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Final Report

Effect of curative and protective pre-harvest fungicide and postharvest hot water applications on decay of papaya

Lynton Vawdrey

Queensland Department of Agriculture and Fisheries

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Fax: (02) 8295 2399

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Summary

Post-harvest decay of papaya caused by a number of fungal diseases continues to be a major constraint to growers with losses of 20-40% being common during the summer wet season. Post-harvest disease control in papaya is traditionally dependent on regular foliar applications with pre-harvest protectant fungicides permitted for the control of leaf diseases and use of the registered post-harvest fungicide prochloraz. However there was no information as to the efficacy of these pre-harvest chemicals in controlling post-harvest rots and according to growers the control achieved both during and following prolonged wet weather is most disappointing.

In recent years, curative fungicides have become available that can eradicate dormant fungal infections as well as protect against their establishment. These chemicals can also be used to reduce disease pressure in the field and in so doing improve the effectiveness of post-harvest fungicides. In papaya, the curative fungicide difenoconazole is currently permitted for the control of the foliar disease black spot but its effectiveness in reducing post-harvest decay is unknown. In addition to this, the removal of infected fruit and dead leaf material is believed to reduce disease inoculum in the field making it important in post-harvest disease management but the significance of this practice is also unknown.

Recent work by the Queensland Department of Agriculture & Fisheries (QDAF) found that under controlled laboratory settings, postharvest hot water dips provided an effective method for controlling disease in papaya fruit. Similar findings have been reported on papaya in Brazil, Malaysia and Fiji, demonstrating an effective disease control response to hot water treatment. This project investigated hot water treatments on a commercial scale on north Queensland fruit for their potential as a viable alternative to the currently registered postharvest fungicide prochloraz.

To answer these questions, field experiments were conducted in Mareeba (dry hinterland area west of Cairns) and in Innisfail (on the wet tropical coast) to assess the efficacy of pre-harvest applications of difenoconazole in spray programs with protectant fungicides. The significance of regularly removing senescent leaves and disease infected fruit in the management of post-harvest rots of papaya was assessed. Postharvest hot water trials were also conducted on a farm in Innisfail with fruit sent through a commercial supply chain (via Brisbane Markets) and assessed in a simulated supermarket shelf environment at the QDAF Maroochy Research Station.

In the field spray trials, results from the post-harvest disease assessments showed that in the Mareeba trial site, 70% of fruit were affected with stem-end rot (*Lasiodiplodia theobromae*), 8% with anthracnose (*Colletotrichum gloeosporioides*), 8% with chocolate spot (*Colletotrichum gloeosporioides*), 40% with diplodia rot (*Lasiodiplodia theobromae*) and 38% with fusarium rot (*Fusarium solani*). In the Innisfail trial site, 83% of fruit were affected with stem-end rot, 17% with anthracnose, 9% with chocolate spot,

28% with diplodia rot and 14% with fusarium rot. The research also showed that the current fungicide spray schedules used by Mareeba and Innisfail growers for the control of foliar diseases during the warm and wet summer months also provide a level of control of many of the post-harvest rots of papaya and that there was no benefit in including the curative fungicide difenoconazole in the spray program. The removal of dead leaf also reduced the number of fruit affected with anthracnose by 1%, chocolate spot by 0.6%, diplodia rot by 4%, fusarium rot by 5.9% and stem-end rot by 5%. Removing dead leaf should be practiced not only because it is a means of reducing disease inoculum levels in the crop but also to provide a clear and unobstructed pathway to the fruit column during fungicide spray applications. This will then provide opportunity for optimal coverage of the chemical on the fruit.

In the postharvest trials, results from disease assessments showed that hot water (HW) temperature treatments between 50° to 52°C for both cultivars provided the optimal treatment range for controlling disease. In the first experiment HW applied as a 52°C treatment resulted in greater than two-fold reduction in the proportion of fruit (incidence) with rots (16-30%) compared to prochloraz-treated fruit (40 - 60% of fruit), and a three-fold reduction when compared with untreated fruit (55 to 97% of fruit). Disease severity was also low in 52°C treated fruit, with ca. 1% of fruit surface area affected compared 4 to 12% for prochloraz or untreated fruit. Almost all fruit treated to higher HW temperatures of 54° or 56°C developed scald, which in turn, provided a wound entry point for rot re-infections over the assessment period. Hence, by the end of the assessment period disease levels in these two treatments were similar to those of untreated (control) fruit. The higher HW treatment temperatures (54° and 56°C) also delayed degreening in both cultivars.

In a second experiment, Ammonium carbonate (AC - 3% solution) was evaluated in addition to HW as a potential fungicidal agent. AC reduced the proportion of fruit that developed rots although there was no effect on rot severity. In cultivar '1B', for example, AC was effective up until the first 5 days of the assessment period, showing a 15% reduction in the incidence of rots when compared to untreated fruit (36%). In 'RB1', the effects of AC were evident by Day 8 but only in the 50°C HW treatment, with rot incidence being 33% lower in AC-treated compared with untreated fruit. A comparison of 50° versus 52°C HW suggested that the latter was slightly better at controlling the incidence and severity of rots, although the potential for scald development was also slightly higher.

Adequate control of post-harvest diseases of papaya can therefore be achieved by combining field sprays with post-harvest treatments of hot water. These results are consistent with overseas research suggesting that the use of hot water is beneficial in managing post-harvest decay of papaya.

Keywords

Papaya; pawpaw; papaw; post-harvest rots; fungicides; crop hygiene; hot water treatments; integrated disease management; ammonium carbonate.

Introduction

Some 90% of the Australian papaya industry which is valued at \$25-30 million is grown in the wet tropics region of far north Queensland between Mossman and Tully and the drier hinterland region near Mareeba and Dimbulah. One of the major constraints effecting fruit quality during the warm and wet summer months is the post-harvest rots caused by anthracnose and chocolate spot (*Colletotrichum gloeosporioides*), black rot (*Phoma caricae-papayae*), wet fruit rot (*Phomopsis caricae-papayae*), stem-end rots (*Lasiodiplodia theobromae* and *Phomopsis caricae-papayae*) and phytophthora fruit rot (*Phytophthora* spp.) (Cooke *et al.* 2009). Phytophthora fruit rot tends to be more of a problem for coastal growers (Joe Zappala, *pers. communication*) than tableland growers. At the present time, post-harvest disease control is carried out by post-harvest treatment with prochloraz with pre-harvest protectant fungicide applications (eg. mancozeb, chlorothalonil and copper formulations) being directed mostly at the control of the foliar diseases black spot and brown spot.

During 2010, a papaya fungicide spray schedule involving the use of the protectant fungicide chlorothalonil (APVMA Permit 12592) and the curative chemical difenoconazole (APVMA Permit 12592) was made available to tableland papaya growers for the control of the leaf disease black spot (Vawdrey *et al.* 2008) which is a problem during the cooler drier months of the year. The timing and use pattern of difenoconazole in this spray schedule was based on the findings of HAL project FR02003 and knowledge of disease and climate interactions occurring during the winter months. Difenoconazole is a systemic fungicide with long lasting, preventative and curative activity against a broad range of fungal diseases. It was not known however if the use of this curative chemical in spray programs with chlorothalonil would be of benefit in controlling post-harvest decay of papaya during the warm and wet summer months.

A similar spray schedule devised for coastal papaya growers involves the use of chlorothalonil and copper hydroxide (APVMA Permit 14417) for the control of the foliar disease brown spot and phytophthora fruit rot (Vawdrey 2014). As phytophthora fruit rot is a significant post-harvest disease for coastal growers, copper hydroxide would therefore play an important role in any pre-harvest spray program aimed at preventing post-harvest fruit rots.

In mangoes, it has been shown that orchard sanitation aimed at removing sources of disease inoculum and the use of curative fungicides is a major step forward in reducing post-harvest rots (Swart *et al.* 2009). With papaya, the removal of all infected and discarded fruit from the field is considered important in reducing the inoculum load of post-harvest pathogens (Alvarez and Nishijima 1987). Although

removing disease-affected leaf is considered impractical by most papaya growers, their removal from the tree on a regular basis would help improve spray coverage and may also help reduce disease inoculum in close proximity to fruit.

From a postharvest perspective, applications of hot water applied as either a dip or spray have long been recognized as an effective method for controlling postharvest diseases in tropical fruit (Fitzell 1979, Couey *et al.* 1984). Fitzell (1979), for example, found that disease incidence in papaya fruit immersed in hot water (55°C) for 20 minutes was substantially lower (53%) compared with undipped fruit (87%), or those dipped in ambient water with hypochlorite (84%). Further, Couey *et al.* (1984) also observed that a hot water spray treatment (54°C) applied for 3 minutes was as effective for controlling anthracnose and stem-end rots as a longer 20 minute hot water (48°C) immersion. Recent laboratory trials by the Queensland Department of Agriculture and Fisheries (QDAF) showed that a 5 minute dip in hot water (52°C) significantly reduced disease severity by over 3-fold in papaya fruit (cultivar '1B') compared with untreated fruit (Diczbalis *et al.* 2015). Moreover, heat-treated fruit also developed significantly less (ca. 30%) disease than those treated with prochloraz, suggesting that the current postharvest disease management program with the use of prochloraz may be producing suboptimal results. Complementary solutions such as the use of ammonium carbonate following a hot water treatment may be effective in controlling postharvest diseases in papaya (Henriod *et al.* 2016).

In this project, field-applied fungicides currently recommended for the control of the leaf diseases of papaya were assessed for their efficacy against the post-harvest rots of papaya. It also assessed the role of crop hygiene (deleafing) on the incidence and severity of post-harvest disease. Further, this project also evaluated on a commercial scale the efficacy of hot water for controlling postharvest diseases in papaya, and also whether ammonium carbonate would be beneficial as an additive to the use of hot water for control of postharvest diseases in papaya.

Methodology

Preharvest spray and deleafing trials

Site description and experimental design

Field trial sites were established within commercial plantings of papaya grown west of Mareeba (average annual rainfall of 918 mm) and just south of Innisfail (average annual rainfall of 3560 mm) under dry and wet climatic conditions respectively. The Mareeba site which was established on the 3 November 2013 consisted of 12 month-old papaya plants of the dioecious yellow fleshed cultivar '1B'. The site was divided into 32 plots consisting of 8 treatments and 4 replications arranged as a randomised complete block. Plots consisted of a single row of 6 fruiting plants 1.5 m apart with a single row of unsprayed plants separating treatments.

The Innisfail trial-site which was established on the 16 December 2014 consisted of 12 month-old papaya plants of the gynodioecious red fleshed cultivar 'RB1'. The trial-site was divided into 18 plots consisting of 6 treatments and 3 replications arranged as a randomized complete block. Plots consisted of a double row of 10 fruiting plants 1.8 m apart with a double row of sprayed plants (same chemical used in the adjacent treated plot) separating treatments.

Treatment application

Mareeba site

The treatments included;

1. Bravo WeatherStik SC (active ingredient 72% chlorothalonil, Syngenta) applied at 994 g a.i./100 L alone;
2. Bravo WeatherStik SC and the weekly removal of senescent leaves;
3. Digger/Bravo Weatherstik program consisting of back to back applications of Digger (a.i. 25% difenoconazole, Nufarm) applied at 40 g a.i./100 L followed by back to back applications of Bravo WeatherStik SC;
4. Digger/Bravo Weatherstik program with the weekly removal of dead leaves;
5. A tank mix of Bravo WeatherStik SC and Penncozeb (a.i. 75% mancozeb, Nufarm) applied at 160 g a.i./100 L, and a tank mix of Bravo WeatherStik and Penncozeb with the weekly removal of dead leaves.
6. The weekly removal of dead leaves alone and an untreated control were included for comparison.

All chemical treatments were applied every two weeks with a motorized backpack mist blower. Chemical

applications commenced on the 21 January 2014 and a total of seven sprays were applied to the appropriate plots. The spray volumes used ranged between 312 L and 347 L/ha. It should be noted; however, that results from this trial site should be treated with caution as farm-staff may have accidentally treated the entire site with a mixture of chlorothalonil and mancozeb on two occasions.

Innisfail site

The treatments included;

1. Champ Dry Prill WG (a.i. 37.5% copper hydroxide, Nufarm) applied at 375 g a.i./100 L;
2. Champ Dry Prill WG with the weekly removal of dead leaves;
3. Digger/Champ Dry Prill program consisting of back to back applications of Digger (a.i. 25% difenoconazole, Nufarm) applied at 40 g a.i./100 L followed by back to back applications of Champ Dry Prill WG;
4. Digger/Champ Dry Prill program with the weekly removal of dead leaves;
5. Bravo WeatherStik/Champ Dry Prill program consisting of back to back applications of Bravo WeatherStik SC applied at 994 g a.i./100 L followed by back to back applications of Champ Dry Prill;
6. And a Bravo WeatherStik/Champ Dry Prill program with the weekly removal of dead leaves.

An untreated control was not included at the request of the grower. All chemical treatments were applied with a motorized backpack mist blower every 2 weeks. Chemical applications commenced on the 13 January 2015 and a total of 6 sprays were applied to the appropriate plots. The spray volumes used ranged between 250 L and 300 L/ha.

Disease assessments

At both the Mareeba and Innisfail sites, fruit were harvested (colour stage 1) using a tractor-drawn picking platform and labeled with the appropriate plot number before being transported to South Johnstone Research Station and placed in a ripening room set at 27⁰ C and 72-78% humidity. Fruit were assessed for ripe fruit rots (the incidence of a particular rot and the area of fruit affected) at colour stage 5 some 7-10 days after harvesting. The incidence of the different fungal rots was obtained by counting the number of representative fungal lesions per fruit. The area of fruit affected by rot was estimated using the following scale, 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; 6, > 51% of fruit area affected. Fungal cultures were obtained from each of the representative rots and these were identified based on morphological characteristics using a compound microscope.

Cost-benefit analysis of deleafing

The removal of dead leaf material and diseased fruit from the field is considered important in reducing

the inoculum load of post-harvest pathogens (Alvarez and Nishijima 1987). During this trial, dead leaf was removed from the appropriate trees (treatments 2, 4 and 6) and placed on the ground. The time to complete the deleafing was estimated by removing dead leaves from forty plants and recording the 'time taken' using a stopwatch. This practice was repeated three times and the mean calculated (Appendix 4).

Data analysis

Mareeba site

The presence of stem-end rot was initially analysed using a generalized linear mixed model (GLMM) with the treatment as the fixed effect and the replicate as the random effect. As the random term was non-significant, the model was simplified to a generalised linear model (GLM) with no random term. The counts of disease incidence were analysed by a two-part conditional GLM. The area of fruit affected by rot was analysed using a residual maximum likelihood (REML).

Innisfail site

Where there was enough non-zero data, the counts recorded at each time assessment were analysed using analysis of variance (ANOVA). A \log_{10} transformation was required for the number of lesions caused by anthracnose, chocolate spot, fusarium rot and diplodia. A small constant (0.1) was added to the counts to allow for the transformation of the zeroes. The area of the fruit affected by the rot was treated as continuous and analysed using ANOVA. The underlying assumptions were satisfied and no data transformation was needed. The presence of stem-end rot, the portion of fruit affected with anthracnose and chocolate spot were analysed using a Binomial generalize linear mixed model (GLMM) with a logit link function. All of the weekly harvest assessments were statistically analysed but only those with significant differences (95% least significant difference) are mentioned.

Postharvest hot water trials

Experimental layout

Two experiments examining the efficacy of hot water and a biocide additive in controlling postharvest diseases commenced on a commercial papaya farm south of Innisfail on 08 March and 29 March 2016, referred to as "Experiment 1" and "Experiment 2", respectively. Trials were conducted using two cultivars, a dioecious yellow flesh cultivar '1B' and a gynodioecious red fleshed cultivar 'RB1'. Harvest times occurred in a month in which rainfall levels were relatively high (monthly total 679 mm) for the season, and when subsequent disease pressure was expected to be highest. Experimental fruit in this study were harvested and handled in accordance to commercial practice, with exception to experimental postharvest treatments conducted on-farm. The fruit were also placed into the same domestic supply chain as commercial fruit.

In both experiments, fruit were harvested at a commercially mature stage (10% colour break) from blocks containing relatively old trees of '1B' (21 months) and 'RB1' (17 months). Experimental fruit were treated on-farm to a range of treatment regimes aimed at controlling postharvest diseases (treatments described in Experiment 1 and 2 below). Fruit were then packed into industry standard 15 kg cardboard cartons and then palletised. The constructed pallet was secured with strapping and placed in the farm ripening room for approximately 2.5 days (60 hours). The air temperature in the room was slowly ramped down over this period from ~24° to 13°C during which time fruit were manually dosed, from a cylinder, with two shots of ethylene (maximum 45 ppm). After 60 hours, the pallet was loaded onto a commercial freight truck along with other pallet consignments and transported to the Brisbane Markets on the morning of 11 March (Experiment 1) or 1 April (Experiment 2) (Appendix 5, Figure 3a and b, respectively). Each experimental consignment arrived two days later at the Brisbane Markets before being collected (06:30) and transported to the QDAF Maroochy Research Station (MRS). Pallets were deconstructed at the MRS and cartons were held for up to 8 days between 23°-24°C to simulate expected retail shelf life conditions in southern supermarkets. Fruit quality assessments of skin colour (% yellow skin coverage), scald and disease severity (% area per fruit affected) were recorded on all fruit at 1, 5 and 8 days after arrival at the MRS. For almost all fruit day 5 was at or near the ideal stage for sale and consumption. The evaluation at Day 8 was used to represent fruit kept for several days after sale. Scald and disease incidence data was calculated based on the proportion of affected to non-affected fruit. Specific on-farm treatments are described below.

Experiment 1

An experiment was conducted to evaluate the effect of hot water versus conventional prochloraz fungicide treatments on fruit quality and disease levels. Fruit of each variety were randomly assigned to one of five treatments. Each treatment consisted of 4 replicate cartons containing up to 9 fruit. Fruit were treated to either;

1. ambient water for 5 minutes (untreated control),
2. prochloraz (55 ml/100 L) for 1 minute spray-to-waste (commercial control),
3. immersion in 52°C water for 5 minutes,
4. immersion in 54°C water for 5 minutes,
5. immersion in 56°C water for 5 minutes.

Hot water-treated fruit were held under water in plastic crates within a 300 L portable hot water tank with recirculating water. After 5 minutes, the fruit were lifted out and then immersed in an ambient hydro-cooling water bath (24°C) for 5 minutes, then removed, dried and packed into standard 15 kg cardboard cartons.

Experiment 2

A second experiment was conducted to refine the hot water treatment temperatures and to investigate whether an additive with known fungicidal properties, ammonium carbonate (AC), further enhanced disease control. Fruit of each variety were randomly assigned to one of six treatments. Each treatment consisted of 4 replicate cartons containing up to 9 fruit. Fruit were treated to either;

1. 5 minute dip in ambient water (untreated control),
2. 5 minute dip in ambient water (untreated control) followed by AC (3% solution for a 5 second dip-to-coat),
3. 50°C water dip for 5 minutes,
4. 50°C water dip for 5 minutes followed by AC (3% solution for 5 second dip-to-coat),
5. 52°C water dip for 5 minutes,
6. 52°C water dip for 5 minutes followed by AC (3% solution for a 5 second dip-to-coat).

Fruit assigned to a heat treatment were first immersed in the hot water tank, then hydro-cooled for 5 minutes (24°C), and then, if specified, dipped in AC, dried and packed into standard 15 Kg cardboard cartons.

Data analysis

A two-way Analysis of Variance (ANOVA) was performed in Experiment 1 to test the main and interactive effects of water temperature and time (day of assessment) on fruit quality. In Experiment 2, a Factorial ANOVA was conducted to test treatment main and interactive effects on fruit quality, using three levels of water temperature and two levels of AC (with or without). Following confirmation of a significant treatment effect ($P \leq 0.05$), a Fisher's Least Square Difference test (at 5%) was used in both experiments to distinguish between treatments differences.

Outputs

Preharvest spray and deleafing trials

Prolonged periods of wet weather which favour the development of severe outbreaks of post-harvest rots failed to eventuate during the summer growing periods in 2014 (Mareeba trial) and 2015 (Innisfail trial) with the Innisfail region receiving only 50% of its average annual rainfall for that time of the year (Anon.

2015, Appendix 1). This resulted in a lower than expected level of disease particularly anthracnose and chocolate spot. The disease assessments conducted as part of the two field trials showed:

1. The fungal diseases causing post-harvest decay of papaya were the same at both the Mareeba and Innisfail trial-sites. Consequently, diseases management practices should be similar in both papaya growing areas during most seasons.

The diseases were identified as stem-end rot (*Lasiodiplodia theobromae*), anthracnose (*Colletotrichum gloeosporioides*), chocolate spot (*C. gloeosporioides*), diplodia rot (*L. theobromae*) and fusarium rot (*Fusarium solani*). In the Mareeba trial, 70% of fruit were affected with stem-end rot, 8% with anthracnose, 8% with chocolate spot, 40% with diplodia rot and 38% with fusarium rot. In the Innisfail trial, 83% of fruit were affected with stem-end rot, 17% with anthracnose, 9% with chocolate spot, 28% with diplodia rot and 14% with fusarium rot (Appendix 2).

2. The current fungicide spray schedules used by tableland and coastal growers for the control of foliar diseases during the warm and wet summer months will also provide a level of control of many of the post-harvest rots of papaya. There was no benefit in including the curative fungicide difenoconazole in the spray program.

In both the Mareeba and Innisfail trials, none of the chemical treatments effectively controlled stem-end rot. This was possibly due to poor spray coverage with the fungicides in the region of the fruit stem-end because of a concentrated fruit column. In the Mareeba trial, a mixture of chlorothalonil+mancozeb was the most effective treatment at controlling anthracnose and reducing the area of fruit affected by rot, and sprays with chlorothalonil gave the best control of diplodia rot. There was also a lower incidence of anthracnose in most deleafed plots but this was not significant over all harvest times. However, results from the Mareeba trial should be treated with caution as they may have been compromised by farm-staff who accidentally sprayed the trial-site on two occasions with a mixture of chlorothalonil and mancozeb. In the Innisfail trial, the chlorothalonil/copper program provided the best control of anthracnose, chocolate spot and diplodia rot and was the best treatment at reducing the 'area of fruit affected by rot' (Appendix 3, tables 1, 2, 3, and 4).

3. Overall, the deleafing treatment had only a small effect in reducing the incidence of the post-harvest rots recorded. Significantly fewer fusarium lesions were recorded on fruit grown on plants that were deleafed.

However, in the Innisfail experiment, the interaction of deleafing and the difenoconazole program did significantly reduce the incidence of diplodia lesions and the proportion of fruit with diplodia rot compared to no deleafing and the difenoconazole program (Appendix 3, tables 3a and 3b). There were also fewer

lesions of anthracnose and chocolate spot following deleafing and sprays with the chlorothalonil program compared to deleafing and sprays of the difenoconazole program (Appendix 3; table 1a). Aside from any direct benefit to post harvest disease control, deleafing should also be done on a regular basis to provide an unobstructed path between the sprayer and the plant's foliage in a bid to control the leaf disease brown spot. This disease is known to cause significant yield loss if left unmanaged.

4. Updates on trial activities and trial results were given at monthly grower meetings of the Innisfail Papaya Growers Association and in articles in the industry newsletter the Papaya Post.

An article based on the results from the Mareeba trial titled 'Pre-harvest fungicides and post-harvest diseases' appeared in Edition 2, September 2014 of the Papaya Post (Appendix 2). An article on the results from the Innisfail trial titled 'Effect of pre-harvest fungicides on post-harvest rots' was forwarded to the editor of the Papaya Post on the 12th May 2015 (Appendix 2).

5. Results from this study suggest the break-even point to offset the cost of deleafing (labour cost at \$24.00/hr) would require an increase of 1938 marketable fruit over a 2 year cropping cycle (Appendix 4). If however deleafing was conducted whilst the fruit is being harvested, the labour cost would be significantly reduced.

Any improvement in fruit rot control following deleafing is unlikely to lead to a reduction in chemical applications. Fungicide applications in papaya are primarily aimed at the control of the foliar disease brown spot and when severe outbreaks occur control is dependent on a program of fortnightly fungicide sprays (Vawdrey *et. al.* 2008).

Postharvest hot water trials

Experiment 1

Experimental fruit were treated on-farm and then sent by commercial road freight to the Brisbane Markets. Fruit were collected and evaluated at the Maroochy Research Station, QDAF over 8 days. Headspace air and relative humidity readings recorded along the supply chain were consistent with commercial recommendations, including maintenance of fruit between 13° - 15°C during freighting and 23° - 24°C during a simulated retail shelf stage (Figure 3a).

Fruit quality assessments conducted during the simulated retail shelf period showed that hot water (HW) treatments significantly delayed skin colour development. In cultivar '1B', delays in skin colour development was particularly evident in the 56°C treatment, and less so in the 52° and 54°C treatments (Figure 4a). Control and prochloraz-treated fruit reached 50% colour by day 2 of the shelf life compared day 4 and 7 for 52°/54°C and 56°C, respectively. Delays in skin colour development also occurred in cultivar 'RB1' although only in the 54° and 56°C-treated fruit, reaching 50% colour-break approximately 3

and 4 days, respectively, later than control fruit (Figure 4b).

Scald formed as a grey-coloured blemish on some of the hot water-treated fruit. Cultivar '1B' appeared more susceptible to developing scald than 'RB1'. Scald symptoms developed in all three hot water treatments although the incidence and severity overall was lower at 52°C compared with the 54° and 56°C HW treatments (Table 5a). In 'RB1', scald developed only in the 54° and 56°C treatments, although the incidence and severity of scald was between 2-4 times greater in the latter treatment (Table 5b).

In cultivar '1B', disease was evident on fruit by Day 5 of the simulated retail shelf environment, with the exception to those treated with 52°C HW (Table 6a; Appendix 6). By Day 8, over 60% of the fruit in the Control, Prochloraz, 54° and 56°C HW treatments had developed rots, ranging in severity from 5.6 to 11%. This was in contrast to the 52°C-treated fruit where only 31% of fruit had developed rots, with a severity score of <2%, being significantly lower (ca. 3-6 fold lower) than the other treatments.

In cultivar 'RB1', fruit disease was evident from Day 1 of the simulated retail shelf environment on all treatments except those dipped in 52°C HW (Table 6b; Appendix 6). Rots in this latter treatment were observed only on Day 8. By this day, only ca. 30% of 52°C-treated fruit had developed rots compared to ≥50% of fruit from the other treatments. Similarly, disease severity on Day 8 was also lowest in the 52°C treatment (score 1.4%), followed by 54°C (score 5.8%), and highest in the Control, Prochloraz and 56°C HW treatments (mean score of 14%).

Experiment 2

Experimental fruit treated on-farm to hot water (HW) and Ammonium Carbonate (3% solution) (AC) treatments were sent by commercial road freight to the Brisbane Markets and then assessed at the Maroochy Research Station. Headspace air and relative humidity recorded along the supply chain were in line with commercial specification, with fruit being freighted between 13° - 15°C and then held at 23° - 24°C as part of a simulated retail shelf environment, being similar to conditions found in a southern city grocery store or supermarket (Figure 3b).

During the simulated retail shelf phase, fruit from both cultivars reached full colour by Day 8 of the assessment period, irrespective of treatment type (Figure 5a and b). With respect to the rate of colour change, 52°C HW treated fruit of cultivar '1B' fruit were initially slower to ripen (colour up) than the other treatments. Applications of AC had no effect on skin colour development, irrespective of the treatment or cultivar type.

Scalding in both cultivars was present on fruit treated to HW (Table 7a and b). Applications of AC however had no effect on scald development in either variety ($P>0.05$). Symptoms of scald appeared on fruit by Day 5 in the 52°C treatments, and by Day 8 in both HW treatments. The incidence and severity of scald differed slightly between the two cultivar types, with '1B' being more sensitive to expressing

symptoms. By Day 8, for example, 58% of '1B' fruit expressed symptoms of scald compared to 1.4% of 'RB1' fruit.

Disease was evident in both varieties after 5 and 8 days in the simulated retail shelf environment, although the incidence and severity differed depending on treatment type. In cultivar '1B', HW-treated fruit generally had significantly lower incidences and severities of disease than control fruit (Table 8a; Appendix 6). AC was effective in reducing the incidence but not the severity of disease. This was evident on Day 5 where only 21% of AC-treated fruit had rots compared to 36% of untreated fruit.

In cultivar 'RB1', there was a significant three-way interaction of HW treatment type, time (day of rating) and AC (present / absent) on disease incidence (Table 8b; Appendix 6). In general terms, disease incidence was lower with increasing water temperature, and comparatively lower on Day 8 in 50°C HW fruit treated with AC (67%) as opposed to without AC (100%). Disease severity across all 'RB1' treatments was relatively low (<6% severity score), although there was a significant effect of water treatment temperature (but not AC) on rot severity (Table 8c). In this case, rot severity increased with time, although was consistently lower in the HW treatments compared with the Control.

Outcomes

Significant knowledge was gained as to the identity and incidence of the various post-harvest rots affecting papaya in the Mareeba and Innisfail growing areas. The same diseases were recorded in both growing areas. There was also a higher incidence of diplodia rot and fusarium rot at the Mareeba site. Both these diseases are known to be pre-disposed by abrasion/injury (Persley *et al.* 2003) and can be more of a problem with fruit which have 40% or more colour. Post-harvest handling practices play a significant role in the management of these diseases.

One of the main objectives of the research was to assess the efficacy of pre-harvest applications of the curative fungicide difenoconazole in spray programs with the protectant fungicides copper hydroxide and chlorothalonil. Research conducted in Brazil indicated that fungicides from the demethylation inhibitor group (DMI's) were effective at controlling post-harvest diseases such anthracnose and chocolate spot of papaya (da Silva Pereira 2012). Similarly, stem-end rot of mango was effectively controlled with pre-harvest sprays of the DMI propiconazole (Swart *et al.* 2009). Our research identified that including the DMI fungicide difencoconazole in a spray program with either chlorothalonil or copper hydroxide did not improve the control of post-harvest diseases compared to chlorothalonil and copper hydroxide in a spray program. Consequently, the current spray schedule of chlorothalonil and copper hydroxide recommended to growers for the control of leaf diseases during the summer months is possibly the most cost effective control.

In papaya, the removal of dead leaf (deleafing) is believed to help reduce disease inoculum in close proximity to fruit (Alvarez and Nishijima 1987). Our research showed that the practice of defoliation did reduce the incidence of some of the fruit post-harvest rots. However under the conditions of our trials, the effect of defoliation on post-harvest rots was small and therefore unlikely to have any environmental benefits such as reducing the number of chemical spray applications. Growers would also be aware that the main reason for fungicide sprays is to manage the leaf disease brown spot which can be most destructive causing defoliation of the plant and subsequent sunburn on fruit (Vawdrey *et al.* 2008). Although the direct impact of defoliation in reducing post-harvest rots may be small, the practice also provides the added benefit of optimizing spray coverage in the control of leaf diseases.

A second objective of the research was to assess the efficacy of post-harvest hot water applications and AC for controlling disease in papaya. Research conducted in a number of countries that grow papaya has reported positive benefits of using postharvest hot water dips or sprays for disease control, particularly for anthracnose and stem-end rots (Martins *et al.* 2010, Diczbalis *et al.* 2015, Stice *et al.* 2016). These studies have shown that the efficacy of hot water treatments is dependent upon an interaction of water temperature and exposure time. Fruit treated to excessively high temperatures or with lengthy dipping times may be effective, at least initially, in controlling disease. However, the trade-off is the increased likelihood of heat related damage on tissue (eg. skin scald) and / or disruptions in the ripening processes, such as a delay or inhibition of skin degreening (Chavez-Sanchez *et al.* 2013). Our research clearly showed that for a 5 minute exposure time, a hot water temperature of between 50° and 52°C was the optimum combination for effectively controlling disease in papaya cultivars '1B' and 'RB1', without incurring significant damage to fruit. When hot water treatment temperatures exceeded 52°C, an increase in scald damage and delays in degreening were observed.

Research evaluating fruit coating additives such as ammonium carbonate (AC) or sodium bicarbonate have shown promising results in minimising disease incidence in papaya (Sivakumar *et al.* 2002). Sivakumar *et al.* (2002), for example, reported that AC in a wax formulation effectively reduced anthracnose incidence by 60% compared with untreated control fruit (90%) following 21 days in cool storage and another 2 days under marketing conditions. Our past research using fruit dipped in a 3% ambient water-based solution of AC also resulted in a marked reduction in disease; in this case rot severity was reduced by 50% compared with untreated fruit (Henriod *et al.* 2016). Interestingly, in the present study AC reduced the incidence of rots but not the severity, suggesting that its efficacy was either absolute or not at all. Future improvements in its efficacy may be achieved with experimentation of different formulations of AC, including its incorporation into a wax rather than water-based solution.

Evaluation and Discussion

Conducting field trials of this size on grower properties can be challenging as there is a heightened risk of outside influences compromising the results. Although significant steps were taken to prevent such an occurrence (e.g. discussions with the grower and key farm staff as to the layout of the trial and when the trial would commence; clear marking out of the boundaries of the trial-site), the trial area at the Mareeba site was accidentally sprayed on two occasions with a mixture of the fungicides chlorothalonil and mancozeb. Consequently, it is highly likely that this action confounded the results of the trial and contributed to a lower than expected level of disease. In addition to this, the number of treated plants in the trial was significantly reduced by the misuse of herbicide (a mixture of glyphosate and glufosinate ammonium) by farm-staff (Appendix 2, Papaya Post Article). This had a negative impact on the number of fruit harvested from the trial plots and the quality of the data. In the Innisfail trial the following year, steps (described previously) were taken to prevent a repeat of the Mareeba experience. The grower in this case was a small producer who applied all chemical sprays himself and assisted in the weekly harvesting of fruit. Consequently there were no mishaps and no confounding of data. It could therefore be concluded that regular communication with those involved in the daily maintenance of the crop is important in preventing the compromising of results.

Distinguishing between the various post-harvest rots proved most effective in delivering on project outputs. By identifying each of the diseases on each fruit, we were able to show the limitations or lack of efficacy of many of the treatments in relation to that particular disease e.g. none of the chemicals alone or in combination with deleafing had an impact on stem-end rot of papaya. Other researchers (Alvarez and Nishijima 1987) came to a similar conclusion regarding the control of stem-end rot and recommended that field sprays be combined with postharvest hot-water or fungicide treatments.

Chlorothalonil alone and in mixtures with mancozeb or in an alternating spray program with copper hydroxide provided a level of control of anthracnose, chocolate spot and diplodia rot whereas the curative fungicide difenoconazole in alternating programs with chlorothalonil or copper hydroxide was not as effective at controlling these diseases. The reason for this poor disease control is not clear as DMI fungicides such as difenoconazole are used in Brazil to control papaya diseases such as anthracnose and chocolate spot (Da Silva Pereira *et al.* 2012). One possible explanation is that the timing of the difenoconazole application could have influenced the efficacy of the spray program. Another possibility was a low sensitivity to difenoconazole in the anthracnose and chocolate spot populations because of exposure to the chemical which is used to control the leaf disease black spot (*Asperisporium caricae*)

during the winter months. A loss of sensitivity to DMI fungicides used on papaya has been reported previously in Brazil (Da Silva Pereira *et al.* 2012).

In the Innisfail field trial, seasonal conditions were warm and dry and generally not favorable for the on-going development of post-harvest rots. Deleafing alone was shown to cause a small reduction in the incidence of fruit rots. Premature leaf death brought about by poor plant nutrition or leaf disease has been shown to provide a source of disease inoculum close to developing fruit. Consequently, good plant nutrition and the management of the leaf disease brown spot during the warm summer months are an essential part of the integrated management of post-harvest rots of papaya. When extreme wet weather events which favor nutritional problems and leaf diseases occur, deleafing is more likely to play a much greater role in managing post-harvest rots.

A lack of prolonged wet weather during both field trials is most likely to have contributed to the low level of disease in these trials and an inability to discriminate between treatments at some of the assessment times. Consideration was therefore given to extending the life of the trial with the hope that weather conditions favoring disease development would occur. Unfortunately hot dry climatic conditions which prevailed just prior to the commencement of the trial lead to a reduced fruit set and a significant gap in the fruit column, leaving some plots with insufficient fruit to harvest.

In the postharvest hot water trials, trial commencement was delayed due to the onset of an El Nino event. El Nino events typically brings lower than normal rainfall across northern Queensland and often results in a late start to the wet season (Anon., 2015). Nonetheless, two trials were successfully undertaken during this latter part of the season (March to April) when rainfall levels were highest, along with expected field inoculum loads. The increased disease pressure during this period provided a disease baseline that allowed the testing to deliver results to validate the use and efficacy of hot water for controlling disease.

Interestingly, in this study the 50° to 52°C hot water treatments, and to a lesser degree, the inclusion of AC, had a greater impact in reducing disease than that of Sportak[®], the currently registered postharvest fungicide. Sportak[®] has been registered since the early 1980's for the postharvest control of anthracnose and stem-end rots, although in recent wet seasons, reports have surfaced that between 30-40% of papaya fruit within consignments show high levels of disease at wholesale markets in Brisbane and Sydney (Anon. papaya growers, pers. comm.). As a consequence, Australian papaya supply chain participants have been concerned over the efficacy of prochloraz, considering the lack of approved fungicide alternatives. The findings from this study therefore provide justification for the industry to consider hot water as an effective alternative to prochloraz. Papaya producers in other countries such as Brazil and recently Fiji are now using hot water as part of their quarantine protocols and for effective management of postharvest diseases. For Queensland papaya producers, the decision to install a hot

water treatment system in farm packing sheds would require consideration of the cost benefit that will include a reduction in the need for postharvest chemical fungicides, increased profit through reduced spoilage in supply chains and opportunities to use hot water from a 'clean-green' marketing stand-point. End users would also benefit by having disease-free fruit, with a longer shelf life most fully realized at times of the year when disease pressure is high..

Recommendations

- The fungicide spray schedule consisting of fortnightly sprays of a mixture of chlorothalonil and mancozeb (Mareeba area) or an alternating program of chlorothalonil and copper hydroxide (Innisfail area) will provide the most cost effective control of post-harvest rots of papaya.
- Using protectant fungicides such as chlorothalonil, mancozeb and copper hydroxide in spray programs avoids the risk of a loss of sensitivity which has been previously reported in papaya overseas.
- Although the direct impact of deleafing in reducing post-harvest rots may be small, the practice also provides the added benefit of optimizing spray coverage in the control of leaf diseases.
- The removal of dead leaf material has two benefits and although the overall effect was not significant there were arithmetic reductions in disease incidence as a result. If it was able to be done cost effectively it would be a recommended practice.
- Postharvest hot water treatments provide a more effective disease control measure than the currently registered fungicide Sportak[®].
- Producers in the Australian papaya industry should consider the merits further of installing and using a hot water system, particularly during times of the year when disease pressure is highest.
- Ammonium carbonate provides some efficacy against disease but it would be recommended that future research consider the evaluation of different formulations to order to improve further its efficacy.

Scientific Refereed Publications

Journal article

Vawdrey, L.L., Male, M., Grice, K.R.E., 2014. Field and laboratory evaluation of fungicides for the control of Phytophthora fruit rot of papaya in far north Queensland, Australia. *Crop Protection* **67**, 116-120.

Intellectual Property/Commercialisation

No commercial IP generated.

References

- Alvarez, A.M., Nishijima, W.T., 1987. Post harvest diseases of papaya. *Plant Disease* **71**, 681-86.
- Anon., 2015. Australian Bureau of Meteorology.
- Chavez-Sanchez, I., Carrillo-Lopez, A., Vega-Garcia, M., Yahia, E.M. 2013. The effect of antifungal hot-water treatments on papaya postharvest quality and activity of pectinmethylesterase and polygalacturonase. *Journal of Food Science and Technology* **50**, 101-107.
- Cooke, A., Persley, D.M., House, S., 2009. Diseases of fruit crops in Australia. CSIRO Publishing, Oxford Street, Collingwood Victoria, Australia.
- Couey, H.M., Alvarez, A.M. and Nelson, M.G. 1984. Comparison of hot water spray and immersion treatments for control of postharvest decay of papaya. *Plant Disease* **68**, 436-437.
- Da Silva Pereira, A.V., Martins A.B., Michereff S.J., Da Silva M.B., Camara M.P.S., 2012. Sensitivity of *Lasiodiplodia theobromae* from Brazilian papaya orchards to MBC and DMI fungicides. *European Journal of Plant Pathology* **132**, 489-498.
- Diczbalis, Y., Henriod, R., Campbell, T., Sole, D. 2015. Strengthening the Fiji papaya industry through applied research and information dissemination. ACIAR final report. HORT/2008/003.
- Fitzell, R. 1979. Papaw dipping controls post-harvest disease. *Banana Bulletin*, March, 14.
- Henriod, R., Diczbalis, Y., Sole, D., Stice, K., Tora, L. 2016. Investigation into various fungicides and alternative solutions for controlling postharvest diseases in papaya fruit. *Acta Horticulturae* **1111**, 113-119.
- Martins, D.M.S, Blum, L.E.B, Sena, M., Dianese, A.C. 2010. Effect of hot water treatment on the control of papaya (*Carica papaya* L.) post harvest diseases. *Acta Horticulturae* **864**, 181-185.
- Persley D.M., Ploetz R.C., 2003. Diseases of papaya. In: Cooke T., Persley D., House S., (Eds.) Diseases of tropical fruit crops. CABI Publishing, Wallingford, Oxon UK, pp. 373-412.

Sivakumar, D., Hewarathgamagae, N.K., Wijeratnam, R.S.W. and Wijesundera, R.L.C. 2002. Effect of ammonium carbonate and sodium and bicarbonate on anthracnose of papaya. *Phytoparasitica* **30**, 486-492.

Stice, K.N., Tora, L., Henriod, R., Diczbalis, Y., Sole, D. 2016. Developing a commercial hot water treatment to control post-harvest rots on 'Fiji Red' papaya. *Acta Horticulturae* **111**, 125-132.

Swart S.H., Swart G., Labuschagne C., 2009. The effect of strategically timed pre-harvest fungicide applications on post-harvest decay of mango. *Acta Horticulturae* **820**, 511-519.

Vawdrey L.L., Grice K.R.E., Westerhuis D., 2008. Field and laboratory evaluations of fungicides for the control of brown spot (*Corynespora cassicola*) and black spot (*Asperisporium caricae*) of papaya in far north Queensland, Australia. *Australasian Plant Pathology* **37**, 552-558.

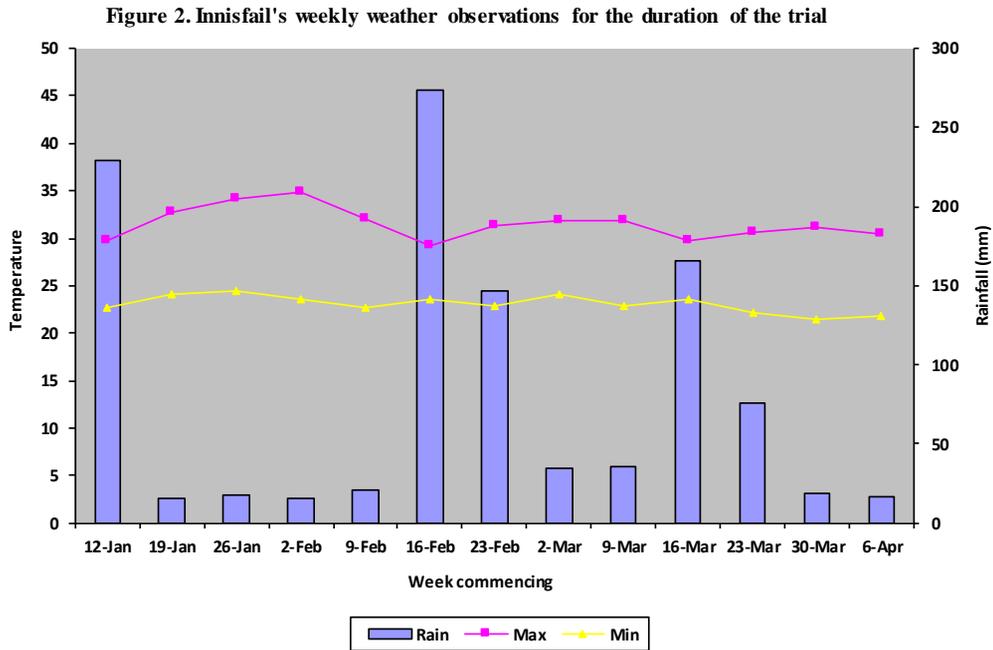
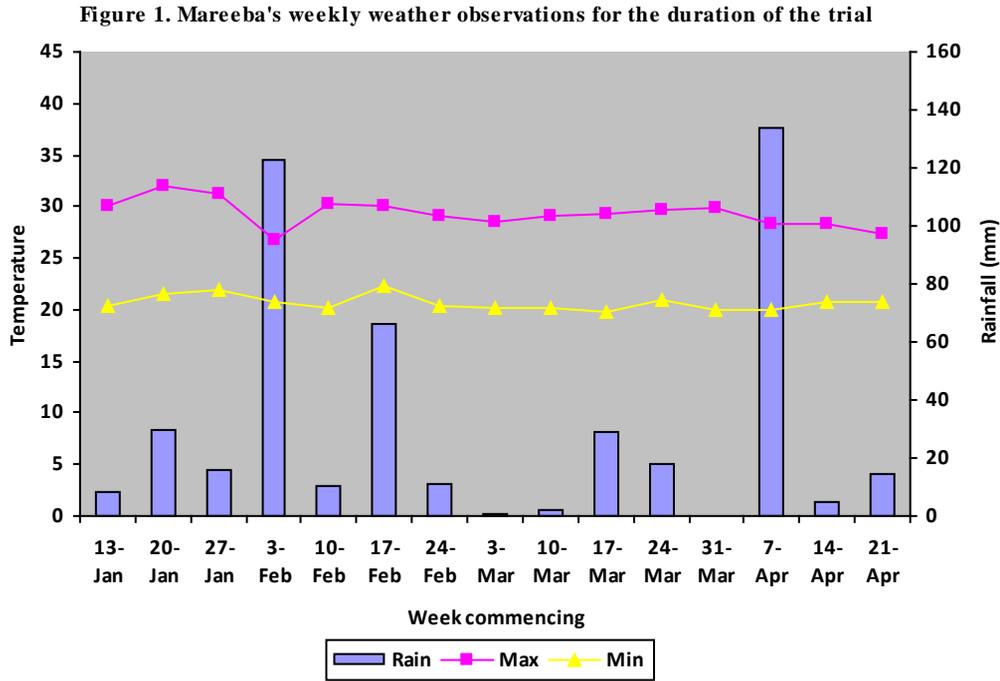
Vawdrey L.L., Male M., Grice K.R.E., 2014. Field and laboratory evaluation of fungicides for the control of Phytophthora fruit rot of papaya in far north Queensland, Australia. *Crop Protection* **67**, 116-120.

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Appendices

Appendix 1. Temperature and rainfall for the pre-harvest spray component of the project.



Appendix 2.

Photos of the main post-harvest diseases of papaya



Stem-end rot (*Lasiodiplodia theobromae*)



Dipodia rot (*Lasiodiplodia theobromae*)



Anthraxnose (*Colletotrichum gloeosporioides*)



Chocolate spot (*C. gloeosporioides*)



Fusarium rot (*Fusarium solani*)

Pre-harvest fungicides and post-harvest rots

Lynton Vawdrey
Principal Plant Pathologist
South Johnstone Research Station

Post-harvest rots caused by fungal diseases are a major constraint to papaya growers during the wet season. In addition to this, the cost of the fruit being rejected at the market and the cost of freight is borne by the grower. In December 2013, a field trial was established on a Mareeba grower's property to examine the effectiveness of fortnightly applications of the fungicides Bravo WeatherStik[®], Digger[®] and Penncozeb[®] and canopy hygiene (removal of infected fruit and dead leaf material) in reducing post-harvest rots and leaf diseases. Fungicide applications and the harvesting of fruit commenced on the 20 January. Treated fruit (colour stage 1) were harvested weekly, transported to South Johnstone Research Station and placed in a ripening room at 27^o C and 72-78% humidity. Fruit were assessed for ripe fruit rots at colour stage 5 (some 7-10 days after harvest).

Prolonged periods of wet weather which favour fruit rots and leaf diseases did not eventuate over the summer period. The two wettest months were February and April with 210 and 152 mm respectively. Unfortunately, the entire trial-site was accidentally sprayed with protectant fungicides by farm staff on two occasions in February. This action and the occurrence of climatic conditions less favourable for disease development significantly reduced the disease pressure in the trial. A leaf disease assessment conducted on the 11 March showed this to be the case.

The trial concluded on the 29 April and the results from the fruit rot and leaf disease assessments showed:

- more than 70% of fruit were affected with stem-end rot (Photo 1-*Lasiodiplodia theobromae*). None of the treatments effectively controlled stem-end rot. This is most likely due to poor chemical coverage to the stem-end region of the fruit.
- *Diplodia* rot (Photo 2-*L. theobromae*) and *Fusarium* rot (*Fusarium solani*) were found on 40% and 38% of fruit respectively. Fewer *Diplodia* rot affected fruit were found in Bravo WeatherStik treated plots. None of the treatments effectively controlled *Fusarium*-related rots.
- anthracnose (Photo 3-*Colletotrichum gloeosporioides*) was only recovered during April and affected only 8% of fruit harvested. There were fewer anthracnose affected fruit in plots treated with fungicides and deleafed.
- All of the chemical treatments effectively controlled the leaf diseases in the trial compared to deleafing alone and the untreated.

In wet growing seasons, it is necessary to apply fungicides such as Bravo Weatherstik from the time of fruit set to harvest. Combining pre-harvest fungicides and post-harvest hot water dips or sprays is most likely to provide the greatest level of disease control. It is proposed that a second trial be conducted on the wet tropical coast during the summer of 2015.

Effect of pre-harvest fungicides on post-harvest rots

Post-harvest fungal rots of papaya can cause losses of 20-40% during the summer wet season. Post-harvest disease control in papaya at this time of year is dependent on fortnightly foliar sprays with protectant fungicides and the use of the registered post-harvest fungicide prochloraz. However according to some growers, the control achieved both during and following prolonged wet weather can be most disappointing.

In December 2014, a field trial was established on a grower's property in Innisfail to identify the various fungal diseases associated with post-harvest rots and to evaluate the effectiveness of fortnightly applications of the fungicide copper hydroxide (Champ Dry Prill[®]) alone and in alternating programs with chlorothalonil (Bravo WeatherStik[®]) and difenoconazole (Digger[®]). The influence of crop hygiene (removal of infected fruit and dead leaf material during weekly harvests) in reducing post-harvest rots was also investigated. Weekly fruit harvests (colour stage 1) of red papaya (RB1) were conducted and fruit was transported to South Johnstone Research Station and placed in a ripening room at 27°C and 72-78% humidity. Fruit were assessed for ripe fruit rots at colour stage 5 (some 7-10 days after harvest).

Prolonged periods of wet weather which favour the development of severe outbreaks of fruit rot failed to eventuate, with the Innisfail region receiving only 50% of its average rainfall for that time of the year. The trial concluded on the 8 April after 12 weekly harvests.

The results of the fruit rot assessments showed:

- the diseases causing post-harvest decay of papaya were stem-end rot (*Lasiodiplodia theobromae* - Photo 1), anthracnose (*Colletotrichum gloeosporioides* – Photo 2), chocolate spot (*Colletotrichum gloeosporioides* – Photo 3), Diplodia rot (*Lasiodiplodia theobromae* - Photo 4) and Fusarium rot (*Fusarium solani* – Photo 5).
- 83% of the fruit harvested were affected with stem-end rot. None of the chemical treatments with or without deleafing had a significant effect at reducing the number of fruit with stem-end rot.
- 17% of fruit harvested were affected with anthracnose. At 3 harvest times there were significantly fewer anthracnose lesions where fruit was treated with the Bravo[®]/Champ[®] program compared with the Digger[®]/Champ[®] program.
- 9% of fruit harvested were affected with chocolate spot. At 2 harvest times there were significantly fewer chocolate spot lesions where fruit was treated with the Bravo[®]/Champ[®] program compared with the Digger[®]/Champ[®] program.
- 28% of fruit harvested were affected with Diplodia rot. At two fruit harvests there were significantly fewer Diplodia lesions on fruit treated with the Bravo[®]/Champ[®] program compared with the Digger[®]/Champ[®] program and Champ[®] alone.
- 14% of fruit were affected with Fusarium rot. At one fruit harvest there were more rots caused by *Fusarium solani* in Bravo/Champ[®] treated plots than in Champ[®] alone treated plots. Fusarium rots are known to be pre-disposed by physical damage to the fruit.
- The removal of dead and dying leaf material caused a small reduction in the incidence of post-harvest rots.

The results of this research showed none of the chemicals will effectively control stem-end rot. A tight fruit column and subsequent lack of chemical coverage at the stem-end of the fruit is the most likely cause of this. The Bravo/Champ program provided the best control of anthracnose and chocolate spot of

papaya. Fortnightly sprays of Bravo® alternated with Champ Dry Prill® followed by a post-harvest treatment with prochloraz (label recommendation) will provide the best level of control of the fungal diseases causing post-harvest decay of papaya.

Papaya Post Article 2014.

Trunk rot and lodging in papaya

Recently, I have come across severe trunk rot (photo 1) and in some cases lodging (tree trunk breaking above the soil line) (photo 2) on a few papaya properties both on the coast and on the tablelands. At the time, these growers were of the belief that the damage was caused by the plant pathogen *Phytophthora* (photo 3). One such grower stated that he had seen this problem for many years and had suffered substantial yield losses due to trees lodging and partial ring-barking of trees.

Numerous samples of rotted trunk tissue from affected trees were collected and assayed for the presence of *Phytophthora* at the plant pathology laboratory at the Centre for Wet Tropics Agriculture, South Johnstone. *Phytophthora* was not recovered from these samples so additional samples were taken a week later and again assayed at South Johnstone with additional samples sent to the Centre for Tropical Agriculture laboratory in Mareeba. Again, all samples from both laboratories proved negative for *Phytophthora*.

Following these results, it was suggested to the grower that herbicide damage was the most likely cause of the problem. The herbicide Basta® in combination with glyphosate has been used extensively on the farm for many years. Basta® is known to cause damage to papaya stems when applied to green (uncalloused) bark but it is not known what effect its combination with glyphosate may have on the development of stem damage.

When applying herbicides, growers are advised to pay close attention to the label recommendations and to contact the Department of Agriculture, Fisheries and Forestry plant pathology staff at either South Johnstone or Mareeba if they need confirmation of *Phytophthora* on their property.

		
<p>Photo 1. Suspected herbicide damage</p>	<p>Photo 2. Lodging due to suspected herbicide damage</p>	<p>Photo 3. Phytophthora trunk rot</p>

Appendix 3.

Table 1. Mean number of anthracnose lesions per fruit at the Innisfail trial-site.

Harvest date	Chemical Treatment		
	Chlorothalonil program	Difenoconazole program	Copper hydroxide alone
2.03.15	-0.72 a (0.09)	0.31 b (1.9)	-0.75 a (0.08)
23.03.15	-0.64 a (0.13)	0.66 b (4.48)	0.09 b (1.12)
31.03.15	-0.73 a (0.08)	0.57 b (3.60)	0.41 b (2.45)

Numbers in parentheses are the back-transformed means. Means within a row followed by the same letter are not significantly different ($P>0.05$).

Table 1(a). Mean number of anthracnose lesions per fruit harvested on the 23 March 2015 at the Innisfail trial-site.

	Chemical treatment		
	Chlorothalonil program	Difenoconazole program	Copper hydroxide alone
No deleafing	-0.28 ab (0.43)	0.64 c (4.31)	-0.33 a (0.37)
Deleafing	-1.00 a (0.00)	0.68 c (4.65)	0.50 bc (3.06)

Numbers in parentheses are the back-transformed means. Means within a row followed by the same letter are not significantly different ($P>0.05$).

Table 2. Mean number of chocolate spot lesions per fruit at the Innisfail trial-site.

Harvest date	Chemical Treatment		
	Chlorothalonil program	Difenoconazole program	Copper hydroxide alone
2.03.15	-0.79 a (0.06)	0.45 b (2.72)	-0.79 a (0.06)
23.03.15	-1.00 a (0.00)	0.28 b (1.79)	-0.50 ab (0.21)

Numbers in parentheses are the back-transformed means. Means within a row followed by the same letter are not significantly different ($P>0.05$).

Table 3. Mean number of diplodia lesions on fruit at the Innisfail trial-site.

Harvest date	Chemical Treatment		
	Chlorothalonil program	Difenoconazole program	Copper hydroxide alone
23.03.15	-0.660 a (0.12)	0.140 b (1.27)	0.200 b (1.48)

Numbers in parentheses are the back-transformed means. Means within a row followed by the same letter are not significantly different ($P>0.05$).

Table 3(a). Mean number of diplodia lesions on fruit harvested on the 16 March 2015 at the Innisfail trial-site.

	Chemical Treatment		
	Chlorothalonil program	Difenoconazole program	Copper hydroxide alone
No deleafing	-0.400 a (0.30)	0.564 c (3.57)	0.289 bc (1.84)
Deleafing	0.012 abc (0.93)	-0.264 ab (0.44)	-0.124 ab (0.65)

Numbers in parentheses are the back-transformed means. Means within a row followed by the same letter are not significantly different ($P>0.05$).

Table 3(b). Mean proportion of fruit affected with diplodia rot harvested on the 16 March 2015 at the Innisfail trial-site.

	Chemical treatment		
	Chlorothalonil program	Difenoconazole program	Copper hydroxide alone
No deleafing	-1.012 a (0.267)	0.693 b (0.667)	1.012 b (0.733)
Deleafing	-0.134 ab (0.467)	-1.012 a (0.267)	-0.406 ab (0.400)

Numbers in parentheses are the back-transformed means. Means within a row followed by the same letter are not significantly different ($P>0.05$).

Table 4. Mean area of fruit affected by rot at the Innisfail trial-site..

Harvest date	Chemical Treatment		
	Chlorothalonil program	Difenoconazole program	Copper hydroxide alone
07.04.15	1.733 a	2.400 b	1.733 a

A mean of 1 denotes, 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. Means followed by the same letter are not significantly different ($P>0.05$).

Appendix 4.

Cost-benefit of deleafing:

The removal of dead leaf and diseased fruit from the field is considered important in reducing the inoculum load of post-harvest pathogens (Alvarez and Nishijima 1987). During this trial, dead leaf was removed from the appropriate plots (treatments 2, 4 and 6) and the cost of this practice was estimated. Forty plants were deleafed and the time to complete this practice was recorded using a stopwatch. This practice was repeated three times and the mean calculated. Results showed that a 1 hectare block of mature papaya grown at this site during the summer would take 3.4 hours to deleaf. Therefore, labour costed at \$24.00/hour (Joe Zappala, pers. communication) would deliver a cost of \$82.00/ha per fortnight or a total of \$4264/ha over a two year cropping cycle.

Results from the post-harvest rot assessments showed that deleafing would reduce the number of fruit affected by anthracnose by 1%, chocolate spot by 0.6%, diplodia rot by 4%, fusarium rot by 5.9% and stem-end rot by 5%. However a non-significant p-value for the main effect (deleafing) suggests the overall mean across all disease assessments was not significantly different. Consequently, reporting an estimate of the potential increase in gross margin may convey a greater degree of certainty than is justified. This said the 'break-even point' is a better estimate of the cost-benefit as it represents the amount of additional fruit that would need to be produced to offset the cost of deleafing. Given the cost parameters outlined in the study, the 'break-even point' would be an increase in the number of marketable fruit of 1938, which at \$2.20 per fruit (Joe Zappala, pers. communication) would offset the deleafing cost of \$4264/ha. Any increase in the number of marketable fruit above this amount would result in a positive impact on the gross margin.

As a general comment, most growers would have their workers remove diseased fruit and dead leaf when the fruit was being harvested. Therefore there would be no additional labour cost to the grower if they were to carry out this practice.

Appendix 5.

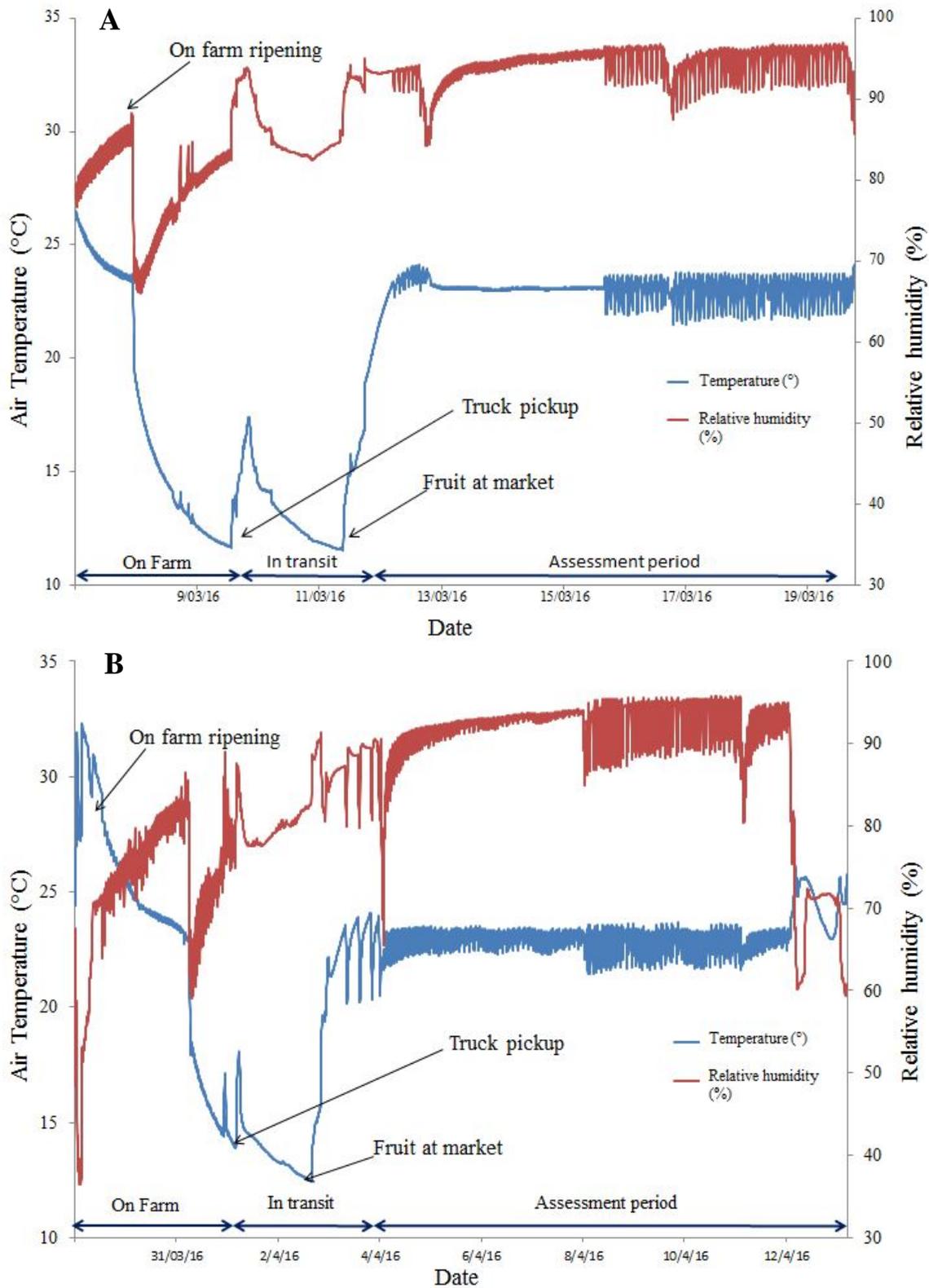


Figure 3. Headspace air temperature and relative humidity of papaya fruit in cartons along a supply chain in ‘Experiment 1’ (A) and ‘Experiment 2’ (B). Fruit were palletised and ripened on-farm, road freighted to the Brisbane Markets and assessed at the Maroochy Research Station.

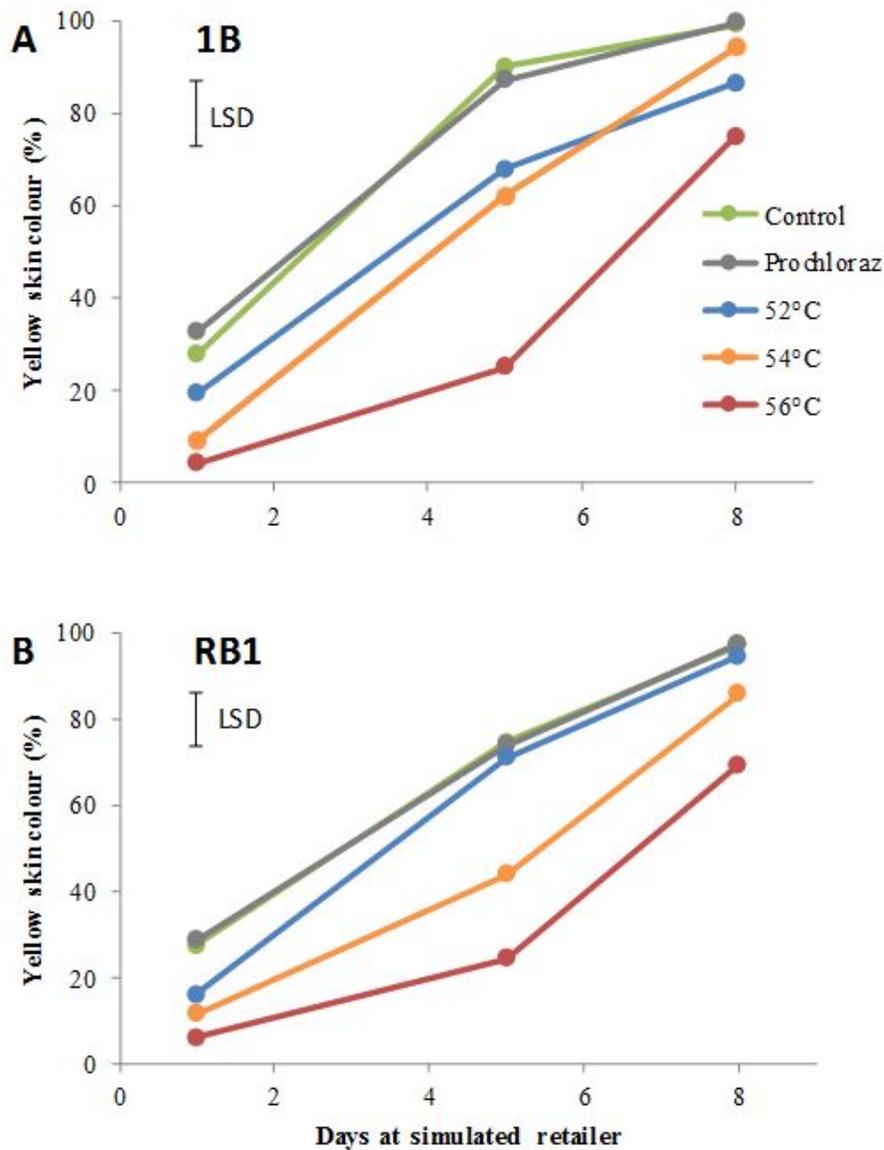


Figure 4. Hot Water trial – Experiment 1. Changes in mean skin colour of papaya cultivar A) ‘1B’ and B) ‘RB1’ over 8 days in a simulated retail shelf environment following on-farm treatments of prochloraz and hot water dips. Fig. A and B: treatment x time interactions, 95% LSD; $P < 0.01$.

Table 5a. Mean incidence and severity of scald on hot water treated papaya cv. ‘1B’ fruit.

Treatment	Incidence (%)				Severity (%)			
	Day 1	Day 5	Day 8	Mean	Day 1	Day 5	Day 8	Mean
52°C	19.8	58.7	51.7	43.4 a	4.0 a	12.9 ab	9.3 ab	8.7
54°C	80.6	91.7	91.7	88.0 b	15.0 ab	49.7 c	58.0 cd	40.9
56°C	97.2	94.4	100.3	97.3 b	19.2 b	69.5 de	75.0 e	54.6
Mean	65.9 a	81.6 b	81.2 b		12.7	44.0	47.4	

Control and prochloraz treatments (not shown) were not heat-treated and subsequently had no scald. Incidence analysis: treatment main effect, $P<0.001$; time (day) main effect, $P<0.05$. Severity analysis: treatment x time interaction, $P<0.001$. Incidence or severity means followed by the same letter are not significantly different ($P>0.05$).

Table 5b. Mean incidence and severity of scald on hot water treated papaya cv. ‘RB1’ fruit.

Treatment	Incidence (%)				Severity (%)			
	Day 1	Day 5	Day 8	Mean	Day 1	Day 5	Day 8	Mean
52°C	0	-	0		0	-	0	
54°C	44.4	-	47.2	45.8 a	6.5 a	-	15.8 a	11.2
56°C	100.0	-	97.2	98.6 b	14.7 a	-	63.8 b	39.3
Mean	72.2	-	72.2		10.6	-	39.8	

Control and prochloraz treatments (not shown) were not heat-treated and subsequently had no scald. Statistical analyses only compared Day 1 with Day 8 (no data was collected on Day 5) and excluded the 52°C HW treatment as all data were 0's. Incidence analysis: treatment main effect, $P<0.01$. Severity analysis: treatment x time (day) interaction, $P<0.01$. Incidence or severity means followed by the same letter are not significantly different ($P>0.05$).

Table 6a. Mean incidence and severity of rots on papaya cv. ‘1B’ fruit following an on-farm dip treatment in ambient water (control), hot water (52° - 56°C) or ambient spray of prochloraz.

Treatment	Incidence (%)				Severity (%)			
	Day 1	Day 5	Day 8	Mean	Day 1	Day 5	Day 8	Mean
Control	0	20.5	88.5	54.5 bc	0	0.7	7.4	4.1 b
Prochloraz	0	15.6	64.2	39.9 b	0	1.9	6.2	4.1 b
52°C	0	0.0	30.9	15.5 a	0	0.0	1.8	0.9 a
54°C	0	33.3	75.0	54.2 bc	0	1.8	5.6	3.7 b
56°C	0	41.7	86.1	63.9 c	0	3.7	11.2	7.5 c
Mean		22.2 a	68.9 b			1.6 a	6.4 b	

Incidence / Severity analyses: treatment main effect, $P<0.001$; time main effect, $P<0.001$. Incidence or severity means followed by the same letter are not significantly different ($P>0.05$). Analyses excluded Day 1 as all data were 0's.

Table 6b. Mean incidence and severity of rots on papaya cv. ‘RB1’ fruit following an on-farm dip treatment in ambient water (control), hot water (52° - 56°C) or ambient spray of prochloraz.

Treatment	Incidence (%)				Severity (%)			
	Day 1	Day 5	Day 8	Mean	Day 1	Day 5	Day 8	Mean
Control	5.6 a	65.6 c	97.2 d	56.1	1.0 a	6.7 bc	15.3 d	7.7
Prochloraz	5.6 a	27.8 b	63.9 c	32.4	0.8 a	4.9 ab	11.6 cd	5.8
52°C	0a	0a	30.6 b	10.2	0a	0a	1.4 a	0.5
54°C	2.8 a	16.7 ab	50.0 c	23.2	0.6 a	3.1 ab	5.8 ab	3.2
56°C	2.8 a	52.8 c	100.0 d	51.9	0.1 a	4.8 ab	15.2 d	6.7
Mean	3.4	32.6	68.3		0.5	3.9	9.9	

Incidence analysis: treatment x time interaction, $P < 0.001$. Severity analysis: treatment x time interaction, $P < 0.05$. Incidence or severity means followed by the same letter are not significantly different ($P > 0.05$).

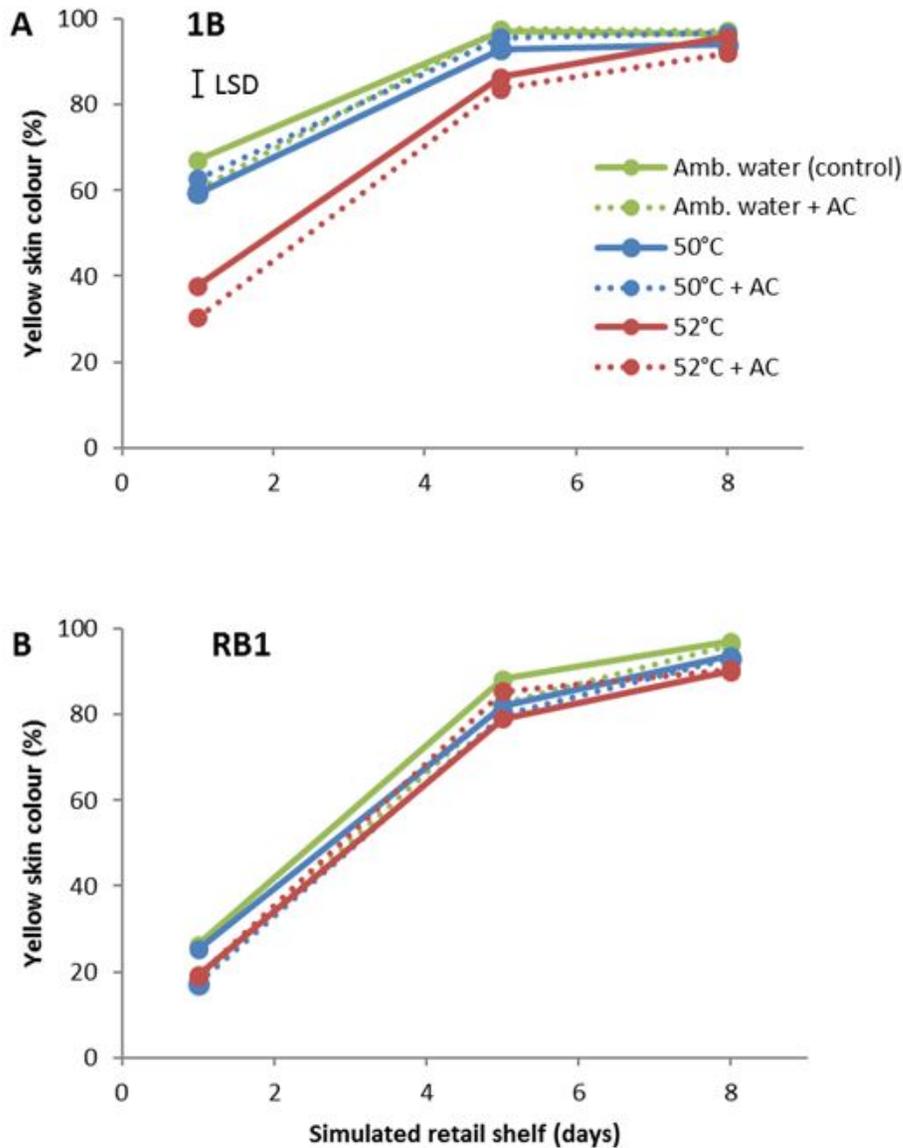


Figure 5. Hot Water trial – Experiment 2. Changes in mean skin colour of papaya cultivar A) ‘1B’ and B) ‘RB1’ over 8 days in a simulated retail shelf environment following on-farm treatments of prochloraz and hot water dips. Fig. A: treatment x time interactions, 95% LSD; $P < 0.01$. Fig. B: treatment x time interactions, 95% LSD, $P > 0.05$ (not significant).

Table 7a. Mean incidence and severity of scald on hot water treated papaya cv. '1B' fruit.

Treatment	Incidence (%)			Severity (%)		
	Day 5	Day 8	Mean	Day 5	Day 8	Mean
Control	0	0	0	0	0	0
50°C	0a	58.3 b	29.2	0a	8.0 b	4.0
52°C	82.8 c	66.1 b	74.5	21.1 c	10.3 b	15.7
Mean	41.4	62.2		10.6	9.2	

Incidence / Severity analyses: treatment x time interactions, $P < 0.001$. Incidence or severity means followed by the same letter are not significantly different ($P > 0.05$). Analyses excluded Day 1 as all data were 0's.

Table 7b. Mean incidence and severity of scald on hot water treated papaya cv. 'RB1' fruit.

Treatment	Incidence			Severity		
	Day 5	Day 8	Mean	Day 5	Day 8	Mean
Control	0	0	0	0	0	0
50°C	0a	1.4 a	0.7	0a	0.1 a	0.1
52°C	1.4 a	43.1 b	22.3	0.3 a	4.1 b	2.2
Mean	0.5	14.8		0.1	1.4	

Incidence / Severity analyses: treatment x time interactions, $P < 0.001$. Incidence or severity means followed by the same letter are not significantly different ($P > 0.05$). Analyses excluded Day 1 as all data were 0's.

Table 8a. Mean incidence and severity of rots on papaya cv. '1B' fruit following an on-farm dip treatment in either an ambient water (control) or hot water (52° - 56°C), followed by a ambient dip either with or without ammonium carbonate (AC).

Treatment	Incidence (%)			Severity (%)		
	Day 5	Day 8	Mean	Day 5	Day 8	Mean
Control	61.2 b	98.6 c	79.9	3.2 bc	10.4 d	6.8
50°C	17.2 a	92.7 c	55.0	0.5 a	4.7 c	2.6
52°C	8.0 a	56.3 b	32.2	0.1 a	1.7 ab	0.9
Mean	28.8	82.5		1.3	5.6	
No AC	36.3 b	82.5 c	59.4	1.6	5.9	3.8
AC	21.3 a	82.5 c	51.9	0.9	5.3	3.1
Mean	28.8	82.5		1.3	5.6	

Incidence / severity analyses of ambient and hot water treatments: treatment x time interaction, $P < 0.001$. Incidence of AC analysis: treatment x time interaction, $P < 0.05$. Severity of AC analysis: Main effect or interaction, $P > 0.05$ (not significant). Means for each of the four statistical tests above followed by the same letter were not significantly different ($P > 0.05$). Analyses excluded Day 1 as all data were 0's.

Table 8b. Mean incidence of rots on papaya cv. ‘RB1’ fruit following an on-farm dip treatment in either an ambient water (control) or hot water (52° - 56°C), along with and without an ammonium carbonate (AC) dip.

Treatment	Day 5		Day 8		Mean
	No AC	AC	No AC	AC	
Control	41.7 c	25.0 bc	100.0 e	97.2 e	66.0
50°C	5.6 a	11.1 ab	100.0 e	66.7 d	45.9
52°C	2.8 a	2.8 a	63.9 d	52.8 cd	30.6
Mean	16.7	13.0	88.0	72.2	

Treatment x time x AC interaction, $P < 0.05$. Means followed by the same letter are not significantly different ($P > 0.05$).

Table 8c. Mean severity of rots on papaya cv. ‘RB1’ fruit following an on-farm dip treatment in either an ambient water (control) or hot water (52° - 56°C). Fruit treated with or without ammonium carbonate were not significantly different and were subsequently pooled for each treatment.

Treatment	Day 5	Day 8	Mean
Control	2.1 bc	5.9 d	4.0
50°C	0.7 ab	2.9 c	1.8
52°C	0.1 a	0.8 ab	0.5
Mean	1.0	3.2	

Treatment x time interaction, $P < 0.05$. Means followed by the same letter are not significantly different ($P > 0.05$).

The analysis excluded Day 1 as all data were 0's.

Appendix 6.

Experiment 1: Photos of cultivar '1B' papaya fruit quality on Day 8 of the assessment.



Experiment 1: Photos of cultivar 'RB1' papaya fruit quality on Day 8 of the assessment.



Experiment 2: Photos of cultivar '1B' papaya fruit quality on Day 8 of the assessment.



Experiment 2: Photos of cultivar 'RB1' papaya fruit quality on Day 8 of the assessment.

