83 **abc**	BC1 23-2(Maz)	3.33 **abc**
Aries	2.83 **abc**	Paz	3.17 **abc**
CLXP1408	2.67 **abc**	BC1 17-5(Mer) 59	3.17 **abc**
LIPARI	2.67 **abc**	BC1 5-1(Maz)	2.83 **abcd**
Flame	2.67 **abc**	BC2 21814 x 7-1(Mer)	2.67 **bcd**
Tycoon	2.17 **bcd**	BC2 Mer x 17-5(Mer)	2.33 **cde**
Toledo	2.17 **bcd**	BC2 22112 x 23-2(Maz)	2.00 **de**
Merlin	2.00 **cd**	Hercules	2.00 **de**
Warlock	1.50 **d**	BC2 Mer x 7-1(Mer)	2.00 **de**
LSD	**1.021**	Dracula	1.50 **e**
		Ingot	1.50 **e**
		BC2 16134 x 23-2(Maz)	1.50 **e**
		LSD	**1.124**

Treatments with the same letter are not significantly different.
* Disease severity scale of 0-5 where: 0= no infection and 5= very severe infection with massive defoliation.

Table 4.9: Disease severity of powdery mildew Series A entries - Ayr

Variety/genotypes	Mean plot disease severity
Flame	2.67 **a**
Aries	2.50 **ab**
Tycoon	1.83 **bc**
CLXP1408	1.67 **c**
Merlin	1.67 **c**
CLXP1483	1.50 **c**
Birdseye	1.50 **c**
Toledo	1.33 **c**
Warlock	1.33 **c**
CLXP1720	1.17 **c**
LIPARI	1.17 **c**
LSD	**0.679**

Variety means with the same letter are not significantly different

Table 4.10: Capsicum cultivar reaction classification to powdery mildew

Cultivar	Foliar Disease Incidence (100%)	Foliar Disease Severity (1-5)	Reaction classification
Toledo	44.6 a	1.33 a	Resistant
Ingot	50.6 a	1.67 a	Resistant
Warlock	65.3 b	2.17 b	Susceptible
Merlin	67.3 b	2.5 c	Susceptible
Tycoon	79.3 c	2.67 c	Very Susceptible
Aries	80.0 c	3.17 d	Very Susceptible

Means followed by the same letter are not significantly different

Discussion

There were definite differences in the resistance levels of the varieties to powdery mildew but they varied between the locations and seasons. Hercules, Ingot and Dracula exhibited high levels of resistance to powdery mildew at the Bowen site but rather lower resistance at Ayr during the 2005 season evaluations. The breeding line, BC1 7-1(Mer) was more resistant than Hercules and Ingot at Ayr but less resistant than both of them at Bowen.

If in 2005 we focus just on the Bowen site data where disease pressure was greater, then the commercial varieties Dracula and Ingot performed quite well out of the series 'B' plantings in terms of both disease incidence and severity. Out of the series 'A' plants, Warlock and Merlin performed well. There are therefore varietal differences to powdery within the most cultivated varieties that the growers currently choose from.

Some varieties showed variation in reaction in terms of disease incidence and disease severity. This may strengthen the need for defoliation or foliage retention data as an additional parameter for resistance screening as was done at the Bowen site in 2004, when the disease pressure was high enough to follow through and collect this data later in the season. Such additional data could give an indication as to which of the entries are least likely to suffer economic damage as a result of severe powdery mildew infection since fruit exposure and sun scalding is the major way economic losses are encountered on infected plants.

There was a significant difference in the susceptibility of plants to the disease recorded at each of the sites. Some of the varieties showed different incidence and severity of powdery mildew between the two sites. At Bowen, where the disease pressure was higher, the commercial varieties Dracula, Ingot, Warlock and Merlin all performed well with low levels of disease incidence and severity.

Absence of symptoms in 2 of the commercial varieties (Warlock and Toledo) evaluated at the early vegetative stage indicates widespread occurrence of juvenile resistance in the Capsicum germplasm. Diop-Bruckler (1989) also described decreased susceptibility in younger leaves of plants at every developmental stage, but did not find evidence of juvenile resistance. Nevertheless, the contrasting response of Capsicum spp to pathogens in the early and late growth stages has been reported for other capsicum pathosystems, for example capsicum and Phythophthora blight (Reifschneider *et al*., 1986). Among the germplasm screened, those that exhibited high levels of resistance generally had a high rate of leaf retention even at the very end of the cropping cycle. Reuveni and Rotem (1974) had also classified capsicum reactions to Leveillula based of leaf abscission.

Of the total of 47 genotypes evaluated in his work between the 2 locations and in the 2 years of evaluation, about 5% can be classified as highly resistant, 15% as resistant and the rest as susceptible. Although seldom observed, immunity in the Capsicum-*Leveillula* system has been reported before, by Ullasa *et al.*, (1981) as resistance class “no symptoms”. Daubeze *et al.*, (1995) working with another capsicum line also defined the synthetic resistance class “zero” to represent plants with no visible sporulation and no leaves infected.

When canopy retention and percent diseased leaf area assessments were carried out in 2004, the expected inverse relationship was observed on these two parameters with entries showing higher canopy retention also having lower percent leaf infection area. In general, however, levels of percent leaf area infected with powdery mildew were low because heavily infected leaves had defoliated. Percent canopy retention as well as leaf area infected scores could not be assessed during 2005 because of the generally lower levels of disease infection on the entries as compared to 2004. Ranking of entry reactions in 2005 season was therefore only based on disease incidence as reflected by the number of infected leaves per plot and by disease severity as reflected by the intensity of infection in each plot.

Immunity or very high resistance to *Leveillula* is not a common occurrence within the cultivated capsicum species *C. annuum*. Scarcity of highly resistant *C. annuum* sources is of concern to plant breeders, as gene transfer among different species is cumbersome and complicates resistance breeding of commercial capsicum varieties which are all in the *C. annuum* genera.

We were unable to identify entries within the germplasm with confirmed multiple resistance to powdery mildew and tospovirus. This was mainly because of seed scarcity resulting in our inability to repeat the findings of the one year evaluations with these entries.

There is certainly some differences in the level of reaction even within the available cultivated genotypes to give the grower a choice to carefully consider what is grown in any particular region depending on the disease pressure in that region. By making such a careful choice could result in production cost savings by cutting back on the number of seasonal fungicide sprays needed when a cultivar with some level of resistance is grown.

Based on the cultivar screening results, Toledo and Ingot should be the cultivars of choice in locations with high seasonal epidemics of powdery mildew and Tycoon and Aries should be avoided at such locations.

Fig 4.1: Production of seedlings in the glasshouse for field screening transplants

Fig 4.2: Collecting leaflets for disease incidence assessments

Chapter 5: Field Control Options – Activators Evaluations

Introduction

Even though fungicides are currently the primary method of control of powdery mildew diseases in most crops including capsicums, resistance to some fungicides by some of the pathogens is increasing pre and postharvest losses to growers. In addition, the continued use of pre and postharvest chemical treatments is increasingly limited due to consumer concerns (Wilson and Wisneiwski, 1989). Besides, chemical control is not always efficient and commercially acceptable resistant varieties of capsicums are not readily available. There is therefore a renewed interest in the development of alternative environment-friendly methods of controlling fungal pathogens especially those like powdery mildew which are widespread with a large host range. The constant use of fungicides can also result in environmental contamination and selection of resistant populations to powdery mildew pathogens (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 for foliar fertilizers with a potential added benefit of disease control. Pasini *et al.*, (1997), verified the effectiveness of JMS Stylet oil, canola oil and syntrol 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 as summarised on Table 5.1.

Most of the above alternatives to fungicide work either as protectants or by inducing resistance to the pathogens in plants. 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 as demonstrated by Reuveni may simultaneously protect against pathogens and provide nutrients as has been demonstrated by the use of potassium mono-phosphate (Reuveni and Reuveni, 1997).

Most of these investigations have focused mainly on cucurbits and very few have looked at the effects of these alternatives on powdery mildew on capsicums. This section of the research was dedicated to evaluating some of these activators or inducers and comparing their performance with that of synthetic fungicides in controlling powdery mildew on capsicums under field conditions.

Materials and Methods

2004 Trials

Products evaluated

During the 2004 cropping season, the following activators and fungicides (with their brief summary properties) were evaluated for their efficacy on controlling powdery mildew under field infection conditions at the DPI&F Research Station at Bowen:

- ***Silicon*** **–** In different formulations, especially in soluble forms, this product has been reported to work as an activator or resistance inducer in boasting 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). It has been demonstrated in studies elsewhere to be effective against powdery mildew on cucurbits and other vegetable crops, but has not been evaluated for its effectiveness on powdery mildew on capsicums. Foliar sprays of silicon have also been shown to reduce aphid populations in field crops. A soluble formulation SKH (Silicon, Potassium and Humus) was obtained from the agrochemical company Agrochem and used in the evaluations.

- ***Cow's Milk* –** In different forms and formulations several studies starting with an early one in Brazil (Bettiol, 1999), milk has been reported to having both resistance inducing as well as fungicidal properties against powdery mildew of vegetable crops. It has been suggested that it could act as a fungicide substitute or supplement based on its ability to significantly suppress powdery mildew on a number of crops on which it has been tested. Even though its exact mode of action is still uncertain, aqueous solutions containing as little as 10% milk concentrations have been demonstrated to be as effective as conventional fungicides in controlling powdery mildew on cucurbits under controlled conditions (Bettiol, 1999). Other studies have also suggested that the powdered formulation would work just as well in appropriate dilutions. Its efficacy has not been evaluated against the powdery mildew pathogen on capsicums. In this study we used the powdered formulation of milk at the 10% dilution rate.

- ***EcoCarb* –** A plant bio-stimulant with activated potassium bicarbonate (Reuveni *et al.*, 1995). EcoCarb has been investigated and 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 not quite clear, 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 has current registration for the control of powdery mildew on a number of crops including rose bushes and grape crops. Its effect has however not be investigated on powdery mildew on capsicums.

- ***Brella Oil* –** Like other petroleum or paraffin oils, this has been reported to have insecticidal as well as fungicidal activity against a number of different foliar diseases especially powdery mildew on a range of crops (Phillip *et al.*, 1990). It has however not been evaluated for efficacy on powdery mildew on capsicums.

- ***Sulphur*** **–** This is the most widely used conventional fungicide for the control of powdery mildew on different crops including capsicums (Baker, 1989). Several formulations are commercially available. 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 has always been effective in providing reasonable protection on capsicums against the disease in Australia until 2000 season when conditions were highly favourable for rapid epidemics of the disease and usual repeated sprays failed to provide acceptable levels of control. It was mainly included in these evaluations to compare its current efficacy against that of the activators that were being evaluated.

- ***Bayfidan*** **-** This is one of the 2 systemic fungicides that currently have emergency use permit against powdery mildew on capsicums. It has been shown to be particularly effective against *Leveillula taurica* on other crops such as tomatoes for which it has been registered. As the temporal permit for its use was just granted when this study was to start, it was desirable to compare how the different activators measure up in their efficacy against powdery mildew when compared with this systemic fungicide.

Trials Location and protocols

The trials were carried out on a field block of 8 rows, each 60m in length. Plot sizes were 6m long by 1.5m wide rows. Each plot was separated by a buffer zone of 2m by 1.5m. There were 2 untreated guard rows each bordering the experimental block to serve as inoculum spread source to increase disease pressure on the plots. The capsicum variety used in the trial was Warlock, which at the time made up more than 70% of the Bowen regional plantings. Six week old seedlings were obtained from a commercial nursery and established on the trial block in late June, 2004.

The experiment design was a randomised block with each treatment replicated 4 times.

Treatment Applications

Three spray treatments with the different activators and fungicide formulations made according to their different recommended rates were applied at the following on growth stages of plants:

- Vegetative – plants with about 10 true fully expanded leaves
- Start of Flowering or at 4 weekly intervals after 1st application at vegetative stage.
- Start of Fruiting or at 4 weekly intervals after last application.

Plot Assessments

Three weeks after the last spray applications at fruiting, assessments were carried out on the plots based on the following parameters: disease severity and disease incidence, percent defoliation, plot yields, fruit quality and postharvest fruit quality. Each parameter was evaluated as follows:

Plot Tagging - In each plot 10 plants were randomly tagged across the rows, based mainly on the general trend within the plot.

Disease Severity - A general disease severity score was given to the entire plot based on visual outlook of the disease intensity on the plants in the plot, using a scale of 0-5 where;

0 = no infection
1 = very light infection
2 = light infection
3 = moderate infection
4 = severe infection
5 = extremely severe infection

Disease Incidence: This was obtained by giving a general plot score on the visual estimated incidence of diseases in the plot.

Another disease incidence score was obtained by determining the number of infected leaves from 50 randomly selected leaves from the total leaves of the 10 tagged plants stripped for defoliation counts.

Effect on Defoliation: A count was taken on the nodes with shaded leaves on each of the 10-tagged plants per plot in the field. The percent defoliation was determined by counting the total number of leaves per plant on the 10-tagged plants per plot after cutting and taking the tagged plants to the shed for yield evaluations.

Yield Evaluations: This was determined by recording the total number of fruits from each of the 10 randomly tagged plants per plot, after cutting and taking them to the shed. The weights of all the fruits from each of the tagged plants were also taken.

Scalded or sunburnt fruits: From the number of tagged plants and per plot, the percentage of scalded fruits was calculated after determining the number of fruits from each plant with visible sunscald signs.

Post harvest evaluations – Ten un-scalded fruits were collected from each plot giving a total of 40 fruits per treatment, on the basis of uniform size, color, firmness and lack of defects or disease markings. They were conveyed to the laboratory at Ayr for further evaluation for shelf life. The fruits were evaluated for post harvest decay incidence after 14 days in storage at 12 C and after an additional 3-5 days at 22-24 C.

2005 Trials

Products evaluated

In addition to the 6 activators and fungicides evaluated at the Bowen Research Station in 2004, 4 others were added to the list and evaluated for efficacy to powdery mildew on capsicums at the Ayr Research Station in 2005. Long service leave by our collaborating colleague from the Bowen Station did not make it possible to continue with evaluations at the Bowen site in 2005.

The new products added to the 2004 listings were:

- ***Nimrod*** – This is the second systemic fungicide to Bayfidan that obtained emergency permit application from APVMA for use on controlling powdery mildew on capsicums. Its approval was necessitated by the fear of possible resistance developing on Bayfidan sooner than expected because of the unregulated frequency at which some growers were using Bayfidan despite guidelines recommending that not more than 3 applications be made per season.

Nimrod has been shown to be effective against other powdery mildew fungi especially *Sphaerotheca fuliginea* (*Podosphaera xanthii*) on cucurbits for which it has current registration

- ***Cabrio and Collis:*** These 2 are experimental products with little known properties. They were provided by the Nufarm Chemical company who were interested in evaluating the performance of the products against powdery mildew on capsicums for possible future registration.
- ***Bion*** **–** This is a widely tested activator that has been shown to induce resistance against 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 capsicums.
- ***Syntrol Oils*** **–** This product was obtained from Organic Crop Protectants, the same company that manufactures and distributes EcoCarb. It was brought in to replace Bella petroleum oil after the first year evaluation results suggested that the Brella oil may have no activator or fungicidal affect against powdery mildew on capsicums. This product has been registered for use singly or in combination with EcoCarb for the control of powdery mildew for a number of crops under organic cropping systems.

Thus the complete listing of the products evaluated in the 2005 field trials was:

- Bayfidan (B)
- Nimrod (Ni)
- Cabrio Top (CT
- Collis (Co)
- Sulphur (S)
- EcoCarb (E)
- Powder milk (M)
- Silicon (Si)

- Bion (Bi)
- Syntrol OCP Oils (O)

For all the systemic fungicides in the list, only 3 spray applications were made during the cropping season, whereas 5 spray applications were made with the protectants evaluated singly.

In addition to evaluating the products as single sprays, spray combinations were also evaluated. Table 5.1 shows the make up of the 5 spray treatment combinations evaluated:

Table 5.1: Schedule of applications of the combined treatments for powdery control

Treatment no.	**Spray 1**	**Spray 2**	**Spray 3**	**Spray 4**	**Spray 5**
1	B	S	B	S	Si
2	S	E	B	M	Si
3	CT	S	CT	S	Si
4	Co	S	Co	S	Si
5	Ni	S	Ni	S	Si
6	Bi	B	S	Ni	M
7	Ni	B	S	B	S
8	Bi	E	M	S	Si
9	S	B	S	B	S
10	Untreated control				

All the single and combination spray treatments were compared to an untreated control.

All treatments were applied with a 6L hand held sprayer. Chemicals were mixed in 10L water and applied at a volume of 2.5L per plot, or until runoff. Quantities used were as per manufacturers instructions on product labels (Table 5.2).

The spray treatments were applied based on the following growth stages of plants, starting with the first detection of infection in the plots.

- Flowering (start) or with first detection of infection - (Late August)
- Flowering (Full) or 2 weekly interval after 1st application
- Fruiting (start) or 2 weekly interval after 2rd application –
- Fruiting (Full) or 2 weekly interval after 3th application
- Fruit Expansion or 2 weekly interval after 4th application

Table 5.2: Application rates of different products for powdery control - 2005

Product	Abbreviation	No. applications	Amount/10L water
Bayfidan	B	3	4ml
Nimrod	N	3	6ml
Cabrio Top	CT	3	4g
Collis	Co	3	4g
Sulphur	S	5	35g
EcoCarb	E	5	35g
Cow's powdered milk	M	5	200ml
Soluble Silicon	Si	5	33ml
Bion	Bi	3	2g
Synertrol OCP Oils	O	5	50ml

Field Plots

Slightly different to 2004, the Ayr trials were carried out on a field block of 10 rows each 60m in length. Plot sizes were 6m long by 1.5m wide rows. Each plot was separated by a buffer zone of 2m by 1.5m. The guard rows for 2005 were planted with the cultivar Aries, 4 weeks before the plot establishment to increase chances of inoculum build up adjacent to the plots

As in 2004, the capsicum variety used in the trial was still Warlock. Six week old seedlings were obtained from a commercial nursery in Ayr and planted in late July.
The experiment design was a randomised block with each treatment replicated 4 times.

Plot Assessments

Plot assessments were same as in 2004 except that infection effects on defoliation were not evaluated due to the generally low disease pressure on the plots and the apparent little effect on defoliation. Treatments effects on yield parameters were not also determined because of the same reason. Disease assessments for 2005 were same as for 2004, giving whole plot disease incidence and severity ratings as well as using leaves collected from plots to determine plot disease incidence.

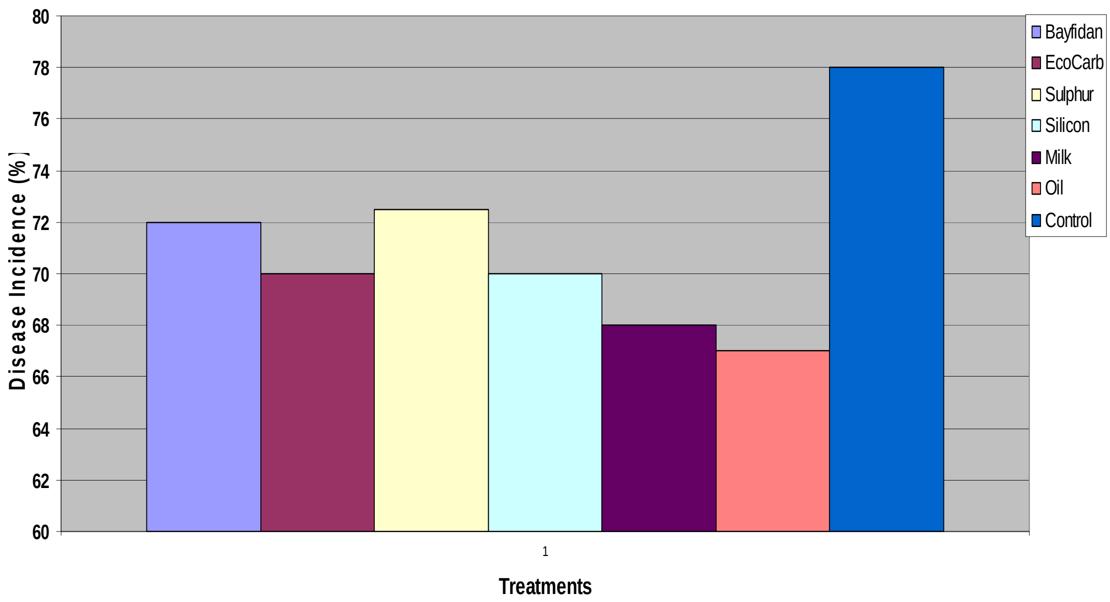
Statistical Analysis

Statistical analysis for both 2004 and 2005 trials was carried out using the Genstat statistical package. All analyses were One-way ANOVAs in randomised block design.

Results

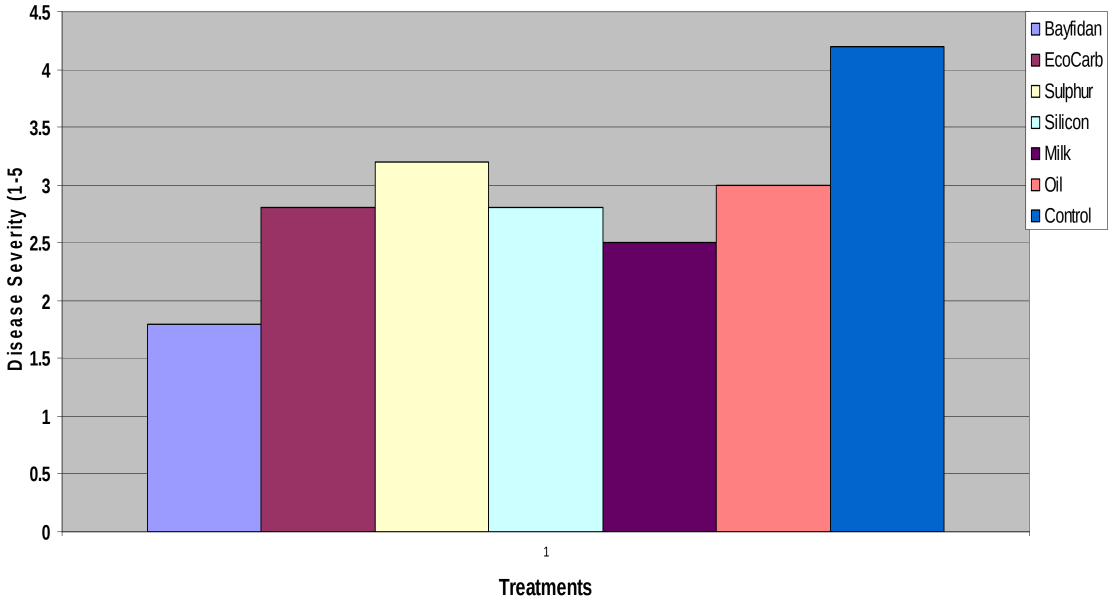
2004 Season

Fig 5.2: Different treatment effects on field powdery mildew disease incidence – 2004



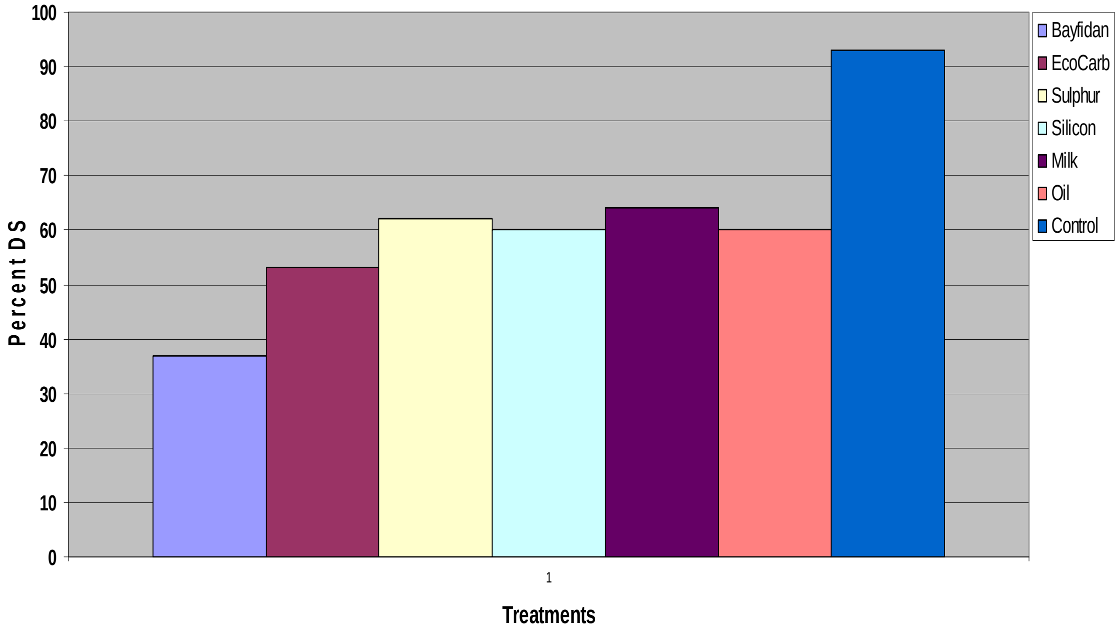
There were significant ($P<0.005$) differences between the untreated control and all the different spray treatments.

Fig 5.3: Different treatment effects on field disease severity – 2004



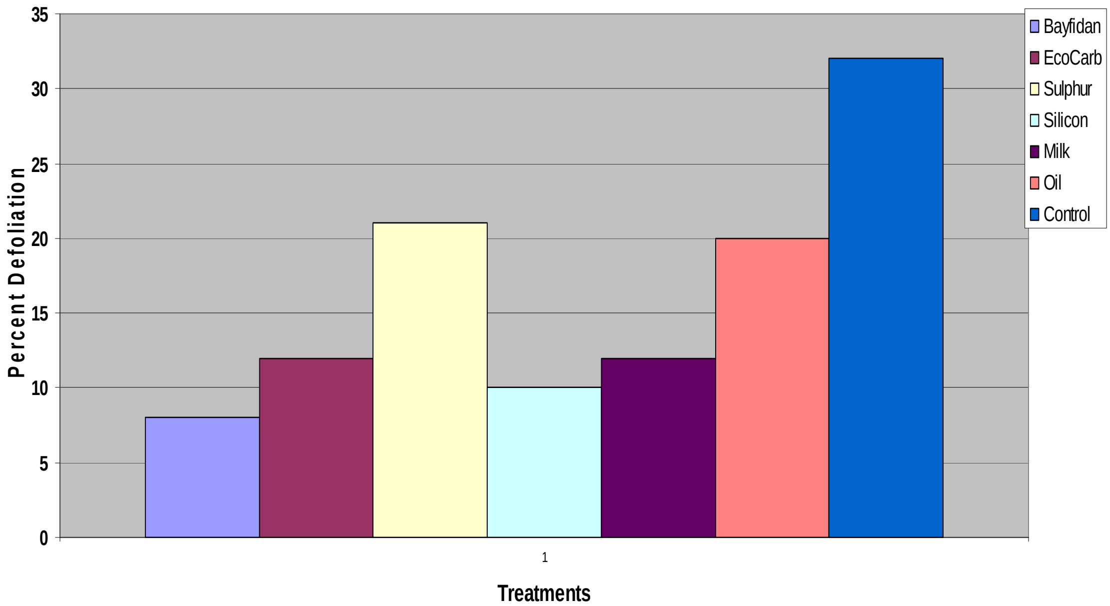
Significant differences in disease severity were recorded only between the untreated control and the Bayfidan treatments.

Fig 5.4: Powdery mildew disease incidence on detached leaves



From disease incidence readings of detached leaves all treatments were significantly different from the untreated control.

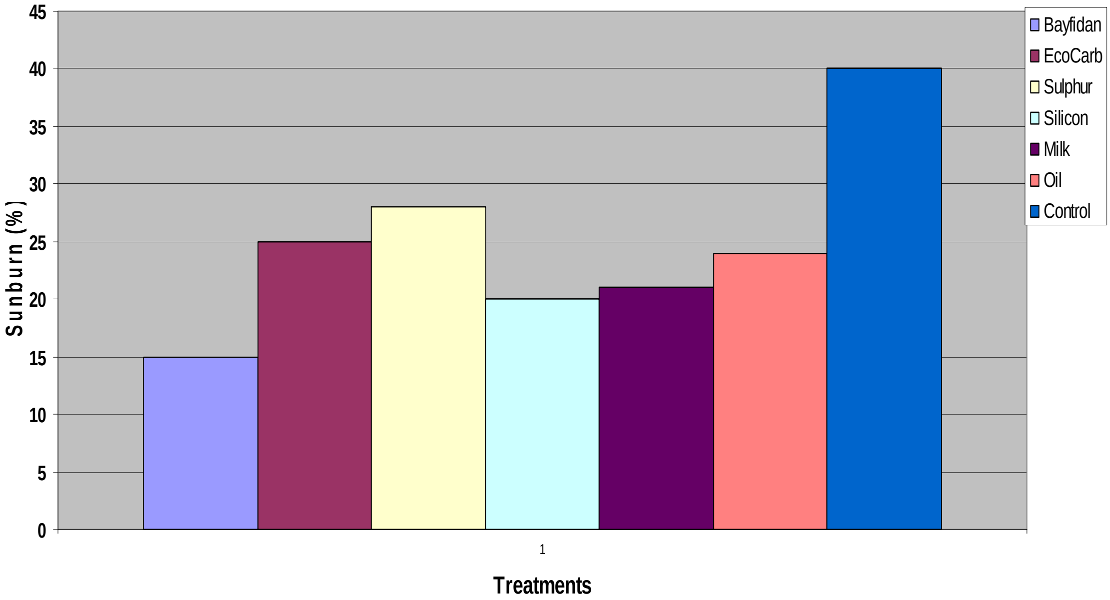
Fig 5.5: Treatments effects on leaf defoliation



All treatments significantly reduced the intensity of defoliation due to powdery mildew infection when compared to the untreated control

Fig 5.6: Sunburn symptoms on exposed fruits

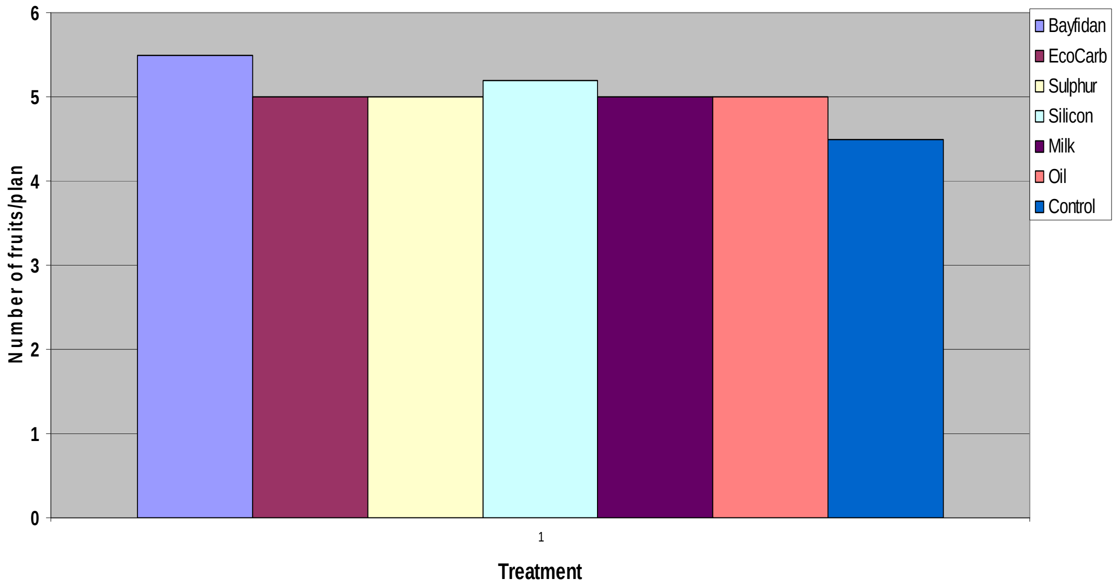
Fig 5.7: Treatment effects on percent fruits with sunburn



There were significant treatment effects for all treatments for percent sunburn on fruits when compared with the untreated control.

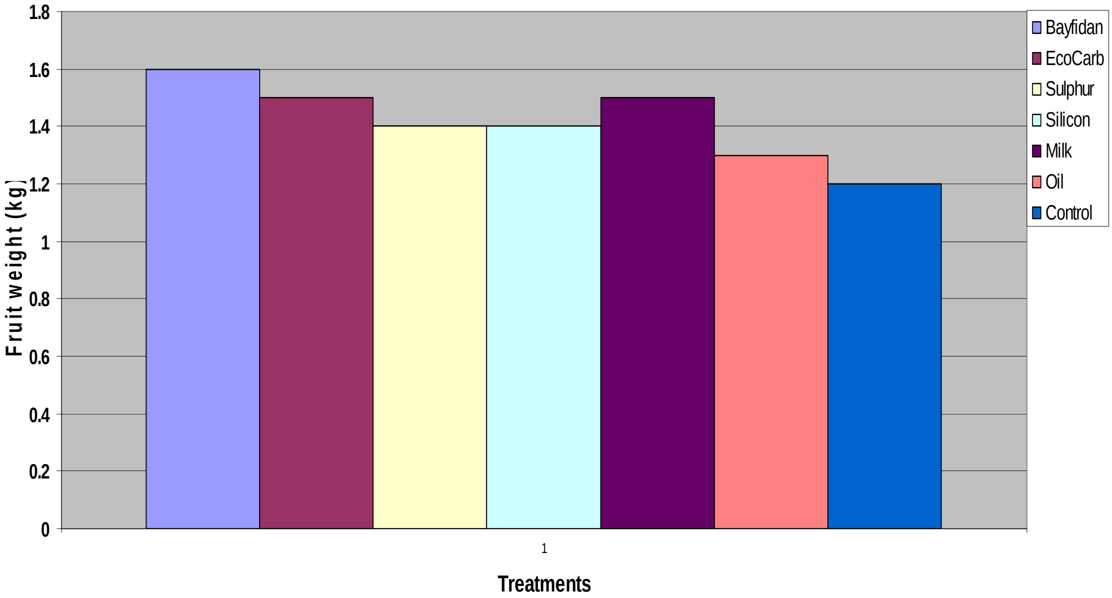
Fig 5.8: Less sun burn on fruits protected with activator sprays

Fig 5.9: Treatment effects on fruit numbers



There were no treatment effects on fruit numbers when compared with the untreated control.

Fig 5.10: Treatment effects on fruit weight (kg)



There were no treatment effects on fruit weight when compared with the untreated control.

2005 Season

During the 2005 season there was generally a low incidence of powdery mildew in the field. Field infection was first detected during the first week of September. The disease then spread through the entire trial but the level of infection remained relatively low when compared to the 2004 season.

A low level of phytotoxicity was observed on the Bion treatment in the single spray trial treatments. This distorted any meaningful disease incidence readings on this treatment.

Disease incidence

Single spray treatments

There was a significant ($P < 0.001$) single treatment effect on the average number of leaves infected with powdery mildew for most of the single spray treatments. All single product treatments except Nimrod showed significantly more infected leaves than Bayfidan (Table 5.3). Synertrol, Silicon and EcoCarb showed significantly more infected leaves than Nimrod. Synertrol showed significantly more infected leaves than Collis, Cabrio Top and Sulphur. It was the poorest performer among all the treatments, if number of infected leaves was the sole criteria to determine the effectiveness of the product treatments.

Table 5.3: Effect of single treatments on leaf disease incidence of powdery mildew

Treatment	**Percentage of leaves infected**
Synertrol oil	61.00 **a**
Silicon	54.00 **ab**
EcoCarb	49.00 **ab**
Bion	41.00 **abc**
Powdered milk	39.00 **abc**
Collis	34.50 **bc**
Cabrio Top	34.00 **bc**
Sulphur	32.00 **bc**
Nimrod	23.50 **cd**
Bayfidan	2.00 **d**
LSD	**22.04**

Treatments with the same letter are not significantly different

Combination treatments

There was a significant (P< 0.004) combination treatment effect on the number of leaves infected with powdery mildew. Of the systemics used in combination with sulphur and silicon, Collis and Cabrio Top were not significantly different from the control while Nimrod and Bayfidan were (Table 5.4). There was no significant difference between some of the treatment combinations even with one, two or three applications of Nimrod and Bayfidan.

Disease severity

Single spray treatments

There was a significant (P < 0.001) single treatment effect on the average plot rating for disease severity. Bayfidan had a significantly lower average plot rating than Synertrol, Silicon and EcoCarb (Table 5.5). Those three together with Collis and Sulphur were significantly worse than Bion and Nimrod. Those five and milk were significantly worse than Nimrod in this trial

Table 5.4: Leaf disease incidence with powdery mildew after combination treatments

Treatment	Percentage of leaves infected
Control	34.00 **a**
CT-S-CT-S-Si	27.5 **ab**
Co-S-Co-S-Si	20.00 **abc**
S-B-S-B-S	16.5 **bcd**
Bi-E-M-S-Si	15.00 **bcde**
S-E-B-M-Si	14.50 **bcde**
Ni-S-Ni-S-Si	13.50 **bcde**
Bi-B-S-Ni-M	8.50 **cde**
Ni-B-S-B-S	4.50 **de**
B-S-B-S-Si	0.50 **e**
LSD	**15.19**

Treatments with the same letter are not significantly different.

Combination treatments

There was a significant (P< 0.001) combination treatment effect on the average plot ratings for disease severity. All of the combination treatments had a significantly lower plot rating than the control (Table 5.6).

Table 5.5:Effect of single trial treatments on plot disease severity scores (0-5)

Treatment	Average plot rating
Synertrol oil	2.75 **a**
Silicon	2.38 **ab**
EcoCarb	2.00 **b**
Collis	1.38 **c**
Sulphur	1.38 **c**
Powdered milk	1.25 **cd**
Cabrio Top	1.13 **cde**
Bayfidan	0.88 **cde**
Bion	0.75 **de**
Nimrod	0.63 **e**
LSD	**0.55**

Treatments with the same letter are not significantly different.

Table 5.6: Effect of combination treatments on plot disease severity

Treatment combination	Average plot rating
Control	2.63 **a**
CT-S-CT-S-Si	1.38 **b**
S-E-B-M-Si	1.13 **b**
Co-S-Co-S-Si	1.13 **b**
Ni-S-Ni-S-Si	1.13 **b**
S-B-S-B-S	1.13 **b**
Bi-B-S-Ni-M	0.63 **c**
Ni-B-S-B-S	0.63 **c**
Bi-E-M-S-Si	0.50 **c**
B-S-B-S-Si	0.38 **c**
LSD	**0.50**

Treatments with the same letter are not significantly different.

Percent defoliation

As disease pressure was generally low throughout the season, plant defoliation evaluations were not undertaken for any of the treatments.

Discussion

Of the single treatments evaluated in this trial, none of the products showed better control of powdery mildew than the industry standard (Bayfidan) in terms of either disease incidence or disease severity. This was to be expected of the protectants which are usually lower in efficacy than the systemics. Bion demonstrated some phytotoxic effects on capsicum plants suggesting that the concentration used might have been a bit too high for capsicums under the conditions of evaluation.

Of the combination treatments, seven out of the nine combinations evaluated showed significantly fewer leaves with powdery mildew than the control and all treatments showed significantly lower disease severity than the control. The effective combination of systemic and protectant chemicals in these trials suggested that it may be possible to replace some systemic treatments with protectants, especially in conditions where the expected infection levels are low.

Based on more recent research, classification of non-chemical methods of powdery mildew control can essentially fall into two categories: products or micro-organisms that protect the plant against powdery mildew infection by inducing host defense mechanisms and micro-organisms that are natural enemies of powdery mildews and attack their different structures through parasitism and/or antibiosis. This studied focused on evaluating the first category of products.

Table 5.7 indicates some of the products that have been reported to protect plants against powdery mildew through induced resistance. Milk, also investigated in this study appears to be an unusual product on the list. While it would appear surprising at first, it is a likely viable alternative as demonstrated in this study with the field results of 2004 when there was high disease pressure. Its exact mode of action is unknown at the moment, but direct fungicidal activity and induction of systemic resistance have been suggested. Among the different plant defense mechanisms elicited as a result of induced resistance to prevent powdery mildew infection, phytoalexin production has been demonstrated to be linked to the use of soluble silicon. Fawe *et al.,* 1998, using soluble silicon were able to identify flavenoids and phenolic acids that were specifically and strongly induced in response to infection of cucumber by powdery mildew. The antifungal activity was only detected following hydrolysis of the plant extracts. Benhamou and Belanger (1998) suggested that these phenolics were released into their active form through the production of enxymatic proteins by the pathogen.

Table 5.7: Reported products with anti-powdery mildew activity

Products	Mode of Action	Reference
Inorganic products		
Potassium bicarbonate	Fungicide	Reuveni *et al.,* 1995
Baking soda (sodium bicarbonate)	Fungicide	Horst *et al.,* 1992
Soluble silicon	Induced resistance (IR)	Belanger *et al.,* 1995
Whitewash or clay	Physical IR	Marco *et al.,* 1994
Organic products		
Paraffin oil	Protectant	Phillip *et al.,* 1990
Detergents	Protectant/fungicide	Cohen *et al.,* 1996
Benzothiadiazole (Bion)	IR	Cole, 1999
Antitranspirants	Protectants	Ziv & Hagiladi 1993
Milk	IR/fungicide (?)	Bettiol 1999
Oils	Protectant	McGrath et al 2000
Plant extracts (Milsana)	IR	Daayf *et al.,* 1995
Neem kernels (Azadirachta indica)	IR	Pasini *et al.,* 1997
Compost extracts	IR/fungicide	Samerski *et al.,* 1988.

Eliciting products listed in Table 5.7 have all been reported to protect against powdery mildew infection in one pathosystem or another. Wurms *et al.*, (1999) had dismissed the effectiveness of Bion at protecting cucumber plants against powdery mildew despite substantial reports and data demonstrating its effectiveness against powdery mildew on cereals. The use of soluble silicon has been widely described as a prophylactic treatment against powdery mildews on a variety of crops including dicots and monocots. There is however, still some controversy over the exact mode of action of silicon *in planta* as well as its true impact on disease resistance. In monocots, the current hypothesis is that absorbed silicon polymerises in the apoplast of leaf cells and creates a mechanical barrier preventing penetration by the hyphal peg (Zhang *et al.,* 1997). In dicots, at least in cucumbers, soluble silicon in the form of silicic acid would act as a signal molecule, inducing defense responses such as phytoalexins (Fawe *et al.*, 2001). There is therefore a need to exploit induced resistance with a caution because of this apparent crop specificity among products inducing resistance with different defense mechanisms reported to retard powdery mildew infection, and progression depending on the crop species. A thorough understanding of the products characteristics will be useful before recommending commercial application. Despite the above caution, it is clear from this study and others that induced resistance is a welcome strategy within an integrated program of managing powdery mildews without or with few chemicals.

Based on our current knowledge of this induction approach with activators, it does not appear realistic to rely on activators or resistance inducers alone to control powdery mildew on capsicums, considering that induced resistance is not curative. It should be exploited as a preventive measure in the early stages of production and be replaced and/or supplemented by limited fungicide sprays when disease pressure increases. This is particularly true of some field and greenhouse crops such as capsicums where powdery mildew progression can be very rapid once initiated because of constant favourable weather conditions during the production season as is the case in northern Queensland districts.

The next chapter in this project study on integrated disease management, focuses on the integration of the activators with fungicide sprays in this holistic approach at managing powdery mildew on capsicums.

Chapter 6: Integrated Management of Powdery Mildew

Introduction

Powdery mildew, *Leveillula taurica* (Lev.) Arm, is a major disease of capsicums in tropical and sub-tropical environments of Australia where the crop is grown. Even though the disease attacks a number of host crops, the pathogen *L. taurica* restricts its attack mainly to capsicums, tomatoes and other solanacious plant species. A powdery mildew infection acts as a sink for plant photosynthates causing reductions in plant growth, premature foliage loss, and subsequently a reduction in yield and quality of fruits depending on time of infection and spread. The yield losses associated with infection is often proportional to the severity of the disease, the time and length of time that plants have been infected. In cucumbers, for example, a negative linear relationship has been established between disease severity and yield (Dik and Albajes, 1999). A heavy infection of powdery mildew can result in severe defoliation of the plant, with consequent sun damage to the fruit and a substantial economic loss. If early infections are not controlled in a timely manner, symptoms can be severe enough to cause these extensive premature leaf curl and defoliation of older leaves exposing already set fruits to sunburn or limiting the yields of new late plantings infected before fruit set.

The disease has traditionally been controlled with sulphur-based fungicides in most capsicum production districts of Australia. The pathogen, however, has in recent years been showing poor response to these sulphur-based spray products suggesting either a change in pathogen population that needed to be investigated or other environmental factors favouring aggressive spread of the disease once initiated in orchards. The poor performance with sulphur sprays led to permits application and temporal registration of two systemic fungicides (Bayfidan and Nimrod) for use in controlling the disease. There is however a concern that growers' sole reliance on these products may lead to an over-use resulting in the development of resistance even before they are fully registered, if other products are not identified to use in breaking the systemic fungicide spray cycles. There are also increasing concerns about the environmental effects of such a reliance on these systemic fungicides as the main means of controlling the disease. The purpose of this study was therefore to take the other softer products identified in earlier trials a step further by incorporating them in integrated management packages for powdery mildew on capsicums in the hope of identifying combinations that were as effective as spray combinations that used sulphur as the main break of the systemics. The specific objectives of this study were: a) Evaluate the efficacy of alternative products (powdered milk and silicon) when used in combination with industry standard fungicides (Sulphur, Bayfidan and Nimrod) in controlling powdery mildew on capsicum; b) Compare the efficacy of these treatment combinations with an industry standard spray program and an untreated control; and c) Evaluate the effect of these treatment combinations on fruit yields and quality;

Materials and Methods

Experimental Sites and Design

The trials were conducted at both the Bowen and Ayr Research Stations of the Queensland Department of Primary Industries and Fisheries in north Queensland.

Ayr Research Station Site

At the Research Station, a block of 10 rows, each 60 m long, was used. The outer two rows of the block were first planted to double lines of Aries (a susceptible powdery mildew variety) 4 weeks before the establishment of the main plots at a spacing of 55 cm. These rows served as guards cum spreader rows, facilitating early establishment of powdery mildew within the trial blocks. The inner eight rows of the trial were planted with the cultivar, Warlock, a widely cultivated capsicum variety across north Queensland. The spacing of the main trial plantings was also 55 cm. The trial design was in an incomplete randomised block design with five different treatments in five replications. Each plot was 14 m long by 1m wide with a 2 m inter-plot spacing. The main trial was in early July.

Bowen Research Station Site

At the Bowen Research Station a block of 8 rows, each 60 m long was used. As with the Ayr site, the outer two of these rows were guard rows of Aries variety while the inner six rows were planted with Warlock variety. Capsicum plants were established in double rows with 55 cm spacing between the plants. The trial design was a randomised complete block of six treatments by six replications. The trial was established in mid July.

At both Research Stations, standard industry crop husbandry practices for irrigation, fertilization and weed control were implemented throughout the duration of the trial.

Inoculation of field plants

At flowering when no signs of infection with powdery mildew could be detected within the plots at both stations, potted glasshouse propagated Aries capsicum varieties heavily infected with powdery mildew were placed at strategic locations along the outer spreader rows to spread inoculum to the spreader rows which could then be spread to the treatment plots. This resulted in the detection of infection symptoms on the spreader rows a couple of weeks after the placement of the infected potted plants that served as sources of trial inoculum.

Treatment Applications

Four spray programs were compared with the untreated control (Table 6.1). These consisted of different combinations of the 2 systemic fungicides with different protectants. The industry standard of sulphur, Bayfidan and Nimrod was compared with the other treatment combinations in which sulphur was replaced by either powdered milk or silicon. The treatment schedule for the different spray program combinations is shown in Table 6.1. Treatment rates used are also shown in Table 6.2.

Each spray treatment was applied using a motorised knapsack sprayer and boom with hollow cone nozzles to give good coverage.

Table 6.1: Treatment schedule for fungicide spray program - Ayr and Bowen

Ayr	Spray 1	Spray 2	Spray 3	Spray 4	Spray 5
Treatment	08-Sep-06	28-Sep-06	12-Oct-06	24-Oct-06	03-Nov-06
1	Control	Control	Control	Control	Control
2	Sulphur	Bayfidan	Sulphur	Nimrod	Sulphur
3	Milk	Bayfidan	Milk	Nimrod	Milk
4	Silicon	Bayfidan	Silicon	Nimrod	Silicon
5	Silicon	Bayfidan	Milk	Nimrod	Sulphur
Bowen	Spray 1	Spray 2	Spray 3	Spray 4	Spray 5
Treatment	04-Oct-07	18-Oct-06	25-Oct-06	02-Nov-06	10-Nov-06
1	Control	Control	Control	Control	Control
2	Sulphur	Bayfidan	Sulphur	Nimrod	Sulphur
3	Milk	Bayfidan	Milk	Nimrod	Milk
4	Silicon	Bayfidan	Silicon	Nimrod	Silicon
5	Silicon	Bayfidan	Milk	Nimrod	Sulphur

Table 6.2: Application rates of the spray products

Product	**Abbreviation**	**Active ingredient (a.i.)**	**a.i./L water**
Sulphur	S	800 g/kg sulphur	2.80 g
Bayfidan	B	250 g/L triadimenol	0.10 g
Nimrod	N	250 g/L bupirimate	0.15 g
Silicon	Si	103 mL/L silica	1.03 mL
Milk	M	Powdered cow's milk	20 g

Disease Assessment

The initial signs of disease infection in plots were first detected in first week of October at the Ayr site. By time of second spray application in late October, disease pressure was still relatively light. The situation however, quickly changed within a matter of days as weather conditions suddenly became favourable for rapid disease spread at the site.

Infection was first detected at the Bowen site only in late October. It progressed rather slowly and a sudden epidemic occurred in early November after the third spray had just been made.

Disease assessments were made at near-harvest when the spray programs had been completed. This was done at Ayr during first week of November and at Bowen during third week. The assessments at both sites were carried out using both disease incidence and disease severity ratings.

Disease Incidence

At near harvest, 60 mature leaves were randomly collected from tagged plants in each trial plot, making sure the very young and the old senescing lower leaves were avoided. Out of the 60 collected and placed in a labelled bag, 50 were again re-selected in the laboratory and assessed for the presence of powdery mildew infection with the aid of a dissecting microscope light. The infected leaves were recorded as disease incidence ratings for the plots.

Disease severity

The leaves identified to be infected from the 50 from each plot were further assessed for the extent of infection by counting the number of infection colonies on each using the same dissecting microscope light. These were recoded as the disease severity ratings for each plot.

Yield and quality Assessment

At harvest, five plants were randomly tagged from each plot for yield assessments. All fruits from each tagged plant were removed, counted and weighed to determine both fruit numbers and weights. The number and weight of fruits observed with sunscald was also recorded for use in quality assessment.

Data Analysis

All the data collected (disease incidence and severity as well as yield and sunscald parameters) were statistically analysed with Genstat 8 statistical package using a one-way Analysis of Variance (ANOVA). Treatment means were compared and separated using Fischer's Least Significant Difference Test. Disease incidence data were transformed using an arc-sine transformation before analysis.

Results

Disease Assessment

Disease incidence

There was a significant treatment effect in the trial at Ayr Research Station site on the number of leaves infected with powdery mildew ($p = 0.002$) with all treatments showing significantly fewer leaves with the disease than the control (Fig 6.1)

There was no significant treatment effect in the trial at the Bowen Research Station site, on the number of leaves infected with powdery mildew ($p = 0.393$).
Disease incidence results for both sites are presented on Table 6.3.

Disease Severity

There was also a significant treatment effect on disease severity as reflected by the number of colonies per leaf at both the Ayr Research Station ($p < 0.001$) and the Bowen Research Station ($p = 0.001$). At Ayr, all treatments had significantly fewer colonies than the control (Fig 6.2), while at Bowen; the industry standard was the only treatment that showed fewer colonies than the control. These results are presented in Table 3 for both sites.

Yield

There was no significant treatment effect on the number of fruits per plant at either Ayr ($p = 0.647$) or Bowen ($p = 0.856$). There was also no significant treatment effect on the weight of fruit harvested at either sites; Ayr ($p = 0.762$) and Bowen ($p = 0.536$). Treatment means are summarised on Table 6.4.

Fruit quality

There was a significant treatment effect on the number of fruit per plant showing sunscald at Ayr ($p = 0.024$), where all treatments performed significantly better than the control. Similarly, there was a significant treatment effect on the weight of fruit showing fruit per plant showing sunscald at Ayr ($p = 0.029$), again with all treatments performing significantly better than the control.

At Bowen, however, there was no significant treatment effect on the number ($p = 0.813$) or weight ($p = 0.649$) of fruit with sunscald.

Treatment means for both fruit quality variables are shown on Table 5.

Table 6.3: Mean percentage of leaves infected (disease incidence) and mean number of colonies per leaf (disease severity) for the treatments at both locations.

		Disease severity	Disease incidence	
	Treatment	**No. of colonies/leaf**	**% leaves infected**	**trans. % leaves infected**
Ayr	S-B-S-N-S	2.15 a	76.0	1.076 a
	Si-B-Si-N-Si	3.57 a	76.0	1.111 a
	M-B-M-N-M	2.31 a	82.4	1.141 a
	Si-B-M-N-S	4.91 a	87.6	1.297 a
	Control	16.68 b	100.0	1.571 b
	Mean LSD* (p = 0.05)	**4.252**	**N/A**	**0.2494**
Bowen	S-B-S-N	12.72 a	95.67	
	Si-B-Si-N	16.39 b	91.00	
	Si-B-M-N	16.39 b	95.00	
	M-B-M-N	16.99 b	98.00	
	Control	18.06 b	94.00	
	LSD (p=0.05)	**2.343**	**Not significant**	

**A mean LSD is given as the experimental design was an incomplete block*

Table 6.4: Treatment effects on number and weight of fruits

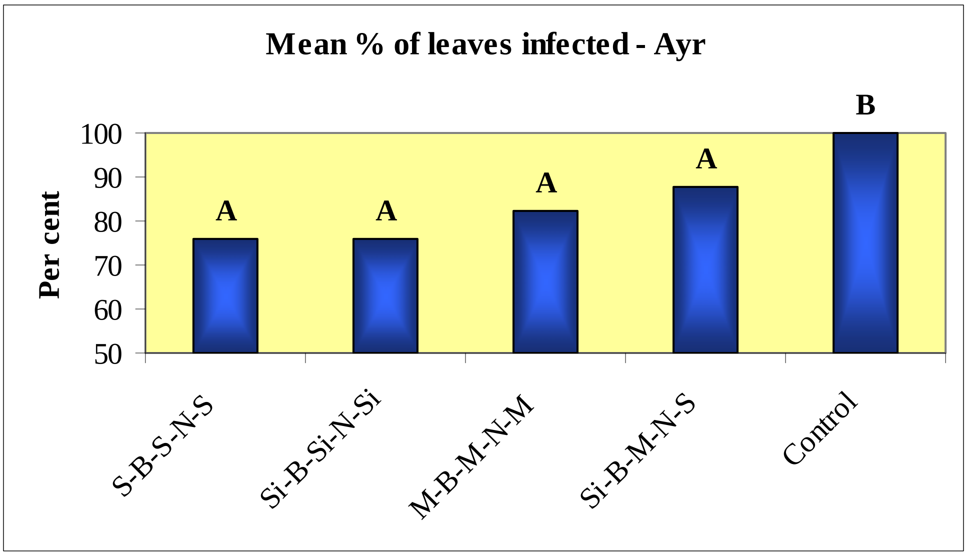
Site	Treatment	Number of fruit per plant	Total weight of fruit per plant (g)
Ayr	Si-B-Si-N-Si	10.24	2157
	S-B-S-N-S	10.00	2196
	M-B-M-N-M	9.96	2150
	Control	9.93	2246
	Si-B-M-N-S	8.96	1949
	LSD	**Not significant**	**Not significant**
Bowen	S-B-S-N	9.0	1742
	Control	8.6	1456
	Si-B-Si-N	8.5	1340
	Si-B-M-N	8.2	1410
	M-B-M-N	7.2	1222
	LSD	**Not significant**	**Not significant**

Table 5: Mean numbers and weight of fruit with sunscald for each treatment at the Ayr and Bowen sites.

Site	Treatment	Number of fruit per plant	Total weight of fruit per plant (g)
Ayr	M-B-M-N-M	0.36 **a**	84 **a**
	Si-B-Si-N-Si	0.40 **a**	83 **a**
	S-B-S-N-S	0.52 **a**	124 **a**
	Si-B-M-N-S	0.76 **a**	155 **a**
	Control	2.10 **b**	425 **b**
	Mean LSD* (p = 0.05)	**1.205**	**243.2**
Bowen	Si-B-Si-N	4.00	628
	Si-B-M-N	4.40	748
	M-B-M-N	4.60	806
	S-B-S-N	4.80	958
	Control	5.40	884
	LSD	**Not significant**	**Not significant**

**A mean LSD is given as the trial was an incomplete block design*

Figure 6.1: ***Treatment effects on incidence of powdery mildew on capsicum leaves.***



Treatment means followed by the same letter are not significantly different.

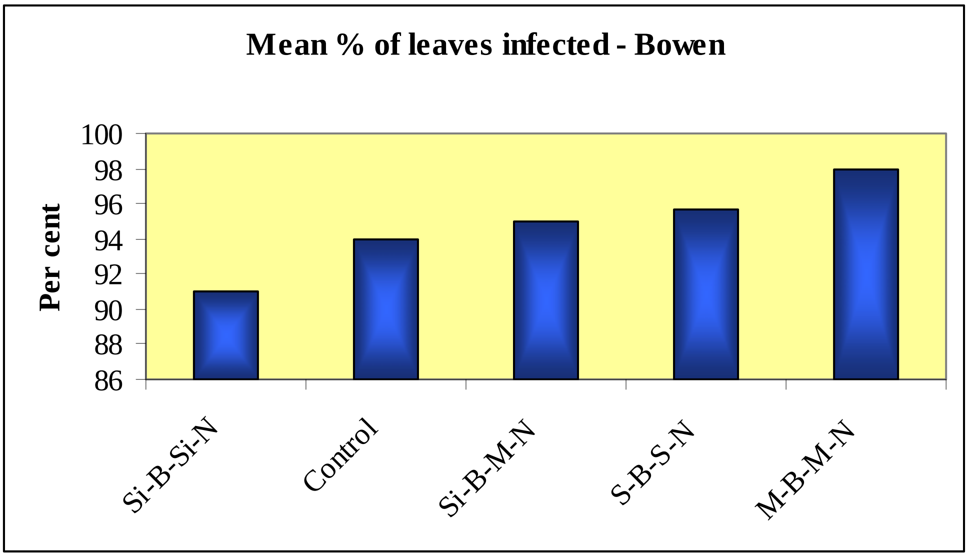
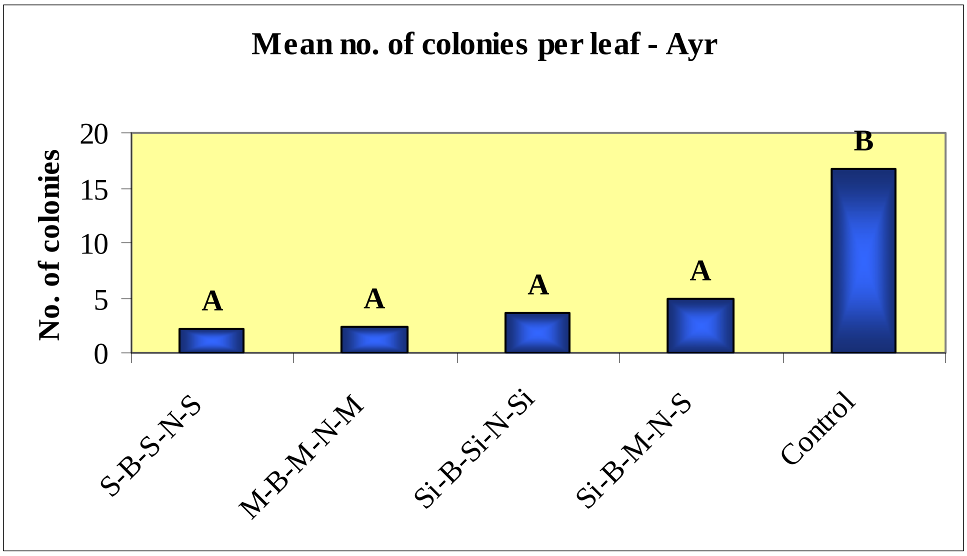
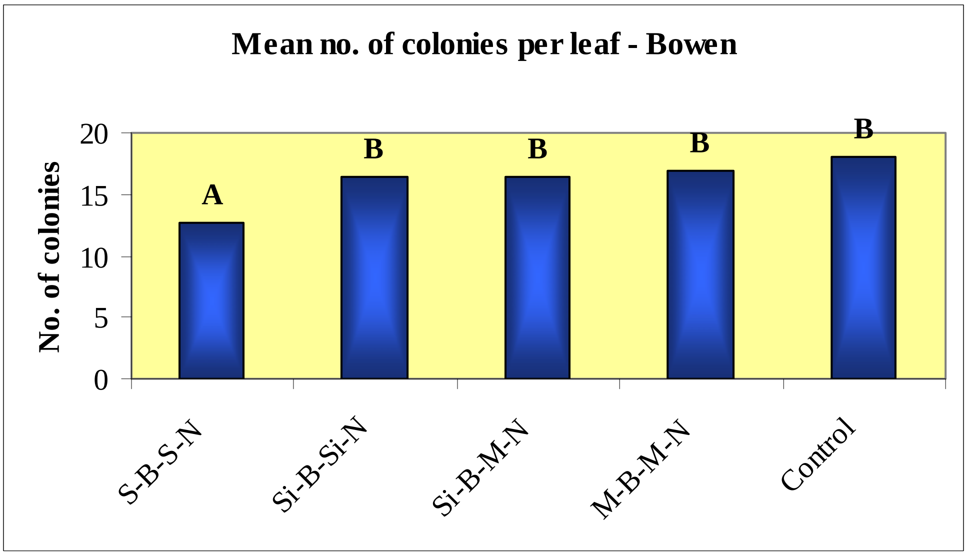


Figure 6.2: ***Treatment effects on severity of powdery mildew on capsicum leaves***

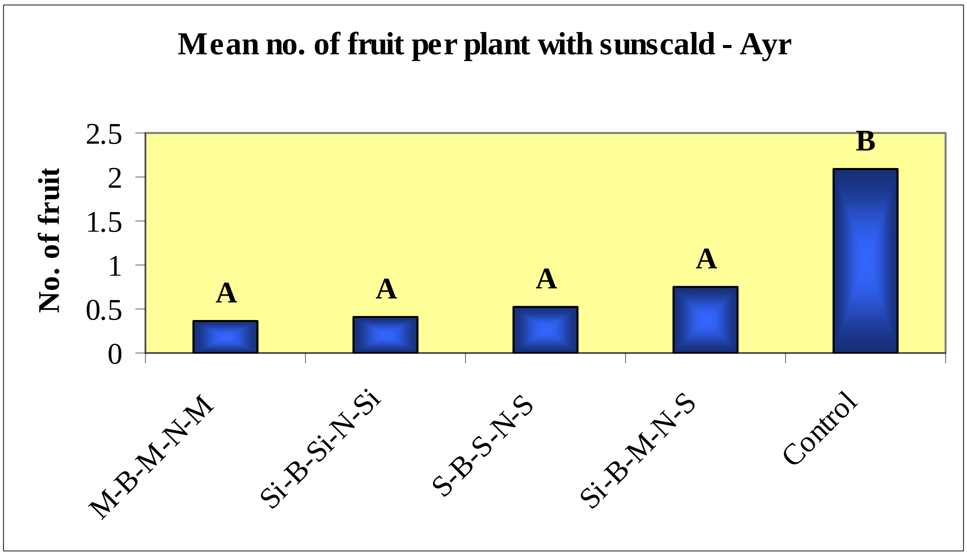


Treatment means followed by the same letter are not significantly different.

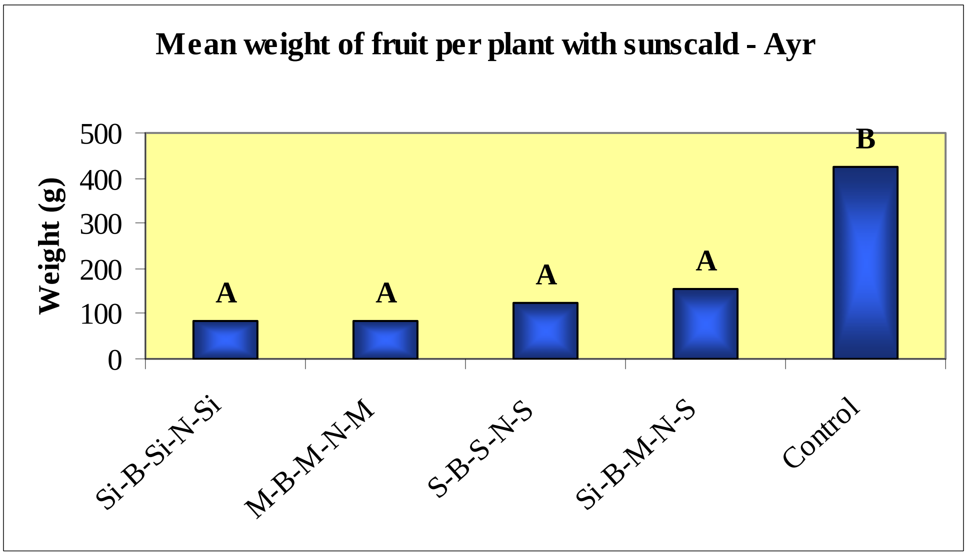


Treatment means followed by the same letter are not significantly different.

Figure 6.3: ***Treatment effects o fruits with sunscald***



Treatment means followed by the same letter are not significantly different.



Treatment means followed by the same letter are not significantly different.

Abbreviations used in figures

S	Sulphur
B	Bayfidan
N	Nimrod
Si	Silicon
M	Milk

Discussion

Powdery mildew on capsicums can best be managed using an integrated approach that combines a number of control practices. Fungicide sprays are still the main parameter to be included in such an integrated approach and would continue to be for sometime. Parameters such as genetic resistance and the use of biological control agents are yet to be exploited in this integrated approach. Cultivating plants with resistance to powdery mildew would be the best method of growing disease-free capsicum plants. Unfortunately many of the cultivars currently cultivated in Australia have been bred overseas and have not been screened for resistance against the prevailing strains of the powdery mildew strains in Australia. An attempt has just been made to begin doing so as part of this research and is presented in another section of this study.

A few biological control agents have been identified with efficacy on colonising and destroying powdery mildew spores. Some of these have even been registered as biofungicides for the control of powdery mildew on cucurbits elsewhere where most of the research has been done. These include AQ10 (Ecogen, Inc) whose active ingredient is fungal spores of *Ampelomyces quisqualis* Ces., which parasitizes and destroy powdery mildew fungi. Another is Serenade (AgraQuest, Inc.) with active ingredient *Bacillus subtilise*. Another more recent one, Sporodex, has been formulated for use against powdery mildew in greenhouse crops (Paulitz and Belanger, 2001). The problem with many biological control agents is that they require higher humidity for survival than do the powdery mildew pathogens. Consequently, biological control agents are not as effective in controlling powdery mildew as fungicides and have not been a main source of the disease control.

Fungicides are thus the main alternate method of powdery mildew management and their use has to be constantly evaluated so that combinations giving the most sustainable effect are being used. In this study a number of combinations were evaluated to identify those that could be used to obtain effective control and at the same time do not expose them to early resistance development. All combinations used were as effective as the current standard combination. It is therefore beneficial to substitute sulphur whenever that is feasible, with the other softer alternatives evaluated in this study. This is more so as other studies have shown that even though sulphur is one of the oldest fungicides to control powdery mildew, its efficacy may not be consistent with certain powdery mildew pathogens and under some environmental conditions. According to Mossler and Nesheim (2005) sulphur only provides moderate level of control to some cucurbits and this has been confirmed for capsicums in our earlier single component control in this study. The poor efficacy of sulphur was also the case in 2000 when there was an apparent breakdown in its efficacy with high powdery mildew disease pressure and great crop losses were experienced. 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 is important to use or rely on it only as necessary

The results from this study have demonstrated that substitution of sulphur with either silicon or milk did not result in a significant increase of disease levels for either disease incidence or severity. The treatment combinations were even more effective at reducing disease severity. Furthermore, even though there was apparently no significant effect on fruit yields, there was a direct effect on fruit quality with some of the treatment combinations showing significantly less damage from sunscald than the untreated control. Of the different treatment combinations evaluated, the combination with powdered milk was as good as the industry standard suggesting that powdered milk could be a good protectant substitute for sulphur in rotations of the systemics.

Chapter 7: Technology Transfer

Industry Field Days and Workshops

Project Field Days

Scheduled project Field Days were held during each of the first 2 years of the project at project trial sites. Both were poorly attended by invited growers. Common excuse was that it was not practical to attend such field days during the cropping season because most growers were busy with field operations. It was suggested that off-season workshops were better during which seasonal results could be presented, even if growers did not have the chance to see and appreciate the trials in the fields. This advice was taken into consideration in scheduling the last end-of project series of workshops off-season.

Project Workshops:

A series of scheduled end of project workshops were held across the main capsicum-production districts of Bowen, Gumlu and Ayr during March 2007 after all project activities were completed. Each workshop was heavily attended by a cross section of growers, chemical company representatives, industry consultants and QDPI&F researchers (Fig 7.1). At each of the workshops a copy of the Brochure ***"Guidelines for Sustainable Management of Powdery mildew in Capsicums",*** an output of the project**,** was given to each attendee.

Conference Presentations

Far North Queensland Organics, May 2005:

The project leader presented a paper at the Far North Queensland Organic Conference titled "*Evaluation of organic treatments to control powdery mildew on capsicums*". The presentation focused on the first year results of screening soft products like silicon, Bion, milk and mineral oil for their efficacy in controlling powdery mildew on capsicums. There was a lot of interest from organic growers on the project findings. One of the companies approached the presenter and requested some follow-up contracted fee-for-service research for a field registration of one of their organic products on the QDPI&F newly certified organic research site.

Australasian Plant Pathology Conference, Geelong September 2005:

The project leader presented another research paper from the project results titled *"Field evaluation of treatments to control powdery mildew on capsicums"*. In this presentation, treatment results from both fungicides and activators were presented and compared. A case was made for the integration of all the available treatments for the sustainable management of powdery mildew instead of relying on any one of the fungicides or activators.

First National Vegetable Conference, Brisbane May 2006

At this first national vegetable conference, a presentation titled *"From disease control to disease management in vegetable crops; the rationale and approach"* was made at the invitation of the Industry Development Officer, involved in the conference organisation. The presentation focused on project results to argue the case for the integrated management of diseases using available control options, instead of relying just on any one method of control. It generated a lot of discussion and interest on the whole concept of integrated crop management that was introduced and recommended as the ultimate aim in a disease management program such as powdery mildew on capsicums.

Media Report

A lot of media interest was generated by the presentation at the Organic Conference. The report of liquid silicon and fresh or powder milk as suitable alternatives to fungicides to control powdery mildew on capsicums and other vegetable crops was of particular interest. The Project Leader was interviewed by ABC local radio in October 2005, following a ***Media Release*** by QDPI&F highlighting the findings of natural products for disease control from the project. The title of the media release was, *"Natural controls for capsicum disease, kind to environment and Reef"* (Appendix B). Following that radio interview, a number of inquiries came in seeking more information on the use of these soft products.

Other Publications

The QDPI&F Media release was picked up by several newspaper sources that published both expanded and summarised versions of the release. Among these were the Burdekin Local Newspaper Section, ***The Burdekin Grower***, which published a version of the media release titled *"Natural controls for capsicum disease"* in the October 2005 edition of the Newspaper Grower insert.

The editors of ***Queensland Fruit and Vegetable News*** also published an expanded version of the media release in Jan 2006 edition of the Magazine with the same title as the Burden Grower article.

In the Research and Development section of the Spring 2006 edition of ***Organic Journal,*** another version of the release was published highlighting the effectiveness of the products in controlling powdery mildew titled "*Powdery mildew treatments"*.

The project leader was approached and interviewed by the editor of ***Vegetable Australia*** Magazine to write an article highlighting the findings of the project. The interview was summarised in the November/December 2006 edition of the magazine (Vol 2.3, pages 20-21) with the title *"A milky solution"*, focusing on the efficacy of milk on the control of powdery mildew on capsicums titled.

Chapter 8: General Discussion

Summary of key project findings:

- Powdery mildew is endemic in the capsicum-production districts of north Queensland where most of the crop is grown in Australia.
- In field surveys it was detected in all fields visited and ranged in prevalence from trace to severe depending on stage of crop development and the management practices in place.
- Tospoviruses and bacterial leaf spots were also detected at concern levels in fields visited during the survey. While the tospoviruses concern is being addressed through a resistant breeding project, the bacterial leaf spot will also need future research attention.
- Powdery mildew is currently controlled mainly with fungicide sprays and shall likely continue to be the main management tool for the disease for sometime. Focus now has to be on ensuring the management of possible fungicide resistance that is likely to result from poor or unregulated sprays.
- No control failure from currently used fungicides has been reported since systemic fungicides were identified and registered for use in controlling the disease following the first widespread epidemic.
- Poor control in some fields is more largely due to poor timing of applications and poor spray coverage than the result of possible changes in pathogen populations as was suspected following the initial epidemic.
- Reactions of current cultivars grown in Australia to powdery mildew have been characterised and selection of a more resistant cultivar should be the first consideration in cultivar choice as this will result in less fungicide spray applications with a savings in production costs and the environment.
- Multiple resistances to powdery mildew and tospoviruses have been identified in germplasm and should be considered in any new cultivar development program or project.
- Liquid silicon in different formulations has been established to be an effective protectant and activator for powdery mildew control in appropriate sprays and

should be considered and included in any powdery mildew management program on capsicums.

- Other forms of foliar fertilizers, such as potassium mono phosphate are effective in powdery mildew control and should be included in holistic crop management programs for the added advantage of the disease control.
- No one control option should be completely relied upon to control the disease. An integrated crop management approach should always be considered in which all the essential elements for powdery mildew management are included. These include crop genetics, judicious fungicide sprays, crop nutrition and other general agronomic practices for good crop production.

Management Guidelines for powdery mildew on capsicums:

1. Select and start production with a more powdery mildew-resistant capsicum cultivar whenever possible.
2. Application of foliar fungicide sprays are currently the principal practice of managing powdery mildew on capsicums and may continue to be the case for some time in conventional production systems.
3. Good spray coverage is critical for effective management, ensuring that the disease is controlled on both leaf surfaces to reduce defoliation and/or premature death of leaves.
4. A fungicide resistance management program at the start of each season is a must, to ensure the continuous presence of the limited fungicides available for managing the disease and to prolong the chances of resistance developing in these fungicides.
5. Considerations for fungicide resistance management should include:
   - Starting the spray program with the use of a foliar fertilizer such as silicon. This has been shown in this study to act as both a protectant and an activator in managing powdery mildew on capsicums.
   - Following up with the first systemic fungicide application only after initial detection of the disease in the field.
   - Not using the systemic fungicide curatively but only as needed following early detection of the disease on the crop after the silicon activator has been applied.

- Alternating among the 2 currently available systemic fungicides from different classes, (Bayfidan – C and Nimrod – H) and mixing them with sulphur or similar compatible protectants.
- Moving to mainly protective fungicides late in the growing season, once infection is readily detected on plants.

6. Other foliar fertilizer sprays such as with mono-potassium phosphate or potassium bicarbonate, available in different formulations have been shown to effectively control powdery mildew and should be integrated and used in the spray program as an additional tool for managing powdery mildew on capsicums.
7. Another spray application with silicon at fruit set will strengthen developing fruits cell walls and minimise damage from sunburn even with increased infection and defoliation.
8. In organic cropping systems, a carefully planned spray program rotating sulphur sprays with diluted solutions of milk and timed spray applications with silicon or similar foliar fertilizers will give adequate control of the disease.
9. Inclusion of a mineral oil in the spray program may give some benefit mainly as an insecticide but application should not be made when sulphur is sprayed and when the crop is near flowering because of possible phytotoxicity.
10. The ultimate approach in the sustainable management of powdery mildew on capsicums should be to move away from unwanted routine sprays, and apply as few or minimal chemicals as possible, but as much as needed to do the job.

NB: The above management guidelines have been produced in a distributable brochure format and were distributed to growers and other industry stakeholders during final project workshops.

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Other colleagues who played significant roles in the success of the project though not directly in the project team are Des McGrath who freely allowed linkages of the project to his capsicum breeding project for tospovirus resistance and made available breeding material from the project to be screened for multiple disease resistance. Ian Walker, Des' right hand person in this breeding work was the direct linkage in making sure we had access to these breeding lines. His assistance in pre-germinating the available lines before field transplants for screening is also gratefully appreciated.

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Appendix A

Grower Survey on Capsicum Disease Control

District:

Bowen________________________ Gumlu ________________________

Burdekin ________________ Other _______________________________

Grower______________________ Contact details____________ ______________

Approximate annual capsicum area _______________________________________

Variety__________________________ Growth Stage ________________________

The Main Diseases Detected in the Field at time of the Survey:

1. ____________________________________
2. ____________________________________
3. ____________________________________

Questionnaire for the Grower:

1. What diseases do you currently consider to be of importance or concern on your capsicum crop? Please list them below.
   a.______________________________ b. _____________________________

   c. _____________________________ d. _____________________________

2. What practices are you using to manage these diseases?

   Disease   Managing with

   ________________________   _______________________________

   _________________________   _______________________________

   _________________________   _______________________________

3. Do you feel that the fungicides now available for capsicum disease control are meeting your needs?

   Yes____________________ No _____________________
   If no, what diseases are not being adequately controlled?
   ____

4. What are you presently using to control **Powdery Mildew** on your Capsicums?

____
___ ____

5. How well are fungicides controlling Powdery Mildew in your crops?"
____

6. For what possible reasons do you think fungicides are not giving good control?"
____

7. What do you think is important for getting good control with fungicides?"
____

8. Is there a need for a new product to be identified and registered for powdery mildew control on capsicums?

   Yes____________________No____________Not Sure ________________

9. What other alternatives/ products are you currently using to control diseases on your capsicums?
____

10. Would you like to see research conducted on alternative disease control methods in capsicums or other vegetables?

   Yes ________________No ____________Not sure__________________

11. Would you be willing to try some of these alternatives for controlling Powdery mildew or any other disease on your capsicums?

   Yes________________ No _________Undecided____________________

   Would you be interested in attending workshops on disease management in capsicum?

   a. Disease identification: Yes_______No _____Maybe_____

   b. Integrated disease management: Yes_______No _____Maybe_____

   c. Optimizing fungicide use Yes_______No _____Maybe_____

   If ***Yes***, or ***Maybe***, please state preferred:

   Period ____________________Time of day? _______________________

   Length of time?_________________Location:______________________

12. Any comments, suggestions or concerns on research on capsicum diseases not covered in this questionnaire? Please list.
____

Appendix B

October 24 2005; DPI&F Media Release

Natural controls for capsicum disease kind to environment and Reef

NEW research shows the strategic use of natural fungicides has the potential to effectively reduce or prevent powdery mildew in capsicums and chillis in tropical regions.

At the same time it will cut costs for farmers and reduce the need for chemical-based fungicides, which is good news for the environment and, ultimately, the Great Barrier Reef.

Ayr-based Department of Primary Industries and Fisheries senior plant pathologist Dr Chrys Akem said the research could have more widespread benefits for other major production areas.

“Bundaberg and the Lockyer Valley districts are seeking solutions to the disease on capsicums and tomato,” Dr Akem said.

“First we need to evaluate more effective natural products and in different combinations with soft chemicals to address the powdery mildew scourge on these vegetable crops,” Dr Akem said.

“Powdery mildew has a wide host range within field and horticultural crops, including capsicums, tomatoes and chillis.

“The same fungal organism attacks these crops in the wet and dry tropics. Therefore control strategies developed for one crop can work effectively on the others.”

The characteristic whitish symptoms of the disease are more obvious on the underside of leaves where the spores develop and can easily disperse.

“Warm and more humid environmental conditions are suitable for its development and spread,” Dr Akem said.

“In the tropics, powdery mildew epidemics on capsicums are more likely to occur towards the end of the cropping season.

“The disease largely affects fruit quality not yield because it occurs late in the season when crops have had enough time to produce flowers and fruit.

“Extensive defoliation caused by the disease exposes the fruit to severe sunburn under tropical conditions.”

Until recently, products that are both effective and environmental-friendly have not been available to farmers.

“The use of sulphur is starting to raise some environmental concerns, but less toxic products have not been available,” Dr Akem said.

“Organic growers, in particular, have had limited options to control powdery mildew under organic production systems.”

Horticulture Australia Limited is funding the DPI&F project to look for sustainable methods to manage powdery mildew on capsicums.

Dr Akem and his team from Ayr and Bowen DPI&F research stations have been screening a range of natural fungicides – including liquid silicon, cow’s milk, petroleum oil and some foliar organic fertilisers – to identify which were the most effective.

“We are getting positive results from cow’s milk and silicon as alternative products that can be used in combination with synthetic or softer fungicides,” he said.

“These combinations can cut back on the many toxic and expensive fungicide sprays needed to control powdery mildew on capsicums.

“They have the potential to reduce growers’ production costs and, as a bonus, protect the Great Barrier Reef from farm run-off.”

Dr Akem said more effective and sustainable alternatives were necessary because powdery mildew was showing signs of developing resistance to present control methods.

“As we are striving for prevention rather than cure, we recommend control measures to be put in place early in the season,” he said.

“Ultimately, we aim to develop guidelines to help farmers take an integrated approach to managing the disease. “Such an approach considers not only natural and synthetic fungicide sprays, but all production practices that may encourage the rapid spread of powdery mildew.”

David Anthony
Senior Media Officer
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