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Field and laboratory evaluation of fungicides for the control of *Phytophthora* fruit rot of papaya in far north Queensland, Australia

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ABSTRACT

Results from the first of two artificially inoculated field experiments showed foliar applications of copper hydroxide (Blue Shield Copper) at 600 g a.i./100 L^{-1} (0% infected fruit), copper hydroxide + metalaxyl-M (Ridomil Gold Plus.) at 877.5 g a.i./100 L^{-1} (0.27%), metiram + pyraclostrobin (Aero) at 720 g a.i./100 L^{-1} (0.51%), chlorothalonil (Bravo WeatherStik) at 994 g a.i./100 L^{-1} (0.63%) and cuprous oxide (Nordox 750 WG) at 990 g a.i./100 L^{-1} (0.8%) of water significantly reduced the percentage of infected fruit compared to potassium phosphonate (Agri-Fos 600) at 1200 g a.i./100 L^{-1} (8.22%), dimethomorph (Acrobat) at 108 g a.i./100 L^{-1} (11.18%) and the untreated control (16%). Results from the second experiment showed fruit sprayed with copper hydroxide (Champ Dry Prill) at 300 (2.0% infected fruit), 375 (0.4%) and 450 g a.i./100 L^{-1} (0.6%) and metiram + pyraclostrobin (Aero) at 360 (2.8%), 480 (0.6%) and 600 g a.i./100 L^{-1} of water (1.0%) significantly reduced the percentage of infected fruit compared to the untreated control (19.4%). Foliar sprays of copper hydroxide at 375 g a.i./100 L^{-1} in rotation with chlorothalonil at 994 g a.i./100 L^{-1} every two weeks is now recommended to growers for controlling *Phytophthora* fruit rot of papaya.

1. Introduction

The northern Queensland papaya industry (latitudes 18.16°S to 17.00°S) comprises approximately 90% of all papaya (*Carica papaya*) grown in Australia (Diczbalis et al. 2012). *Phytophthora*-related diseases (e.g. root rot, stem rot and fruit rot) caused by *P. palmivora* are a significant constraint to the profitability and further expansion of the Australian papaya industry which has an estimated value of $18–25 Million (Diczbalis et al. 2012). These diseases are particularly damaging for growers on the wet tropical coast of far north Queensland (Diczbalis et al. 2012) where the average annual rainfall is in excess of 3000 mm with a distinct wet season from January to April. Following periods of heavy rainfall, entire columns of fruit can be lost to *Phytophthora* fruit rot. Mature fruit infected with *P. palmivora* become covered with off-white mycelium that produces masses of sporangia which contain highly infective zoospores (Hunter and Buddenhagen, 1969). These spores are a source of inoculum dispersed by wind-blown rain (Hunter and Kunimoto, 1973). Observations by Hamill (1987) suggested that sporangia produced in the soil can spread to the aerial parts of the plant by wind-blown rain. Once on the ground, infected fruit are also important reservoirs of inoculum for root and fruit infections (Ko, 1982).

Control of *Phytophthora* fruit rot is dependent on an integrated system of both cultural and chemical control measures. This involves growing papaya on well-drained soils, the removal of infected fruit from the field, the establishment of grassed areas between the rows of papaya to reduce inoculum splash to aerial parts of the plant, and regular foliar spray applications with copper hydroxide (Chay-Prove, 2000). Copper hydroxide has been used at the rate of 100–150 g a.i./100 L but according to growers the results obtained with this chemical at that rate of application are always disappointing (J. Zappala, personal communication). There are presently no other chemicals registered for the control of *Phytophthora* fruit rot of papaya. Although all papaya cultivars are affected by this disease, it is the much sought after red-fleshed Solo types which are most susceptible (Chay-Prove, 2000).

This paper reports on two field experiments conducted from 2009 to 2012 which evaluated a range of chemicals with known efficacy against *Phytophthora* spp. (Alvarez and Nelson, 1982;

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Mathereon and Porchas, 2000; Rebollar-Alviter et al., 2007; Washington and McGee, 2000). The chemicals included copper hydroxide, copper sulphate, cuprous oxide, copper hydroxide + metalaxyl-M, metiram + pyraclostrobin, chlorothalonil, potassium phosphonate and dimethomorph; and were evaluated during the 'wet season' when disease pressure due to *P. palmivora* would normally be high. All these chemicals were used at rates of application well above what is normally recommended in other crops to control *Phytophthora*-related diseases as it was thought that higher rates would be needed to control the severe disease pressure situations which often occur following prolonged wet weather. It was also felt that the use of curative fungicides such as copper hydroxide + metalaxyl-M, metiram + pyraclostrobin and dimethmorph would be of benefit to growers during these periods of high disease pressure. Laboratory experiments further assessed the efficacy of these chemicals against *Phytophthora* fruit rot.

2. Materials and methods

2.1. Site description and experimental design

Two field experiments were conducted on red-brown light clay (Innisfail Series) soil at the Queensland Department of Agriculture, Fisheries and Forestry, South Johnstone Research Station near Innisfail. Each trial-site had been under weed fallow for many years. The experimental sites were deep-ripped and rotary-hoed and single row mounds (0.60 m high) formed. Both trials received an application of basal fertiliser (12.7% N, 14.2% P, 10.9% K, 2.4% S, and 2% Zn) at the rate of 266 kg/ha, a side dressing of 19.3% N, 0% P and 28.4% K at the rate of 336 kg/ha and two applications of urea (39 kg/ha) throughout the growing season. The urea was applied via a mini-sprinkler irrigation system. Papaya seedlings of the red papaya cv. Sunrise Solo which is highly susceptible to *Phytophthora* fruit rot were grown in pasteurized potting mix for 10 weeks before transplanting. As this cultivar is gynodioecious, four seedlings were transplanted at each plant position and these were thinned to a single hermaphrodite plant per position at flowering (approximately 16 weeks after transplanting) when the sex could be determined.

The site of the first experiment was transplanted on the 11 June 2009 and was divided into 32 plots (each 15 m × 4 m) consisting of 8 treatments and 4 replications arranged as a randomised complete block. Plots consisted of a single row of 10 plants 1.5 m apart with a single row of unsprayed plants separating treatments. Trees had a column of fruit at the commencement of the experiment.

The site of the second experiment was transplanted on the 9 June 2011 and was divided into 35 plots (each 10.5 m × 4 m) consisting of 7 treatments and 5 replications arranged as a randomised complete block. Plots consisted of a single row of 7 treated plants with a single row of unsprayed plants separating treatments. Trees had a column of fruit at the commencement of the experiment.

2.2. Inoculum preparation and plant inoculation

Due to the likelihood of little or no natural infection, both experimental sites were artificially inoculated with *P. palmivora*. An isolate of *P. palmivora* was acquired from a diseased papaya fruit by excising small sections of rotted fruit and plating onto P_{10} ARP + H culture media. Inoculum was produced from a single sporangium isolate (BRIP 61509) obtained from a sporulating sector of the P_{10} ARP + H colony. Inoculum used in experiments consisted of 3–4 week-old axenic cultures of the single sporangium isolate grown on potato carrot agar (potato/carrot infusion consisting of potato, 20 g; carrot, 20 g; Bacto agar, 15 g; distilled water, 1000 mL) under near UV light at 27 °C. The agar cultures (heavy with sporangia) were macerated in a small amount of distilled water in a Waring Blender for 45 s before being further diluted in distilled water to give a total volume of 150 mL of water per culture plate. Sufficient of the spore/mycelia suspension was prepared and approximately 100 mL of the suspension was sprayed with a Solo garden sprayer onto both sides of the fruit column of a single tree in the guard row directly opposite the centre of each treated plot. The sprayed fruit column was then covered with a polythene sheet which was tied off at the top, stapled down the side and tied-off at the bottom with flagging tape (Fig. 1). The polythene sheet remained in place for 4 days to retain a high humidity and so encourage the development of the disease. Fruit columns were inoculated on the 12 March 2010 (experiment 1) and the 22 February 2012 (experiment 2) when rain was forecast for the local area. As the disease developed within the fruit column (Fig. 1), affected fruit were moved to adjacent fruit columns within the guard rows to help spread the disease uniformly throughout the trial-site. Rainfall data was also collected from the nearby South Johnstone weather station.

2.3. Treatment application

2.3.1. Experiment 1

The chemical treatments included Blue Shield Copper DF (active ingredients: 50% copper hydroxide, Bayer) applied at 600 g ai/100 L^{-1}, Ridomil Gold Plus WG (a.i.: 81% copper hydroxide, 6.75% metalaxyl-M, Syngenta) applied at 877.5 g a.i./100 L^{-1}, Aero WG (a.i.: 55% metiram, 5% pyraclostrobin, Nufarm) applied at 720 g a.i./100 L^{-1}, Bravo WeatherStik SC (a.i. 720 g/L chlorothalonil, Syngenta) applied at 994 g a.i./100 L, Red Copper WG (a.i. 75% cuprous oxide, Nordox Australia) applied 990 g a.i./100 L^{-1}, Agri-Fos Supa 600 L (a.i. 60% potassium phosphonate, Agrichem) applied at 1200 g a.i./100 L^{-1} and Acrobat SC (a.i. 50% dimethomorph, BASF) applied at 108 g a.i./100 L^{-1} of water. Eight applications of these treatments were made to the appropriate plots every two weeks commencing on the 5 January 2010. Approximately 167 L/ha of water were used to spray the fruit columns. The wetting agent Agral was applied at the rate of 0.04% with all chemical treatments except chlorothalonil as this mixture is known to be phytotoxic (CDMS, 2014). All chemical treatments were applied with a motorized backpack mist blower (Solo). An untreated control plot was included for comparison.

2.3.2. Experiment 2

The chemical treatments used were the two most effective chemicals from experiment 1, Champ Dry Prill-WG (a.i. 37.5% copper hydroxide, Nufarm) applied at 300, 375 and 450 g a.i./100 L^{-1} and Aero WG (a.i. 55% metiram, 5% pyraclostrobin, Nufarm) applied at 360, 480 and 600 g a.i./100 L^{-1} of water. Seven applications of these treatments were made to the appropriate plots every two weeks commencing on the 23 January 2012. Approximately 238 L/ha^{-1} of water was used to spray the fruit columns and foliage. The wetting agent Agral was applied at the rate of 0.04% with all chemical treatments. All chemical treatments were applied with a motorized backpack mist blower (Solo). An untreated control plot was included for comparison.

2.4. Disease assessments

In experiment 1, fruit was harvested weekly for 12 weeks commencing on the 8 February 2010. The total number of *Phytophthora* affected fruit and the total number of fruit harvested during this period was recorded and the cumulative total percentage disease affected fruit calculated. All fruit with a diameter greater than 7.0 cm were harvested. Following the establishment of

Fig. 1. Artificial inoculation of papaya fruit columns with *Phytophthora palmivora*.

the disease in the guard rows, disease severity assessments were conducted on the 12 April and the 27 April 2010. Three fruit columns were assessed per plot using the following disease severity scale; 1, no disease, 2, 1–10% of fruit column affected, 3, 11–20% of fruit column affected, 4, 21–30% of fruit column affected, 5, 31–50% of fruit column affected, 6, >51% of fruit column affected. In experiment 2, fruit was harvested weekly for 7 weeks (number of fruit with and without disease) commencing on the 6 March 2012 and the cumulative total number of marketable fruit was recorded and the cumulative total percentage of *Phytophthora* infected fruit calculated. Fruit were considered marketable if they had a diameter greater than 7.0 cm and were free of major blemishes including *Phytophthora* rot.

2.5. In vitro studies

In 2010, an *in vitro* fruit bioassay was used to further assess the efficacy of the seven chemical treatments used in the 2010 field experiment. Two mature fruit (at colour break stage) were each sprayed with the appropriate chemical treatment and allowed to dry before being sprayed with 200 sporangia/mL of *P. palmivora* (BRIP isolate 61509) and placed in a hardened plastic container. The inoculum used in this study was prepared as previously mentioned. Three replicate plastic containers per treatment were placed in an incubator in the dark at 27 °C for 3 days in a completely randomised design. An inoculated untreated control was included for comparison. Fruit were checked every 24 h for fungal growth and were assessed 4 days after inoculation for fruit rot. The following scaled index of disease symptom severity was used where 1, no disease; 2, 1–10% of fruit area affected; 3, 11–20% of fruit area affected; 4, 21–30% of fruit area affected; 5, 31–50% of fruit area affected; and 6, >51% of fruit area affected. The experiment was repeated once.

In 2012, a similar laboratory experiment compared four rates of application of copper hydroxide with two rates of copper sulphate and an inoculated untreated control. Two mature fruit (at colour break stage) were each sprayed with the appropriate chemical treatment and allowed to dry before being sprayed with 200 sporangia/mL of *P. palmivora* (BRIP isolate 61509) and placed in a hardened plastic container. The inoculum used in in this study was prepared as previously mentioned. Three replicate plastic containers per treatment were placed in an incubator in the dark at 27 °C for 6 days in a completely randomised design. Fruit were checked daily for fungal growth and assessed on days 4, 5 and 6 using the scaled index of disease symptom severity mentioned previously. The experiment was repeated once.

2.6. Data analysis

Statistical analyses were conducted using Genstat 5 release 4.1 data analysis software (Lawes agricultural Trust, Rothamsted Experimental Station). A one-way ANOVA was used to analyse the disease severity assessments, cumulative totals of percentage disease affected fruit and number of disease affected fruit. Where a treatment effect was found to be significant, pair-wise testing was performed between treatment means using the protected least significance difference test.

3. Results

3.1. Field experiments

3.1.1. Experiment 1

Symptoms of *Phytophthora* fruit rot were apparent at the removal of the polythene sheets 4 days after inoculation (Fig. 1) and the disease continued to develop slowly throughout the trial-site following periods of heavy rainfall. As the trial progressed, some of the inoculated guard row trees developed *Phytophthora* stem rot and died. Results from the assessments of disease damage to the fruit column conducted on the 12 April showed copper hydroxide, copper hydroxide + metalaxyl-M, metiram + pyraclostrobin, chlorothalonil and cuprous oxide significantly ($P < 0.05$) reduced the severity of damage to the fruit column compared to potassium phosphonate, dimethomorph and the untreated control (Table 1). The assessment conducted on the 27 April showed copper hydroxide, copper hydroxide + metalaxyl-M, metiram + pyraclostrobin, chlorothalonil and cuprous oxide significantly ($P < 0.05$) reduced the severity of disease on the fruit column compared to dimethomorph and the untreated control. The disease severity in dimethomorph treated plots was not significantly different ($P < 0.05$) to the untreated control. Potassium phosphonate significantly ($P < 0.05$) reduced the

Table 1
Disease severity and cumulative totals of the percentage incidence of Phytophthora fruit rot of papaya following the spray application of various fungicides in a field experiment established in June 2009.

Treatment	Application rate (g a.i./100 L^{-1})	Disease severity[a,b] (12 April)	Disease severity[a,b] (27 April)	% infected fruit[b]
1. Untreated	–	1.50 b	1.75 c	16.55 c
2. Copper hydroxide	600	1.00 a	1.00 a	0.00 a
3. Copper hydroxide + metalaxyl-M	810 + 67.5	1.05 a	1.00 a	0.27 a
4. Metiram + pyraclostrobin	660 + 60	1.05 a	1.05 a	0.51 a
5. Chlorothalonil	994	1.00 a	1.00 a	0.63 a
6. Cuprous oxide	990	1.10 a	1.00 a	0.80 a
7. Potassium phosphonate	1200	1.45 b	1.30 ab	8.22 b
8. Dimethomorph	108	1.50 b	1.55 bc	11.18 bc
LSD ($P = 0.05$)	–	0.311	0.447	6.920

[a] Treatment means are a scaled index of disease severity where 1, no disease, 2, 1–10% of fruit column affected, 3, 11–20% of fruit column affected, 4, 21–30% of fruit column affected, 5, 31–50% of fruit column affected, 6, >51% of fruit column affected.

[b] Means followed by the same letter are not significantly different ($P = 0.05$).

severity of *Phytophthora* fruit rot compared to the untreated control. The cumulative total percentage of disease affected fruit calculated from the weekly fruit harvests showed copper hydroxide (0% diseased fruit), copper hydroxide + metalaxyl-M (0.27%), metiram + pyraclostrobin (0.51%), chlorothalonil (0.63%) and cuprous oxide (0.80%) effectively controlled the disease ($P < 0.05$) compared to dimethomorph (11.18%), potassium phosphonate (8.22%) and the untreated control (16.55%). The disease severity ratings and the cumulative totals of the percentage disease affected fruit showed similar treatment differences.

3.1.2. *Experiment 2*

Weekly fruit harvests were conducted from the 20 February to the 11 April 2012. A heavy prolonged wet season favourable for disease development failed to develop over the summer, however disease did develop following the artificial inoculation of the site with *P. palmivora*. Results from the cumulative total percentage of disease affected fruit harvested (Table 2) showed that all chemical treatments (0.4–2.8% diseased fruit) significantly reduced the incidence of *Phytophthora* fruit rot compared to the untreated control (19.4%) and produced more marketable fruit than the untreated control. Copper hydroxide at 375 g a.i./100 L^{-1} had the lowest incidence of fruit rot but was not significantly different from the other chemical treatments (see Table 2).

3.2. *In vitro studies*

Table 2
Cumulative totals of the number of marketable fruit and percentage incidence of Phytophthora fruit rot of papaya following spray applications with copper hydroxide and pyraclostrobin + thiram in a field experiment established in June 2011.

Treatment	Application rate (g a.i./100 L^{-1})	No. of marketable fruit[a]	% infected fruit[a]
1. Untreated control -	-	34.8 b	19.4b
2. Copper hydroxide	300	61.4 a	2.0 a
3. Copper hydroxide	375	62.4 a	0.4 a
4. Copper hydroxide	450	63.8 a	0.6 a
5. Metiram + pyraclostrobin	330 + 30	53.6 a	2.8 a
6. Metiram + pyraclostrobin	440 + 40	54.2 a	0.6 a
7. Metiram + pyraclostrobin	550 + 50	66.4 a	1.0 a
LSD ($P = 0.05$)	-	16.26	6.08

[a] Means followed by the same letter are nor significantly different ($P = 0.05$).

Table 3
In vitro study of various fungicides on Phytophthora fruit rot severity, 4 days after inoculation with sporangia of *P. palmivora.*

Treatment	Application rate (g a.i./100 L^{-1})	Disease severity[a,b] (1–6)
1. Untreated control	-	4.67 b
2. Copper hydroxide	600	1.17 a
3. Copper hydroxide + metalaxyl-M	810 + 67.5	1.00 a
4. Metiram + pyraclostrobin	660 + 60	1.00 a
5. Chlorothalonil	994	4.33 b
6. Cuprous oxide	990	1.00 a
7. Potassium phosphonate	1200	3.33 b
8. Dimethomorph	108	1.00 a
LSD ($P=0.05$)	-	1.6

[a] Fruit were assessed on a scaled index of disease symptom severity where 1, no disease; 2, 1–10% of fruit area affected; 3, 11–20% of fruit area affected; 4, 21–30% of fruit area affected; 5, 31–50% of fruit area affected; and 6, >51% of fruit area affected).

[b] Means followed by the same letter are not significantly different ($P = 0.05$).

In the *in vitro* experiment conducted in 2010, off-white mycelial growth was evident on fruit in the untreated control treatment 3 days after inoculation. *P. palmivora* was re-isolated from these disease affected fruit. The disease assessment conducted 4 days after inoculation (Table 3) showed there was no significant ($P < 0.05$) difference in *Phytophthora* fruit rot severity between copper hydroxide at 600 g a.i./100 L^{-1}, copper hydroxide + metalaxyl-M at 810 + 67.5 g a.i./100 L^{-1}, metiram + pyraclostrobin at 660 + 60 g a.i./100 L^{-1}, cuprous oxide at 990 g a.i./100 L^{-1} and dimethomorph at 108 g a.i./100 L^{-1}. Chlorothalonil at 994 g a.i./100 L^{-1} and potassium phosphonate at 1200 g a.i./100 L^{-1} were significantly ($P < 0.05$) less effective than the other chemical treatments.

In the second *in vitro* experiment conducted in 2012, (Table 4) off-white mycelial growth reminiscent of *Phytophthora* was evident 3 days after inoculation. As with the previous experiment, *P. palmivora* was re-isolated from disease affected fruit. Results from the experiment showed that 4 days after inoculation, fruit treated with copper hydroxide at 225, 300 and 375 g a.i./100 L^{-1} had significantly ($P < 0.05$) less fruit rot than the untreated control. Copper hydroxide at 375 g a.i./100 L^{-1} and copper sulphate at 380 g a.i./100 L^{-1} proved more effective ($P < 0.05$) than copper hydroxide at 150 g a.i./100 L^{-1} and copper sulphate at 152 g a.i./100 L^{-1}. The assessments done 5 and 6 days after inoculation showed copper hydroxide at 225, 300 and 375 g a.i./100 L^{-1} and copper sulphate at 380 g a.i./100 L^{-1} effectively controlled the disease ($P < 0.05$)

Table 4
In vitro study of various rates of application of copper hydroxide and copper sulphate on Phytophthora fruit rot severity, 4, 5 and 6 days after inoculation with sporangia of *P. palmivora*.

Treatment	Application rate (g a.i./100 L^{-1})	Disease severity on[a,b]		
		Day 4	Day 5	Day 6
1. Copper hydroxide	375	1.00 a	1.16 a	1.66 a
2. Copper hydroxide	300	1.66 ab	1.66 a	2.33 a
3. Copper hydroxide	225	1.66 ab	1.83 a	1.83 a
4 Copper hydroxide	150	2.83 b	3.16 b	4.33 b
5. Copper sulphate	380	1.33 a	1.83 a	2.33 a
6. Copper sulphate	152	2.66 b	3.33 b	4.16 b
7. Untreated	–	5.00 c	5.66 c	6.00 c
LSD ($P=0.05$)	–	1.25	1.31	1.68

[a] Fruit were assessed on a scaled index of disease symptom severity where 1, no disease; 2, 1–10% of fruit area affected; 3, 11–20% of fruit area affected; 4, 21–30% of fruit area affected; 5, 31–50% of fruit area affected; and 6, >51% of fruit area affected).

[b] Means followed by the same letter are not significantly different ($P = 0.05$).

compared to copper hydroxide at 150 g a.i./100 L^{-1}, copper sulphate at 152 g a.i./100 L^{-1} and the untreated control.

4. Discussion

Phytophthora fruit rot proved to be a damaging disease following periods of high rainfall causing a significant reduction in marketable fruit (16–19 % of fruit in untreated plots). Although the incidence of disease was not as severe as in some seasons, the artificial inoculation of both field experiments with *P. palmivora* proved a suitable method of establishing a disease epidemic in the field which enabled the reliable identification of effective chemicals. Hunter and Kunimoto (1973) reported that the germination and growth of sporangia is dependent on many hours of 100% relative humidity. The artificial inoculation methods used in our field experiment and *in vitro* studies enabled us to reproduce conditions of high relative humidity which was favourable for disease development.

Pyraclostrobin plus metiram and metalaxyl-M plus copper hydroxide are formulated fungicide mixtures with both systemic and protectant properties (Worthing and Hance, 1991). In our experiments, these fungicides proved very effective at controlling *Phytophthora* fruit rot in both the laboratory and field studies. Unfortunately, the continuous use of these fungicides is known to lead to the development of fungicide resistance strains (Lucas et al. (1990) and as chemical applications are required every two weeks during the 'wet season,' the risk of fungicide resistance is very high. CropLife Australia (2013) recommends that growers rotate applications of the 'at risk' systemic fungicide with fungicides from a different chemical group and limit the number of systemic fungicide applications per season as a means of managing fungicide resistance.

Chlorothalonil is a broad spectrum protectant fungicide and our research showed it was more effective against *P. palmivora* in the field than in the *in vitro* study. Similar research by Alvarez and Nelson (1982) also found that weekly field sprays with chlorothalonil resulted in 25–34% fewer *Phytophthora* affected papaya trees. However research by Alvarez et al. (1977) showed papaya fruit which were sprayed in the field with chlorothalonil and then harvested and inoculated with zoospores of *P. palmivora* had only slight protection against *Phytophthora* fruit rot. They concluded that the inoculum level and the incubation time used in the detached fruit bioassay exceeded that which would occur naturally in the field. As chlorothalonil at 994 g a.i./ha effectively controlled *Phytophthora* fruit rot in our field experiment it would also be a suitable candidate in an alternating spray program with copper hydroxide. Chlorothalonil is currently permitted for use by the Australian papaya industry for the control of the leaf diseases, brown spot and black spot, at the rate of 1296–1656 g a.i./ha^{-1}.

In previous research, Vawdrey and Westerhuis (2007) showed that foliar sprays with potassium phosphonate every two weeks significantly reduced the incidence of *Phytophthora* root rot in papaya by 47%. However our use of potassium phosphonate to control *Phytophthora* fruit rot showed it provided a level of control but was not as effective as the majority of other chemicals tested. The poor result achieved with dimethomorph was also most surprising as Mathereon and Porchas (2000) had reported that dimethomorph was a systemic fungicide which was most effective at reducing mycelial growth, sporangium formation and the germination of encysted zoospores of *Phytophthora capsici*, *Phytophthora citrophthora* and *Phytophthora parasitica*. As dimethomorph has never been used before in the growing of papaya locally and has a mode of action different to either potassium phosphonate or metalaxyl-M (Albert et al. 1988) which are currently used by the Australian papaya industry to manage *Phytophthora* root rot, it is unlikely the lack of efficacy was due to fungicide resistance.

In our experiments, copper hydroxide at rates of application of 375–600 g a.i./100 L consistently provided an extremely high level of disease control. However the regular use of copper fungicides particularly at high rates of application raises concerns of copper accumulation in soils and in crops and a potential risk to human health (Khan et al. 2013; Kelepertzis, 2014). Consequently using copper hydroxide in a spray program with the other effective chemicals would not only provide a high level of disease control but also reduce the potential risk to consumer health and the environment. In 2014, the results of our research were used to obtain a minor use permit for copper hydroxide at 375 g a.i./100 L^{-1} of water from the Australian Pesticide and Veterinary Association.

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