Investigations and developing integrated management stategies for carrot powdery mildew

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This report covers project activities undertaken from October 2008 to May 2012 to assess the impact of powdery mildew on carrot growth, harvest, yield and quality, to assess the efficacy of chemical and non-chemical products for powdery mildew control and to develop integrated methods for disease control.

Report Completed–May 2012.

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MEDIA SUMMARY

Information on carrot powdery mildew has progressed rapidly since it was first observed in Australia in 2007. Disease incidence and levels have fluctuated in the carrot growing regions where the disease was first observed i.e., South Australia, Tasmania and New South Wales. The first observations were made in these states, but since then, the disease has been reported in Queensland and Victoria. This disease is going to be sporadic in occurrence, and if left untreated will cause leaf death in some instances, reducing the ability to pull carrots out of the ground.

Environmental conditions have reduced powdery mildew incidence in all the states with the change from the drought conditions experienced at the time of its discovery to wetter than normal conditions. Field and greenhouse trials have indicated that the disease is controllable but not eliminated by fungicide application. Fungicides successful at controlling the disease include Amistar®, Folicur®, Cabrio®, Sulphur and Amistar Top®, the latter two having registration. Early detection of the disease is critical as control is best managed with fungicides where disease pressure is still low.

In a trial, overhead irrigation reduced disease compared to drip irrigation, indicating that production areas such as New South Wales that use furrow irrigation are likely to experience more disease than in areas using pivot-applied irrigation. This has been observed in Tasmania, with the disease more severe when irrigation water was in short supply and water was therefore applied sparingly by pivot.

The powdery mildew fungus spreads easily from infected to uninfected plants, especially through the movement of people and equipment. Overlapping plantings and volunteer carrots are also important sources of new infections.

The temperature preferred by the fungus is around 27ºC, with temperatures below 20ºC and above 33ºC reducing disease progress. However, infection appears to occur over a range of temperatures. This confirms that the disease is most severe in spring, summer and autumn, with periods of high and low temperatures reducing disease incidence. Varietal differences to susceptibility to powdery mildew have been identified.

Information collected provides a suitable integrated management approach to powdery mildew based on variety selection, careful monitoring, and tactical fungicide sprays which are applied with the best coverage possible.

TECHNICAL SUMMARY

Information on carrot powdery mildew (*Erysiphe heraclei*) has progressed rapidly since it was first observed in Australia in 2007. It was suggested by some that it had been here prior to that date but not reported. Disease incidence and levels have fluctuated in the carrot growing regions where the disease was first observed i.e. South Australia, Tasmania and New South Wales. Since the first observations in these states it was revealed, that the disease had also been found in Queensland and Victoria.

Environmental conditions have affected powdery mildew incidence in all the states. With the change from the drought conditions experienced at the time of its discovery to wetter than normal conditions, the incidence of powdery mildew has been reduced.

The temperature trial indicated that powdery mildew of carrots prefers temperature conditions that match spring and autumn conditions in much of Australia. These conditions however may be closer to summer temperatures in Tasmania, indicating that the disease could be a problem in that state. Autumn infections will continue where the autumn stays warmer and drier, and early cool and wetter conditions, as observed in the field in autumn in the southern states have reduced infection. The conditions favoured by powdery mildew however coincide with much of the carrot growing season in Queensland. If climate change suggests that drier and warmer conditions will occur, then autumn conditions may become ideal for powdery mildew infection in carrots. Climate change has been shown to have occurred in Australia with an increase in temperatures since 1950 by 1°C, and the eastern carrot growing areas have had fewer frosts and less rain.

The powdery mildew fungus spreads easily from infected to uninfected plants especially through the movement of people and equipment. During trials, powdery mildew was found to be readily transported on people, and infections were easily caused by the accidental movement from an infected to a non-infected greenhouse.

Early detection of the disease is critical, as control is best managed with fungicides from a low disease pressure base. Fungicides have to be applied at the early stages of disease development for them to be successful at controlling the disease. Field and greenhouse trials have indicated that the disease is controllable, but not eliminated, by fungicide application.

Amistar®, Amistar Top®, Folicur®, Cabrio® and sulphur control the disease. Amistar Top® and sulphur have been registered for powdery mildew on carrots. These fungicides can be applied as part of a general disease programme to control other carrot leaf diseases. The work on baseline sensitivity for Amistar® gives a historical perspective for future reference to indicate the potency of the fungicide even if Amistar Top® is used. DPX-LEM1720 (penthiopyrad) is a product that has shown potential for powdery mildew control. It may provide an alternative active ingredient to the strobilurins, the group to which Amistar® and Amistar Top® belong.

Overhead irrigation reduced disease compared to drip irrigation in a greenhouse trial indicating that growing areas in New South Wales with furrow irrigation are likely to experience more disease than those areas with pivot-applied irrigation. Conversely, growers with overhead irrigation may reduce disease by application of water. This has been observed in Tasmania, where the disease was less severe when the limited available water was applied by pivot.

Variety trials have been useful in identifying more tolerant varieties and the best options for growers. However, choice of variety depends on the requirements for end use. The carrot variety Stefano has shown to have a high resistance to disease and should be considered in the periods of high disease pressure. Other members of the Apiaceae in these trials, and weeds, were not hosts of the powdery mildew found on carrots. Therefore it must be assumed that there are races of *Erysiphe heraclei* present in Australia, one that infects carrots and one that infects parsnips. Trials were successful in establishing the potential yield loss in carrot yield to powdery mildew in a greenhouse. However, this was not confirmed in the field. Amistar® successfully controlled the disease in the greenhouse under high disease pressure, even with less than three sprays. Disease control was maintained when only one application of the fungicide was applied to the carrots.

Information collected enables a suitable integrated management approach to powdery mildew based on variety selection, careful monitoring, and tactical fungicide sprays, which are applied with the best coverage possible. This disease will not be a threat every year, and this complicates preparation for outbreaks.

Fungicide options for Cercospora leaf blight caused by *Cercospora carotae* were also identified within the project with products containing azoxystrobin also controlling this disease.

INTRODUCTION

Carrots are the fourth most valuable vegetable crop in Australia. Approximately 20% of Australian carrots are produced for export to more than 20 countries. In order to maintain its competitiveness in the domestic as well as export markets, the Australian carrot industry must compete by maintaining or increasing its high productivity compared to other countries. Powdery mildew was not previously recorded on carrots in Australia, and yet within a short space of time in 2007 and 2008, it was found and confirmed in the major carrot production regions in New South Wales, South Australia and Tasmania. Later it was also found in Queensland and Victoria. However it may have been here longer without being reported. Many growers were concerned with issues faced including the difficulty in controlling powdery mildew and the potential yield loss not only from the direct effect of the disease but also the reduced ability to mechanically pull the carrots out of the ground at harvest. The latter process requires healthy leaves for the operation to be successful. Growers in New South Wales observed powdery mildew on their carrots in late February 2007. It was the first time they had observed the disease affecting carrots, and it caused problems because fungicides proved ineffective at controlling the disease. In Tasmania the following year the disease was also severe.

Carrots can be grown all year round and are often planted in overlapping plantings. Diseases therefore may be carried from one planting to the next. Carrots are irrigated by various means across different growing regions and soil types, and they can be watered through overhead pivot irrigation which is common in the majority of states, or with furrow irrigation as is common in the Murrumbidgee Irrigation Area in the Riverina region of New South Wales.

There are a number of diseases of carrots found in Australia (Table 1).

Table 1. The more common diseases found on carrots in Australia with diseases during the growing season on the left and the postharvest diseases on the right.

Field diseases	**Causal Organism**
Leaf blight	*Alternaria dauci* and/or *Alternaria radicina*
Leaf blight	*Cercospora carotae*
Sclerotinia rot	*Sclerotinia sclerotiorum*
Damping off	*Pythium* species, *Rhizoctonia solani*
Cavity spot	*Pythium* species
Root lesion nematode	*Pratylenchus* species
Root knot nematode	*Meloidogyne* species
Virus disease	Carrot virus Y (transmitted by aphids)

Postharvest diseases	**Causal Organism**
Black Root Rot	*Thielaviopsis basicola* and /or *Chalaropsis thielavioides*
Bacterial soft rot	*Erwinia caratovora*

NEW SOUTH WALES RESEARCH ACTIVITIES

1. REVIEW-INTEGRATED MANAGEMENT OPTIONS FOR CARROT POWDERY MILDEW

Powdery mildews

Powdery mildews are a group of fungi that infect a wide range of plant hosts, and some have been included in Table 1.1. The symptoms are usually the same - white cottony or felt-like growth across either upper and/or lower leaf surfaces. The growth can be rubbed off and therefore may be mistaken for soil. Powdery mildews consist of mycelium (the felt-like growth seen) that grows external to the leaf surface. There are some exceptions, but the majority of powdery mildews (carrot powdery included) grow as epiphytes (surface) rather than endophytes (grow within the plant) (Belanger *et al.* 2002). As the growth is external, it is very obvious on the leaves and other plant parts that powdery mildews infect. The mycelium grows across the leaf surface and at regular intervals the hyphae (single pieces of mycelium) produces lumpy growths (appressoria) that attach the mycelium to the leaf surface. These appressoria have characteristics that may be typical of some genera of powdery mildew. From these appressoria develop another part of the fungus known as the haustoria. These are actually the feeding structures of the fungus. The haustoria enter by breaking down the cell wall with enzymes and then mechanically penetrate the cell (Ellingboe 1972).

The reproductive structures of powdery mildew mainly consist of conidia or spores (seed-like structures) that are asexual spores formed in short single chains. This characteristic is also different from the downy mildews whose conidia are not formed in chains, therefore a key diagnostic aid. Shapes of these conidia vary, and this can assist in the identification of the species of powdery mildew. Powdery mildew conidia consist of only one cell whereas many other fungi have multi-celled conidia. The conidia are also colourless but look white when observed on the leaf surface with a dissecting microscope. These conidia arise from hyphae on the leaf surface and are then picked up by wind, rain splash, equipment and people, and assist in the movement from crop to crop, from farm to farm, from state to state, and country to country. Humans can easily carry powdery mildew spores on their hands and clothing. Farm equipment, such as harvesting equipment, easily carries these conidia from one planting to the next.

Another fruiting structure may develop in powdery mildews known as cleistothecia. These are harder tougher structures that may assist in the carryover of the fungus from season to season. Ascospores are produced within these structures but they are rarely found in some powdery mildews, and when produced, may serve no role in the infection process.

The main effect of powdery mildew on the hosts is leaf death, which results from heavily infested leaves. Secondary issues, which may vary from host to host, include sunburn of fruit as the leaves fall off and expose the fruit to more sunlight. This is especially important in cucurbits and grapes. Overall, however, yield loss is the main affect of powdery mildews on their hosts. Plants usually survive till harvest, but quantity and quality of fruit can be affected. Leaf survival is important not only to maintain yield but where harvest requires the presence of strong intact leaves that assist in pulling the crop from the ground by machinery e.g., carrots. It has been suggested that as powdery mildews are so widespread across the plant kingdom, the total loss from this disease would be higher than any other single plant disease (Agrios 1997).

Powdery mildews that affect the Apiaceae

Members of the Apiaceae include carrot, fennel, parsley, parsnip, celery, dill, angelica and coriander. The main powdery mildew that infects these crops is *Erysiphe heraclei* (Spencer 1978). *Leveillula lanuginosa* and *Leveillula taurica* have also been recorded in the Middle East and India. They are not considered to be as aggressive as *E. heraclei* (Davis and Raid 2002).

Erysiphe heraclei has been reported in Africa (Morocco, Sudan, Tanzania, Egypt), Asia (Afganistan, Burma, India, Iran, Israel, Japan, Turkey, USSR, Pakistan), Europe, South America and the USA. The fungus reportedly infects carrot, fennel, parsley and other umbelliferous crops (Kapoor 1967).

Table 1.1. Powdery mildew species and their associated hosts.

Fungal Organism	Host
Golovinomyces cichoracearum	Sunflower
Erysiphe cruciferarum	Brassicas
Erysiphe graminis hordei	Barley
Erysiphe graminis tritici	Wheat
Erysiphe heraclei	Carrots
Erysiphe pisi	Peas
Erysiphe polygoni	Field peas
Oidium mangiferae	Mango
Erysiphe necator	Grapes
Podosphaera leucotricha	Apples
Podosphaera xanthii	Cucurbits
Sphaerotheca humuli	Strawberry
Sphaerotheca macularis	Strawberry
Sphaerotheca pannosa var. rosae	Roses
Leveillula taurica	Tomato

Erysiphe heraclei has been found in various states of the United States. Powdery mildew was first observed on carrots in California and Texas in 1975, New York State (1991), Washington State (2002), and Florida (2007) (Abercrombie and Finch 1976; Dillard *et al.* 1992; Glawe *et al.* 2005; Raid *et al.* 2007). It was also found in Japan in 1976 (Abiko 1976), and in Brazil in 2008 (Rosa *et al.* 2008).

The causal agent of powdery mildew of carrot in Australia was found to be *Erysiphe heraclei* (Cunnington *et al.* 2008). Figure 1.1 shows the conidial shape of *Erysiphe heraclei* compared to powdery that infects cucurbits. The disease had not been recorded on carrots before in Australia but had been recorded on parsnips. It is assumed that a new strain has been introduced into Australia, following on from its spread through Europe, USA and Japan.

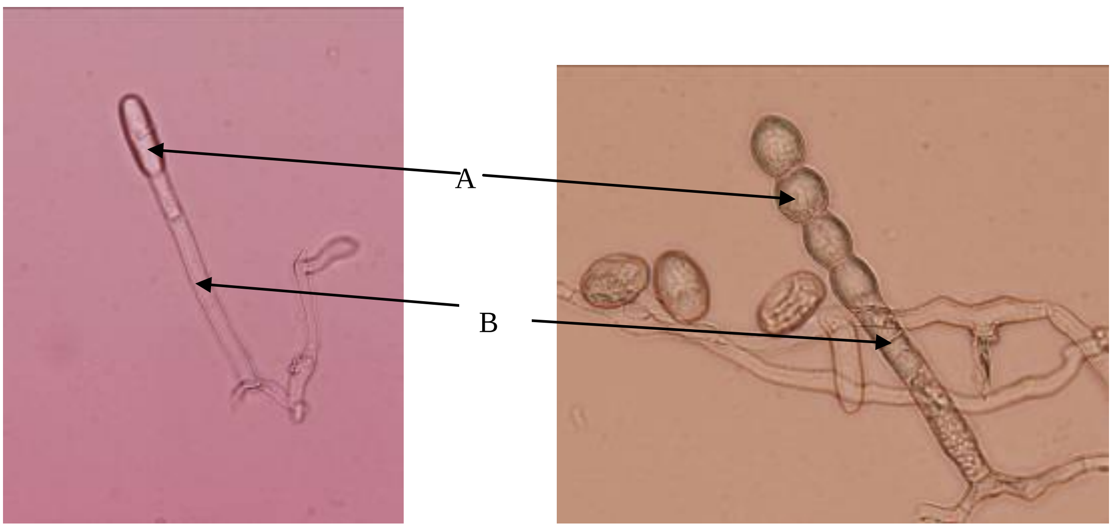

Figure 1.1. Microscopic comparison of conidia (A) and conidiophores (B) in *Erysiphae heraclei*-carrot powdery mildew (left), and in *Podosphaera xanthii*-cucurbit powdery mildew (right).

Methods for disease assessment and epidemiological studies

Powdery mildews are obligate parasites and therefore they need a living host to survive. They can be difficult to work with compared to other pathogens that can be cultivated on artificial media, as powdery mildews must be maintained on living plant material. Continual transfer to fresh plant material must be maintained if experiments are to be continued, especially out of season. This periodic transfer has also been required in the past to preserve cultures in culture collections. Other options have included air-drying spores and then freezing in liquid nitrogen (O'Brien and Weinert 1994). However these methods vary in success with different genera of powdery mildew fungi.

Conidia are the main method of transferring the powdery mildew from host to host. One of the simplest methods of transfer is by touching disease free leaves with leaves that are covered in conidia. This method is quick and easy, but movement from the infection site can also be monitored. One drawback with this method is quantification of inoculum. A time consuming, yet more precise approach, is to infect host tissue with single spores of the powdery mildew being studied (Nicot *et. al.* 2002).

Large numbers of plants can be infected by just shaking or blowing spores from infected plant material. Various methods using dry spores have been examined, including settling towers, often in combination with various carriers such as cornmeal. Problems with these carriers included the growth of saprophytic fungi (fungi that may contaminate the fungus being studied). Further work has been examined that used spore suspensions.

The suspension of spores in some liquid provides a method to not only spread the spores apart, but also to measure the concentration and to provide a method of inoculation. The number of spores can be counted using a haemocytometer. This is a measuring device that when loaded with a known liquid volume, allows the number of spores to be counted under a compound microscope.

Water is a common suspension medium used but may have a deleterious effect on spore germination. Spores of powdery mildew do not need free water to germinate, and therefore in some species, spore germination is restricted by the water. Most fungi require water for spore germination but with powdery mildews the presence of water is not necessary. This can explain why powdery mildews are often common in more arid regions and in glasshouses.

Levels of disease need to be determined and rated when undertaking any studies where comparisons of varietal resistances or fungicide treatments are being carried out. Assessments are usually undertaken using a visual method. This method may either compare numbers of diseased leaves or the percentage of the leaf surface infected with powdery mildew. Colonies may be counted where they are separated. Quantification uses logit scales, or scales of 0 (nil disease)-5 (heavy disease). The disease levels may be compared using an incidence i.e. a proportion of diseased individuals (0-100) in a block, or severity that measures the quantity of disease on individuals in a block. Incidence can be measured using the percentage of infected plants in a block whereas severity can be measured using the level by percentage of the leaf area affected. Sometimes scales are set to describe incidence, such as 0=no powdery mildew, 2=colonies on lower leaves, and 3 =colonies on most leaves (Belanger *et al.* 1994).

The effect of environment on powdery mildews

The effect of temperature on powdery mildews depends on the host/pathogen species. Powdery mildew of cucurbits caused by *Podosphaera xanthii* (previously known as *Sphaerotheca fuliginea*) prefers temperatures around 22°C, but its extremes are 9°C and 34°C. Winter growing crops such as wheat and barley are affected by powdery mildews which prefer the temperatures of the host plant. Excessive moisture can hinder the germination of powdery mildews, but spores do need moisture in

the form of humidity or dew on the leaf surface. Rain, on the other hand, may provide conditions that wash away the fungus for a short period before it reestablishes (Belanger *et al.* 2002).
Light may hinder powdery mildew, as often the highest levels are on leaves that are shaded, although conclusive evidence for this has been difficult to obtain. Often experimental designs include other parameters such as humidity, which, in turn, provide some changes in disease levels.

Control of powdery mildews

Powdery mildews are controlled by the use of varietal resistance, fungicides, including common chemical fungicides, or alternative fungicides such as biofungicides. The development of varieties with resistance to powdery mildews has been carried out with various levels of success in crops such as wheat, barley, cucurbits, and ornamentals. This method of disease control obviously provides benefits including reducing the reliance on fungicides which converts to monetary gains on reduced fungicide use and reduced environmental impacts. However, the development of resistant varieties is costly and not always successful, often leading to other traits that are not acceptable.

Fungicides have long been used to control powdery mildews. Sulphur, for example, was used in the 1800’s and is still used today. Benomyl, introduced in the 1960’s, was one of the most successful broad spectrum fungicides. Benomyl is no longer registered in Australia, and overseas there have been records of powdery mildews being resistant to this fungicide (Sedlakova and Lebeda 2008). It is a common occurrence for powdery mildews to develop resistance to fungicides. Races of powdery mildew with resistance to fungicides have been detected in Australia.

Fungicides available for powdery mildew control are divided into two groups: those that are protective and those that are systemic. Protective fungicides have multi-site modes of action whereas systemic fungicides have single-site modes of action. Strobilurins are a group of systemic fungicides that were released for use in the late 1990’s. The mode of action of strobilurins is through the inhibition of respiration in the fungus. They give excellent control of powdery mildews, however resistance to one in this group has been recorded (McGrath and Shishkoff 2003). Thorough reviews of fungicides for plant disease control have been carried out (Lyre 1995).

There are a number of fungicides available for powdery mildew control in Australia (Table 1.2). These fungicides are not registered for all hosts. The fungicides are split into different groups which reflect their mode of action. Managing powdery mildews is best by using a range of fungicides available so resistance is less likely to develop. For cucurbit powdery mildew, the fungicide program should include both systemic and protectant fungicides. The ideal program usually consists of applying systemic fungicides from at least two chemical groups alternately, and to include a protectant fungicide with the systemic fungicide in at least every other application (Horlock and McGrath 2004). Protectant fungicides are important for resistance management because they control both sensitive and resistant strains of the pathogen. Systemic fungicides should not be applied curatively.

Products such as the bicarbonates (Dik *et al.* 1998), oils (McGrath and Shishkoff 2000), and even milk, provide some control of powdery mildews (Watson and Snudden 2000). Bicarbonate ions produce a fungicidal effect on the leaf surface that directly affects the fungi (Belanger *et al.* 1997). Biological control with other fungi such as *Ampelomyces sp.*, *Tilletiopsis sp.*, and the bacterium *Bacillus sp.* (Romero *et al.* 2007) have been, and continue to be, investigated (Urquhart *et al.* 1994). These products, although having variable effect, do have a role in an integrated approach to controlling powdery mildews. Systemic acquired resistance has also been investigated as a method of controlling powdery mildews. This involves the use of chemicals such as salicylic acid, which although not antifungal, do activate plant responses and increase resistance to disease (Salmeron *et al.* 2002).

Table 1.2. Table of active ingredients registered in Australia for powdery mildew control on various hosts (source: Infopest). The fungicide group system lists those with similar modes of action in the same group.

Fungicide Group	Active Ingredient	Fungicide Group	Active Ingredient
K	trifloxystrobin	C	Flusilazole
K	azoxystrobin	C	Flutriafol
H	bitertanol	C	Hexaconazole
H	bupirimate	C	Tebuconazole
A	carbendazim	C	Propiconazole
Y	copper	C	Sulphur
Y	chlorothalonil	C	Triadimefon
Y	potassium bicarbonate	C	Triforine
C	epoxiconazole	C	Triticonazole
C	fenarimol	M	Quinoxyfen
C	fluquinconazole	N/A	petroleum oil

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2. FUNGICIDE FIELD TRIAL 2008/09

Introduction

Trials were established to examine the effect of fungicides known to control, or with the potential to control, powdery mildew. Apart from breeding for resistance in plants, fungicide sprays are the most common way to control powdery mildews. The trials were to be conducted on growers' properties but with the potential clash of grower fungicide applications it was decided to move the trials onto the research station at Yanco Agricultural Institute on a sandy loam site. A block was sown in winter 2008 (referred to as Block 1 below) to act as a powdery mildew source for crops planted to mature in autumn 2009. With a lack of experience of the new disease it was not known the best time for disease expression on carrots. In 2007 the disease was found on growers' properties from late February until May/June. Powdery mildew had been collected in 2007 from a grower's property and maintained in the greenhouse on carrots for use in trials.

Method

Carrot variety Stefano was sown on the Yanco Agricultural Institute site in winter for maturing in spring. Another block was sown to coincide with the summer/autumn period. The carrots were sown in four rows on a 1.5 metre-wide bed. Each of the two rows was 10 cm apart, and drip tape was between both rows. Drip was preferred in the trial as overhead irrigation may have complicated disease levels and fungicide efficacy. The environment during the trials was typically dry.

Block 1

The first block of carrots (Block 1) was sown in May 2008 as a trap crop for powdery mildew. It was initially planted for the sole purpose of developing powdery mildew, as none had been seen previously, except on farms. It consisted of six beds, 40 metres in length and was sown with an Earthway precision seeder which with on average 48 carrots per metre. Powdery mildew appeared in the block in November, 2008. The block was then mown with a tractor-mounted slasher in January 2009. New leaves grew rapidly on the carrots and these were used for one of the fungicide spray trials in late summer/autumn 2009. No yield measurements were carried out on this trial. The block was divided up into four replicates consisting of 12 different treatments, with each treatment five metres long.

Block 2

Block 2 was sown in early December 2009. This was the main block for disease development and fungicide control options. This block was sown in the same manner as block 1. Disease was found in February 2009. Plots in this block were three metres long and there were 11 treatments. Yield was measured in this trial on two one-metre lengths of row. Carrots were harvested, weighed and counted.

Weather information

Weather information was collected for the site, and the blocks were monitored for disease by assessing regularly the percentage of disease on the leaves.

Fungicide application

Fungicide application was carried out with a gas-powered backpack sprayer with a water rate of 300 L/ha. Fungicides were applied at the rate and the time period recommended. Fungicide applications commenced on the 25th February for Bock 1, and the 18th February for Block 2. Fungicides used are listed in Table 2.1.

Table 2.1. Fungicides used in field trials in 2008/09.

Fungicide	Active Ingredient	Rate (ml or g/ha)
Amistar® Rate 1	250 g/L azoxystrobin	1000
Amistar® Rate 2	250 g/L azoxystrobin	750
Amistar Top®	250g/L azoxystrobin 125g/L difenoconazole	1000
Cabrio®	250 g/L pyraclostrobin	400
DC036	Experimental fungicide	520
DC086	Experimental fungicide	200
Filan®	500g/kg boscalid	400
Folicur®	430 g/L tebuconazole	580
Ecocarb® + synertrol horti oil®	940g/kg potassium bicarbonate	3000
Pristine®	252 g/kg boscalid and 128 g/kg pyraclostrobin	800
Thiovit Jet®	800g/kg Elemental sulphur	1300

Disease progress

Disease was monitored in untreated plots weekly, previous to, and during the fungicide trials where the percentage leaf area affected by powdery mildew was assessed visually on the top 6 leaves. Both surfaces of the leaves were examined, and the level of infection was assessed up to 100%.

Fungicide efficacy measurement

One to two weeks after the final spray application, plots in all blocks were assessed by removing plants and assessing the leaves for powdery mildew. In Block 1, twenty plants were selected and the top six leaves were assessed. In Block 2, ten plants were selected for disease assessment.

Statistics

All data presented, except for disease progress information, was analysed using Genstat 11th Edition using Analysis of Variance or Regression.

Results

Disease occurrence

Powdery mildew was not seen in Block 2 until mid February in 2009. This appearance coincided with low light levels and a drop in temperature. Before the 7th February, the region had experienced 14 days at 40^{o}C or above (Figure 2.1 and Figure 2.2). After this, temperatures dropped, and there was a drop in solar radiation due to the Victorian bushfires. The sun was masked by smoke for a number of days, and on some of these days the temperature dropped due to cloud and a small amount of rain.

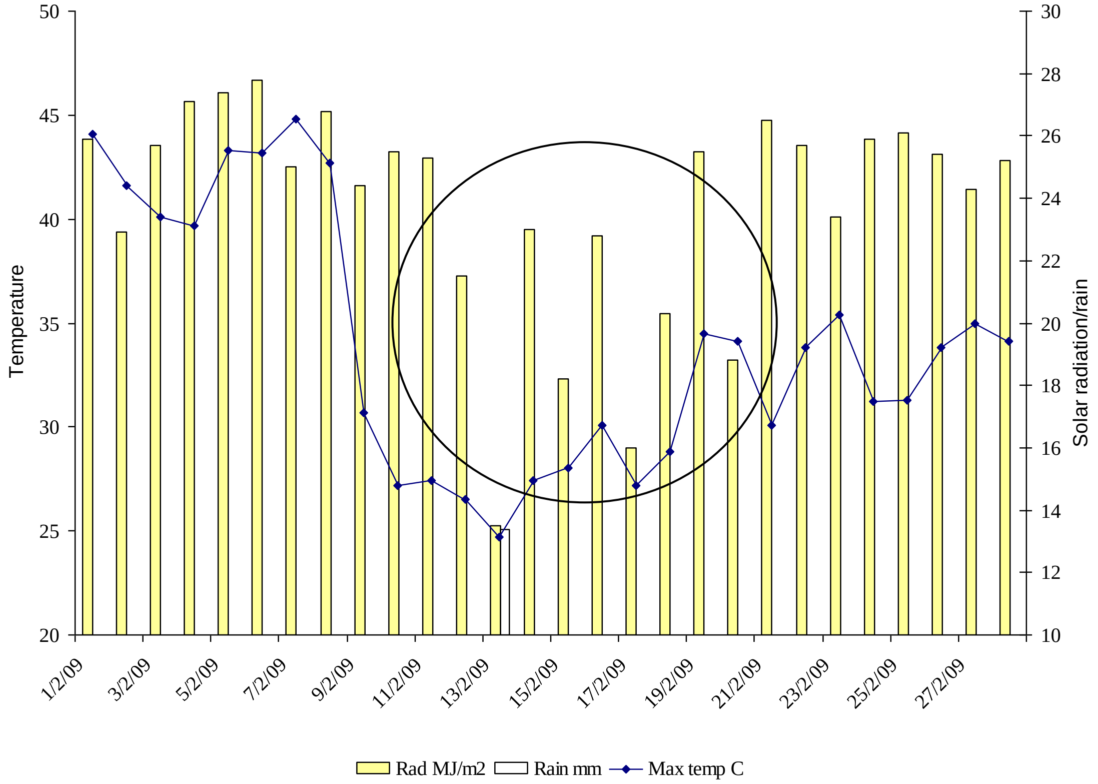


Figure 2.1. Temperatures, solar radiation and rainfall for February 2009 at the field site at Yanco Agricultural Institute. Circle shows period of reduced temperatures and solar radiation.

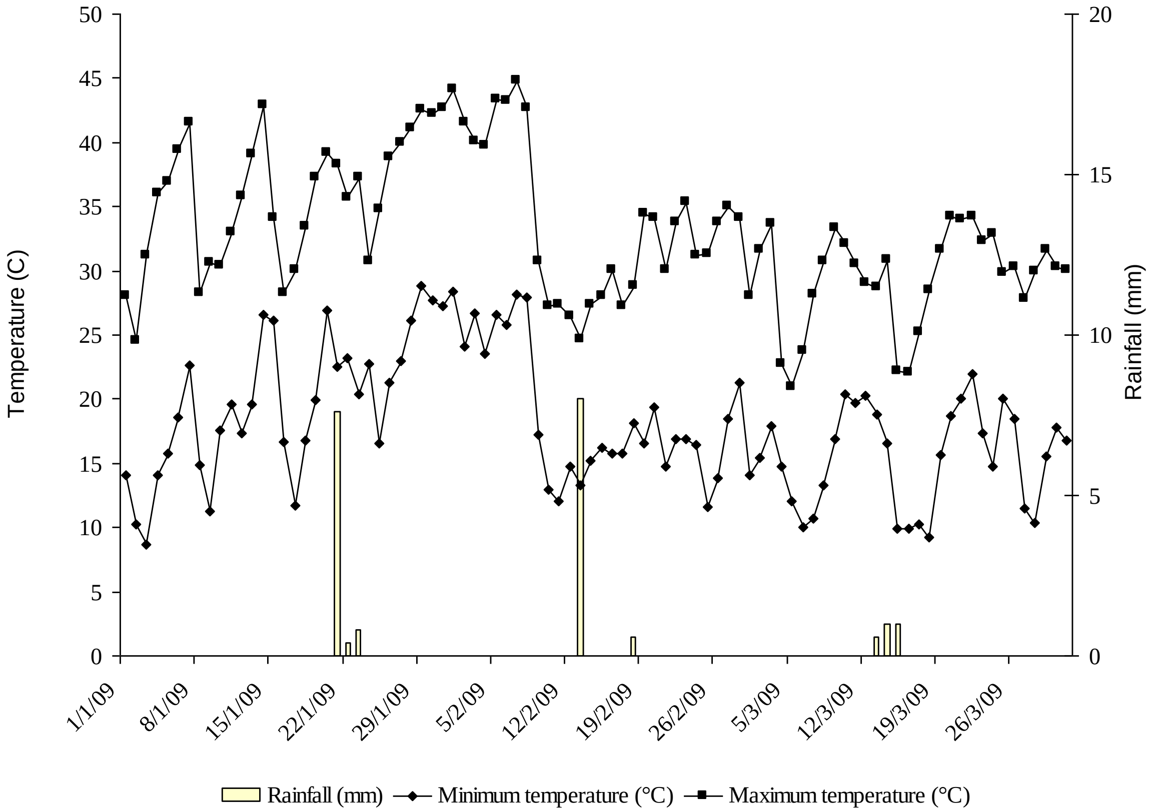


Figure 2.2 The maximum and minimum temperatures and rainfall at the field site at Yanco Agricultural Institute carrot trial site.

Disease progress

Block 1

As the leaves were cut off in January, lush new leaf growth was rapid. With the rapidly expanding new leaves, disease progress in this block was slow as seen in Figure 2.3. Disease levels declined after the first measurement date due to rapidly growing leaves, and thereafter due to a general reduction in powdery mildew activity.

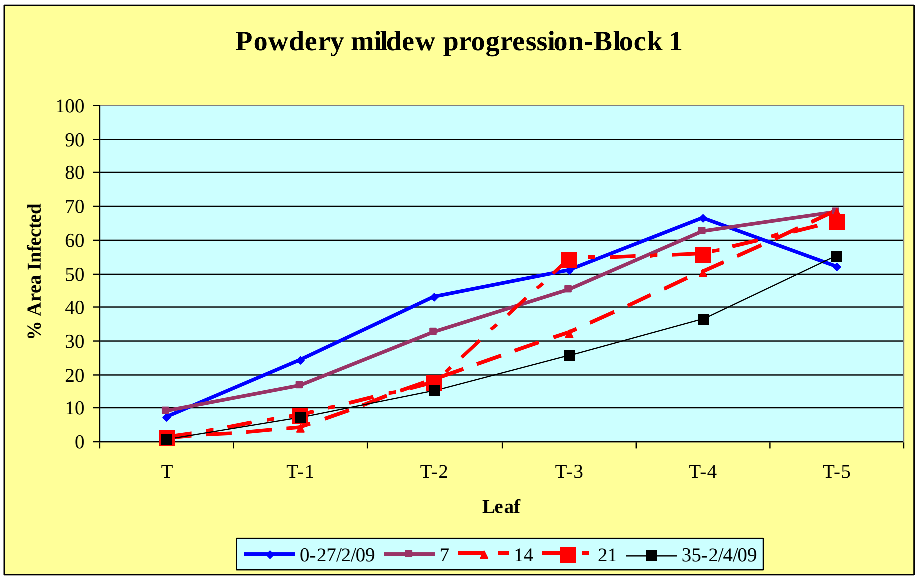


Figure 2.3. Disease progress in Block 1. T is the youngest fully expanded leaf. Each line represents the percentage leaf area affected for each of the top six leaves at weekly assessments. 0-27/2/09 is the first assessment followed by weekly assessments.

Block 2

In this block, disease progress was rapid (Figure 2.4), and disease appearance coincided with low solar radiation levels and reduced temperature. Disease levels increased for two weeks after the initial assessment and then progressively decreased.

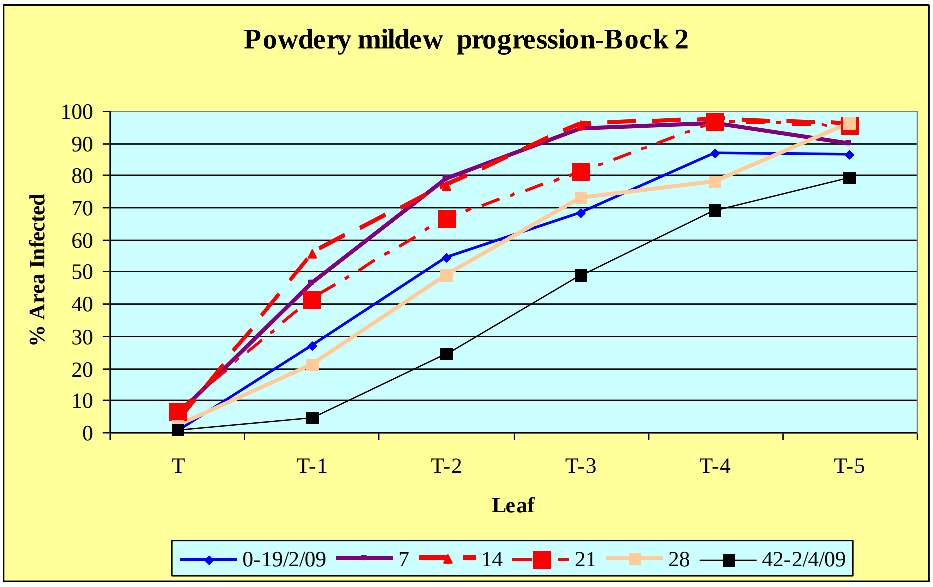


Figure 2.4. Disease progress in Block 2. T is the youngest fully emerged leaf. Each line represents the percentage leaf area affected. 0-19/2/09 is the first assessment followed by weekly assessments.

Fungicide efficacy

Block 1
The growth rate of carrot leaves in this block was rapid and disease levels were low. In this block the plots without any treatment i.e. the control (Nil treatment) showed the highest disease levels. All other treatments had some effect on disease and these were all significantly different (P<0.001) to the nil treatment.

Fungicides controlled disease well on the upper leaves but the efficacy was not so clear cut on the lower leaves (Figure 2.5 and Table 2.2). There was not a wide variety of fungicides used in this block, generally those with a permit, and sulphur. There were some combinations of these also trialled.

Table 2.2. Disease levels for Block 1 as assessed across all leaves as represented in Figure 2.5. Values with the same letter are not significantly different (P<0.001,LSD 5% =2.26).

Treatment	The mean percentage of powdery mildew across the six leaves assessed.
Folicur® (3 @14 days apart)	5.65 a
3Sulphur/2Amistar®	8.94 ab
Sulphur (3@14 days apart)	10.33 bc
Sulphur/Folicur®(SFS@10 days apart)	10.70 bc
Amistar®(1litre rate 3 @10 days apart)	12.05 bc
3Sulphur/2Amistar®	12.22 cd
Amistar Top® (3@10 days apart)	13.69 d
Ecocarb®/Synertrol oil® (3@14 days apart)	15.00 d
Amistar ® (0.75 litre rate 3 @ 10 days apart)	15.45 d
Synertrol® oil (3@14 days apart)	18.74 d
Nil	25.90 e

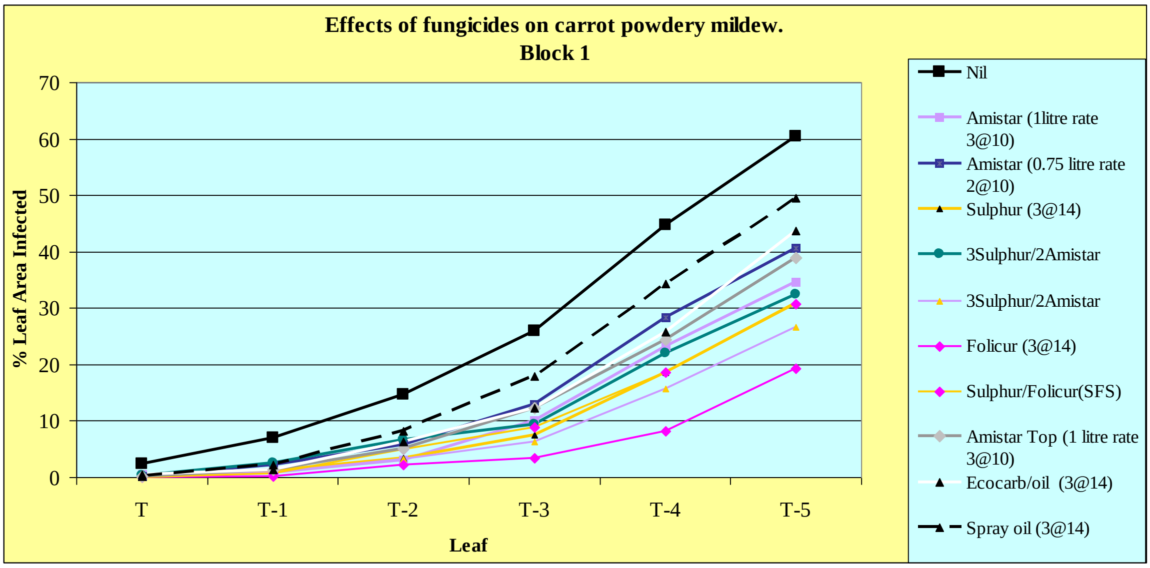


Figure 2.5. Disease levels after regular fungicide applications. The frequency of application is indicated in the legend, and for example, Amistar® was applied 3 times, 10 days apart.

Block 2.
Disease progress was rapid in this block. Upper leaf control was good with the majority of the fungicides (Table 2.3, Figure 2.6). Amistar®, Cabrio®, DC036 (experimental product) and sulphur/water performed the best. Rates of the fungicides applied were the same as for Block 1. Some products had not arrived at the time of the first application so an alternative was applied. For example,

the Amistar® plots were sprayed with sulphur first, and after nine days were followed by the Amistar® treatments every ten days. This information has been included in the legend on the graph.

Table 2.3. Disease levels for Block 2 as assessed across all leaves as represented in Figure 2.6. Values with the same letter are not significantly different (P<0.001, LSD 5% =4.5).

Treatment	The mean percentage of powdery mildew across the six leaves assessed.
Cabrio® (3@14 days apart)	10.95 a
Amistar® (1Sulphur @ 9, 3&10 days apart)	11.87 a
Sulphur (3@14 days apart)	13.14 ab
DC036 (3@14 days apart)	13.25 ab
Amistar Top® (1 Sulphur @ 9, 3&10 days apart)	16.68 bc
Filan® (3@14 days apart)	18.81 c
DC086 (3@14 days apart)	18.86 cd
Sulphur1/Water	20.50 cd
Nil	22.72 de
Pristine® (3@14 days apart)	24.93 e
Folicur® (2@19 days apart)	25.58 e

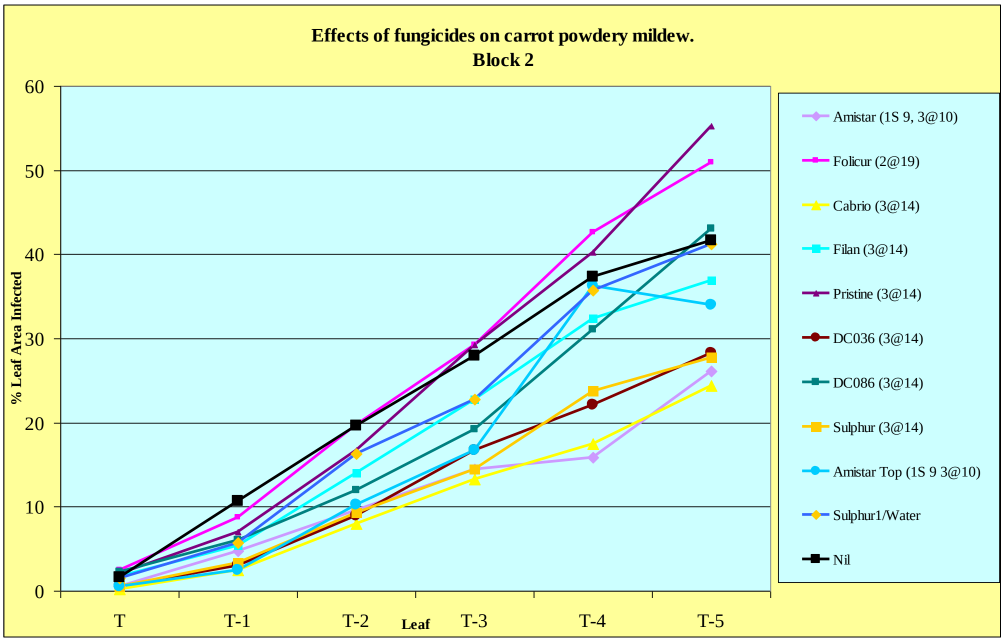


Figure 2.6. Disease levels after regular fungicide applications. Data represented are the means for each leaf assessed.

Yield evaluation.
A yield evaluation was undertaken on this block but there were no significant differences between treatments.

Discussion

Powdery mildew was controlled well by most of the fungicides selected. Each block displayed different characteristics. Block 1 showed vigorous growth and slow disease development whereas Block 2 showed rapid disease development. The temperature was hot in the early part of 2009 and was not conducive to powdery mildew on the carrots. Once conditions changed (solar radiation and temperature dropped), the disease progressed rapidly.

It was also confirmed that the disease would be worse in the summer/autumn conditions experienced in the Murrumbidgee Irrigation Area.

Across the two blocks, some fungicides worked well with the slower disease development whereas others worked as well with rapid disease development. Sulphur performed well in trials and there was no sign of any leaf burn that is often found when other crops are treated with sulphur.

Tracking the disease in untreated crops was valuable by providing an indication on disease progress i.e. whether it was increasing or not.

It is clear from observations for this season that disease monitoring is critical to find the disease as early as possible. It is very difficult to see powdery mildew on carrot leaves early in the infection process and an outcome of the trials is that fungicides have to be applied at the early stages of disease development for them to be successful at controlling the disease. Therefore, early detection is critical.

3. FUNGICIDE FIELD TRIAL 2009/10

Introduction

To continue evaluating fungicides, efficacy trials were established for the 2009/10 season. These trials were to examine the current products with registration or permits including sulphur, Amistar® and Folicur® as well as new chemistries and alternative products that could be used for powdery mildew on carrots. As powdery mildew in this region becomes established in the February to April period, carrots were sown to allow for maturing during this period by planting in mid December. Fungicides were to be applied at the manufacturers' recommendations, and disease assessments of the leaves would be undertaken once the disease became established.

Method

Carrot variety Stefano was sown in two blocks on a sandy loam site at Yanco Agricultural Institute in mid December, 2010. The carrots were in two rows on a 1.5 metre bed. The two rows were 30 cm apart and irrigated with drip tape. Drip was preferred in the trial as overhead irrigation may complicate disease levels and fungicide efficacy.

There were 19 different treatments (Table 3.1) applied to five metre plots, and each treatment was replicated four times and randomised into each replicate.

Table 3.1. Treatments applied to carrot powdery mildew trial in March 2010 at Yanco Agricultural Institute.

Treatment	Active ingredient
Amistar® (1L /ha)	250 g/L azoxystrobin
Amistar® (0.5L /ha)	250 g/L azoxystrobin
Amistar Top®	200g/Lazoxystrobin 125g/L difenoconazole
Amistar®/Sulphur (1L/ha and 1300g/ha)	250 g/L azoxystrobin /800 g/kg elemental sulphur
Bravo®	720 g/L chlorothalonil
Cabrio®	250 g/L pyraclostrobin
DC036	Experimental
DC086	Experimental
Ecocarb® + synertrol horti oil®	940 g/kg potassium bicarbonate
Filan®	500 g/kg boscalid
Folicur®	430 g/L tebuconazole
Molasses	1% v/v
Peratec®	250 g/L hydrogen peroxide and 50g/l peroxy acetic acid 1%
Potassium Silicate	15% potassium, 17% silicon w/v
Pristine®,	252 g/kg boscalid and 128 g/kg pyraclostrobin
Sulphur	800 g/kg elemental sulphur
Thiovit Jet®	800 g/kg elemental sulphur
Water	
Untreated	

Fungicide applications were carried out with a gas powered backpack sprayer using a water rate of 300 litres per ha at the recommended chemical rates and application times. The carrots were monitored for powdery mildew, and at the period of expected development of powdery mildew, the first application was carried out (on the 15th March 2010). Powdery mildew was first seen on the 25th March, 2010. The next application of fungicide was then undertaken on the 30th March 2010.

Results

Plots were assessed two weeks after the last application, but disease did not develop this season.

Discussion

In comparison to a dry summer/autumn in 2009, the late summer/autumn period of 2010 received regular rain events (Figure 3.1) with an especially heavy fall (for this region) in March of 55 mm. It is assumed that this contributed to reducing infection levels. No powdery mildew was found in the Tasmanian trials in this season, but staff undertook trials targeting leaf blight. It is apparent that powdery mildew is going to be a sporadic disease in carrots, dependent on weather conditions, and is going to be most severe in times of dry late summer/autumn. These conditions are common in many carrot growing regions.

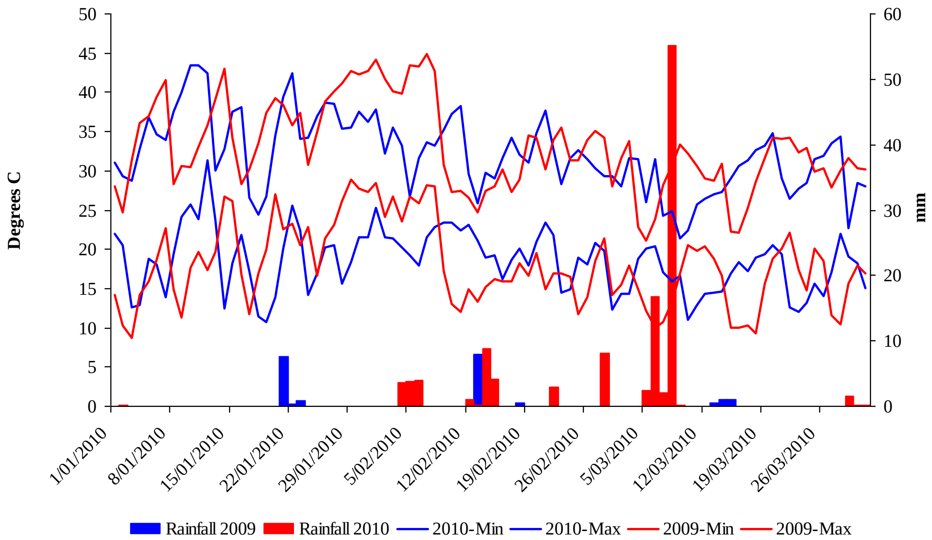


Figure 3.1. Yanco Agricultural Institute weather data for January to March comparing 2009 and 2010 data. Clearly rainfall in 2010 was much higher and more regular than in 2009.

4. FUNGICIDE FIELD TRIALS 2010/11

Introduction

Fungicide trials were established again this season after failure of disease to develop in 2009/10. There were some new fungicides examined with some repeated from previous trials. By the time this trial was established, variety trials had indicated that Stefano was one of the more powdery mildew tolerant varieties, so therefore the variety Ricardo, which had been shown to be more susceptible to disease, was used.

Method

Ricardo carrot was sown on the 13th December 2010 in two blocks on a sandy loam site at Yanco Agricultural Institute with a hand seeder. The carrots were sown at this time so they would mature over the mid to late summer period which appears to be the time when powdery mildew develops on carrots. From experience, growing carrots at this time can be a problem due to the difficulty in maintaining moisture during the germination and post-germination stages. The carrots were sown in two rows on a 1.5m bed. The two rows were 30 cm apart with drip tape along both rows. After sowing, the carrots were maintained by irrigating, fertilising, and weeding, and observed for powdery mildew. The plants were also thinned to provide a uniform distance between the carrots.

The fungicides used included the products with permits and sulphur (which is registered for vegetables) and other fungicides selected for powdery mildew control (Table 4.1). Fungicide application was carried out with a gas-powered backpack sprayer with a water rate of 300 L/ha. Fungicides were applied at the rate recommended.

Powdery mildew was assessed in both blocks by examining all the leaves on ten plants from each plot and assessing the amount of disease covering the leaf as a percentage of the total leaf. Due to the patchiness of powdery mildew, each plot was assessed before treatments began and again after treatments were applied. The later assessment was conducted two weeks after the last treatment. In all, there were two applications of each fungicide two weeks apart. Plots were eight metres long and there were four replicates with each treatment randomised into each replicate. Disease control was therefore calculated on the total percentage amount of disease observed per leaf before treatment minus the total percentage amount of powdery mildew per leaf after treatment. Data were analysed using Genstat 11th Edition.

Results

The season was wetter than average making the chance of a serious powdery outbreak less likely as experience indicated that the disease was reduced with regular rainfall. After the crop had reached maturity, it was left in the ground to allow further development of powdery mildew. By the 9th March, powdery mildew was observed in the blocks in hotspots. The disease was allowed to progress naturally for one month to allow better spread throughout the block. The application of fungicides at the level of powdery mildew that were observed is not a recommended practice. Fungicides should be applied at the first sign of disease, but the disease was late and slow in developing. There was an outbreak of Cercospora leaf blight (*Cercospora carotae*) in the blocks due to the wet conditions which favour this disease and made assessing for powdery mildew difficult. The level of Cercospora leaf blight was also assessed by examining each plot and determining ratings as a percentage of the plot affected by the disease.

Block 1

Block 1 had more disease than the Block 2. Fungicides (all except Pristine® and DC096) applied to Block 1 showed a significant reduction ($P<0.001$, LSD 5%=72.9) in disease levels compared to the water only treatment (Figure 4.1). The data presented is the total disease for all leaves per plant, rather than a mean disease per leaf per plant.

Table 4.1. Fungicides that were applied on the two blocks for powdery mildew control of carrots.

Block 1 Fungicide	**Active Ingredient**	**Rate (ml or g/ha)**	**Block 2 Fungicide**	**Active Ingredient**	**Rate (ml or g/ha)**
Amistar® Rate 1	250 g/L azoxystrobin	1000	Talendo® Rate 1	200 g/L proquinazid	125
Amistar® Rate 2	250 g/L azoxystrobin	500	Talendo® Rate 2	200 g/L proquinazid	250
Amistar Top®	200g/L azoxystrobin 125g/L difenoconazole	1000	Talendo® Rate 3	200 g/L proquinazid	500
Cabrio®	250 g/L pyraclostrobin	400	Water	N/A	N/A
DC096	Experimental fungicide	200	Peratec®	250 g/L hydrogen peroxide and 50 g/l peroxy acetic acid	1%
Folicur®	430 g/L tebuconazole	580	DPX-LEM1720 Rate 1	200 g/L penthiopyrad	1250
Thiovit Jet®	800 g/kg elemental sulphur	1300	DPX-LEM1720 Rate 2	200 g/L penthiopyrad	1750
Pristine®	252 g/kg boscalid and 128g/kg pyraclostrobin	800	Timorex Gold®	Tea tree oil	1%
Water	N/A	N/A			

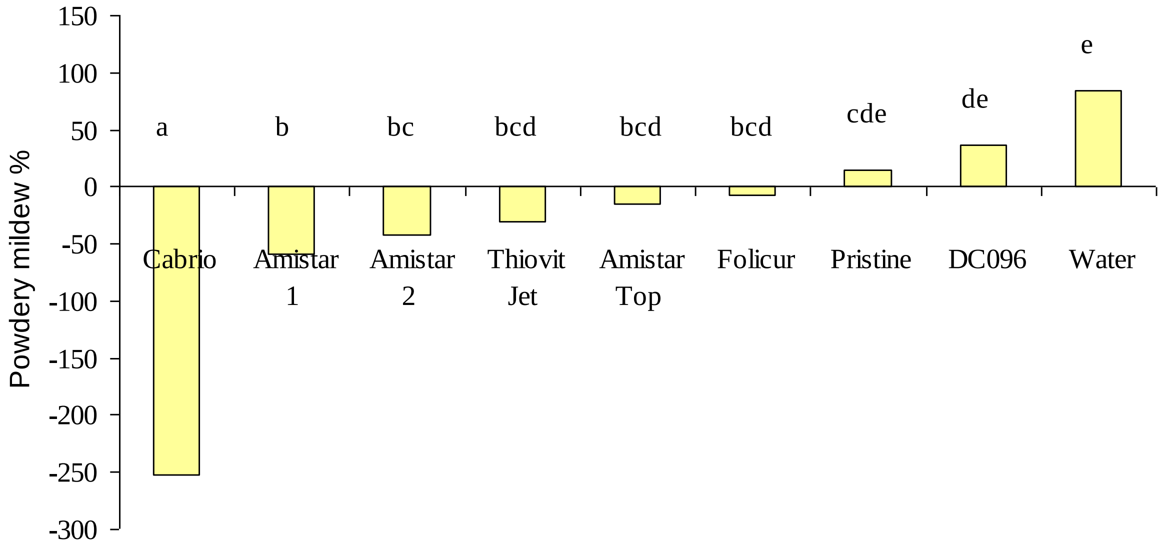


Figure 4.1. Block 1-Total powdery mildew as assessed after the fungicide treatments when subtracted from the assessments before treatments, therefore the lower the value the better the treatment. Therefore it shows how much disease was reduced compared to pre treatment levels. Cabrio® had the highest reduction in powdery mildew however the other fungicides (except DC096 and Pristine®) also significantly controlled disease compared to water ($P<0.001$, LSD 5% =72.9). Y axis is the percentage of powdery mildew reduction or increase.

Block 2

In Block 2, although disease levels were less in the fungicide-treated plots compared to the water treatment, the results were not statistically significant, mainly due to the patchiness and low levels of powdery mildew throughout this block (Figure 4.2).

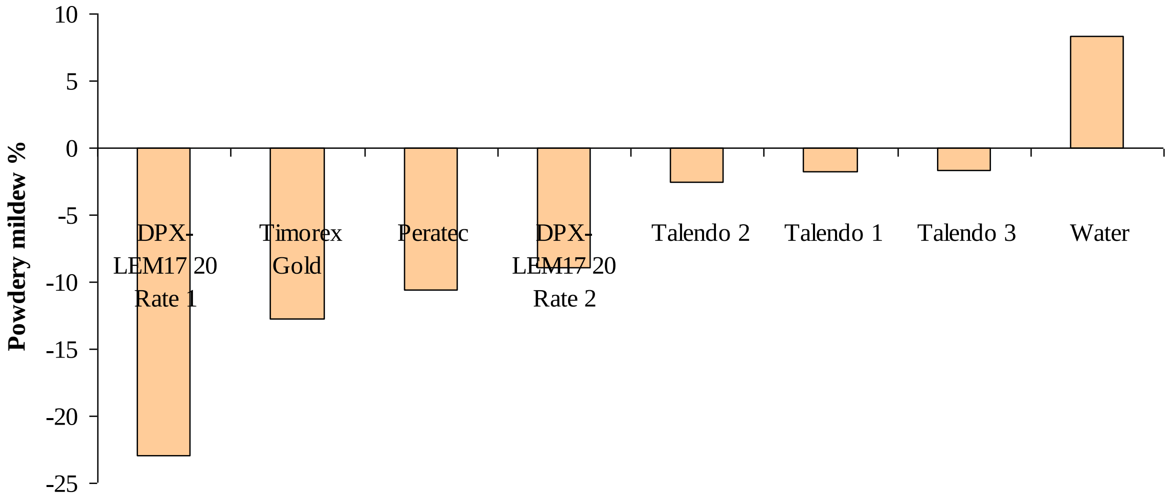


Figure 4.2. Block 2-Total powdery mildew as assessed after the fungicide treatments when subtracted from the assessments before treatments, therefore the lower the value the better the treatment. Note that disease levels were quite low. Y axis is the percentage of powdery mildew reduction or increase. There were no significant differences between any treatments.

Cercospora leaf blight

Data on Cercospora leaf blight incidence are presented in Table 4.2 for Block 1 and Table 4.3 for Block 2. There were some significant differences in block 1 (P<0.01, LSD5%=27.98). There were significant differences with Cabrio®, Amistar Top®, DC096, Folicur®, Amistar® Rate 1 and Amistar® Rate 2 when compared with the water treatment. There were no significant differences in values recorded in Block 2.

Table 4.2. Cercospora leaf blight disease scores observed by assessing the percentage of disease covering plants within the plot for block 1. Those with the same letter were not significantly different (P<0.01, LSD 5%=27.98).

Treatment	**Disease incidence (%)**
Cabrio®	23.8 a
Amistar Top®	33.8 ab
DC096	42.5 ab
Folicur®	42.5 ab
Amistar® Rate 2	51.2 b
Amistar® Rate 1	51.5 b
Pristine®	52.5 bc
Thiovit Jet®	76.2 c
Water	80 c
P	**<0.01**
LSD 5%	**27.98**

Table 4.3. Cercospora leaf blight disease scores observed by assessing the percentage of disease covering plants within the plot for block 2. There were no significant differences.

Treatment	**Disease incidence (%)**
Talendo® 1	26.2
Timorex gold®	27.5
DPX-LEM1720 Rate 1	36.2
Peratec®	37.5
Talendo® 3	37.5
Talendo® 2	41.2
Water	55
DPX-LEM1720 Rate 2	57.5
P	**0.228**

Discussion

The information collected from Block 1 confirmed trials carried out two years previously, with Cabrio® Amistar®, Thiovit Jet® (sulphur) and Folicur® controlling disease successfully. Cabrio® was very successful in controlling powdery mildew and significantly better than the other treatments.

The value of having registration/permits for Folicur® and Amistar® (with the exception of Cabrio®) is justified and provides some rotation of chemistry across groups. Cabrio® should be considered for powdery mildew control on carrots, but it has a similar active ingredient as Amistar®, and there is a need for fungicides in different activity groups. One confusing factor is that Pristine®, although having the same active ingredient, did not perform the same as Cabrio®. This may be related to formulation, rate of product used and time of application.

Block 2 provides some new chemistry data, and although the effects were not significant, there is a trend that Timorex Gold®, Peratec® and Talendo® may offer some alternative to those above. However, they will need to be examined under higher disease pressure.

As the carrots had reached maturity before the powdery mildew developed, yield was not measured on all plots. The untreated and Amistar®-treated plots were harvested and yield measured, but there were no significant differences in yield, as expected.

Both the strobilurins Amistar Top® and Cabrio® controlled powdery mildew and Cercospora leaf blight as did Folicur®. Thiovit Jet® did not control Cercospora leaf blight as well as the other fungicides.

5. FUNGICIDE FIELD TRIALS 2012

Introduction

Due to the reduced disease levels in 2011, a field trial was undertaken after a request for an extension of the project was approved. The trial was the last one of the project and was set up again at Yanco Agricultural Institute.

Methods

Ricardo carrot was sown on the 18th January 2012 in one block on a sandy loam site at Yanco Agricultural Institute with a hand seeder. The seed were sown at this time so plants would mature over the late summer period which appears to be the time when powdery mildew develops on carrots. Growing carrots at this time can be a problem due to the difficulty in maintaining moisture during the germination and post germination stages. The carrots were sown in two rows on a 1.5 m bed. The two rows were 30 cm apart with drip tape along both rows. After sowing, the carrots were maintained by irrigating, fertilising, and weeding, and observed for powdery mildew. Plots were eight metres long and randomised within four replicates.

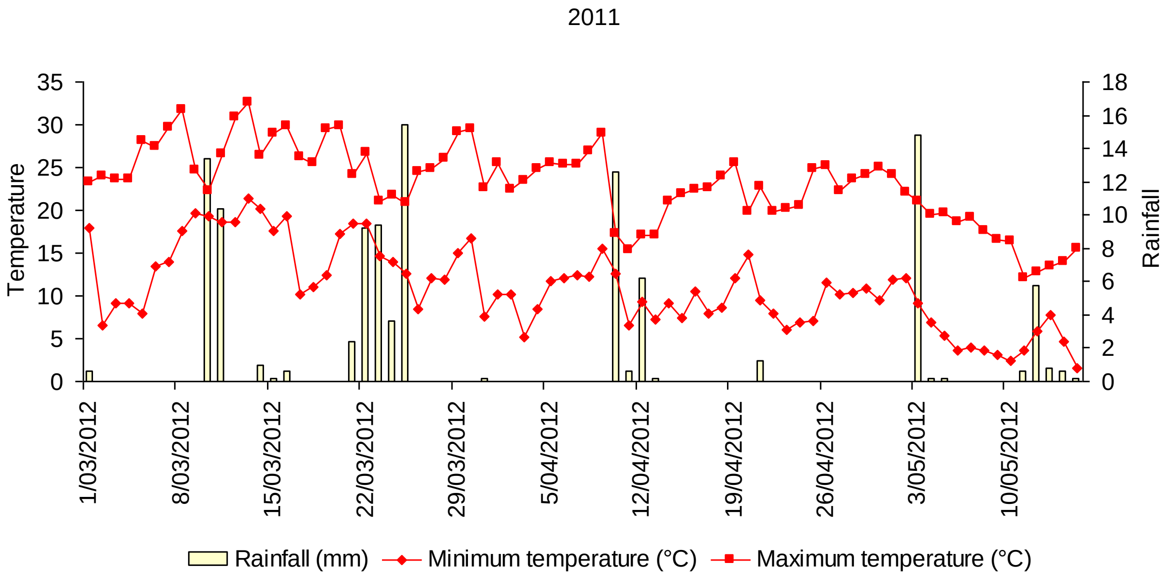
The fungicides used are included in Table 5.1. Fungicide application was carried out with a gas-powered backpack sprayer using a water rate of 300 L/ha. Fungicides were applied at the rate recommended. Powdery mildew was assessed as the percentage of each plot affected by powdery mildew, and assessments were conducted four times, weekly from the first application until one week after the last.

Table 5.1. Fungicides use in the 2012 trials.

Fungicide	Active Ingredient	Rate (unit/ha)
Amistar Top®	200 g/Lazoxystrobin 125 g/L difenoconazole	1000 ml
Cabrio®	250 g/L pyraclostrobin	400 ml
Citrex®	Organic Acids (Citric, lactic and Ascorbic)	300 ml
DPX-LEM1720 Rate 1	200 g/L penthiopyrad	1250 ml
DPX-LEM1720 Rate 2	200 g/L penthiopyrad	1750 ml
Ecocarb® + synertrol spray oil®	940 g/kg potassium bicarbonate	3000 g
Filan®	500 g/kg boscalid	400 g
Folicur®	430 g/L tebuconazole	580 ml
Talendo® 1	200g/L proquinazid	125 ml
Talendo® 2	200g/L proquinazid	250 ml
Talendo® 3	200 g/L proquinazid	500 ml
Timorex gold®	Tea tree oil	1000 ml
Thiovit Jet®	800 g/kg elemental sulphur	1300 g
Water		
Nil		

Results

Fungicides were applied on the 24th April and again two weeks later on the 7th May. This was quite late in the season but powdery mildew was progressing and the information was critical. There was a rainfall event on the 3rd March that was uncharacteristic for the region, with 175 mm falling on the carrot block. With follow up rain in the following two weeks, the continuation of rain events would have reduced powdery mildew levels considerably, as seen in past years. However, April and May were very dry (Figure 5.1). On the final assessment of disease, results showed that some fungicides performed well compared to the untreated plots. Almost all of the fungicides tested were able to reduce disease compared to the water-treated or nil-treated controls. Those that performed better included DPX-LEM1720 Rate 1 and Rate 2, Cabrio®, Thiovit Jet®, Amistar Top® and Folicur®. Filan® did not control the disease when compared with the water treatment. The Nil treatment was not significantly different to the water treatment. Data are presented in two forms. Figure 5.2 is the final assessment minus the first assessment before application of the fungicides, and Figure 5.3 is the final assessment. Both give similar information indicating that the disease had become uniform over the randomised plots. Figure 5.4 indicates the gradual increase in disease in the Nil and Water treatments over each of the assessments when compared to Amistar Top®. Disease progressed rapidly from approximately 20% infection in coverage on the 23rd April to 70% on the 14th May. The setup of the plots is shown in Figure 5.6.



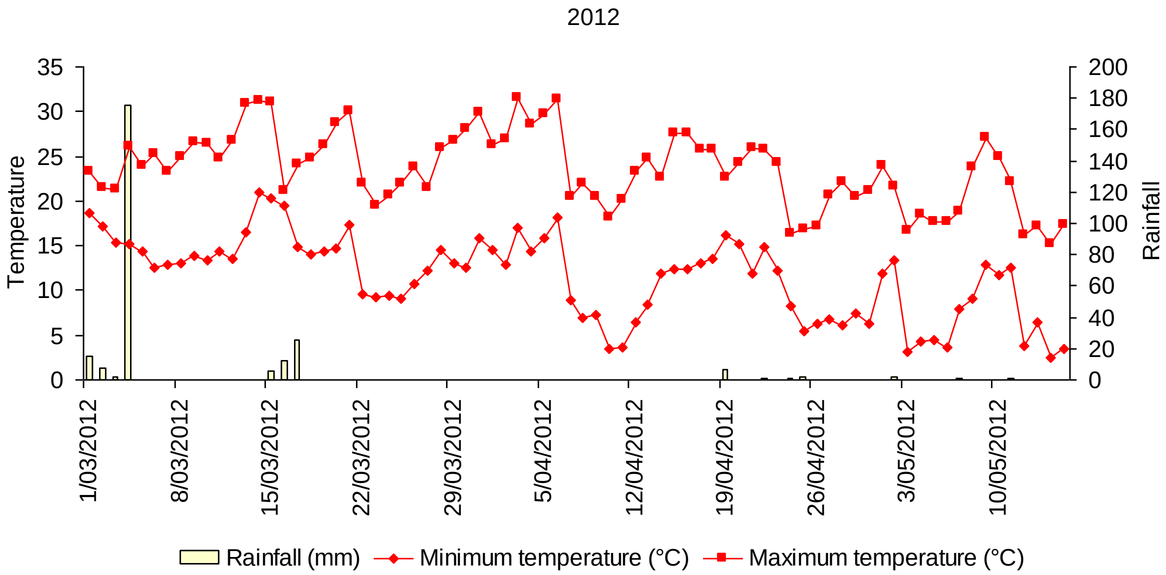


Figure 5.1. Rainfall, maximum and minimum temperatures in 2011 (top) and 2012 (below).

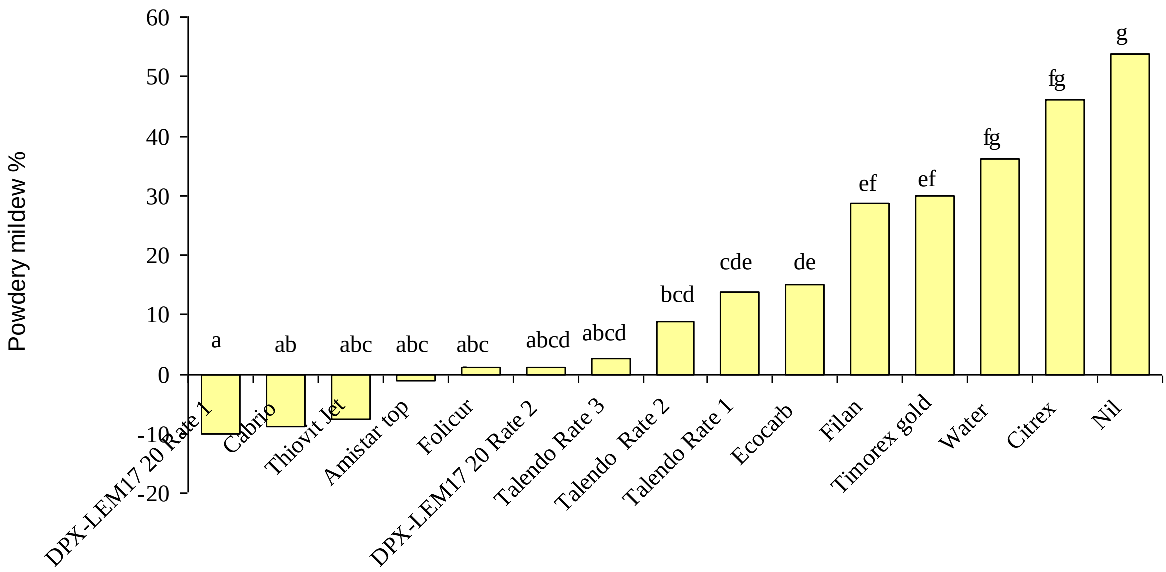


Figure 5.2. Results of the fungicide assessments when subtracting the last assessment from the first, therefore for example Cabrio® was less at the final assessment compared to the first, whereas, as expected, Water and Nil were higher. Values with the same letter are not significantly different (P<0.001, LSD 5%=18.4).

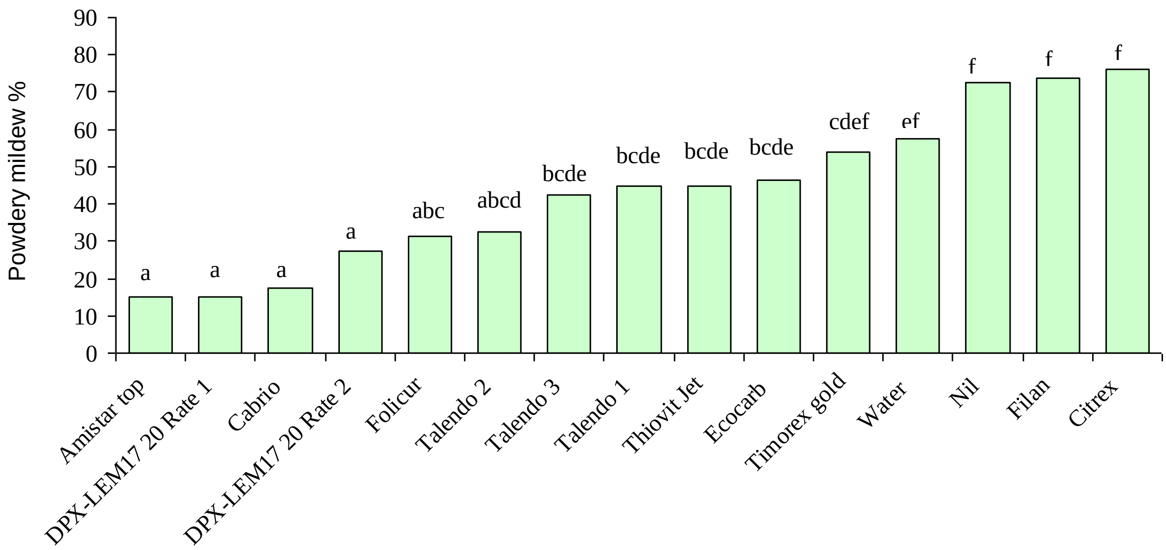


Figure 5.3. Results of the last fungicide assessment indicating that the spread of the disease across the block was reasonably uniform. Values with the same letter are not significantly different (P<0.001, LSD 5%=23.2).

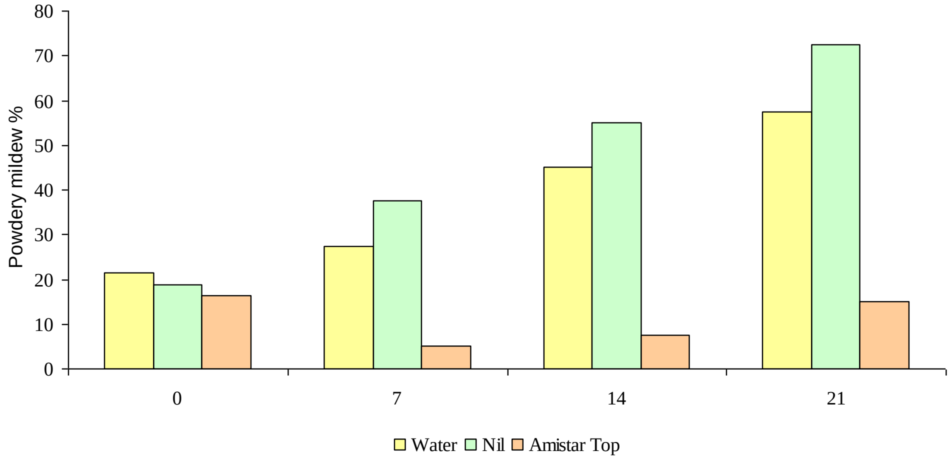


Figure 5.4. The gradual increase in disease over the period of assessments indicated on the x-axis with the initial assessment at 0 (23/4/2012) and the last 21 days later (14/5/2012).

Figure 5.6. Carrot plots in the fungicide trial, two rows per bed.

Discussion

The 2011 trial saw regular rain that reduced disease (Figure 5.1). However, in 2012, regular rain events did not occur and disease continued. The disease progress was rapid, developing from 20% coverage to 70% coverage after 21 days. The fungicides kept the disease lower than the untreated plots indicating good control. Amistar Top® has been registered for powdery mildew control in carrots. Thiovit Jet® and Folicur® performed well in 2012. Cabrio® always performed well and has been shown previously to control Cercospora leaf blight.

6. GREENHOUSE FUNGICIDE TRIALS

Introduction

Fungicide trials within a large greenhouse were established to supplement the information collected from the trials conducted in the field. The trials were to examine the potential for disease control under high disease pressure and protection from any rainfall events. Growers had been concerned about the lack of control from fungicides. It had not been determined whether control was poor because the fungicides were not active, or that disease levels were too high for the fungicides to be effective.

Method

Trial 1

A carrot powdery mildew and fungicide trial was undertaken in a large greenhouse independent of rainfall. Carrots of the variety Ricardo were planted in 40 large tubs measuring 590 mm long, 370 mm wide and 270 mm deep. Soil was added to the tubs and seed planted in two rows with drip tape running along the rows. The greenhouse was maintained at 20-28^{o}C. Carrots were thinned and allowed to grow normally. When the carrots were approaching maturity i.e. after two months, powdery mildew was introduced by placing 200 mm pots of powdery mildew-infected carrots throughout the greenhouse, and natural infection allowed to take place. There were five replicates of the fungicide treatments Amistar®, Pristine®, Peratec®, Talendo®, Timorex Gold®, DPX-LEM1720 and milk. Water served as the as control treatment (Table 6.1). Fungicides were applied using a Silvan battery-powered sprayer which delivered 400 L/ha. At the time of the fungicide application, disease levels were high and uniform throughout the greenhouse. Disease was assessed by examining the percentage coverage of powdery mildew affecting the carrots in each tub. Disease was assessed at the time of the first application. Fungicides were then applied and again two weeks later. Disease was assessed immediately prior to the second fungicide application and again two weeks later.

Table 6.1. Fungicides used in the greenhouse trial 1.

Fungicide	Active Ingredient.	Rate (unit/ha)
Amistar®	250 g/L azoxystrobin	1000 ml
DPX-LEM1720	200 g/L penthiopyrad	1750 ml
Full cream milk		5% solution
Peratec®	250 g/L hydrogen peroxide and 50g/L peroxy acetic acid	3000 ml
Pristine®	252 g/kg boscalid and 128 g/kg pyraclostrobin	800 ml
Talendo®	200 g/L proquinazid	500 ml
Timorex Gold®	Tea tree oil	1000 ml

Trial 2

This was designed as for Trial 1 but a different group of fungicides were tested. Carrots (variety Ricardo) were sown into the same tubs in the same way as in Trial 1, and the greenhouse was maintained at 20-28^{o}C. The fungicides were applied at an earlier stage of disease development compared to Trial 1. This trial included similar fungicides to a field trial that was undertaken at the same time (Table 6.2). Disease was assessed by examining the percentage coverage of powdery mildew affecting the carrots in each tub. The tubs were assessed immediately before the first application, two weeks later before the second application, and again two weeks after. Therefore two applications of fungicide were made. The five top leaves from five carrots from each treatment were also assessed two weeks after the last treatment.

Table 6.2. Fungicides used in the greenhouse trial 2.

Fungicide	Active Ingredient.	Rate (ml/ha)
Amistar top®	250 g/L azoxystrobin	1000 ml
Citrex®	Organic acids (citric, lactic and ascorbic)	300 ml
DPX-LEM1720 Rate 1	200 g/L penthiopyrad	1250 ml
DPX-LEM1720 Rate 2	200 g/L penthiopyrad	1750 ml
Folicur®	430 g/L tebuconazole	580 ml
Talendo®	200 g/L proquinazid	500 ml
Timorex gold®	Tea tree oil	1000 ml

Results

Trial 1

Disease levels were high and uniform at the time of the first fungicide application (Figure 6.1). Measurements two weeks after treatment indicated DPX-LEM1720 had significantly reduced disease slightly ($P<0.05$, LSD 5%=15) (Figure 6.2). Disease levels actually dropped in all treatments but levels were still high indicating that once powdery mildew of carrots had progressed to a high level it was very difficult to control (Figure 6.3). This confirms grower experience with the disease, and indicates that early detection and application of fungicides is critical in controlling carrot powdery mildew. Also disease pressure was extremely high. Even Amistar® which has been shown to be highly effective when applied at the first sign of disease did not reduce disease that was already established on leaves. The need to keep new leaves free of infection is critical once powdery mildew has developed on lower leaves.

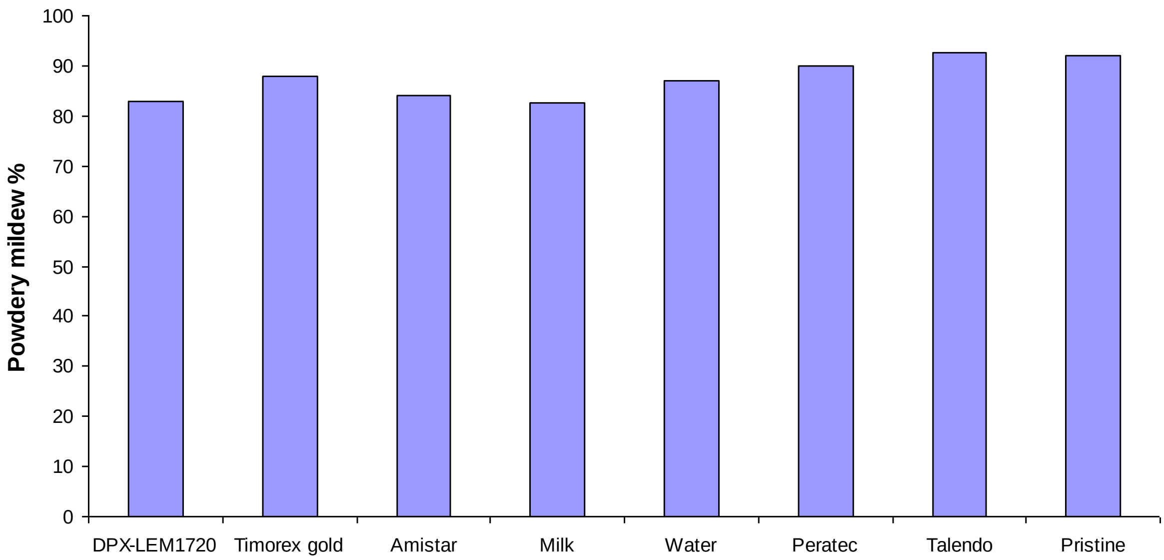


Figure 6.1. Pre-treatment powdery mildew levels showing high levels of disease. The y-axis indicates the percentage of leaves infected with powdery mildew.

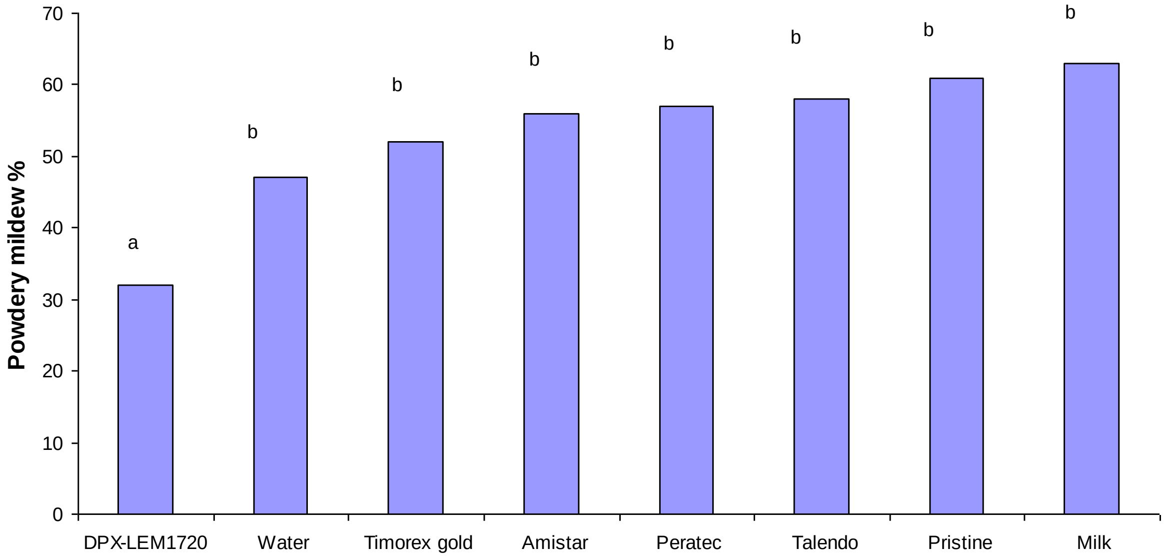


Figure 6.2. Powdery mildew levels two weeks after the first treatment and before the second treatment. Only DPX-LEM1720 showed significantly less disease than the others at P<0.05, LSD=15.

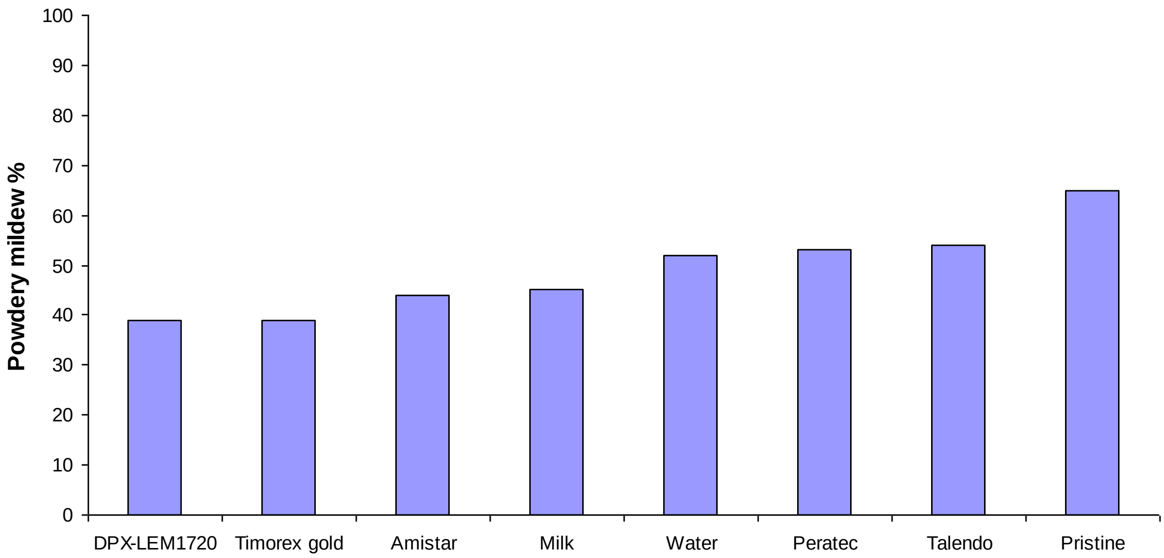


Figure 6.3. Powdery mildew levels two weeks after the second treatment, no significant differences between treatments.

Trial 2

In this trial powdery mildew increased in quantity from the time of the first fungicide application. When assessed as a percentage per tub, the disease was shown to be reduced in the greenhouse trial, with all products resulting in significantly less disease than the water treatment (P<0.001, LSD 5%=20) (Figure 6.4). The disease levels represented in the graph indicate the level of disease at the start subtracted from the level at the end, therefore change due to the application of fungicide.

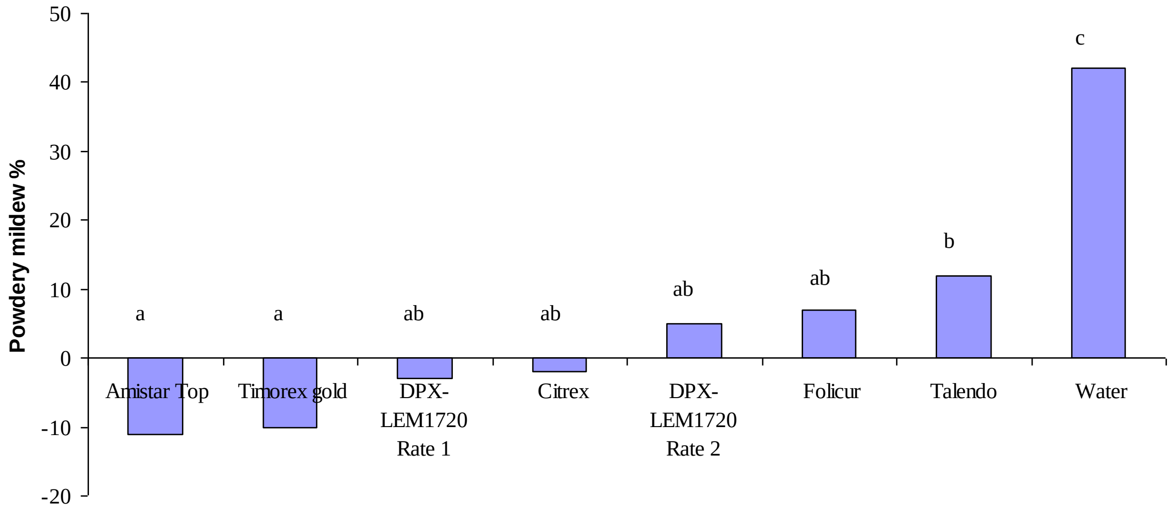


Figure 6.4. Powdery mildew leaf infection two weeks after the final application. Values with the same letter are not significantly different (P<0.001, LSD 5%=20). Y-axis is the difference in powdery mildew levels before and after treatment.

Discussion

The results of the greenhouse trials supported results found in field trials. They were able to provide information where field trials may have failed due to lack of disease. Timorex Gold®, which is a tea tree product, was more effective in the greenhouse trials than in the field trials. DPX-LEM1720 (penthiopyrad) is a product that has shown potential for powdery mildew control. It may provide an alternative active ingredient to the strobilurins, the group to which Amistar® and Amistar Top® belong.

7. GREENHOUSE TRIALS TO EXAMINE THE EFFECT OF POWDERY MILDEW ON CARROT YIELD

Introduction

Three greenhouse trials were established at different times to examine carrot yield loss that could be caused by infection with powdery mildew. This information is not readily available, and field trials are often too variable for any significant differences to be demonstrated between treatments. Two trials were conducted with Stefano and one with Ricardo to examine the complete protection of plants from the effects of powdery mildew through fungicide application on subsequent yield.

Method

Carrots (approximately 20 seeds) were planted in twenty four 280 mm-diameter plastic pots in Yanco Agricultural Institute loam. After emergence, plants were thinned to leave five plants per pot. Plants were fertilised with slow release and liquid fertilisers, and water content was maintained at field capacity through drip irrigation. At the five leaf stage for Trial 1, six leaf stage for Trial 3 and the eight leaf stage for Trial 2, a piece of carrot leaf infected with powdery mildew was placed into each pot i.e. placed on the soil surface. Pots were placed in a greenhouse at 23-27°C. Plants were carefully monitored for powdery mildew infection. Five weeks after emergence, early signs of powdery mildew appeared on the plants at the six leaf stage. Pots were divided into six replicate pots of four treatments. Amistar® at the recommended application rate was applied to plants in six pots of each treatment either once, twice, or three times, and another six replicates were left unsprayed. Application of the fungicide was carried out at two-weekly intervals in the multi-spray applications. The first spray was applied when the fungus was spread throughout the greenhouse, which occurred two weeks after the introduction of powdery mildew.

Eleven weeks after emergence of Stefano (Trials 1 and 2), and fourteen weeks for the Ricardo trial (Trial 3), plants were harvested, and the diameter at the top of the carrot and length was measured together with fresh weights of carrots, and fresh and dry weights of the tops. Each pot was rated for powdery mildew infection (percentage of leaves infected). All data was analysed by analysis of variance using Genstat 11^{th} Edition.

Results

Trial 1

In trial 1, fresh carrot weight of Stefano was increased by approximately 20% (Table 7.1) when there were one, two or three applications of Amistar® compared to the untreated controls. Diameter of the carrots and the percentage of powdery mildew were also significantly different following fungicide treatment. Fresh leaf weight, dry weight, and length of the carrot were not significantly different. Figure 7.1 shows the powdery mildew on an unsprayed plant compared to an Amistar® treated plant.

Figure 7.1. Untreated carrot (left) showing leaves covered in white powdery growth, and fungicide treated carrot (right) in greenhouse trial.

Table 7.1. Measurements of fresh weight of carrots, fresh and dry weights of leaves, length and largest diameter of carrots, and incidence of powdery mildew (trial 1, Stefano).Values with the same letter are not significantly different.

Treatment	**Fresh Carrot Weight (g)**	**Fresh Weight Leaves (g)**	**Dry Weight Leaves (g)**	**Length (mm)**	**Diameter (mm)**	**Powdery (%)**
Amistar® 3	292 a	83.1 a	19 a	13.9 a	30.7 a	48.3 a
Amistar® 2	275 a	87.4 a	21 a	14.4 a	29.0 a	51.7 a
Amistar® 1	294 a	83.8 a	19 a	14.2 a	30.3 a	74.2 b
Nil	230 b	68.4 a	19 a	13.7 a	26.8 b	86.7 b
P	**0.020**	**0.642**	**0.907**	**0.910**	**0.003**	**0.004**
LSD 5%	**42.65**	**NS**	**NS**	**NS**	**1.94**	**21.38**

Trial 2

In Trial 2 with Stefano, a repeat of Trial 1, fresh carrot weight was increased by approximately 23% when there were one, two or three applications of Amistar® when compared to the untreated controls (Table 7.2). This trial had lower disease levels due to the disease developing later than in Trial 1. However, in this trial, fresh leaf weight was significantly higher between the treated carrots compared to the untreated controls, as was dry leaf weight and diameter. All were reduced due the effects of powdery mildew. Powdery mildew was significantly higher on the plants without fungicide treatment.

Table 7.2. Measurements of fresh weight of carrots, fresh and dry weights of leaves, length and largest diameter of carrots, and incidence of powdery mildew (trial 2, Stefano).Values with the same letter are not significantly different.

	Fresh Carrot Weight (g)	**Fresh Weight Leaves (g)**	**Dry Weight Leaves (g)**	**Length (cm)**	**Diameter (mm)**	**Powdery (%)**
Amistar® 3	450.2 a	177.3 a	27.9 a	16.7 a	35.2 a	2.9 a
Amistar® 2	469.2 a	181.6 a	29.0 a	16.5 a	37.1 a	2.1 a
Amistar® 1	494.2 a	187.5 a	33.4 a	17.2 a	36.8 a	11.0 a
Nil	345.8 b	141.5 b	24.1 b	15.1 a	32.5 b	49.8 b
P	**0.015**	**0.007**	**0.012**	**0.22**	**0.003**	**<0.001**
LSD 5%	**93.6**	**23.86**	**4.74**	**NS**	**2.65**	**6.0**

Trial 3

In trial 3, Ricardo carrot fresh weight was increased by approximately 80% when there were one, two or three applications of Amistar when compared to the untreated controls (Table 7.3). In this trial, fresh and dry leaf weight and diameter were significantly higher in treated carrots. Length was not significantly different between all treatments, but powdery mildew incidence was higher in the nil control and single Amistar® treatments than in the double and triple Amistar® treatment, powdery mildew did develop on fungicide-treated carrots as they were left growing for longer than in the previous trials.

Table 7.3. Measurements of fresh weight of carrots, fresh and dry weights of leaves, length and largest diameter of carrots, and incidence of powdery mildew (trial 3, Ricardo).Values with the same letter are not significantly different.

Treatment	**Fresh Carrot Weight (g)**	**Fresh Weight Leaves (g)**	**Dry Weight Leaves (g)**	**Length (mm)**	**Diameter (mm)**	**Powdery (%)**
Amistar® x 3	850 a	311.4 a	57.0 a	15.6 a	36.7 a	48.3 a
Amistar® x 2	556 b	361.3a	61.9 a	11.9 ab	35.8 a	51.7 a
Amistar® x 1	806 ab	330.2 a	56.0 a	15.4 a	36.3 a	74.2 b
Nil	174 c	168.1 b	41.9 b	11.2 b	25.0 b	86.7 b
P	**<0.001**	**<0.001**	**<0.001**	**0.058**	**<0.001**	**<0.01**
LSD 5%	**283.4**	**51.49**	**5.48**	**3.87**	**2.66**	**21.38**

Discussion

The trials were successful in establishing the carrot yield loss to powdery mildew in a greenhouse. Amistar® successfully controlled the disease in the greenhouse under high disease pressure with fewer than three sprays. Disease control was maintained when only one application of the fungicide was applied to the carrots. The disease, however, was controlled by being introduced artificially with careful monitoring after disease appearance, something that does not occur in the field. The greenhouse environment provided ideal conditions for the powdery mildew, as there were uniform temperatures and no rainfall to affect the powdery mildew or remove the applied fungicide. The frequency of application data are useful as a guide for field applications where two applications of Amistar® should suffice in controlling the pathogen.

8. THE HOST RANGE OF *ERYSIPHE HERACLEI* ISOLATED FROM CARROT

Introduction

Powdery mildews are a group of fungi that affect a wide range of plant species, including cucurbits, grapes, pastures, and cereals. The powdery mildews are often specific to a single plant species or closely related species. *Erysiphe heraclei* is the scientific name for the organism causing powdery mildew on carrots. It is also the same name of the powdery mildew organism that affects parsnips and other members of the Apiaceae (carrot family). *Erysiphe heraclei* has been reported in Australia on parsnips for many years, but whether the type of *Erysiphe heraclei* from carrots could infect parsnip was not known. A demonstration that the carrot type could infect parsnips would confirm that cross-infection is real. Weed hosts could also be responsible for carrying over the disease.

Method

The source of the carrot powdery mildew for various trials was from a greenhouse with infected carrot plants. Powdery mildews must be maintained on living host tissue as they are not able to be cultivated on artificial media.

Trial 1
A preliminary trial was undertaken to examine the effect of the carrot powdery mildew on parsley and parsnip. In this trial, three 200 mm pots each of carrots (Stefano), parsnips (Hollow Crown) and parsley (Italian) were grown with powdery mildew infected carrots placed nearby in a greenhouse in temperatures between 20°C and 30°C. The pots were placed close together and leaves were touching and disease incidence was observed. The pots were randomly placed within the greenhouse.

Trial 2
Another trial was established to examine the ability of the carrot powdery mildew that has been found infecting carrots to infect Celery (Green Crunch), Coriander (Cilantro), Parsnip (Hollow Crown), Parsley (Italian) using carrot (Stefano) as the control. Seeds of the members of the Apiaceae to be examined were planted into 300 mm pots with three pots of each randomised throughout a greenhouse which was maintained between 20°C and 30°C. Seed were watered and fertilised, and three weeks after germination, carrot leaves infected with powdery mildew, as the inoculum source, were introduced into the greenhouse.

Ten of each of the weeds listed in Table 8.1 were examined under a microscope for powdery mildew infection each year. These weed were common around carrot crops. Weed members of the Apiaceae were also examined.

Table 8.1. Weeds examined for powdery mildew in the vicinity of carrot crops however none of these weeds belong to the Apiaceae.

Common Name	Scientific name
Black-Berry Nightshade	*Solanum nigrum*
Capeweed	*Arctotheca calendula*
Clover (Button Medic)	*Medicago orbicularis*
Common Sow thistle	*Sonchus oleraceus*
Flax-leaf Fleabane	*Conyza bonariensis*
Indian hedge mustard	*Sisymbrium officinale*
Perennial Ryegrass	*Lolium perenne*
Umbrella Sedge	*Cyperus eragrostis*
Wall Fumitory	*Fumaria muralis*
Wireweed	*Polygonum arenastrum*

Results

The results of the preliminary trial can be seen in Figure 8.1. Only the carrots became seriously infected. There were slight patches on the parsnips, but expansion of symptoms across the leaf did not occur. These plants were grown so that they were touching each other and experiencing extremely high disease pressure.

Fig. 8.1. Symptoms of carrot powdery mildew on the leaves of carrot, parsley, and parsnip.

In the second trial, leaves were examined four weeks after infection, and symptoms of powdery mildew appeared on the carrots only. There were not even patches of powdery mildew on the parsnips. Plants were observed for another six weeks but no other host was found to be infected by the carrot powdery mildew.

From the weed samples collected from around the carrot crops no weeds of any type were found to be infected with powdery mildew. Table 8.2 lists some plants found in western NSW belonging to the Apiaceae (Cunningham *et. al.*1981). Fennel (*Foeniculum vulgare*) is commonly found in the irrigation area, but none examined were found to have powdery mildew.

Table 8.2. Plants belonging to the Apiaceae as listed in Cunningham *et. al.*1981

Common plant name	Scientific name
Gibbons Flannel Flower	*Actinotus gibbonsii*
Clustered Flannel Flower	*Actinotus paddisonii*
Bishops weed	*Ammi majus*
Wild celery	*Apium grovolens*
Slender celery	*Apium leptophyllum*
Australian carrot	*Daucus glochidiatus*
Long eryngium	*Eryngium plantagineum*
Blue devil	*Eryngium rostratum*
Fennel	*Foeniculum vulgare*
Tiny pennywort	*Hydrocotyle callicarpa*
Stinking Pennywort	*Hydrocotyle laxiflora*
Wild Parsley	*Hydrocotyle trachycarpa*
Scrubby Platysace	*Platysace lanceolata*
Purple Parsnip	*Trachymene cyanopetala*
Wild Parsnip	*Trachymene glauciolia*
White Parsnip	*Trachymene ochracea*
Sponge Fruit	*Trachymene ornata*
Creeping carrot	*Uldinia ceratocarpa*

Discussion

Weeds and other members of the Apiaceae examined in these trials were not hosts of the powdery mildew found on carrots. As the fungus appeared previously on parsnips and is now appearing on carrots, it is assumed that there are races of *Erysiphe heraclei* present in Australia. This also indicates that the source of the disease when first observed was not from these other hosts but from other sources. These sources could be seed, visiting machinery, or on people. During trials, powdery mildew was found to be very easy to transport on people, and infections were easily caused by accidental movement from plants in an infected greenhouse to plants in a non-infected greenhouse. Indirectly, the lack of alternate hosts highlights the importance of reducing any carry over carrots from one season to the next. Further, it shows how overlapping plantings may be seriously affected by the disease. A break in the carrot production cycle will reduce the carryover of disease.

9. THE EFFECT OF OVERHEAD IRRIGATION ON POWDERY MILDEW OF CARROT

Introduction

Water has a serious effect on some types of powdery mildew. It has been shown that development across a leaf can be reduced by rain (Sivapalan 1993) and by spraying water (Jarvis and Slingsby 1977). The assumed effect of simulated rain is to wash off germinating conidia. It was also observed that fewer spores (conidia) were produced following rain, but spore production was re-established after three to four days.

A trial was established to confirm observations that water applied to carrots infected with powdery mildew through natural rainfall or overhead irrigation reduced disease levels compared to drip irrigation or furrow irrigation. Carrot powdery mildew disease was observed to be worse in Tasmania when water had become limiting during drought conditions. Carrots grown in the Murrumbidgee Irrigation Area are watered through furrow irrigation, and rainfall is limited in the late summer/autumn period. Powdery mildew pressure during this period can be high.

Method

In a greenhouse, carrot seeds of the variety Ricardo were planted in 35 large tubs measuring 590 mm long, 370 mm wide and 270 mm deep. Soil was added to the tubs and carrots planted in two rows with drip tape run between the rows. Carrots were thinned to 30 carrots per tub and allowed to grow normally. When the carrots were approaching maturity i.e. after two months, powdery mildew was introduced to the greenhouse by placing 200 mm pots of powdery mildew-infected carrots throughout the greenhouse and natural infection allowed to take place.

The carrots were left for a further month to allow powdery mildew to become established. Once the leaves were 100% covered with powdery mildew, various treatments were applied to each of the plants in tubs over a two week period. The trial was divided into five replicates and each treatment was randomly allocated to each. The treatments (Table 9.1) were established to give some indication on the effect of the timing of the irrigation as well as the quantity. Any irrigation effects were to be examined at the end of two weeks by assessing the percentage coverage of powdery mildew on all the leaves of five carrots in each tub. Leaves were numbered such that Leaf 1 was the uppermost (youngest) fully expanded leaf and Leaf 2 the next one down and so on. Tubs were also assessed by examining all plants in the tub and scoring the disease as a percentage of the plants infected. These whole tub assessments were undertaken at the time of the individual leaf assessment as well as seven days later and seven days after that. The leaves had 100% coverage at the time the treatments commenced except for the newest leaves which were small enough (i.e. not fully expanded) not to be infected. The greenhouse was maintained at 18/27 ºC night/day. There were on average ten leaves per carrot. The overhead water was applied through a spray that delivered 750 ml per minute and was restricted to the area of each tub. Drip irrigation was applied daily for 10 mins to all tubs.

Table 9.1. Water treatments applied to tubs during the trial.

Treatment number	Treatment
1	Overhead once a day for 3 mins at 2 pm
2	Overhead one minute-three times a day (6 am, 2 pm and 10 pm)
3	Overhead one minute-twice a day (6 am and 10 pm)
4	Overhead one minute-once a day (2 pm)
5	Overhead one minute-once a day (10 pm)
6	Overhead one minute-once a day (6 am)
7	Drip irrigation only

Results

When the amount of powdery mildew across all the leaves assessed, Treatments 6 and 7 had significantly more disease (P<0.001) than the other five treatments at the end of the two weeks (Figure 9.1). For the top three leaves of each plant a similar result was observed (Figures 9.2, 9.3 and 9.4). The treatments that were applied more than once a day or once but for a longer period or once for one minute in the afternoon or night were better than the drip irrigated tubs or the tubs irrigated overhead for one minute in the morning. In the whole tub visual assessments, by the third assessment two weeks after the treatments finished, there were no differences between any of the treatments (Figure 9.5).

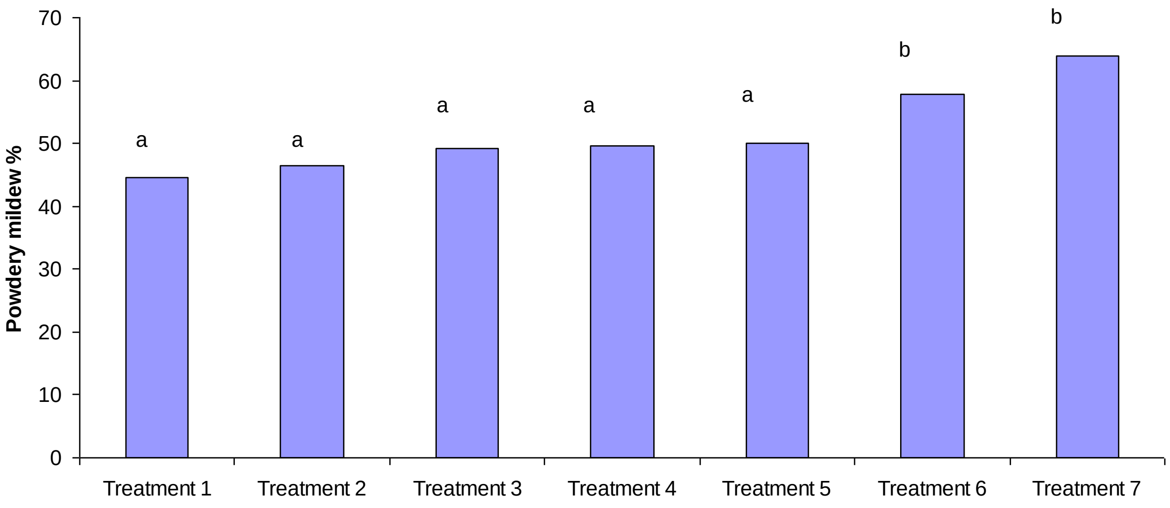


Figure 9.1. Average powdery mildew scores measured across all the leaves assessed. Treatments 1, 2, 3, 4 and 5 were significantly lower than Treatments 6 and 7 (P<0.001, LSD 5%=7.6). Y axis is the percentage of powdery mildew.

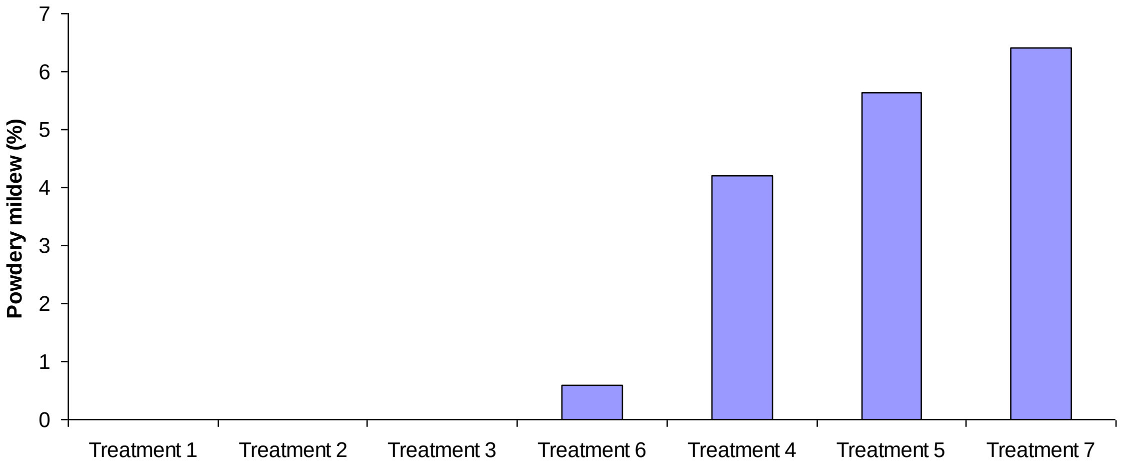


Figure 9.2 Leaf 1 powdery mildew scores, no significant difference between powdery levels. Leaf 1 is the uppermost fully expanded leaf, the one with the least exposure to powdery mildew. It was the leaf that was not fully expanded at the start of the two weeks.

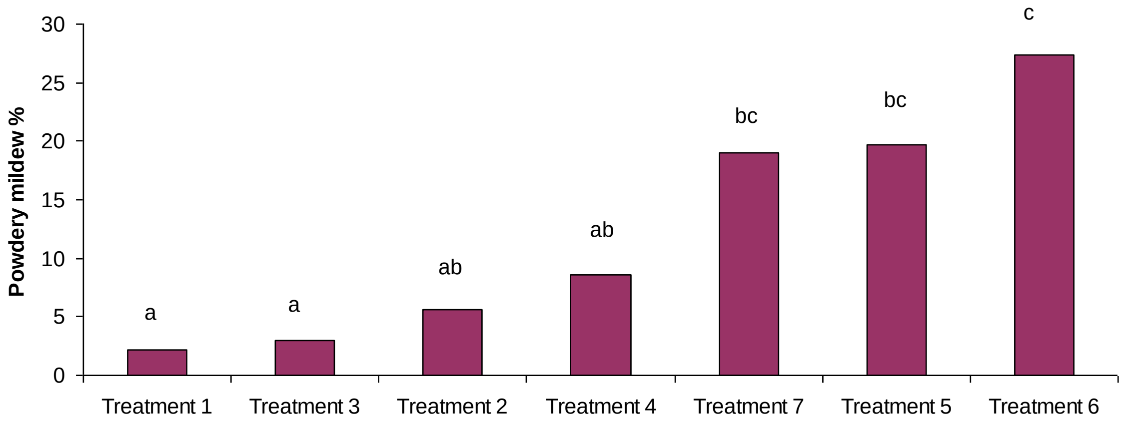


Figure 9.3. Leaf 2 powdery mildew scores, with Treatments 1, 3 and 2 significantly different to Treatments 5, 6 and 7 (P<0.001, LSD 5%=13.5).

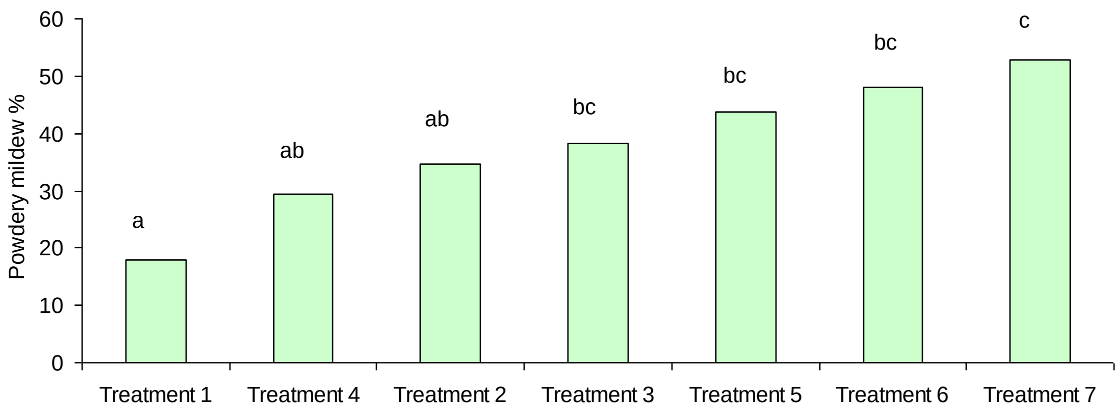


Figure 9.4. Leaf 3 powdery mildew scores. Treatments 1, 4 and 2 significantly different to Treatment 7 (P=0.006, LSD 5%=18.8).

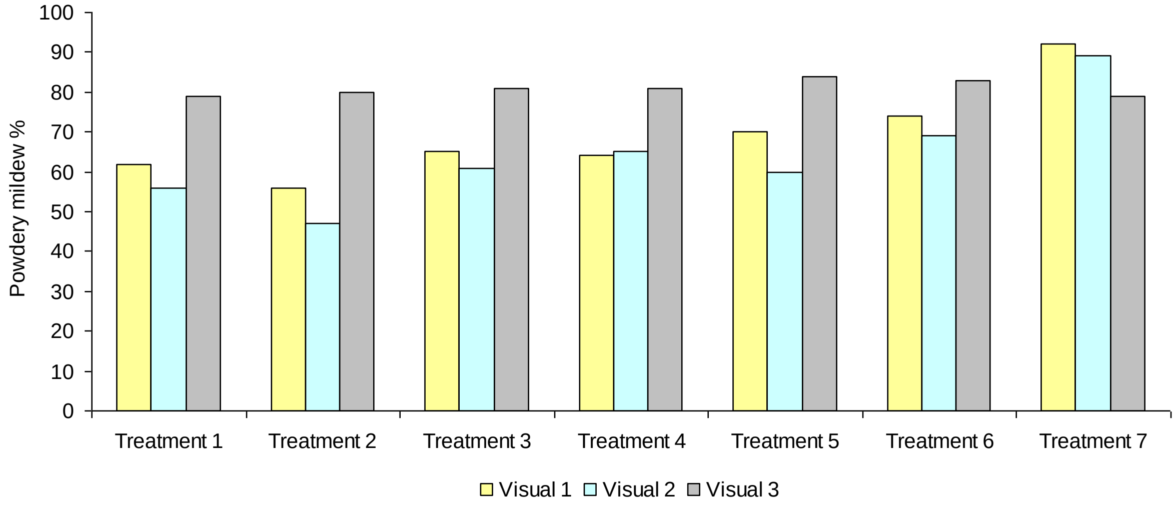


Figure 9.5. Whole tub powdery mildew ratings over a three week period, with the first rating at the same time as the leaf ratings. Y axis is % powdery mildew.

Discussion

The trial was run over a two week period and shows the potential of reducing disease with overhead irrigation and confirms that water applied at the plant base through drip or furrow irrigation will result in higher levels of powdery mildew. There are various reasons that could explain reduced disease due to overhead irrigation including the washing off of conidia, the disruption of growth of the powdery mildew across the leaf, and a restriction of the production of spores. The longer time period of application of water (3 mins) was consistently better than the other treatments.

The results of the trial also indicate why the disease may have become severe in some conditions. The period when the disease was observed in 2007-2009 were the years ending the dry conditions experienced during the recent drought. In Tasmania, water for irrigation (overhead) had become limiting, and powdery mildew was observed for the first time and infection was severe. There have been higher rainfalls and an increased availability of irrigation water since that occurred with less disease being observed.

10. SUSCEPTIBILITY OF CARROT VARIETIES TO POWDERY MILDEW

Introduction

Resistance, or reduced susceptibility, can occur between varieties of plants and plant diseases. Plants are often bred with a resistance to a particular disease which is an effective and economical way to control plant diseases and reduces dependence on fungicides. Therefore some currently grown varieties of carrots were evaluated for reduced susceptibility to powdery mildew in the field and in the greenhouse. The information collected would also benefit studies to determine the best variety for powdery mildew for use in fungicide efficacy trials.

Method

Trial 1-greenhouse

A variety trial was established in a greenhouse that was operating at 20/27 ºC. Pots (200 mm) were filled with soil, and six carrot varieties Stefano, Red Victor, RX 04430762, RS 04472211, CC0018 and Forge were planted into three pots each and randomised throughout the greenhouse. Powdery mildew inoculum was introduced to the pots by placing infected leaves on each pot. By the five leaf stage, all carrots displayed powdery mildew symptoms. Ten weeks after germination, disease levels were assessed as a percentage of leaves infected with powdery mildew on all leaves on six plants per pot per variety. Pots were watered with drippers to reduce overhead irrigation.

Trial 2-field

A trial was conducted in the field at the vegetable block at Yanco Agricultural Institute with the same varieties above to examine any varietal differences in disease susceptibility. Each variety was sown in blocks five metres long with three replicates and three rows per bed per variety. Water was applied by drip irrigation. Sowing was carried out using an Earthway Precision Garden Seeder. Assessment was carried out where each plot was visually assessed for the percentage of plants affected with powdery mildew.

Trial 3-greenhouse

More carrot varieties were provided and planted to determine susceptibility to powdery mildew. Carrots were planted into 200 mm pots in a greenhouse (20/27ºC) and varieties included were Ricardo, Stefano, Ringo, Mojo, Kuroda and Royal Chantenay. There were three replicates of each variety. Powdery mildew was introduced to the pots by placing infected leaves onto each pot after germination. After ten weeks, all leaves on five plants per pot were assessed for the percentage covering of powdery mildew on each leaf.

Trial 4-field

The same carrot varieties as in Trial 3 were planted in the field. The carrots were planted adjacent to a fungicide trial on similar beds, and disease assessment was carried out at maturity. Powdery mildew levels were assessed by examining leaves of five plants of each variety and rating the amount of the leaf covered with powdery mildew. There were three replicates, and each double row plot was three metres long.

Data for all trials were analysed with Genstat Version 11.

Results

Trial-greenhouse

Disease levels were high in all varieties indicating the high disease pressure in the enclosed greenhouse environment. Stefano, Red Victor, CC0018 and RX04430762 were less susceptible to powdery mildew than Forge and RS04472211 (Figure 10.1) when the mean powdery mildew levels were recorded for the leaves assessed for each variety. Figure 10.2 indicates the mean disease levels on each of the assessed leaves.

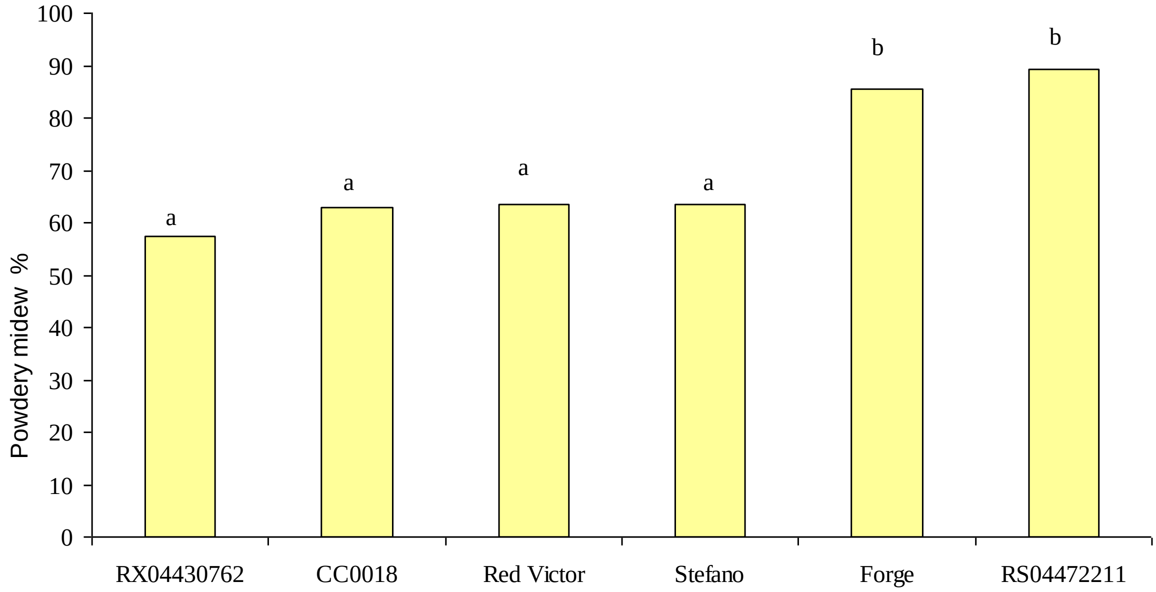


Figure 10.1. The percentage of disease assessed on the leaves of each variety in trial 1. Values with the same letter are not significantly different (P<0.001 and LSD 5%=11).

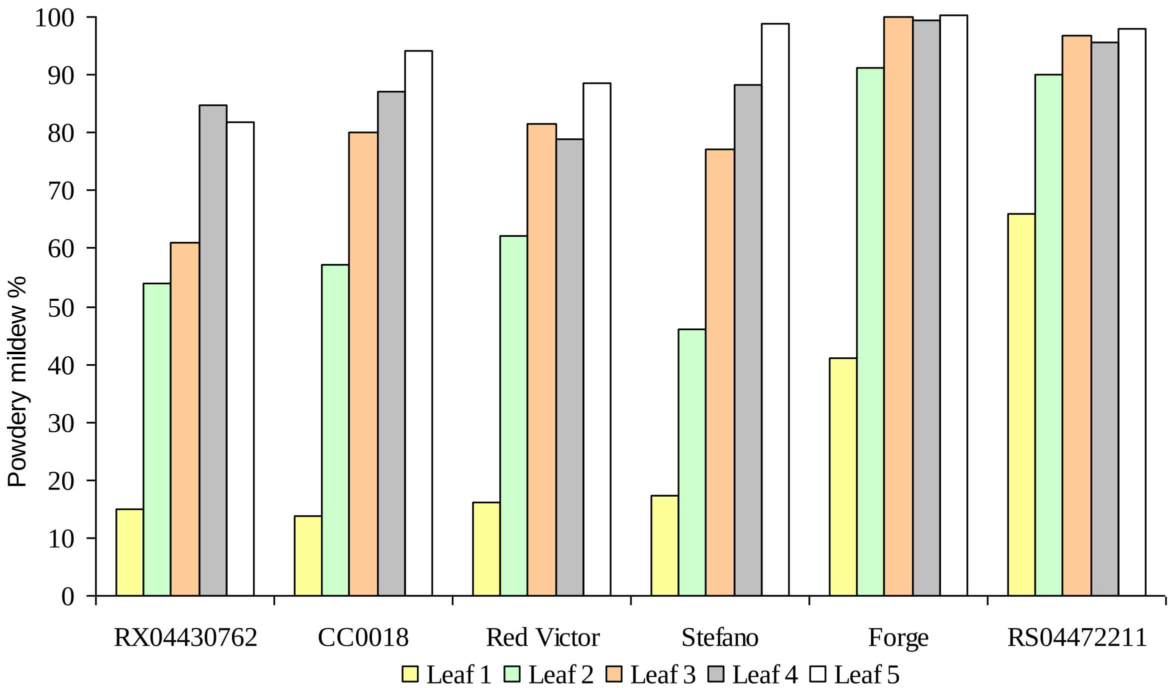


Figure 10.2. The disease levels across each of the five leaves examined from each variety in trial 1.

Trial 2-field

Stefano had the lowest incidence of disease of all varieties, but Stefano, RS 04472211 and RX 04430762 had significantly less disease than Red Victor, Forge and CC0018 (Figure 10.3). The disease levels for RS 04472211 were lower than those in the greenhouse, indicating that disease infection pressure was higher in the greenhouse compared to the field.

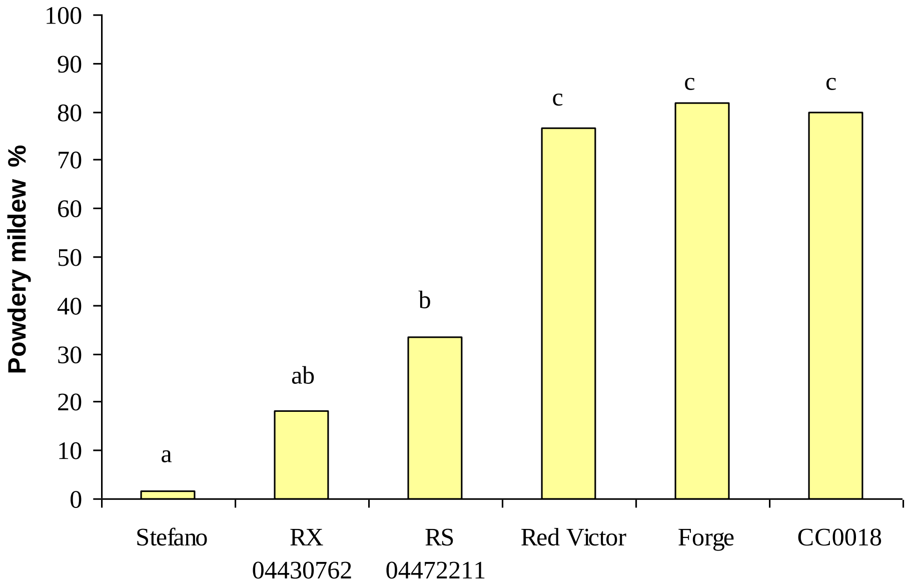


Figure 10.3. Powdery mildew infection scores in the field with six carrot varieties. Values with the same letters are not significantly different (P<0.001, LSD 5%=30.15).

Trial 3-greenhouse
Stefano showed a significantly lower disease level compared to other varieties (Figure 10.4). Ricardo had high susceptibility to powdery mildew confirming the decision to use that variety for fungicide trials.

Trial 4-field
Trends were similar to the greenhouse trial (Figure 10.5) where Ricardo and Ringo had high disease scores whereas Stefano had low scores. Mojo had high incidence of powdery mildew in the greenhouse trial but lower incidence in the field trial.

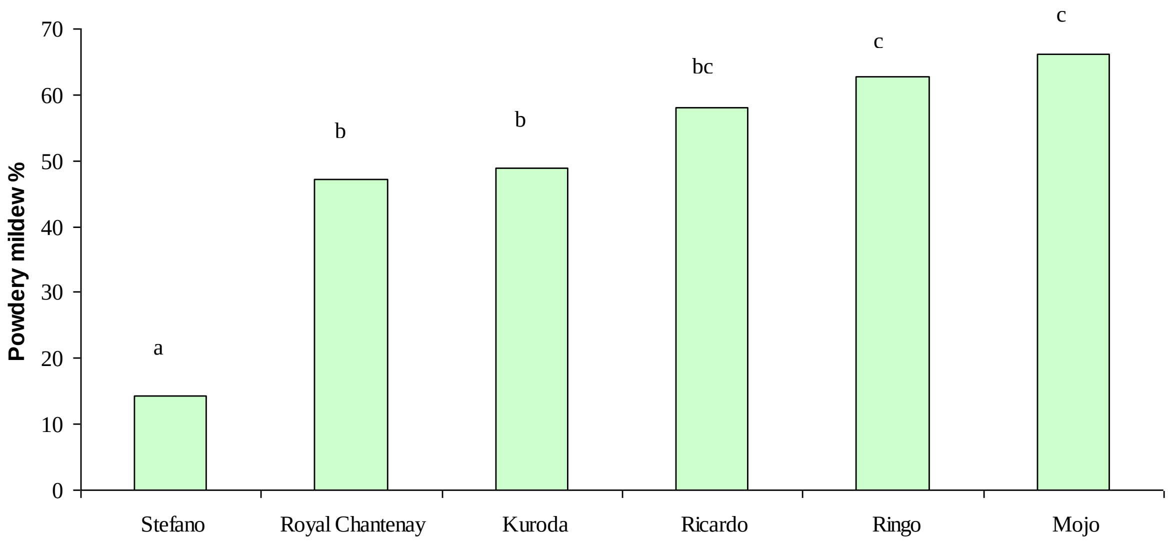


Figure 10.4. Powdery mildew incidence on carrot varieties in Trial 3. Values with the same letters are not significantly different (P<0.001, LSD 5%=13.5)

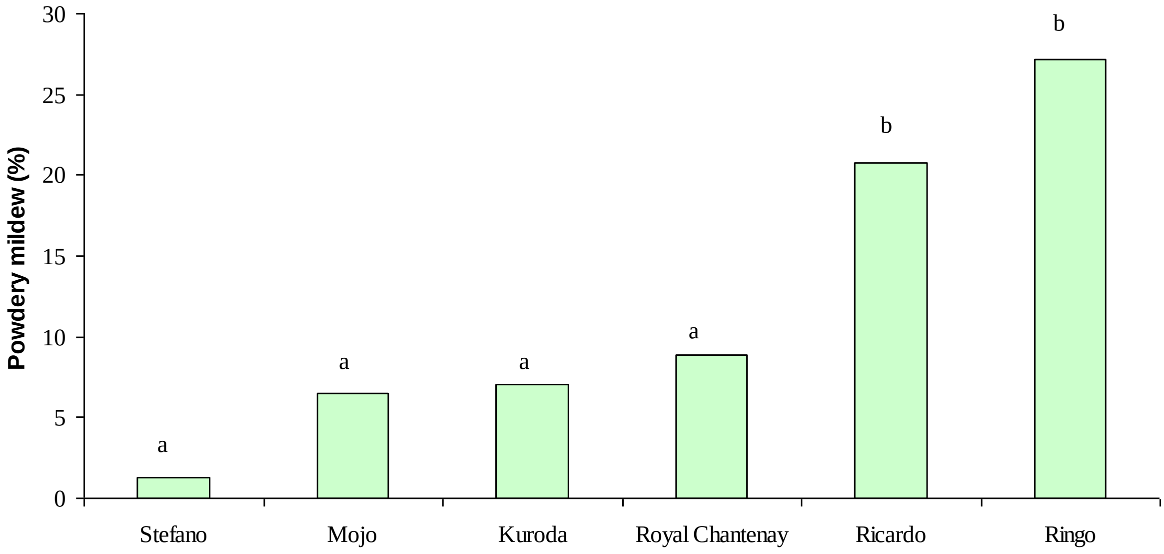


Figure 10.5. Powdery mildew incidence on carrot varieties in field Trial 4. Values with the same letters are not significantly different ($P<0.001$, LSD 5%=10.7).

Discussion

This information collected highlights the variability among the carrot varieties to powdery mildew. This has been shown to occur with other crops, but this is the first time that it has been demonstrated on carrots in Australia. It also is an important demonstration for what carrot variety to use for fungicide trials because the original variety chosen (Stefano) was the most resistant varieties in all trials. The use of this variety should be considered by growers if the carrot is suitable for the end use needed. Greenhouse trials were found to have more disease than those in the field. This could be due to higher disease pressure, uniform temperatures, and no rainfall. The variety trials have been valuable for the industry and give some guidance into priorities for varietal selection. It also is important for seed companies to develop varieties with some resistance to powdery mildew for the Australian market.

The selection of more tolerant varieties gives a useful tool for growers to use in an integrated approach to disease management by optimising the variety combined with tactical fungicide applications.

11. THE EFFECT OF TEMPERATURE ON POWDERY MILDEW OF CARROT

Introduction

An investigation into the effect of temperature on powdery mildew was undertaken to find whether cooler or warmer temperatures favoured disease infection and development. Temperature, moisture and light all have some influence on powdery mildews which affects when and how they infect and when crops are at most risk. Powdery mildew of carrots was first observed late summer and autumn; but whether it could affect carrots during winter was not known at the time. From experience, the disease is found the same time each year but it also occurs occasionally in spring. Carrots can be grown all year round in some parts of Australia so this information, combined with field observations, is critical. A trial was therefore conducted to examine optimal temperatures for powdery mildew disease. The temperatures selected were to represent typical spring conditions, more like summer temperatures and one cooler for much of the southern states growing regions. Night temperatures were kept as close as possible to particularly examine daytime temperatures.

Method

Three greenhouses were used at night/day temperatures of 15/22 ºC, 15/35 ºC and 17/28 ºC. Five pots each of Ricardo and Stefano carrots were planted into 200 mm pots and later thinned to five plants per pot. The carrots were kept free of disease by being isolated from any powdery mildew. At the same time, an equivalent number of pots were placed in a greenhouse (20/25 ºC), and once established, infected with powdery mildew. Ten weeks after planting, the pots with carrots that were free of powdery mildew were moved to the greenhouses with the pots that were 100% infected with powdery mildew. The carrots were at the six leaf stage. The pots were watered from underneath so that leaves were kept dry. The newly introduced plants were then observed for the establishment of powdery mildew. Once powdery mildew was first observed, leaves were then monitored every three days.

Results

Powdery mildew was first observed on leaves five days after the plants were moved into the greenhouses and exposed to the infected carrots. Symptoms were observed in all greenhouse temperatures at the same time. Three leaves were then randomly selected from each pot, marked, and observed, and powdery mildew rated as a percentage of leaf area affected. The newest emerging leaf was not selected.

The progress of powdery mildew was most rapid in the greenhouse at 17/28ºC and slowest at 15/35ºC (Figures 11.1, 11.2 and 11.3). Disease spread was more rapid on Ricardo than Stefano at all three temperature regimes. Disease at the higher temperature (15/35ºC) was significantly lower by the end of the assessment period than at the other temperatures (for Stefano $P<0.001$ and LSD 5% =5.81, Ricardo $P<0.001$ and LSD 5%=5.54–Figure 11.4.) The growth of the powdery mildew was more pronounced on Ricardo compared to Stefano (Figure 11.5). In previous yield loss studies in the greenhouse, Stefano showed a 20% yield loss due to powdery mildew indicating the effect on Ricardo yield loss may be greater. Humidity in each of the greenhouses was measured at 73-85% for the 15/22ºC greenhouse, 60-82% for the 15/35ºC greenhouse and 67-81% for 17/28ºC greenhouse. These small humidity differences suggest humidity should not affect powdery mildew infection or development.

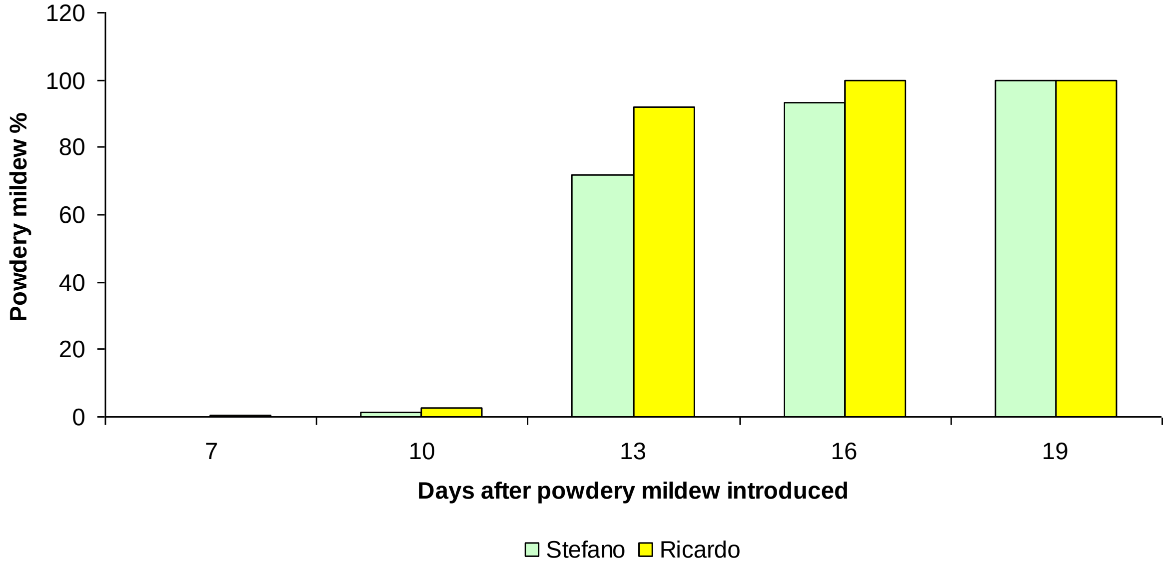


Figure 11.1. Powdery mildew leaf infection development in the greenhouse with night/day temperatures 15/22ºC.

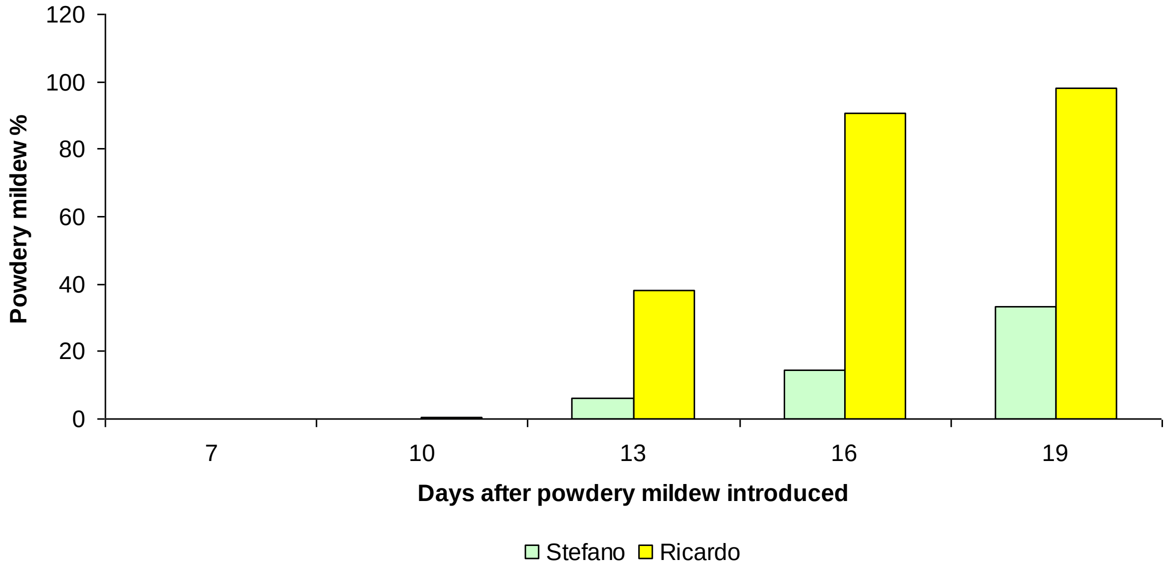


Figure 11.2. Powdery mildew leaf infection development in the greenhouse with night/day temperatures 15/35 ºC.

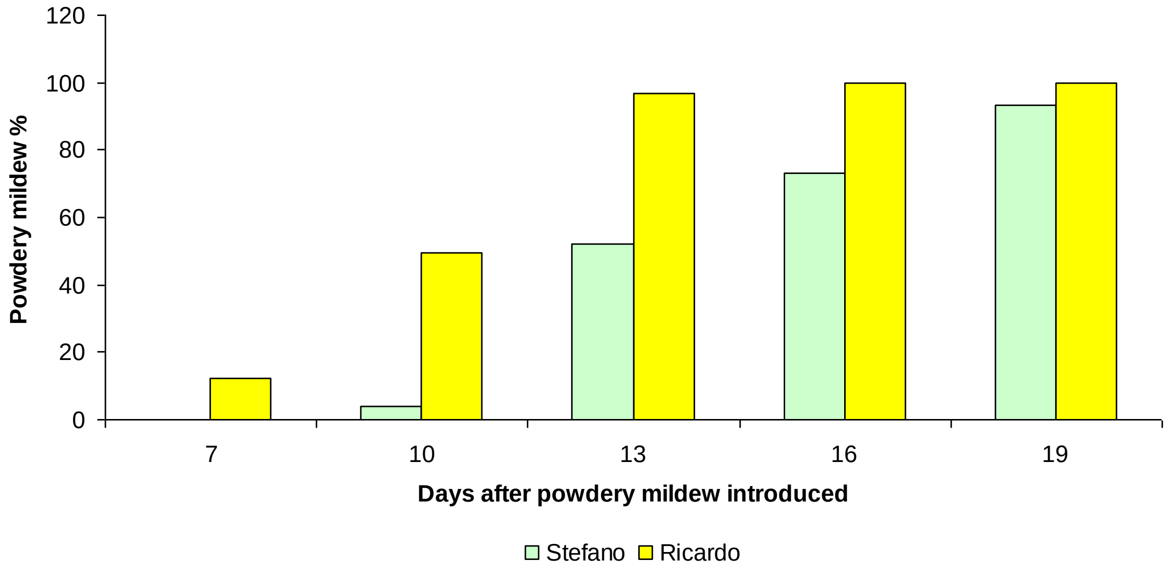


Figure 11.3. Powdery mildew leaf infection development in the greenhouse with night/day temperatures 17/28 ºC.

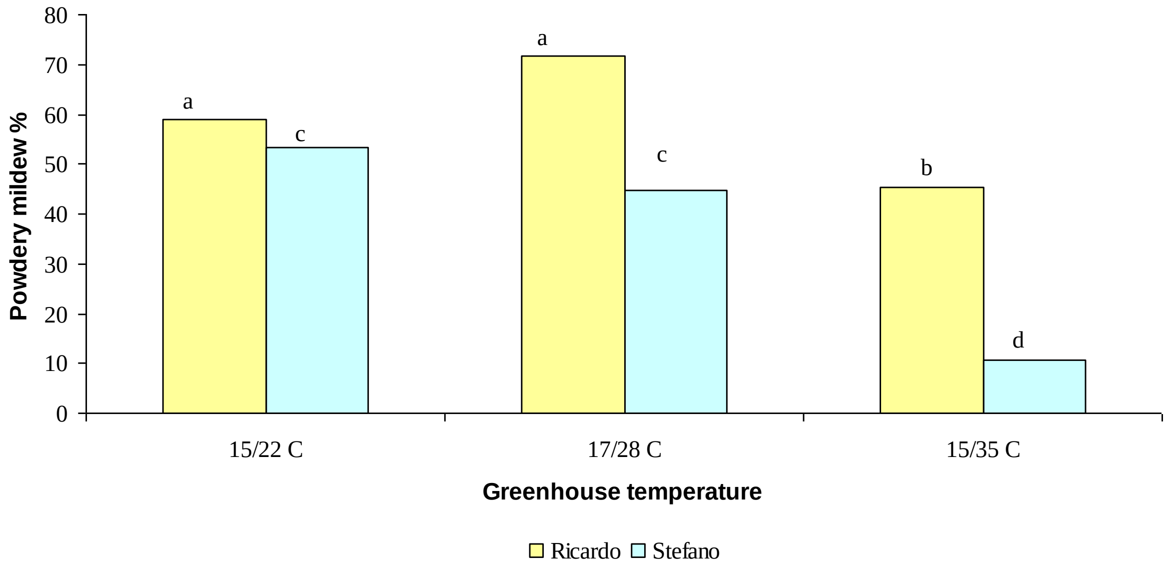


Figure 11.4. Growth of powdery mildew was significantly reduced at the higher temperature of 35 ºC. For Stefano P<0.001 and LSD 5% =5.81, Ricardo P<0.001 and LSD 5%=5.54. Values with the same letter are not significantly different.

Figure 11.5. Plants from the 17/28 ºC greenhouse with Ricardo on the right showing distinctive white powdery growth and Stefano on the left displaying less obvious powdery growth.

Discussion

The 17/28 ºC greenhouse had the most rapid disease establishment indicating that from the three temperatures selected this was more favoured by the powdery mildew infection process. These trials showed how rapid powdery mildew can develop with Ricardo leaves in the 17/28 ºC totally covered within 13 days after the powdery mildew was introduced to the room. However this was under a high inoculum load, no rain or overhead irrigation and an ideal temperature.

This result also indicates that powdery mildew of carrots prefers temperature conditions that match spring and autumn conditions in much of Australia. These conditions, however, may be closer to summer temperatures in Tasmania, indicating that the disease could be problem in that state. For spring infections, the onset of hot weather in summer would reduce disease levels, as 15/35ºC restricted growth. Conversely, infections will continue where the autumn stays warmer and drier, and remains cool. Wetter conditions in the autumn may reduce infection.

The main carrot producing season coincides with the powdery mildew favoured periods in most states. If climate change suggests that drier and warmer conditions will occur, then autumn conditions may become ideal for powdery mildew infection in carrots. Climate change has been demonstrated to have occurred in Australia with an increase in temperatures since 1950 of 1°C, and the eastern carrot growing areas have had fewer frosts and less rain.

12. GROSS MARGINS

The costs incurred associated with powdery mildew on farm income using gross margins are presented in summary under three scenarios. First no powdery mildew, second powdery mildew with fungicide costs included, and third with powdery mildew and a yield reduction of 20%. This yield loss was measured as carrot weight difference between infected and powdery mildew-free carrot plants, and does not account for losses due to the inability to pull the carrots out of the ground due to damage to the tops of the carrots. A summary of the gross margins is represented in Table 12.1 and should only be considered as a guide as costs change, and are variable from region to region, and farm to farm. The gross margin is $681.56 if a yield loss of 20% is considered, a loss of $1000 compared to if no powdery mildew occurs.

Table 12.1. Gross margin data for processing carrots indicating the effect of powdery mildew on the costs for fungicides and application as well as the potential effect on yield. Note that this is only a guide; costs change and are variable from region to region, and farm to farm.

	No powdery mildew	**With powdery mildew including extra sprays and no yield loss**	**With powdery mildew no control assuming 20% yield loss.**
Gross Margin /ha	$1,686.56	$1,392.56	$681.56
Gross Margin /ML	$337.31	$278.51	$136.31

Acknowledgements

The assistance of seed companies that provided seed is appreciated especially South Pacific Seeds that provided quantities of Stefano and Ricardo for field trials.

TASMANIAN RESEARCH ACTIVITIES

SUMMARY

Erysiphe heraclei was identified as the causal agent of powdery mildew in Tasmanian carrot crops. The disease was first confirmed on carrots in Tasmania in March 2008. The onset of widespread and severe powdery mildew appeared to be related to very dry weather conditions and water shortages for irrigation in 2008 and 2009. However, with the return to wetter weather conditions in 2010 and 2011, powdery mildew became less frequent and less severe. *Cercospora carotae*, which causes foliage blight on carrots, was endemic because of constant wet conditions in March and April 2010. The most obvious impact of both powdery mildew and Cercospora leaf blight was in yield loss in severely affected crops because infected foliage broke off easily during the lifting of carrots in the harvesting operation of the fresh market crops. In crops that are infected early, yield reduction may occur due to reduced shoot biomass and crop vigour. In our study, the weight of carrot roots harvested from plants that had severe powdery mildew were found to be approximately 12% to 14% lower than roots that were harvested from adjacent plants that had mild infections.

As powdery mildew on carrots is relatively new in Australia, there was no product registered for use to control powdery mildew on carrots. Although, emergency permits have been issued to allow the use of Amistar® 250 SC in 2008 and Folicur® 430 SC in 2009 in commercial crops for disease control, there have been no studies to validate the efficacy of these products for carrot powdery mildew control in Australia, or to compare them against other fungicides that are also used in other horticultural crops. Under this project, six field trials and a pot trial were conducted to determine the efficacy, application rate and timing of Amistar® and Folicur®, as well as to evaluate other fungicides that are registered for powdery mildew control in other horticultural crops in Tasmania.

- Under high disease pressure, Amistar® SC at 0.3 and 1.0 L/ha, Cabrio® EC at 0.3 L/ha and Folicur® SC at 0.58 L/ha were shown to be more effective than Bayfidan® EC at 0.12 L/ha and Nimrod® EC at 0.18 L/ha for powdery mildew control on carrots. Amistar® SC applied at 0.3 L/ha gave an equivalent level of disease control as 1.0 L/ha for powdery mildew control, reducing leaf coverage by approximately 74% compared to the untreated control.
- In comparing the efficacy of non-residual soft products, applied at the onset of low powdery mildew incidence, wettable sulphur applied at 0.2% w/v was shown to be the most effective product, reducing leaf coverage by 88%. Micro Plus® (*Bacillus lydicus*, a biocontrol agent), Des-O-Germ® (quaternary ammonium, a disinfectant) and Bozul® (sulphur dioxide + benzoic acid, a food grade anti-fungal compound) reduced leaf coverage by 14%, 28% and 32%, respectively. Eco-oil® and a paraffinic oil, applied on their own, had little or no effect on the disease.
- Amistar® applied at 0.3, 0.6 and 1.0 L/ha, was also highly effective in controlling Cercospora leaf blight, reducing leaf blight by 79%, 88% and 92%, respectively, compared to the untreated control. Bravo Weatherstik® at 1.8 L/ha, Folicur® at 1.0 L and Tri-Base Blue® reduced leaf blight by 69%, 49% and 49%, respectively. Sulphur, Eco-oil®, paraffinic oil and Eco-carb® only had relatively weak activity against leaf blight. However, sulphur applied in a tank mix with Eco-oil® or paraffinic oil, resulted in enhanced disease control, reducing leaf blight by 45% and 60% of untreated control.
- A pot trial was conducted in 2011 to determine the effects of sulphur applied alone or in combinations with Amistar®, Bayfidan® and Folicur® fungicides as well as its combination with Hasten® (oil + non-ionic surfactant) and Eco-oil® (emulsified canola oil). Under very high and constant powdery mildew pressure in a glasshouse, sulphur, applied on its own had little or no effect. Sulphur applied with Eco-oil® showed synergistic effect in enhancing disease control, providing greater level of powdery mildew control than Amistar®, Bayfidan® or Folicur® alone. Sulphur applied in combinations with Amistar®, Bayfidan®, Folicur® or Hasten® did not enhance disease control.

Six lots of commercial seeds were obtained from carrot producers in Tasmania to evaluate susceptibility to powdery mildew in a pot trial in November 2010 to January 2011. Two varieties, Mojo and Stefano, were found to have high resistance to powdery mildew. The other varieties, Ringo, Kuroda and Chantenay were susceptible.

13. MONITORING OF POWDERY MILDEW INFECTED CARROT CROPS IN TASMANIA

Powdery mildew infected crops were monitored in Tasmania, to determine the impact of the disease on carrot productivity. *Erysiphe heraclei* was identified as the causal agent of powdery mildew in Tasmanian carrot crops. The disease was first confirmed on carrots in Tasmania in March 2008, although it was believed to be first observed in 2007. The following key observations were made:

- In 2008 and 2009, powdery mildew was evident in carrot crops in north-west Tasmania, especially in February and March. This coincided with the onset of dry weather conditions, which is ideal for the disease.
- The pathogen produces dense white mycelium and spores that covered all above ground plant parts. Infected foliage eventually becomes chlorotic and senesces prematurely, resulting in the thinning of foliage (Figure 13.1). Therefore, the disease generally reduces crop foliage, photosynthesis and crop vigour. Crops may recover from powdery mildew by producing new shoots and leaves, but with substantially reduced foliage (Figure 13.2).
- The most obvious impact of a severely infected crop was in yield loss that occurred when infected foliage broke off easily during the lifting of carrots in the harvesting operation of the fresh market crops, hence leaving many carrots behind in the ground (Figures 13.3-13.4). Processing carrots, which are lifted from below ground by a different harvesting mechanism, were not affected.
- The direct impact of the disease on carrot roots is dependent upon the disease severity and crop stage at onset of the disease. In plants that are infected early, root yield reduction can occur. In our study, the weight of carrot roots harvested from plants that have severe powdery mildew were found to be approximately 12% to 14% lower than roots that were harvested from adjacent plants that have mild infections.

Figure 13.1. Desiccation of powdery mildew infected leaves

Figure 13.2. New shoot growth by plants in severe powdery mildew infected plants

Figure 13.3. Lifting and harvesting of fresh market carrots

Figure 13.4. Carrot roots left in ground because infected leaf stems break off easily during lifting in the harvesting operation

14. SCREENING OF SOFT PRODUCTS FOR CARROT POWDERY MILDEW CONTROL IN 2009

Abstract

In 2009, a field trial was conducted in Tasmania to assess the efficacy of non-residual soft products applied in three spray applications, at the onset of low incidence of leaf infections for protection against powdery mildew.

Sulphur applied at 0.2% w/v gave the most effective disease control. Micro Plus®, Des-O-Germ® and Bozul® had some effect in reducing disease severity, but were not as effective as sulphur.

Eco-oil and a paraffinic oil, applied on their own, were found to have little or no effect on the disease. Eco-oil, applied in a tank mix with sulphur, enhanced disease control.

Introduction

Erysiphe heraclei, the causal agent of powdery mildew in Tasmanian carrot crops, was a relatively new disease on carrots in Australia. There was no product registered to control powdery mildew on carrots. In horticultural crops like apples, cucurbits and grapevines, soft products such as sulphur and oil are commonly used for powdery mildew control. Other soft products such as biocontrol agents, food grade anti-fungal agents and disinfectants are also believed to be suitable for use to protect foliage from powdery mildew. The efficacies of these soft products, however, are not proven for carrot powdery mildew control. Therefore, this study was conducted in 2009 to determine the efficacy of these products when applied to plants at the early onset of the disease, when the disease pressure was initially low.

Materials and Methods

The trial was conducted within a commercial carrot crop (cv. Ringo) sown on 28/08/08 in Red Ferrosol soil at Wesley Vale, Tasmania. The trial design was a randomised complete block with five replicates. Plot size was 1.2 m x 5 m. Spray treatments were applied in three applications on 20/02/09, 28/02/09 and 08/03/09 at 8 day intervals, with 306 L water/ha at 400 kPa with an air-pressurized knapsack precision sprayer fitted with a 1.5 m boom and three TX12 hollow cone nozzles. The first spray was applied at the early onset of powdery mildew infection in the crop. Foliage was assessed for powdery mildew on 30/03/09 and 07/04/09 at close to harvest. Weights of carrots harvested from the middle of each plot (1 m x 1.6 m) were recorded and then adjusted to tonnes per hectare. Disease and carrot yield were analysed using analysis of variance with ARM 7 software. When the analysis of variance indicated a significant treatment effect, Fisher's LSD tests (5% level) were used to compare means of the treatments.

Table 14.1. Treatments evaluated for powdery mildew control

Treatment	Type	Active ingredient	Product rate
Untreated control	Nil	Nil	Nil
Paraffinic oil	paraffinic oil	paraffinic oil	1.0 %
Eco-oil®	botanical oil	canola oil	0.5%
Micro Plus ®	biocontrol agent	*Bacillus lydicus*	0.1%
Des-O-Germ®	disinfectant	quaternary ammonium chloride	0.5%
Bozul®	Food grade broad spectrum biocide	sulphur dioxide + benzoic acid	1.0%
Wettable sulphur	fungicide	sulphur	0.2%
Eco-oil + sulphur	botanical oil + fungicide	canola oil + sulphur	0.05% + 0.2%

Results and Discussion

Sulphur, applied at 0.2% w/v, was the most effective soft product in controlling powdery mildew on carrot foliage (Table 14.2). Sulphur, applied alone or in combination with Eco-oil, gave the greatest disease control compared to all other treatments. The two types of oil products, Eco-oil® and Paraffinic oil, applied on their own, had little or no effect on the disease. Micro Plus®, Des-O-Germ® and Bozul® only showed weak activity in reducing the disease severity.

Although there were no significant differences in the yield of marketable carrots between all treatments, yields tended to be higher in treatments that were effective in reducing powdery mildew severity (Table 14.2).

Figure 14.1. Effects of non-residue soft products in the trial

Table 14.2. Effects of protective treatments applied at the early onset of powdery mildew on disease severity and marketable carrot yield

Treatment	Disease severity rating (0-5) 30/03/09	% Leaf coverage 8/04/09	Weight of marketable carrots (adjusted to tonnes/ha) 8/04/09
Untreated control	4.0 a	100 a	34.2 ± 4.2*
Paraffinic oil 1.0%	4.0 a	100 a	32.7 ± 3.4
Eco-oil® 0.5%	3.8 ab	96 ab	36.4 ± 5.7
Micro Plus® 0.1%	3.4 bc	86 b	37.1 ± 4.3
Des-O-Germ® 0.5%	3.0 cd	72 c	35.1 ± 6.1
Bozul® 1.0%	2.6 d	68 c	37.3 ± 9.8
Wettable sulphur 0.2%	1.8 e	12 d	40.6 ± 4.0
Eco-oil® 0.05% + Sulphur 0.2%	1.4 e	22 d	38.1 ± 5.4
p-value	**0.0001**	**0.0001**	**0.429**

Disease severity rating: 0 = no disease, 1 < 20%, 2 = 20-40%, 3 = 40-60%, 4 = 60-80% and 5 = 80-100% leaf coverage. Numbers in a column followed by the same letter are not significantly different at P =0.05, Fisher's Protected LSD Test.
* ± standard error

15. SCREENING FUNGICIDES FOR CARROT POWDERY MILDEW CONTROL IN 2009

Abstract

A field trial was conducted, within a commercial carrot crop at Wesley Vale, Tasmania in 2009, which had severe and high incidence of powdery mildew, in order to assess the efficacy of fungicides applied in three spray applications, in protecting new foliage and reducing disease severity. Amistar®, Cabrio® and Folicur® were more effective than Bayfidan® and Nimrod® in reducing disease severity on new leaves. Amistar® applied at 0.3 L/ha gave similar level of disease control as the rate of 1.0 L/ha.

Introduction

Erysiphe heraclei the causal agent of powdery mildew is a relatively new disease in Australia. There was no product registered to control powdery mildew on carrots in Australia. Two emergency permits have been issued to allow the use of Amistar® 250 SC in 2008 and Folicur® 430 SC in 2009 in commercial crops. There have been little or no studies to validate the efficacy of these products for carrot powdery mildew in Australia. This trial was therefore conducted in 2009 to compare the efficacy of Amistar® and Folicur®, as well as Bayfidan®, Cabrio® and Nimrod®, which are registered for powdery mildew control in other horticultural crops in Australia.

Materials and Methods

The trial was conducted at Wesley Vale, within a commercial carrot crop (cv. Ringo), sown on 28 August 2008. The trial design was a randomised complete block with five replicates. Plot size was 1.2 m x 5 m. Spray treatments were applied in two foliar spray applications at 8 day intervals on 20/02/09 and 28/02/09, with 306 L water/ha and at 400 kPa using an air-pressurized knapsack precision sprayer fitted with a 1.5 m boom and three TX12 hollow cone nozzles. The first spray was applied when the crop already had widespread and severe powdery mildew on the foliage. New foliage that developed after the first spray applications were assessed for powdery mildew on 30/03/09 and 08/04/09 at close to harvest. Weights of carrots harvested from the middle of each plot (1 m x 1.6 m) were recorded and then adjusted to tonnes per hectare. Disease and carrot yield were analysed using analysis of variance with ARM 7 software. When the analysis of variance indicated a significant treatment effect, Fisher's LSD tests (5% level) was used to compare means of the treatments.

Table 15.1. Treatments evaluated for powdery mildew control

Treatment	Active ingredient	Product Rate
Untreated control	Nil	Nil
Nimrod® 250 EC	bupirimate	0.18 L/ha
Bayfidan® 250 EC	triadimenol	0.12 L/ha
Folicur® 430 SC	tebuconazole	0.58 L/ha
Amistar® 250 SC	azoxystrobin	0.3 L/ha
Amistar® 250 SC	azoxystrobin	1 L/ha
Amistar® 250 SC + Du-Wett®*	azoxystrobin + adjuvant	0.3 L/ha
Cabrio® 250 EC	pyraclostrobin	0.3 L/ha

* Du-Wett® is 500 g/L trisiloxane ethoxylate, an organosilicone-based spray adjuvant. Numbers in a column followed by the same letter are not significantly different at P =0.05, Fisher's Protected LSD Test.

Results and Discussion

Plots showed the effect of fungicides as shown in Figure 15.1. Amistar® at 0.3 and 1.0 L/ha, Cabrio® at 0.3 L/ha and Folicur® at 0.58 L/ha gave highly effective disease control, substantially reducing the percentage of leaf coverage in the plot area and the disease severity rating (Table 15.2). These fungicides were generally more effective than Nimrod® at 0.18 L/ha and Bayfidan® at 0.12 L/ha.

Amistar® applied at 0.3 L/ha had equivalent level of disease control as the rate of 1.0 L/ha (Table 15.2). However, at the end of the trial, in field observations, Amistar® at 1.0 L/ha consistently held back leaf infections on new leaves by approximately one week longer compared to Amistar® at 0.3 L/ha. This indicates that the higher rate may have a slightly longer residual effect, which helped prolong the disease control. Cabrio® at 0.3 L/ha was as effective as Amistar® at 0.3 and 1.0 L/ha. The spray adjuvant, Du-Wett®, did not appear to improve disease control by Amistar® at 0.3 L/ha.

Figure 15.1. Fungicide treatment effects in the trial

Although there were no significant differences in the yield of marketable carrots between all treatments, there tended to be higher yields in all the fungicide treatments.

Table 15.2. Effects of systemic fungicides applied after the onset of widespread powdery mildew in reducing disease severity on new leaves and marketable carrot yield

	Powdery mildew		
Treatment	**Disease severity rating (0-5) 30/03/09**	**% Leaf coverage 8/04/09**	**Weight of marketable carrots (adjusted to tonnes/ha) 8/04/09**
Untreated control	5.0 a	100 a	33.5 ± 4.4*
Nimrod® 0.18 L/ha	4.6 a	80 b	36.0 ± 2.2
Bayfidan® 0.12 L/ha	3.6 b	46 c	35.8 ± 3.3
Folicur® SC 0.58 L/ha	3.0 bc	32 cd	37.0 ± 3.7
Amistar® 0.3 L/ha	3.0 bc	28 d	35.1 ± 2.9
Amistar® 1 L/ha	3.0 bc	24 d	39.2 ± 3.8
Amistar® 0.3 L/ha + Du-Wett®	2.8 c	24 d	38.4 ± 3.3
Cabrio® EC 0.3 L/ha	2.4 c	26 d	37.7 ± 6.6
p-value	**0.0001**	**0.0001**	**0.202**

Disease severity rating: 1 < 20%, 2 = 20-40%, 3 = 40-60%, 4 = 60-80% and 5 = 80-100% leaf coverage. Numbers in a column followed by the same letter are not significantly different at P =0.05, Fisher's Protected LSD Test.
* ± standard deviation of replicate plot values

16. THE EFFICACY OF DIFFERENT RATES OF AZOXYSTROBIN AND TEBUCONAZOLE FOR FOLIAR DISEASE CONTROL ON CARROTS IN 2010

Abstract

In 2010, a field trial was conducted in Tasmania to determine the optimum rate of Amistar® (azoxystrobin) and Folicur® (tebuconazole), applied at 0.3, 0.6 and 1.0 L/ha in three spray applications with 400 L water/ha. The efficacy of three other products, TriBase Blue® (copper sulphate), Bravo Weatherstik® (iprodione) at 1.8 L/ha and wettable sulphur at 0.8 kg/ha, were also examined. There was no powdery mildew in the crop, but it was severely affected by foliage blight caused by *Cercospora carotae*.

All fungicide treatments reduced Cercospora leaf blight and petiole necrosis, and hence increased the shoot biomass compared to the untreated control. Amistar® and Bravo Weatherstik® were the most effective fungicides in controlling Cercospora leaf blight. Folicur® and Tribase Blue® also have activities in controlling Cercospora leaf blight, but they were not as effective as Amistar® and Bravo Weatherstik®. There were rate responses with Amistar® and Folicur®, where higher rates tend to provided slightly greater level of disease control.

Introduction

Currently, temporary permits have been issued for the commercial use of Amistar® 250 SC and Folicur® 430 SC for the powdery mildew control in carrots. The permit's recommended rates are 1.0 L/ha for Amistar® and 580 ml/ha for Folicur®. A previous trial conducted in 2009 in Tasmania showed that Amistar® applied at 0.3 L was as effective as 1.0 L. The use of the lower application rate could provide substantial savings to growers. There have been little or no studies to determine the optimum rates of Amistar® or Folicur® on powdery mildew and other foliar diseases of carrots. Therefore, this study was conducted to compare the efficacy of three rates of Amistar® and Folicur®. The efficacy of three other products TriBase Blue® (copper sulphate), Bravo Weatherstik® (iprodione) and wettable sulphur, were also evaluated.

Materials and Methods

The trial was conducted at Wesley Vale, within a commercial carrot crop (cv. Ringo), sown on 05/11/09. The trial design was a randomised complete block with four replicates. Plot size was 1.2 m x 5 m. Spray treatments were applied in three foliar spray applications at 7 day interval on 25/02/10, 04/03/10 and 11/03/10, with 400 L water/ha and at 400 kPa using an air-pressurized knapsack precision sprayer fitted with a 1.5 m boom and three TX18 hollow cone nozzles. Leaf spots to *Cercospora carotae* were first noted in some untreated control plots in early March. Foliage was assessed for leaf and petiole blight due to *Cercospora* instead on 13/04/10 and 22/04/10 at close to harvest. There was no powdery mildew in the crop.

Table 16.1. Treatments evaluated in the trial at Wesley Vale in 2010

Product	Active ingredient	Product Rate
Untreated control	Nil	
Amistar® 0.3 L/ha	azoxystrobin	0.3 L/ha
Amistar® 0.6 L/ha	azoxystrobin	0.6 L/ha
Amistar® 1.0 L/ha	azoxystrobin	1.0 L/ha
Folicur® 0.3 L/ha	tebuconazole	0.3 L/ha
Folicur® 0.6 L/ha	tebuconazole	0.6 L/ha
Folicur® 1.0 L/ha	tebuconazole	1.0 L/ha
Tribase blue® 1.12 L/ha	Tribasic copper sulphate	1.12 L/ha
Bravo Weatherstik®	iprodione	1.8 L/ha
Wettable sulphur 0.8 kg/ha	sulphur	0.8 kg/ha or 200 g/ 100 L

Plants in each plot were assessed for Cercospora leaf blight coverage based on estimation of the percentage of leaves in the whole plot that were affected by leaf blight. Leaf petioles caused by Cercospora leaf blight were also examined and rated according to the rating scale:

1 Healthy and vigorous
2 few petiole lesions, no petiole necrosis
3 petiole lesions numerous, no petiole necrosis
4 1 to 20% petiole necrosis
5 21 to 40% petiole necrosis
6 41 to 60% petiole necrosis
7 61 to 80% petiole necrosis
8 81 to 90% petiole necrosis
9 91% petiole necrosis
10 100% petiole necrosis

At crop maturity, plants were harvested from a 2 m row from each plot and were assessed for shoot weights and root weights. Disease and carrot yield were analysed using analysis of variance with ARM 7 software. When the analysis of variance indicated a significant treatment effect, Fisher's LSD tests (5% level) was used to compare means of the treatments.

Results and Discussion

In the summer of 2010, powdery mildew was not an issue on carrot crops in Tasmania. This was due to relatively wet weather conditions, which were not favourable to the disease. Instead, the crop in the trial was affected by severe Cercospora foliage blight in April. Leaf and petiole blight were caused by *C. carotae* infections. Therefore, the fungicide treatments were evaluated for leaf blight control (Table 16.2).

Table 16.2. Treatment effects on leaf blight and petiole necrosis due to *Cercospora* infections

	Cercospora blight			
Treatment	**% Leaf blight**	**Petiole necrosis (rating 0-10)**	**Shoot biomass fresh weight kg/2 m row**	**Carrot yield root weight kg/2 m row**
Untreated control	68 a	6.3 a	0.77 bc	3.43 ± 0.13*
Amistar® 0.3 L/ha	14 de	3.8 bc	1.12 a	4.30 ± 0.28
Amistar® 0.6 L/ha	8 de	4.0 bc	1.05 a	3.49 ± 0.28
Amistar® 1.0 L/ha	5 e	3.5 c	1.10 a	4.18 ± 0.11
Folicur® 0.3 L/ha	38 b	4.3 bc	0.83 bc	3.86 ± 0.51
Folicur® 0.6 L/ha	40 b	4.5 bc	0.85 bc	3.37 ± 0.21
Folicur® 1.0 L/ha	35 bc	4.5 bc	0.84 bc	3.51 ± 0.33
Tribase blue® 1.12 L/ha	35 bc	4.8 b	0.90 b	3.67 ± 0.28
Bravo Weatherstik®	21 cd	4.3 bc	1.05 a	4.04 ± 0.13
Wettable sulphur 0.8 kg/ha	75 a	6.8 a	0.75 c	3.86 ± 0.09
p-value	**0.0001**	**0.0001**	**0.0001**	**0.0791**

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

All fungicide treatments reduced leaf blight and leaf petiole necrosis, and hence increased the above ground plant biomass with increases in the shoot fresh weights compared to the untreated control (Table 16.2). There was no significant difference in the carrot root yield between treatments because of high variability between replicate plots. Amistar® was the most effective fungicide in controlling Cercospora leaf blight, followed by Bravo Weatherstik®. Folicur® and Tribase Blue®, also have activities in controlling Cercospora leaf blight, but they were not as effective as Amistar® and Bravo

Weatherstik®. There were rate responses with Amistar® and Folicur®, where the highest rate at 1.0 L/ha gave the greatest level of disease control.

Figure 16.2. Cercospora leaf blight (left) and petiole necrosis (right)

Figure 16.3. Shoot biomass of untreated control and Amistar® treated plants (left)

17. THE EFFECTS OF THE TIMING OF AZOXYSTROBIN AND SULPHUR APPLICATIONS FOR FOLIAR DISEASE CONTROL IN CARROTS IN 2010

Abstract

In 2010, a field trial was conducted in Tasmania to assess the timing of Amistar® at 0.3 L/ha, Folicur® at 0.58 L/ha and sulphur at 0.8 kg/ha, applied in four combinational spray applications with 400 L water/ha. There was no powdery mildew in the crop, but it was severely affected by Cercospora leaf blight. Amistar®, applied alone or in spray programs with sulphur, was the most effective treatment in controlling Cercospora leaf blight, reducing leaf blight by 85% compared to the untreated control. Folicur® applied in two sprays, before or after two sulphur applications, gave relatively weak disease control, reducing leaf blight by 33%. Sulphur only treatments at all application timings, generally gave poor leaf blight control. The timings of Amistar® applications did not appear to produce any consistent effect on the levels of leaf blight control.

Introduction

Conventionally, protectant fungicides such as sulphur are recommended for use on crops before the onset of foliar diseases. Systemic fungicides, such as Amistar, however, are usually used after the onset of widespread foliar infections. Because systemic fungicides are usually more effective than protectant fungicides for foliar disease control, they are often used as eradicant fungicides to reduce and control foliar diseases. However, most systemic fungicides are not true eradicants and are most effective when applied before or at the early onset of infections. Once a disease has become widespread and severe, there is a very high risk of developing fungicide resistance if growers continued using systemic fungicides. This study was conducted to determine the impact of fungicide application timings of Amistar®, Folicur® and sulphur for powdery mildew control.

Materials and Methods

The trial was conducted at Wesley Vale, within a commercial carrot crop (cv. Ringo), sown on 5/11/09. The trial design was a randomised complete block with four replicates. Plot size was 1.2 m x 5 m. Spray treatments (Table 17.1) were applied in two to four foliar spray applications at 7 to 8 day intervals on 09/02/10, 16/02/10, 24/02/10 and 04/03/10, with 400 L water/ha and at 400 kPa using an air-pressurized knapsack precision sprayer fitted with a 1.5 m boom and three TX18 hollow cone nozzles. Leaf spots to *Cercospora carotae* were first noted in some untreated control plots in early March. There was no powdery mildew in the crop, but there was widespread and severe Cercospora leaf blight in April due to relatively wet weather conditions in March and April of 2010. Foliage was assessed for leaf and petiole blight due to *Cercospora* instead on 13/04/10 and 22/04/10 at close to harvest, as described in the previous trial. Disease and carrot yield were analysed using analysis of variance with ARM 7 software. When the analysis of variance indicated a significant treatment effect, Fisher’s LSD tests (5% level) were used to compare means of the treatments.

Table 17.1. Treatments evaluated in the trial

No.	Treatment	Application schedule			
1	Untreated control	09/02/10	16/02/10	24/02/10	04/03/10
2	2xSulphur/Nil	Sulphur	Sulphur	Nil	Nil
3	4xSulphur	Sulphur	Sulphur	Sulphur	Sulphur
4	Nil/2xSulphur	Nil	Nil	Sulphur	Sulphur
5	2xAmistar®/Nil	Amistar®	Amistar®	Nil	Nil
6	Nil/2xAmistar®	Nil	Nil	Amistar®	Amistar®
7	2xSulphur/2xAmistar®	Sulphur	Sulphur	Amistar®	Amistar®
8	2xAmistar®/2xSulphur	Amistar®	Amistar®	Sulphur	Sulphur
9	2xSulphur/2xFolicur®	Sulphur	Sulphur	Folicur®	Folicur®
10	2xFolicur®/2xSulphur	Folicur®	Folicur®	Sulphur	Sulphur

Sulphur 800 WP applied at 200 g/100 L or 0.8 kg/ha at 400 L
Amistar® 250 SC applied at 0.3 L/ha
Folicur® 430 SC applied at 0.58 L/ha

Results and Discussion

There was no powdery mildew in the trial area, so no comparisons are possible for the disease control. The trial area, however, was affected by widespread and severe Cercospora leaf blight. Therefore, plants were assessed for leaf blight and petiole necrosis due to infections by *C. carotae*.

Generally, all treatment programs containing Amistar® or Folicur® reduced Cercospora leaf blight and petiole necrosis, and hence increased the shoot fresh weight compared to the untreated control (Table 17.2).

Amistar, applied alone or in spray programs with sulphur, was the most effective treatment in controlling Cercospora leaf blight, reducing % leaf blight by 85% compared to the untreated control.

Folicur applied in two sprays, before or after two sulphur applications, gave relatively weak disease control, reducing leaf blight by 33% compared to the untreated control.

Sulphur only treatments at all application timings, generally gave poor leaf blight control and had little or no effect in increasing shoot biomass.

Timings of Amistar® applications did not produce any consistent trends in the levels of leaf blight control. It is interesting to note that two early applications of Amistar® resulted in significantly higher shoot biomass and carrot yield than all other treatments (Table 17.2).

Table 17.2. Treatment effects on leaf blight and petiole necrosis due to *Cercospora* infections

Treatment	% Leaf blight		% Petiole necrosis rating		Shoot fresh biomass weight kg/2 m row		Carrot yield root weight kg/2 m row		
Untreated control	73	a	7	a	0.67	f	3.71	b	± 0.27*
2xSulphur/Nil	48	b	5	c	0.80	ef	4.09	b	± 0.49
4xSulphur	60	ab	6	b	0.79	ef	3.95	b	± 0.34
Nil/2xSulphur	75	a	6	ab	0.73	ef	3.93	b	± 0.34
2xAmistar®/Nil	8	c	4	c	1.18	a	5.42	a	± 0.39
Nil/2xAmistar®	14	c	4	c	1.02	bc	3.96	b	± 0.46
2xSulphur/2xAmistar®	10	c	4	c	1.06	ab	4.43	b	± 0.23
2xAmistar®/2xSulphur	23	c	4	c	0.98	bcd	4.10	b	± 0.29
2xSulphur/2xFolicur®	48	b	5	c	0.86	cde	4.11	b	± 0.21
2xFolicur®/2xSulphur	50	b	5	c	0.83	def	3.82	b	± 0.22
p-value	**0.0001**		**0.0001**		**0.0001**		**0.0345**		

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

Figure 17.2. Severe leaf blight due to *Cercospora*

Figure 17.3. Differences in leaf blight severity between treatment plots in the field

18. THE EFFECTS OF SOFT PRODUCTS FOR FOLIAR DISEASE CONTROL IN CARROTS IN 2010

Abstract

In 2010, a field trial was conducted in Tasmania to determine the effects of non-residual soft products, applied alone and in combinations, for powdery mildew control.

There was no powdery mildew in the crop. The trial area, however, was affected by widespread and severe Cercospora leaf blight. Sulphur and paraffinic oil had some activity in reducing the blight disease severity, whereas Eco-oil® had little or no effect on the disease. Enhanced disease control was recorded when sulphur was applied in a mixture with either Eco-oil® or paraffinic oil. Sulphur plus Eco-carb® had no effect in disease control.

Introduction

This study was conducted to examine the efficacy of soft products such as sulphur, horticultural oils (Eco-oil® and paraffinic oil) and potassium bicarbonate (Eco-carb®) for the control of powdery mildew. The products were also combined as tank mixes to determine if there are synergistic effects for powdery mildew control.

Materials and Methods

The trial was conducted at Wesley Vale within a commercial carrot crop (cv. Ringo) sown on 5/11/09. The trial design was a randomised complete block with four replicates. Plot size was 1.2 m x 5 m. Spray treatments (Table 18.1) were applied in three foliar spray applications at 7 day interval on 25/02/10, 04/03/10 and 11/03/10, with 400 L water/ha and at 400 kPa using an air-pressurized knapsack precision sprayer fitted with a 1.5 m boom and three TX18 hollow cone nozzles. Leaf spots to *Cercospora carotae* were first noted in some untreated control plots in early March. There was no powdery mildew in the crop, but there was widespread and severe Cercospora leaf blight in April due to relatively wet weather conditions in March and April of 2010. Foliage was assessed for leaf and petiole blight due to *Cercospora* instead on 13/04/10 and 26/04/10 at close to harvest, as described in the previous trial. Weights of carrots harvested from the middle of each plot (2 m row) were recorded. Disease and carrot yield were analysed using analysis of variance with ARM 7 software. When the analysis of variance indicated a significant treatment effect, Fisher's LSD tests (5% level) were used to compare means of the treatments.

Table 18.1. Treatments evaluated in the trial

No.	Treatment	Active ingredient	Rate
1	Untreated control	Nil	200 g/100 L
2	Sulphur 0.2%	wettable sulphur	200 g/100 L
3	Eco-oil® 0.2%	canola oil	200 ml/100 L
4	Paraffinic oil 1%	paraffinic oil	1.0 L/100 L
5	Eco-carb® 0.4%	potassium bicarbonate	400 g/100 L
6	Eco-oil® + sulphur	canola oil + sulphur	200 ml + 200 g / 100 L
7	Eco-oil® + Ecocarb®	canola oil + potassium bicarbonate	200 ml + 400 g per 100L
8	Paraffinic oil + sulphur	paraffinic oil + sulphur	1.0 L + 200 g/100 L

Results and Discussion

There was no powdery mildew in the crop. The trial area, however, was affected by widespread and severe Cercospora leaf blight. Therefore, the products were evaluated for Cercospora blight control. Sulphur and paraffinic oil showed some activity in reducing leaf blight and petiole necrosis (Table 18.2). Eco-oil®, on its own, had little or no effect on the disease. Sulphur, applied in a mixture with either Eco-oil® or paraffinic oil, was significantly more effective in reducing leaf blight than when each product was applied alone. Sulphur plus Eco-carb® had no effect in disease control.

Table 18.2. Treatment effects on leaf blight and petiole necrosis due to *Cercospora* infections

Treatment	% Leaf blight	% Petiole necrosis rating	Shoot biomass fresh weight kg/2 m row	Carrot yield root weight kg/2 m row
Untreated control	88 a	7.8 a	0.64	4.00 ± 0.28*
Sulphur 0.2%	63 bc	6.5 cd	0.69	4.13 ± 0.20
Eco-oil® 0.2%	75 ab	7.3 ab	0.66	4.24 ± 0.34
Paraffinic oil 1%	60 cd	6.3 cd	0.63	4.17 ± 0.31
Eco-carb® 0.4%	65 bc	6.5 cd	0.62	4.17 ± 0.08
Eco-oil® + sulphur	48 de	6.0 d	0.72	4.45 ± 0.14
Eco-oil® + Ecocarb	80 a	6.8 bc	0.55	3.95 ± 0.27
Paraffinic oil + sulphur	35 e	5.3 e	0.70	4.03 ± 0.14
P-value	**0.0001**	**0.0003**	**0.1485**	**0.8511**

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

19. THE POTENTIAL OF FUNGICIDE COMBINATIONS FOR ENHANCING POWDERY MILDEW CONTROL IN CARROTS IN 2011

Abstract

A pot trial was conducted in 2011 in a glasshouse in Tasmania to determine the effects of sulphur applied alone or in combinations with Amistar®, Bayfidan® and Folicur® fungicides as well as in combinations with Hasten® (oil + non-ionic surfactant) and Eco-oil® (emulsified canola oil). Under very high and constant disease pressure in a glasshouse, sulphur, applied on its own had little or no effect. Sulphur applied with Eco-oil® showed a synergistic effect in enhancing disease control, providing the most effective treatment in reducing the disease incidence and severity. But sulphur applied in combinations with either Amistar®, Bayfidan®, Folicur® or Hasten® did not enhance disease control.

Introduction

This study was conducted to determine if there were synergistic effects for powdery mildew control, when sulphur was applied in combinations with Amistar®, Bayfidan® and Folicur® fungicides or in combinations with Hasten® (oil + non-ionic surfactant) and Eco-oil (emulsified canola oil).

Materials and Methods

The trial was conducted in a glasshouse at Devonport (cv. Ringo) sown on 06/10/12. Treatments evaluated are listed in Table 19.1. The trial design was a randomised complete block with four replicate pots. Pot size was 190 x 150 mm. Three foliar spray applications were applied at 7 day intervals on 29/02/12, 07/03/12 and 14/03/12, using an air-pressurized hand sprayer fitted with a hollow cone nozzle and sprayed until run-off. The first spray was applied when all plants already had powdery mildew. Only new leaves produced after the first spray application were assessed for powdery mildew in order to determine the effectiveness of treatment applications in preventing infections on the new leaves. Data was analysed using analysis of variance with ARM 7 software. When the analysis of variance indicated a significant treatment effect, Fisher's LSD tests (5% level) was used to compare means of the treatments.

Table 19.1. Treatments evaluated in the pot trial

No.	Treatment	Active ingredient	Rate
1	Untreated control	Nil	-
2	Sulphur	wettable sulphur	200 g/100 L
3	Sulphur + Eco-oil®	sulphur + emulsifiable canola oil	200 g/100 L + 500 ml/100 L
4	Sulphur + Hasten®	sulphur + a blend of esterified canola oil and non-ionic surfactant	200 g/100 L + 500 ml/100 L
5	Folicur®	tebuconazole	190 ml/100 L
6	Folicur® + sulphur	tebuconazole + sulphur	190 ml/100 L + 200 g/100 L
7	Amistar®	azoxystrobin	100 ml/100 L
8	Amistar® + sulphur	azoxystrobin + sulphur	100 ml/100 L + 200 g/100 L
9	Bayfidan®	triadimenol	40 ml/100 L
10	Bayfidan® + sulphur	triadimenol + sulphur	40 ml/100 L + 200 g/100 L

Results and Discussion

Under very high disease pressure, only Amistar® and Bayfidan® gave significant powdery mildew control. Sulphur, applied on its own had little or no effect. Sulphur applied with Eco-oil® was the most effective treatment in reducing the disease incidence and severity (Table 19.2). But sulphur applied in combinations with either Amistar®, Bayfidan®, Folicur® or Hasten® did not enhance disease control.

Table 19.2. Treatment effects on powdery mildew control in a pot trial, 2010-11

No.	Treatment	Powdery mildew Incidence (% leaves infected)	Powdery mildew Severity (% leaf area infected)
1	Untreated control	70 a	53 a
2	Sulphur	60 ab	41 ab
3	Sulphur + Eco-oil®	25 c	10 c
4	Sulphur + Hasten	50 ab	29 bc
5	Folicur®	55 ab	34 ab
6	Folicur® + Sulphur	70 a	43 ab
7	Amistar®	40 bc	25 bc
8	Amistar® + Sulphur	55 ab	36 ab
9	Bayfidan®	43 bc	25 bc
10	Bayfidan® + Sulphur	48 abc	29 bc
	p-value	**0.0162**	**0.0332**

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

20. SUSCEPTIBILITY OF COMMERCIAL CARROT VARIETIES IN TASMANIA

Abstract

Six lots of commercial seeds were obtained from carrot producers in Tasmania and evaluated for their susceptibility to powdery mildew in a pot trial in November 2010 to January 2011. Two varieties, Mojo and Stefano, were found to have high resistance to powdery mildew. The other varieties, Ringo, Kuroda and Chantenay were susceptible.

Introduction

This study was conducted to compare the susceptibility of carrot varieties that are commonly used in Tasmania in 2010-11.

Materials and Methods

The study was conducted as a pot trial in a glasshouse at Devonport. Six lots of commercial seeds obtained from producers in Tasmania were sown on 18/11/10, with fifty seeds in each pot (Table 20.1). The trial design was a randomised complete block with three replicate pots. Powdery mildew infected plants in pots were placed adjacent to the pots sown with the carrot varieties. The percentage leaf area covered by powdery mildew and percentage of leaf senescence due to the disease were estimated on 14/01/11. Data were analysed using analysis of variance with ARM 7 software. When the analysis of variance indicated a significant treatment effect, Fisher's LSD tests (5% level) was used to compare means of the treatments.

Results and Discussion

Two varieties, Mojo and Stefano were found to have high resistance to powdery mildew (Table 20.1). Ringo, Kuroda and Royal Chantenay were highly susceptible.

Table 20.1. Susceptibility of carrot varieties to powdery mildew

No.	Commercial variety	Processor	Powdery mildew % Leaf coverage (14/01/11)	Powdery mildew % Leaf senescence (17/02/11)	Mean plant height (cm)
1	Ringo	Simplot	41 a	30 abc	8.7
2	Kuroda	Premium Fresh	33 a	52 a	13.7
3	Royal Chantenay	Simplot	25 ab	40 ab	14.7
4	Mojo	Premium Fresh	7 b	12 bcd	16.0
5	Stefano	Harvest Moon (big seed)	8 b	10 cd	12.4
6	Stefano	Premium Fresh (small seed)	9 b	0 d	2.0
		p-value	**0.403**	**0.054**	**0.269**

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

SOUTH AUSTRALIAN RESEARCH ACTIVITIES

21. SURVEY OF CARROT CROPS IN SOUTH AUSTRALIA

Introduction

South Australia produces 17% of the national carrot production, after Western Australia (31%) and Tasmania (23%) (Ausveg 2010). South Australia and Western Australia have a relatively small number of growers with large properties. The average production per grower was over 2,100 tonnes in South Australia and 2,400 tonnes in Western Australia compared to an average in the other four states of 420 – 720 tonnes per grower.

Powdery mildew was first confirmed as present in South Australia in 2008, following the New South Wales detection in 2007 (Cunnington *et al.* 2008, Watson 2009).

This work was undertaken to determine the extent and severity of the disease in South Australia.
Carrots are grown in three main areas in South Australia (Figure 21.1). Carrots grown in the South east of South Australia are predominantly seed crops, whereas in the other areas carrots are grown for fresh consumption.

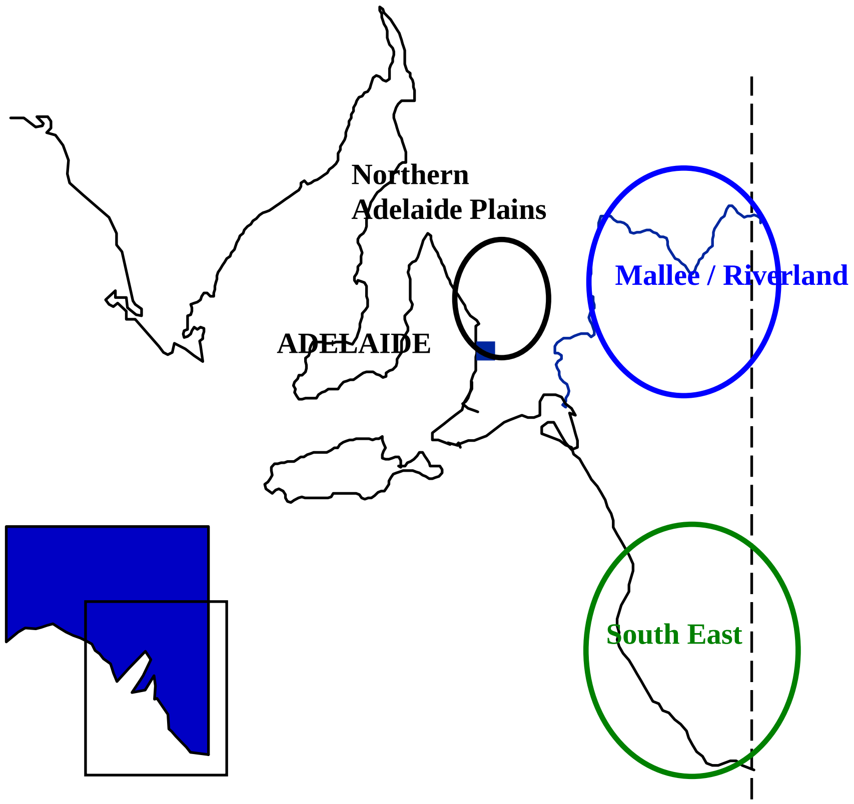


Figure 21.1. *Carrot growing areas in South Australia*

Materials and methods

Carrot crops were inspected mid crop for the presence of powdery mildew in 2009 by walking from one corner to the opposite corner of each paddock in a zig zag pattern. Depending on the size of the paddock, ten plants were inspected in each of at least ten areas selected at random along the transect, with a minimum of 100 plants inspected per crop.

Results and Discussion

No mildew was observed in the planting areas of the South East (6 growers, 8 crops inspected) or the Mallee (2 growers, 4 crops inspected) in 2009. Only low levels were observed in the Virginia area (12 growers, 12 crops inspected) in 2009. The weather in SA during the cropping season was not conducive to high levels of mildew. The mildew was observed as a sparse white growth on the leaves (Figure 21.2), and on some plants the disease caused leaf death (Figure 21.3).

In the Northern Adelaide Plains, plantings were usually less than 8 ha and often planted in close rotation to other carrot crops. There was almost continual planting in the district, with crops often being planted before mature crops nearby had been harvested. Weeds were prevalent in and around carrot crops in Virginia (Figure 21.4, Appendix). One of the largest issues was volunteer carrots from previous crops. Fennel (*Foeniculum vulgare*) was the only Apiaceae weed identified, however no mildew was detected on this weed during the survey.

Powdery mildew was also observed on parsley in the Virginia area (Figure 21.5.).

In the Riverland/Mallee plantings were much larger (up to 40 ha) and irrigated with pivots. Rotations were over five years, and only one crop was grown per year. In this area there was less chance for the mildew to become established, and volunteer plants were eradicated before the start of the next crop.

The South East plantings were seed crops from 5 to 120 ha, also with only one crop per year. Seed crop growers are required to conform to the company's strict protocols, including planting only into new ground, separation from other carrot crops, and removal of any Apiaceae weeds. This would therefore minimise the risk of mildew infection and issues with volunteer plants.

Figure 21.2. *Mildew on carrot leaf, Virginia © D. Cavallaro*

Figure 21.3. *Mildew causing minor leaf death, Virginia © D. Cavallaro.*

Figure 21.4. *Carrot crop in Virginia area with weeds © D. Cavallaro*.

Figure 21.5. *Powdery mildew on parsley © D. Cavallaro.*

Discussions with growers

There is a lack of understanding of the disease by some growers, and management issues exist that could be addressed with improved technology transfer.

- Growers observed powdery mildew occurred from April to July each year.
- Some growers reported no powdery mildew if they are not harvesting in the April to July period.
- Some growers harvest 6 weeks prior to the normal harvest period for bunching carrots and have no issues with the disease.
- One grower reported yield losses of carrots to powdery mildew, with a one ha block unable to be mechanically harvested due to loss of tops.
- The main chemicals used are Folicur®, Amistar®, Filan® with oil (e.g. Hort oil) and mineral oil, all at recommended rates. Filan has been used for *Sclerotinia*, and growers have reported a combined benefit on powdery mildew.
- Possible reasons for mildew outbreaks include:
    - Poor nutrition close to harvest
    - Excess nutrition causing soft growth
    - Starting fungicide sprays too late to control the disease
- Some growers are seeing more of the disease each year and a few growers feel that the disease spreads from parsnips.
- There is little understanding of spray rotation and the need to apply early.
- 40% of the growers in the area consider powdery mildew is still an issue.

22. MONITORING OF CROPS

Twelve crops in the Northern Adelaide Plains were selected to monitor from planting to harvest: four in spring 2009, four in autumn 2010, and four in Spring 2010.

Materials and methods

Information was collected on each crop, including:

- Area of crop
- Variety
- Date of planting
- Previous crop history
- Isolation of crop – nearest carrot crop to this one
- Fungicides used in current crop
- Powdery mildew history
- Fungicides used in previous crops
- Irrigation type
- Estimated yield loss
- Harvest date

Powdery mildew was assessed either weekly (2009) or every two weeks (2010) from emergence. Carrot crops were inspected by walking from one corner to the opposite corner of each paddock in a zig zag pattern transects. The transects were alternated each inspection between the two diagonals (Figure 22.1). Depending on the size of the paddock, ten plants were inspected in each of at least ten areas selected at random along the transect, with a minimum of 100 plants inspected per crop. Both the crop infection and the leaf area infected were assessed using a 1-5 scale rating system where: 0 = no infection, 1 = < 10%, 2 = 10 to 25%, 3 = 25 - 50 %, 4 = 50 - 75% and 5 = >75% of crop or leaf area infected.

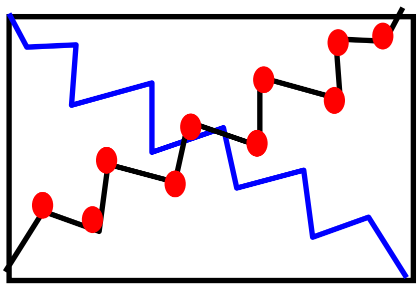


Figure 22.1. *Inspection pattern of opposite zig zag transects used to assess levels of powdery mildew. Transect 1 with sample points in red. Transect 2 on opposite diagonal (sample points not included).*

Results and Discussion

The development of powdery mildew appeared to have a limited relationship with the weather. There was no obvious correlation with rainfall (Figures 22.2-22.5). The winter-planted crops developed mildew towards maturity, when the temperature started to rise (Figures 22.2). However summer-planted crops also developed mildew late, which was when the temperature dropped (Figure 22.3). This suggests that disease development is related to the age of the crop in the warmer weather. Crops planted in March with most of their growing in winter did not develop disease (Figure 7, Table 22.2).

Fungicide applications were either on a schedule or on appearance of the disease. One grower commenced spraying from 8-10 weeks after planting, applying Folicur (500 ml/ha) and wettable sulphur (Thiovit–2 kg/ha) every 2-3 weeks until 3 weeks before harvest. However, mildew still developed late in the season.

Another grower applied a tank mix of Amistar® and Bravo® when the disease was first seen (approximately 6-8 weeks before harvest) and this resulted in very low levels of disease at the final assessment.

All growers used overhead watering and rotated with potato or fallow. Most were within 2 km of another carrot crop, and often grew two carrot crops in succession.

Spring crop, 2009

Planting dates of the four crops were from 20th June to 10th July 2009 (Table 22.1). All crops were sprayed with Amistar® to control mildew, and other fungicides used in the crop were Rovral®, Amistar®, and Bravo®. In the previous three years, rotations included fallow, potatoes, and carrots.

Mildew was not observed until late in the season (Tables 22.1, 22.4). The mildew in crop 2, first seen in early November, gradually decreased, and by assessment on 7th December, none was observed. In crop 3, no mildew was observed, possibly due to the relative isolation of the growing area from the other infected crops. Mildew was observed late in the other two crops.

There was an unprecedented heat wave in November in South Australia, and this may have retarded the development of mildew. No yield loss from mildew was observed on any of the properties.

Autumn crop, 2010

Planting dates of the four autumn crops were more variable than in spring, with two crops planted in December 2009 (10th and 15th), and two in March 2010 (10th and 20th) (Table 22.2). The crops had different fungicides applied (Rovral®, Amistar®, Score® and Folicur®). All growers used Amistar® to manage mildew. In the previous three years, rotations included fallow, potatoes, and carrots.

No mildew was observed in either of the crops planted in March 2010. This was most likely due to their isolation from other infected crops. No mildew has been seen in this area previously, so there is unlikely to be any inoculum present.

In the two crops planted in December 2009, mildew was detected in the last 6 weeks of the crop (Table 22.5). The more severe infection in crop 1 appeared to be related to nutrient deficiency in the tops. Although fungicides were applied in crop 1 for various other leaf diseases, there were no applications targeted for powdery mildew.

No yield loss from mildew was observed on any of the properties.

Spring crop, 2010

Planting dates of the four crops were from 15th to 21st July 2010 (Table 22.3). All crops had the same fungicides applied with Amistar® used to manage mildew. Other fungicides used in the crop were Rovral®, Amistar® and Bravo®. In the previous three years, rotations included fallow, potatoes, and carrots.

Mildew was not observed until late in the season, and only low levels (<10%) detected (Table 22.3, 22.6).

Weeds

Weeds commonly found around carrots have been listed in the Appendix.

Table 22.1. *Information on four crops monitored in the Northern Adelaide Plains, spring 2009.*

Crop and variety	Planting date (2009) and area	Fungicides used	Previous mildew management	Rotation history	Distance to other carrot crops	Irrigation	Disease first seen	Maximum disease levels*		Harvest date (2009)
								Crop	Leaf	
Crop 1 Saturno	30 June 4 Ha	Rovral® Amistar® Bravo®	Amistar®	potato potato carrots	400m	Overhead sprinklers	3 December	2	2	4 December
Crop 2 Mojo & Ricardo	23 June 8 Ha	Rovral® Amistar® Bravo®	Amistar®	carrots fallow carrots	400m	Overhead sprinklers	6 November	3	2	7 December
Crop 3 Ricardo	20 June 4 Ha	Rovral® Amistar® Bravo®	No mildew	carrots fallow carrots	10 km	Overhead sprinklers	-	0	0	10 December
Crop 4 Ricardo	10 July 1.8 Ha	Rovral® Amistar® Bravo®	Amistar®	carrots fallow carrots	500m	Overhead sprinklers	30 November	2	2	7 December

* 0 = no infection, 1 = < 10%, 2 = 10 to 25%, 3 = 25 - 50 %, 4 = 50 - 75% and 5 = >75% of crop or leaf area infected.

Figure 22.2. *Rainfall and temperature during the growth of carrot crops planted June/July 2009 and appearance of powdery mildew.*

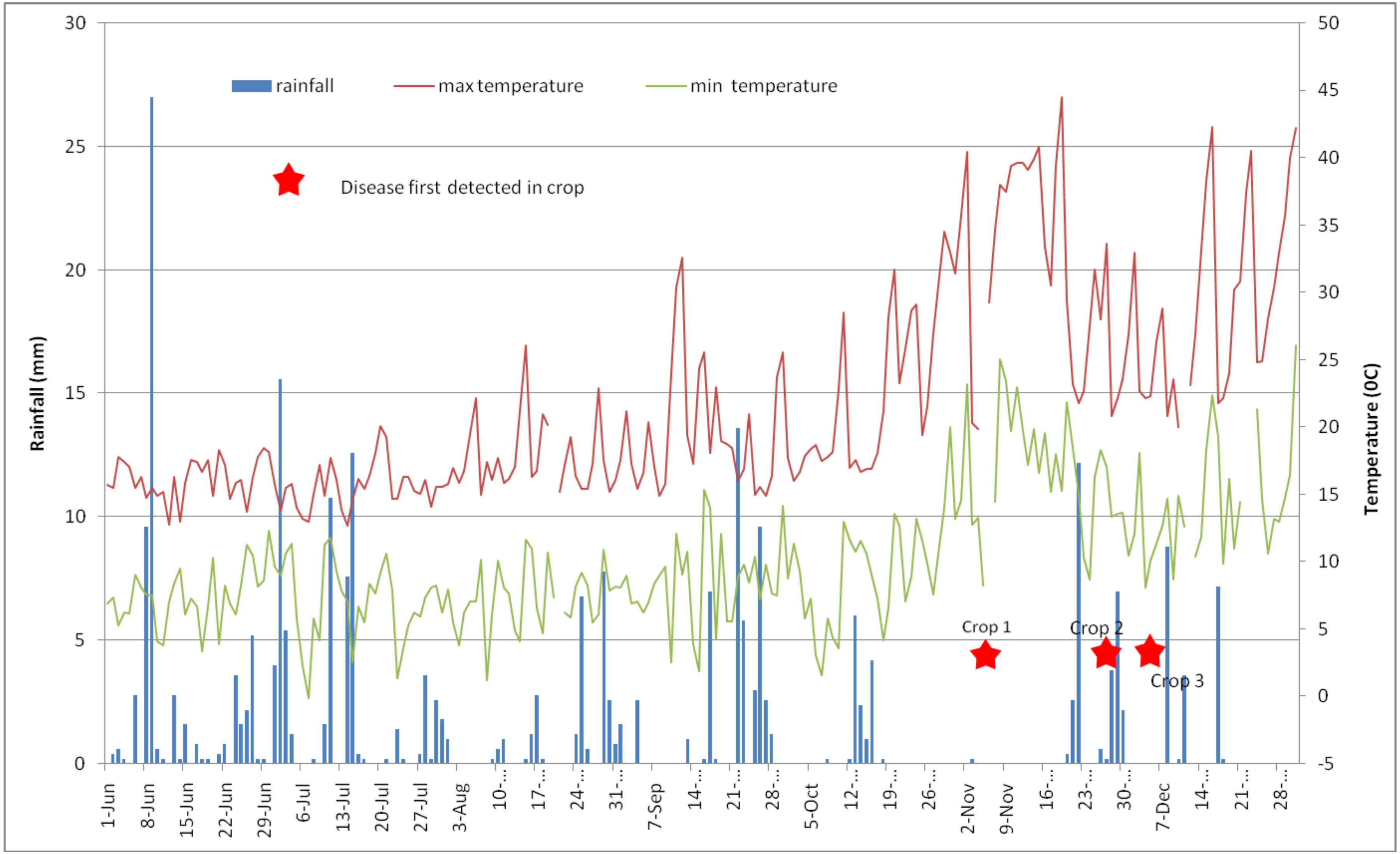


Table 22.2. *Information on four crops monitored in the Northern Adelaide Plains, autumn 2010.*

Crop number and variety	Planting date and area	Fungicides used	Previous mildew management	Rotation history	Distance to other carrot crops	Irrigation	Disease first seen	Maximum disease levels*		Harvest date (2010)
								Crop	Leaf	
Crop 1 Ricardo	10 Dec 2009 8 Ha	Rovral® Folicur®	Amistar®	carrot fallow carrots	1.5 km	Overhead sprinklers	9 April	4	3	25 May
Crop 2 Ricardo	10 March 2010 5.7 Ha	Rovral® Amistar®	Amistar®	potato fallow carrots	2 km	Overhead sprinklers	-	0	0	4 Sept
Crop 3 Ricardo	15 Dec 2009 2 Ha	Score® Amistar®	Amistar®	fallow carrots carrots	1.5 km	Overhead sprinklers	23 April	2	2	1 June
Crop 4 Ricardo	20 March 2010 5.7 Ha	Rovral® Amistar®	No mildew	fallow potato carrots	2 km	Overhead sprinklers	-	0	0	14 Sept

* 0 = no infection, 1 = < 10%, 2 = 10 to 25%, 3 = 25 - 50 %, 4 = 50 - 75% and 5 = >75% of crop or leaf area infected.

Figure 22.3. *Rainfall and temperature during the growth of carrot crops planted in December 2009 and appearance of powdery mildew.*

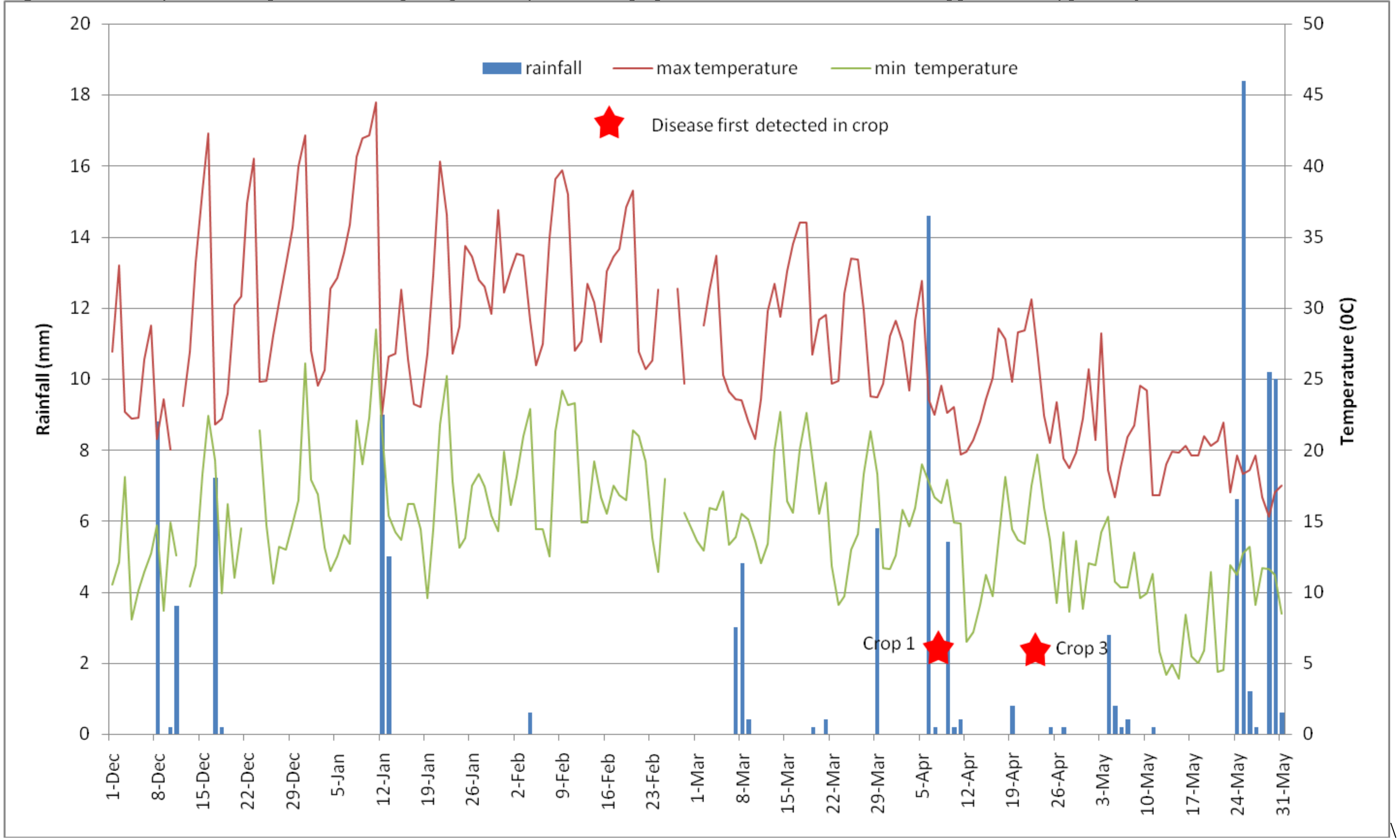


Figure 22.4. *Rainfall and temperature during the growth of carrot crops planted in March 2010. No powdery mildew was detected.*

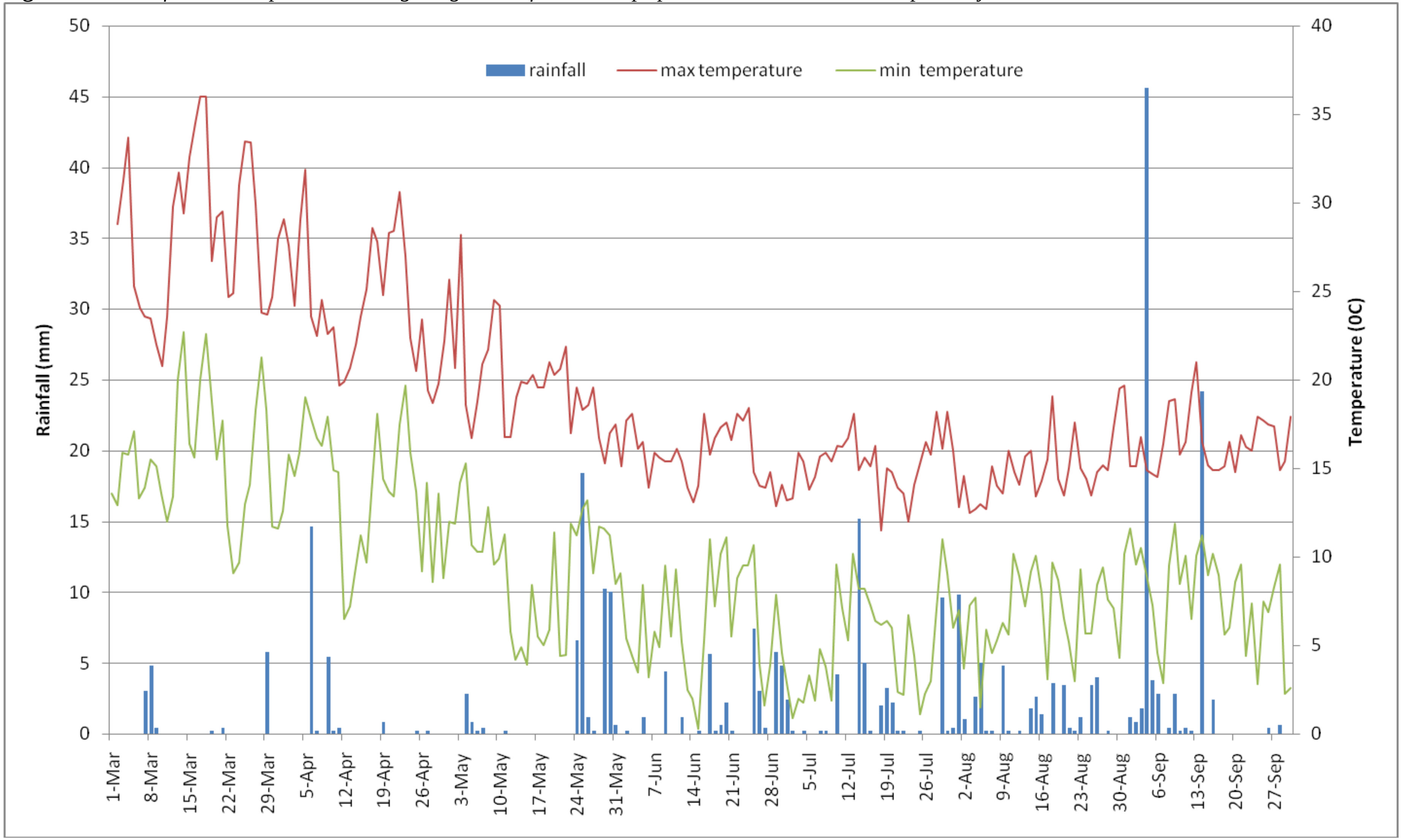


Table 22.3. *Information on four crops monitored in the Northern Adelaide Plains, spring 2010.*

Crop number and variety	Planting date in 2010 and area	Fungicides used	Previous mildew management	Rotation history	Distance to other carrot crops	Irrigation	Disease first seen	Maximum disease levels*		Harvest date (2010)
								Crop	Leaf	
Crop 1 Ricardo	21 July 2 Ha	Rovral® Amistar® Bravo®	Amistar®	carrot fallow carrots	4 km	Overhead sprinklers	26 Nov	1	1	28 Nov
Crop 2 Ricardo	15 July 4 Ha	Rovral® Amistar® Bravo®	Amistar®	potato carrots potato	2 km	Overhead sprinklers	-	0	0	5 Dec
Crop 3 Ricardo	20 July 1.8 Ha	Rovral® Amistar® Bravo®	Amistar®	carrots fallow carrots	4 km	Overhead sprinklers	-	0	0	15 Nov
Crop 4 Ricardo	20 July 1 Ha	Rovral® Amistar® Bravo®	Amistar®	carrots fallow potato	2 km	Overhead sprinklers	26 Nov	1	1	2 Dec

* 0 = no infection, 1 = < 10%, 2 = 10 to 25%, 3 = 25 - 50 %, 4 = 50 - 75% and 5 = >75% of crop or leaf area infected.

Figure 22.5. *Rainfall and temperature during the growth of carrot crops planted in July 2010 and date powdery mildew was first detected.*

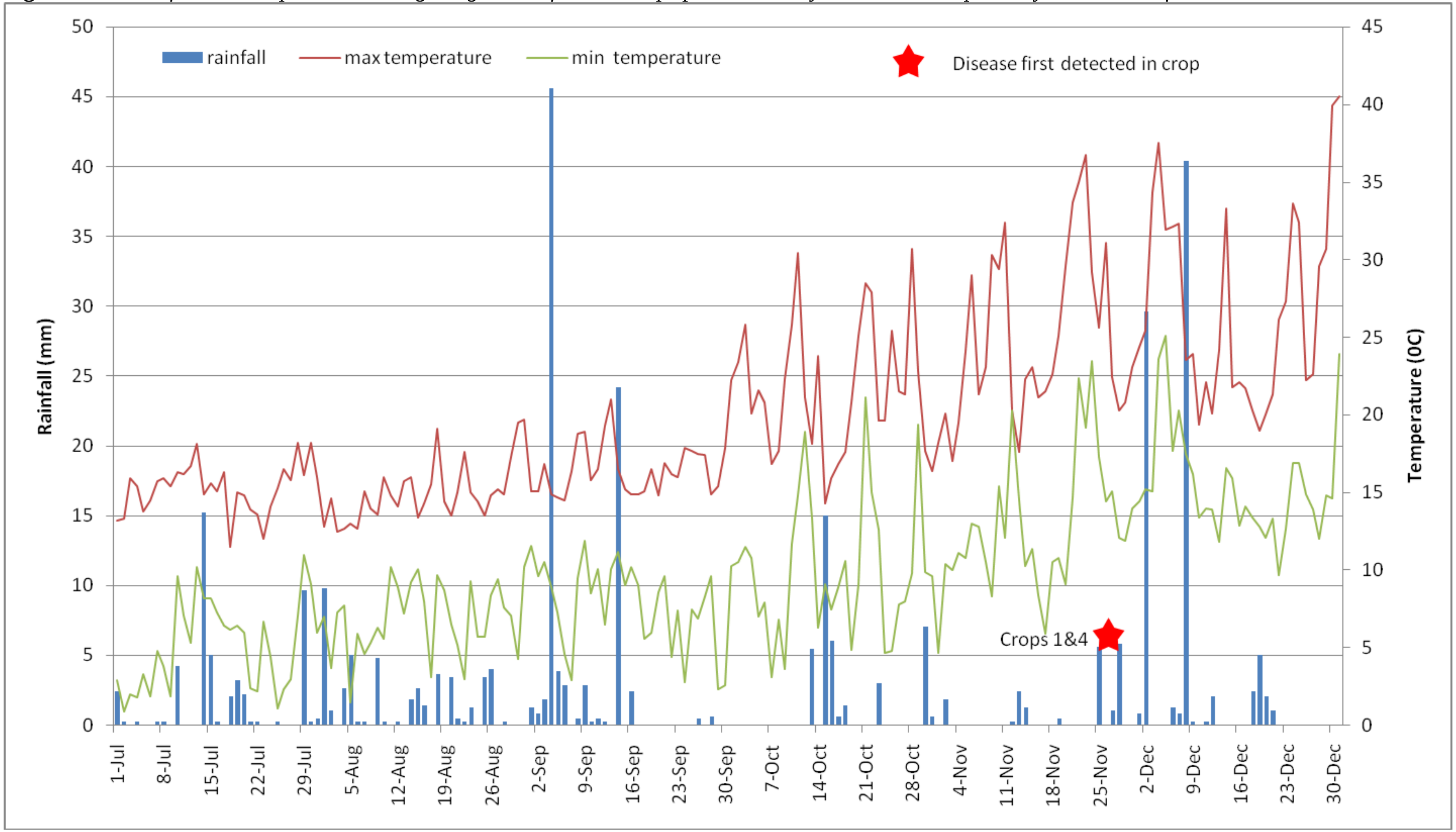


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Table 22.4. *Powdery mildew levels in each affected crop, spring 2009.*

Assessment date*	Crop 1		Crop 2		Crop 4	
	crop	**leaf**	**crop**	**leaf**	**crop**	**leaf**
6/11/2009	0	0	25-50%	<10%	0	0
11/11/2009	0	0	25-50%	10-25%	0	0
16/11/2009	0	0	10-25%	10-25%	0	0
23/11/2009	0	0	10-25%	10-25%	0	0
30/11/2009	<10%	<10%	<10%	<10%	<10%	<10%
7/12/2009	10-25%	10-25%	0	0	10-25%	10-25%

* Assessed weekly, early assessments without disease not included
Crop 3 with no disease not included.

Table 22.5. *Powdery mildew levels in each affected crop, autumn 2010.*

Assessment date*	Crop 1		Crop 3	
	crop	**leaf**	**crop**	**leaf**
9/4/2010	<10%	10-25%	0	0
23/4/2010	10-25%	10-25%	<10%	<10%
7/5/2010	50 - 75%	25-50%	<10%	10-25%
21/5/2010	50 - 75%	25-50%	10-25%	10-25%

* Assessed every 14 days, early assessments without disease not included

Table 22.6. *Powdery mildew levels in each affected crop, spring 2010.*

Assessment date*	Crop 1		Crop 4	
	crop	**leaf**	**crop**	**leaf**
5/11/2010	0	0	0	0
26/11/2010	<10%	<10%	<10%	<10%

* Assessed every 14 days, early assessments without disease not included

23. SENSITIVITY TO AZOXYSTROBIN

Azoxystrobin is the main fungicide used to control powdery mildew in carrots. Resistance exists to the fungicide in other crops, and investigations were undertaken to see if isolates from areas using mildew showed resistance, and to develop base-line data of sensitive isolates to azoxystrobin to enable resistance to be detected in future.

Methods

Plants infected with powdery mildew were collected from commercial crops from either South Australia (SA) or New South Wales (NSW). The SA isolate had been exposed to azoxystrobin and the NSW isolate had not been exposed.

Spores of powdery mildew were collected by shaking infected leaves in demineralised water with a drop of Tween 20 and filtering the suspension through gauze. The concentration was adjusted to ~10^5 spores/mL using a haemocytometer. Carrot seedlings cv. Stefano of various ages were inoculated to provide a fresh spore source for further experiments. To prevent cross contamination, the SA isolate was tested first, all plants removed, and the greenhouse cleaned before the NSW isolate was tested. Plants were grown in a separate growth room from the infected carrots prior to the testing.

Carrot seedlings cv. Stefano with 4-6 true leaves fully developed were sprayed with various rates of azoxystrobin (Table 23.1) to run-off using a hand-held atomiser. There were 15-20 replicate plants per treatment, and control plants were sprayed with water. The leaves were allowed to dry for 2-3 hours before they were inoculated with a suspension of ~10^5 powdery mildew spores. Plants were maintained in a greenhouse (~22^{o}C) and watered by placing pots in trays of water. Thrive® was applied at recommended rates, approximately four weeks after planting.

Table 23.1. *Rates of azoxystrobin (mg a.i./L). RR = label rate of 100 ml Amistar (250g a.i./L)/100L.*

Treatment	Experiment 1 (SA)*	Experiment 2 (SA)	Experiment 3 (NSW)
Control	0	0	0
1/100,000RR	-	0.0025	0.0025
1/10,000RR	-	0.025	0.025
1/1000RR	-	0.25	0.25
1/500 RR	0.5		
1/100 RR	2.5	2.5	2.5
1/50 RR	5		
1/10 RR	25	25	25
1/5 RR	50	-	-
RR	**250**	**250**	**250**

*Source of mildew: SA = South Australia, NSW = New South Wales

Plants were inspected every 7 days after inoculation and assessed once mildew was detected in the control plants. Experiment 1 was assessed at 15 days, Experiment 2 at 28 days, and Experiment 3 at 15, 21, and 27 days. The severity of mildew was rated on the first five fully expanded leaves using a 0-4 rating, where 0=no mildew, 1=<5%, 2=5-25%, 3=25=50% and 4=>50 % of the leaf surface infected.

Results

Experiment 1. Mildew was observed on the control plants 7 days after inoculation. At 15 days, all control plants were infected, but no infection was observed in any of the sprayed plants (data not presented).

Experiment 2. Mildew was first observed 7 days after inoculation; however it was slow to develop and was not widespread on the control plants until 21 days after inoculation. The plants were assessed at 28 days. At this stage all treatments including the recommended rate had some mildew present, and 4 of the 18 plants treated with the recommended rate were infected with mildew (Figure 23.1).

There was a dose response of both incidence and severity.

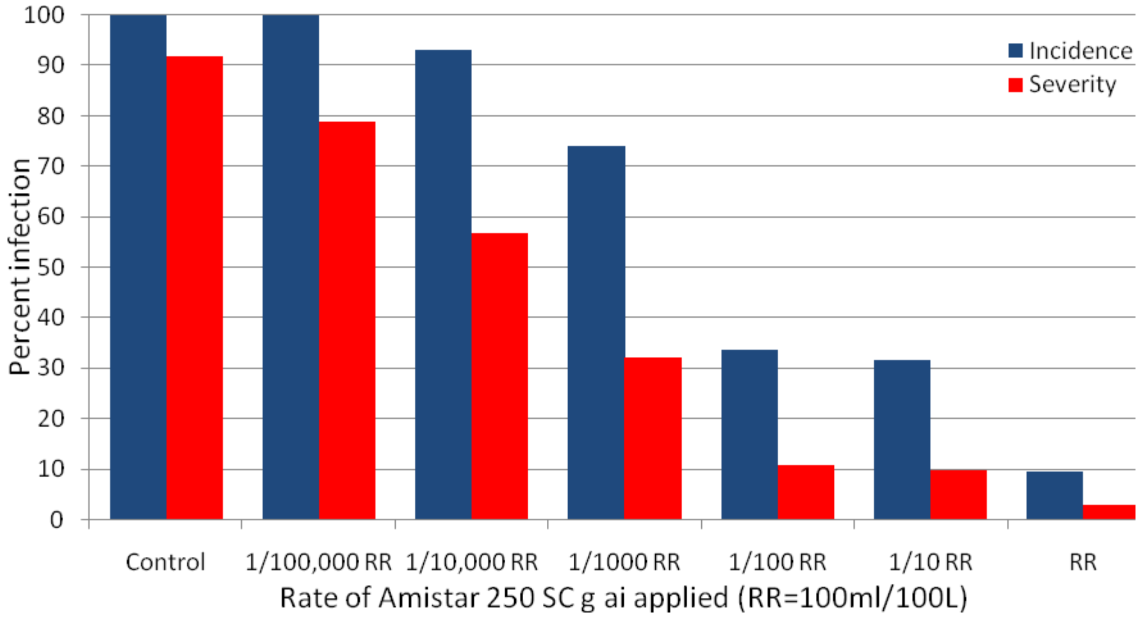

Figure 23.1. Incidence and severity of powdery mildew 28 days after carrots were sprayed with various rates of azoxystrobin and inoculated with powdery mildew (South Australia isolate).

Experiment 3. As in Experiment 2, mildew was first observed 7 days after inoculation and was not widespread on the control plants until 21 days after inoculation. At 28 days no mildew had developed on any of the plants treated with the recommended rate (Figure 23.2).

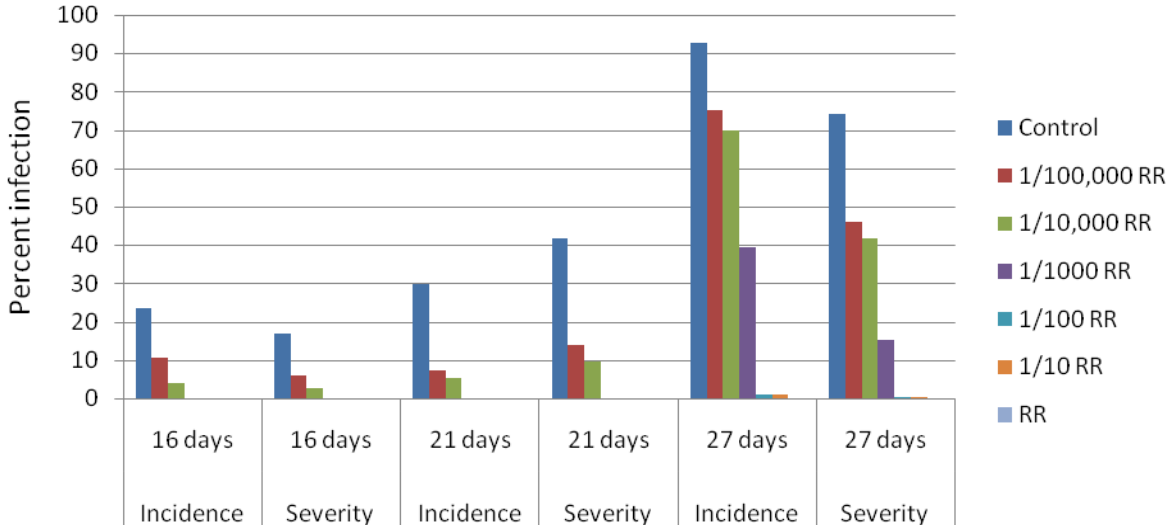

Figure 23.2. Incidence and severity of powdery mildew 16, 21, and 27 days after carrots were sprayed with various rates of azoxystrobin and inoculated with powdery mildew (New South Wales isolate).

The percent inhibition of both isolates followed a similar pattern for both incidence (Figure 23.3) and severity (Figure 23.4). However, at every rate of fungicide, the SA isolate was less sensitive, with a lower degree of inhibition.

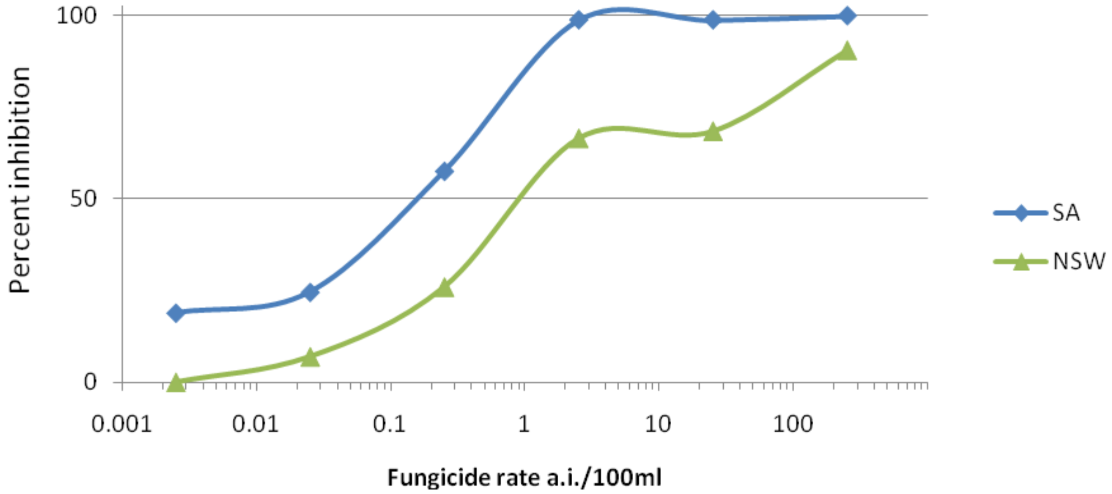

Figure 23.3. Percent inhibition of incidence of powdery mildew 27 (NSW) or 28 (SA) days after carrots were sprayed with various rates of azoxystrobin and inoculated with powdery mildew. Fungicide rate is on a $\log_{10}$ scale.

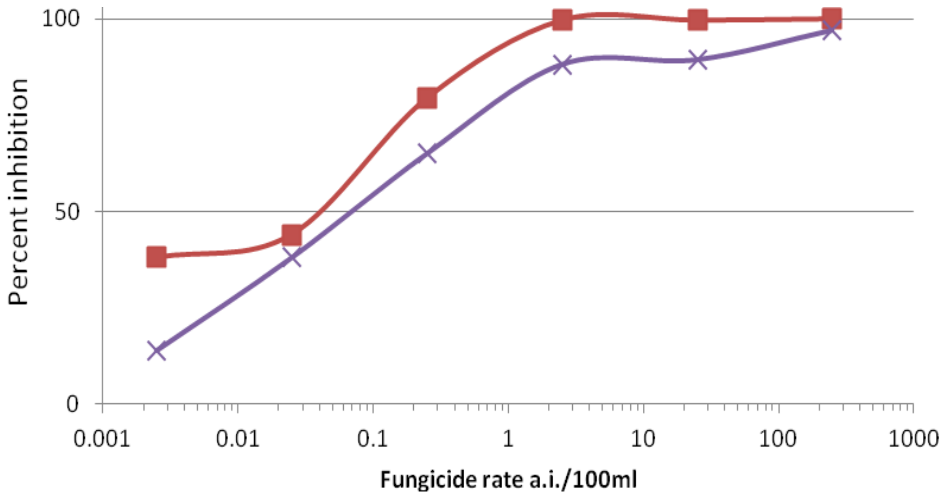

Figure 23.4. Percent inhibition of severity of powdery mildew 27 (NSW) or 28 (SA) days after carrots were sprayed with various rates of azoxystrobin and inoculated with powdery mildew.

Discussion

The isolate from South Australia, sourced from carrots sprayed with the fungicide over several seasons, was less sensitive to azoxystrobin than the isolate from NSW which had not been exposed to the fungicide.

The test method used was able to detect this shift in sensitivity, and should be able to be used in future to monitor potential resistance development. However it is time consuming and a more rapid test would be beneficial.

Acknowledgements

We wish to acknowledge and thank the growers for supplying information and allowing access to their properties.

GENERAL DISCUSSION

Information on carrot powdery mildew (*Erysiphe heraclei*) has progressed rapidly since it was first observed in Australia in 2007. Disease incidence and levels have fluctuated in the carrot growing regions where the disease was first observed i.e. South Australia, Tasmania, and New South Wales, but during the course of the project the disease was also reportedly found in Queensland and Victoria about the same time. This disease is going to be sporadic in occurrence, and if left untreated it will cause leaf death in some instances, and, reduce the ability of machinery to pull carrots out of the ground.

Environmental conditions have affected powdery mildew incidence in all the states with the change from the drought conditions experienced at the time of its discovery to wetter than normal conditions. It is clear that powdery mildew has been reduced by these conditions.

The temperature trial indicated that powdery mildew of carrot prefers temperature conditions that match spring and autumn conditions in much of Australia. These conditions however, may be closer to summer temperatures in Tasmania, indicating that the disease could be a problem in that state. Autumn infections will continue where the autumn stays warmer and drier. Early cool and wetter conditions, as observed in the field in autumn, have reduced infection. The period of growing carrots coincides with powdery mildew favoured periods in most states. If climate change suggests that drier and warmer conditions will occur in future, then autumn conditions may become ideal for powdery mildew infection in carrots. Climate change has been shown to have occurred in Australia with an increase in temperatures since 1950 by 1°C. The eastern carrot growing areas have had fewer frosts and less rain.

The powdery mildew fungus spreads easily from infected to uninfected plants especially through the movement of people and equipment. During trials, powdery mildew infections were easily caused by accidental movement from an infected greenhouse to a non-infected greenhouse. Early detection of the disease is critical, as control is best managed with fungicides from a low disease pressure base. Fungicides applied at the early stages of disease development were successful at controlling the disease. Field and greenhouse trials have indicated that the disease can be controlled but not eliminated by fungicide application.

Amistar®, Amistar Top®, Folicur® and sulphur have shown success at controlling the disease, and Amistar Top® and sulphur have been registered for powdery mildew on carrots. These fungicides can be applied as part of a general disease programme to control other carrot leaf diseases. The work on baseline sensitivity for Amistar® gives a historical perspective for future reference to indicate the potency of the fungicide, even if Amistar Top® is used. DPX-LEM1720 (penthiopyrad) is a product that has shown potential for powdery mildew control. It may provide an alternative active ingredient to the strobilurins, the group to which Amistar® and Amistar Top® belong.

Overhead irrigation reduced disease compared to drip irrigation in trials, indicating that growing areas in New South Wales with furrow irrigation are likely to experience more disease compared to growers with pivot-applied irrigation. Conversely, growers with overhead irrigation may reduce disease by the application of water. This has been observed in Tasmania, where the disease was more severe when insufficient water was available for irrigation by pivot, and regular watering was not possible. However, overhead irrigation would increase disease incidence caused by Cercospora and Alternaria leaf blight.

Variety trials have been useful in identifying more tolerant varieties and the best options for growers but they are highly dependent on the agronomic requirements for end use. The carrot variety Stefano has a high resistance to disease and should be considered in the periods of high disease pressure. The other members of the Apiaceae in these trials, and weeds, were not hosts of the powdery mildew found on carrots. Therefore it must be assumed that there are races of *Erysiphe heraclei* present in Australia as the fungus appeared on parsnip, but only recently has it appeared on carrot. This also indicates that the initial source of the disease was not from these other hosts but from other sources. These sources could be seed, visiting machinery, or carried on people. Indirectly, the lack of alternate hosts highlights the importance of reducing any carry-over carrots from one season to the next, and how overlapping plantings may be seriously affected by this disease. A rotational break from carrots will reduce the carryover of disease. Fennel (*Foeniculum vulgare*), was common to both South Australia and New South Wales growing regions however in both cases powdery mildew was not found on it.

Trials were successful in establishing the potential yield loss in carrot yield to powdery mildew in a greenhouse, but this loss was not confirmed in the field. Amistar® successfully controlled the disease in the greenhouse under high disease pressure even with less than three sprays, and disease control was maintained when only one application of the fungicide was applied to the carrots. The disease was controlled by being introduced artificially coupled with careful monitoring after disease appearance, and early treatment, something that does not occur in the field. The greenhouse environment provided ideal conditions for the powdery mildew with uniform temperatures and no rainfall to remove the fungus or the applied fungicide.

The frequency of fungicide application data is useful as a guide for field applications, and two applications of Amistar Top® should suffice in controlling the disease, or one Amistar Top® and one sulphur. Amistar Top® is a mixture of azoxystrobin and difenoconazole both providing control of powdery mildew with the azoxystrobin providing some protective ability as shown in trials, when Amistar® was used, in this report and the difenoconazole as a curative product, and the mixture reducing the chances of resistance occurring. The best fungicide options include both a protective and a curative fungicide. It will also assist in controlling other leaf spots such as Alternaria and Cercospora.

The management of powdery mildew links with strategies for controlling other foliar diseases of carrot such as Cercospora leaf blight. Fungicides that were found successful in controlling Cercospora leaf blight and powdery mildew included Amistar®, Amistar Top®, Cabrio®, and Folicur®.

The project covered three states, provided two different growing regions for fungicide trials and developed more information on the disease and achieved all the outcomes required in a relatively brief time period. Powdery mildew incidence each season since the 2007/2008 has been different with low levels of disease in most carrot growing regions, the 2008/09 season having more disease than the subsequent ones. This appears to have been related to changing weather conditions.

Information collected provides a suitable integrated management approach to powdery mildew control based on variety selection, careful monitoring, where possible and with some controls in place reduced movement of equipment and people from infected to uninfected blocks, tactical fungicide sprays, and thorough coverage of the canopy. Each new leaf takes approximately two to three weeks to fully emerge, this time period is recommended for fungicide application. This disease will not be a threat every year, making it difficult for growers to be prepared for outbreaks making monitoring critical.

TECHNOLOGY TRANSFER

Vegetable Pathology Program Workshop

Presentation at Vegetable Pathology Program Workshop, Best Western Airport Motel and Convention Centre, 33 Ardlie Street, Attwood, Vic., November 27th and 28th, 2008.
The project and current disease information was presented to attendees at the meeting. Those present included plant pathologists, extension staff, and agricultural consultants.

NSW IDO Newsletter

A contribution was made to the NSW Industry Development Officer (IDO) newsletter indicating the beginning of the project. This was also distributed to IDO newsletters in other states.

Field day in Devonport

A field day with field officers and consultants on 7 April 2009 at Wesley Vale was carried out in Tasmania.

Vegie Bites

A note was written for Vegiebites-Edition 37 (an NSW DPI Yanco Agricultural Institute publication) and at http://www.dpi.nsw.gov.au/aboutus/resources/periodicals/newsletters/vegiebites-newsletter (see appendix)

Root vegetable think tank

Information on the project was provided at the "Root vegetable think tank" 19th /20th April 2010 in Adelaide.

Andrew Watson had a meeting with growers in March 2011, in the Lockyer Valley, Queensland, regarding powdery mildew. Extension provided by Cardinal Horticultural Services (Dominic Cavallaro) allowed continual discussion with growers in South Australia.

Chemical companies have been consulted including requests for new fungicides for carrot powdery mildew control, Talendo® (Dupont) is one proposed for the industry. Amistar Top® (Syngenta) has been registered for carrots.

Grower meetings

Growers were met in Queensland regarding powdery mildew 16th March 2011.
Growers in South Australia were consulted through the extension provided by Cardinal Horticultural Services (Dominic Cavallaro).
A meeting to discuss disease with growers was held in Griffith on October 7th 2010.
A meeting with South Pacific Seeds agronomists was held in 15th August 2011 in Griffith.

Grower Visit

IDO, vegetable growers and resellers were visited in Lindenow, Victoria on the 28th-30th May 2012, powdery mildew was discussed as were best management options. Powdery mildew presence in Victoria was not confirmed before the visit, but it was apparently seen there in the same period as the other states i.e. 2007.

Conference

Watson A, Pung H, Browne SL, Snudden MG, Cross S (2011) Powdery mildew of carrots, new to three states of Australia. Poster presentation. Australasian Plant Pathology Conference, Darwin, April.

Pung H, Watson A, Cross S (2011) Powdery mildew disease management in carrot crops in Australia Poster presentation. Australasian Plant Pathology Conference, Darwin, April.
Pung H, Watson A, Cross S (2011) Cercospora leaf blight on carrots and disease control. Poster presentation. Australasian Plant Pathology Conference, Darwin, April.

Australasian Plant Pathology Society-Pathogen of the month

A short article on powdery mildew of the Apiaceae was written for the 'Pathogen of the Month' (September 2011). http://www.appsnet.org/Publications/potm/index.html

Primefacts

Two editions were written, one before the project started, and the other an updated version in September 2009. http://www.dpi.nsw.gov.au/aboutus/resources/factsheets The Primefact will again be updated.

Vegetable Australia article

November/December 2011

Vegenotes

Carrot powdery mildew-July 2012.

RECOMMENDATIONS

Fungicide resistance management should be encouraged. New registrations need to be pursued.

That technology transfer is continued with growers to improve their understanding of the epidemiology of the disease.

Further research could be considered including the specific effects of nutrition, a further examination of alternative fungicides and further work on overhead irrigation and it effects on powdery mildew.

Further work on where the powdery mildew is actually coming from as no weed hosts have been identified,

Further work should be considered on the relationship with other powdery mildews found on others in the Apiaceae such as parsnip powdery mildew.

An update on the sensitivity to azoxystrobin should be carried out in 5-10 years time.

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APPENDIX

Weeds found in and around carrots in South Australia.

Three corner jack (*Emex Australis*)
Capeweed (*Arctotheca calendula)*
Wild radish (*Raphanus raphanistrum)*
Deadnettle (*Lamium sp).*
Turnip weed (*Rapistrum rugosum*)
Fat hen (*Chenopodium album*)
Pig weed (*Portulaca oleracea*)
Blackberry nightshade (*Solanum nigrum*)
Chickweed (*Stellaria media*)
Wireweed (*Polygonum aviculare*)
Common sowthistle (*Sonchus oleraceus*)
Fumitory (*Fumaria officinalis*)
Bed straw (*Galium tricornutum*)
Caltrop (*Tribulus terrestris*)

Powdery Mildew Trial on Carrots

Andrew Watson, I&I NSW, Yanco

Powdery mildew has now been found on carrot crops in three states of Australia. The disease was first found in the Murrumbidgee Irrigation Area of New South Wales in 2007. It has subsequently been found in Tasmania and South Australia in 2008. The organism causing the disease is commonly found in parsnip crops but powdery mildew has not previously been recorded on carrots in Australia.

Powdery mildew infection can be seen on the carrots where no treatments were applied (right)

The causal agent is *Erysiphe heraclei*, a fungus that usually affects members of the Apiaceae family which includes carrots, parsnips and parsley. Preliminary information has indicated that this is a different form of *E. heraclei* that does not infect parsnip or parsley, indicating that it may be specific to carrots. The disease affects the foliage and stems with patches of white, fluffy fungus appearing on the lower leaves first, and then spreading to the terminal growth. The fungus often covers entire leaves with its masses of white mycelium and powdery spores. Infected foliage becomes brittle, and may eventually turn brown, shrivel, and die. Severe infection will result in loss of foliage which may result in lower yields and poor seed quality in seed crops.

Fungicide trials in New South Wales and Tasmania have shown that applications of sulphur, Amistar® or Folicur® can help control powdery mildew on carrots. Sulphur has a general vegetable registration, Amistar® has a minor-use permit valid until May 2014 while Folicur® has a permit valid until March 2011. These products don't stop the disease totally, but they do significantly reduce disease levels. Alternative products still need to be investigated, as resistance to fungicides can develop especially to products such as Amistar®. Therefore a complete control package needs to consider fungicide options and timing.

Initial trials conducted in the field have shown no significant yield loss due to powdery mildew infections. However this needs to be further tested as greenhouse trials have shown a yield reduction of 20% when powdery mildew was left uncontrolled. A yield loss has also been shown to occur where the carrots are lifted from the ground by the leaves. This was due to the leaves being weakened by powdery mildew and breaking off during harvest thus leaving some carrots in the ground.

To assist control of the disease, growers should consider:

- careful monitoring young crops regularly. Powdery mildew is very difficult to see on leaves early. Once powdery mildew is seen infecting many leaves, control is not as successful.
- limiting the movement of machinery and chippers from infected paddocks to non-infected properties or carrot crops. Powdery mildew can be easily spread and preventative action can help limit the spread of the disease throughout the district.
- maintain proper crop nutrition to optimise leaf development.

The powdery mildew trial was funded by NSW Department of Primary Industries and HAL. For more information on powdery mildew in carrots, contact Andrew Watson at Yanco Agricultural Institute on (02) 6951 2611.