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VI1451: Impact of covered structures on the progression of Psa-V: Phase Two

Casonato S, Bent S

October 2014

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Trials were set up in the kiwifruit growing season of 2012–13 on three orchards to test whether plastic, breathable covers erected over existing kiwifruit vines could reduce the incidence, progression and severity of *Pseudomonas syringae* pv *actinidiae* (Psa-V) infections. These structures had been erected in an attempt to slow the progression of Psa-V. Vines were already infected with Psa-V, with varying levels of symptoms expressed. Across the three sites the varieties *Actinidia chinensis* 'Zesy002' (Gold3), *A. chinensis* 'Zesy003' (Gold9), *A. deliciosa* 'Zesh004' (Green14) and *A. chinensis* 'Hort16A' were assessed, along with Gold3 scions that had been notch grafted onto existing rootstocks. Grafted seedlings were planted out at each site and used as trap plants that would indicate infection from Psa.

During the season of 2013–14 two sites were lost from the project due to weather damage to the protective canopies. Only the covers over the 'Hort16A' mature vines remained intact. There, vines were monitored until the progression of the Psa disease in the non-covered area led to their removal in January 2014.

Prior to removal of the 'Hort16A' vines there was a visible difference between the covered and non-covered areas of the trial, with more infection on the canes and leaders in the non-covered area. The covers appeared to be slowing the progression of the disease in the vines. The newly grafted Gold3 scions were relatively healthy with no difference between the covered and non-covered areas. The grafted seedlings of 'Hort16A' and Gold3 planted during the 2014 season at one trial site showed vast differences in disease between covered and non-covered areas: covered areas had significantly fewer diseased plants.

This trial has indicated there is merit in continuing with the use of covers for high value kiwifruit cultivars. It may be possible to slow the progression of the disease in already infected vines whilst new grafts are established. Infection did not progress as rapidly in healthy plant material placed under covers.

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1 Introduction

Pseudomonas syringae pv *actinidiae* (Psa-V) proliferates in moist environments, with rain events shown to promote new infections and symptom development (Horner et al. 2011). In drier, warmer conditions the progression and expression of Psa-V is lessened. Based on this knowledge a number of growers have constructed large plastic shelters over existing kiwifruit blocks. The proposition is that if vines are kept under cover, the reduced wetness will lessen disease prevalence within a kiwifruit canopy.

In 2012, breathable plastic covers were erected over selected blocks on one Paengaroa and two Katikati kiwifruit orchards. These covers were, at that time, prototypes in the Bay of Plenty and were used to assess the ability of crop covers to reduce the incidence of Psa-V. The covers are one option that could be used to protect high-value vines of gold *Actinidia chinensis* varieties that provide a higher monetary return than the green *A. deliciosa* varieties. During the 2012–13 growing season, the three covered orchards were monitored for Psa infection (Casonato et al. 2013).

Findings from the 2012–13 study compared the incidence of Psa-V on vines under covers with uncovered vines: a slower rate of progression of the disease in vines under cover occurred (Casonato et al. 2013). In 2013–14 it was decided to continue observations for a second year to observe the effect of the covers on progression of the disease in vines already infected with Psa to determine whether the covers would slow the rate of spread of the disease.

The aim of this project was to improve our understanding (from studies carried out in 2012–13) of the effectiveness of vine covers in reducing the incidence of Psa-V in vines already infected with Psa and to gain more knowledge of the ability of covers to slow the rate of spread of Psa-V in clean plant material. This was to be achieved by continuing the monitoring of mature *Actinidia chinensis* 'Hort16A', *A. deliciosa* x *A. chinensis* 'Zesh004' (Green14) and *A. chinensis* 'Zesy002' (Gold3) scions at the three covered orchards and the healthy Gold3 and 'Hort16A' grafted seedlings.

2 Materials and methods

2.1 Sites

Covered structures were erected at three sites: Canon Rd and Tuapiro Rd at Katikati, and Maungarangi Rd in Paengaroa, during late October and early November 2012. In all three study orchards, part of the covers were damaged and were either replaced or removed during the 2013–14 growing season. At the beginning of the 2013–14 season the status of the trial orchards was as follows.

2.1.1 Canon Rd, Katikati

The Canon Rd site had mature 'Hort16A' vines and on the same rootstock, *A. chinensis* 'Zesy002' (Gold3) notch grafted scions. In January 2014 the 'Hort16A' leaders were removed and only the Gold3 notch grafts remained. The plastic covered structures were erected in three areas over one block. Each covered area was three full rows, two of which were datum rows, and five to eight bays long (Figure 1). Covered areas were three bays apart in the row. Artificial shelters made of shade cloth were adjacent to one row of datum vines.

Data loggers were placed at the Canon Rd site but no data were collected as some of the dataloggers were removed when the covers were disestablished and other dataloggers were water damaged.

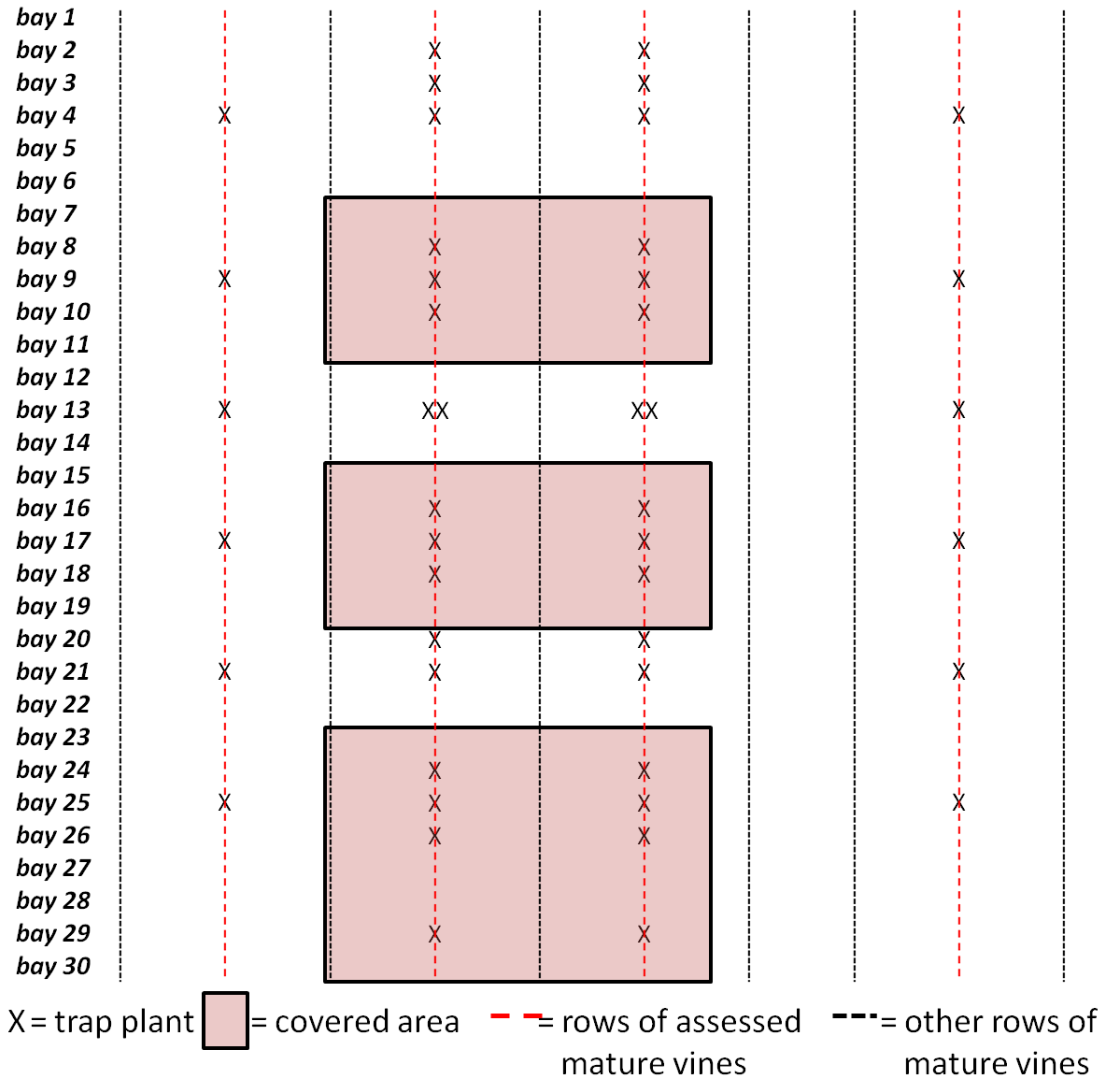

Figure 1. Canon Rd block plan showing covered areas (opaque red area with dark black lines), no cover areas in-between and 'control' rows to the sides of the structures. The mature vines were *Actinidia chinensis* 'Hort16A' notch grafted with *A. chinensis* 'Zesy002' (Gold3). Trap plants (*A. chinensis*) are also depicted (marked with X). Trap plants were located in the rows in covered and no cover areas, with two further "control" rows not in the vicinity of the covered area.

2.1.2 Tuapiro Rd, Katikati

The mature *A. chinensis* 'Zesy003' (Gold9) vines that formed the canopy at Tuapiro Rd were removed in May 2013 due to a high level of Psa infection (Casonato et al. 2014; Figures 2 and 3). This left only the Gold3 scions, grafted in 2011, which were subsequently trained across the wires on the pergola system to form the new canopy (Figure 4).

Figure 2. An *Actinidia chinensis* 'Zesy003' (Gold9) vine at Tuapiro Rd, Katikati, exhibiting symptoms of *Pseudomonas syringae* pv *actinidiae* (Psa) infection. Psa ooze is visible down the leader, down the scion and to the rootstock.

Figure 3. An *Actinidia chinensis* 'Zesy003' (Gold9) vine at Tuapiro Rd, Katikati, showing ooze and red exudate caused by *Pseudomonas syringae* pv *actinidiae* (Psa) at the Tuapiro Rd, Katikati orchard. This scion was not under a protective, plastic cover.

Figure 4. *Actinidia chinensis* 'Zesy002' (Gold3) vines under a protective plastic cover at Tuapiro Rd, Katikati orchard. These notch grafted scions were trained across the wires on the pergola system after the removal of *A. chinensis* 'Zesy003' (Gold9) vines in May 2013 due to Psa-V infection. The red arrow indicates a supporting arch on the cover that collapsed after excessive weight caused by rain accumulation.

The trial block at Tuapiro Rd consisted of four rows each 26 bays long, with two being datum rows. Each covered area spanned four rows and was 4–5 bays long. The uncovered area consisted of four rows, each 2–4 bays long (Figure 5). Artificial shelters, made of shade cloth, were on one side of the datum row (Figure 4)

The covers were removed after harvest in 2013, leaving the vines uncovered for the entire 2013–14 growing season. Observations in this block were therefore made to determine how rapidly Psa progressed in the Gold3 notch grafted scions.

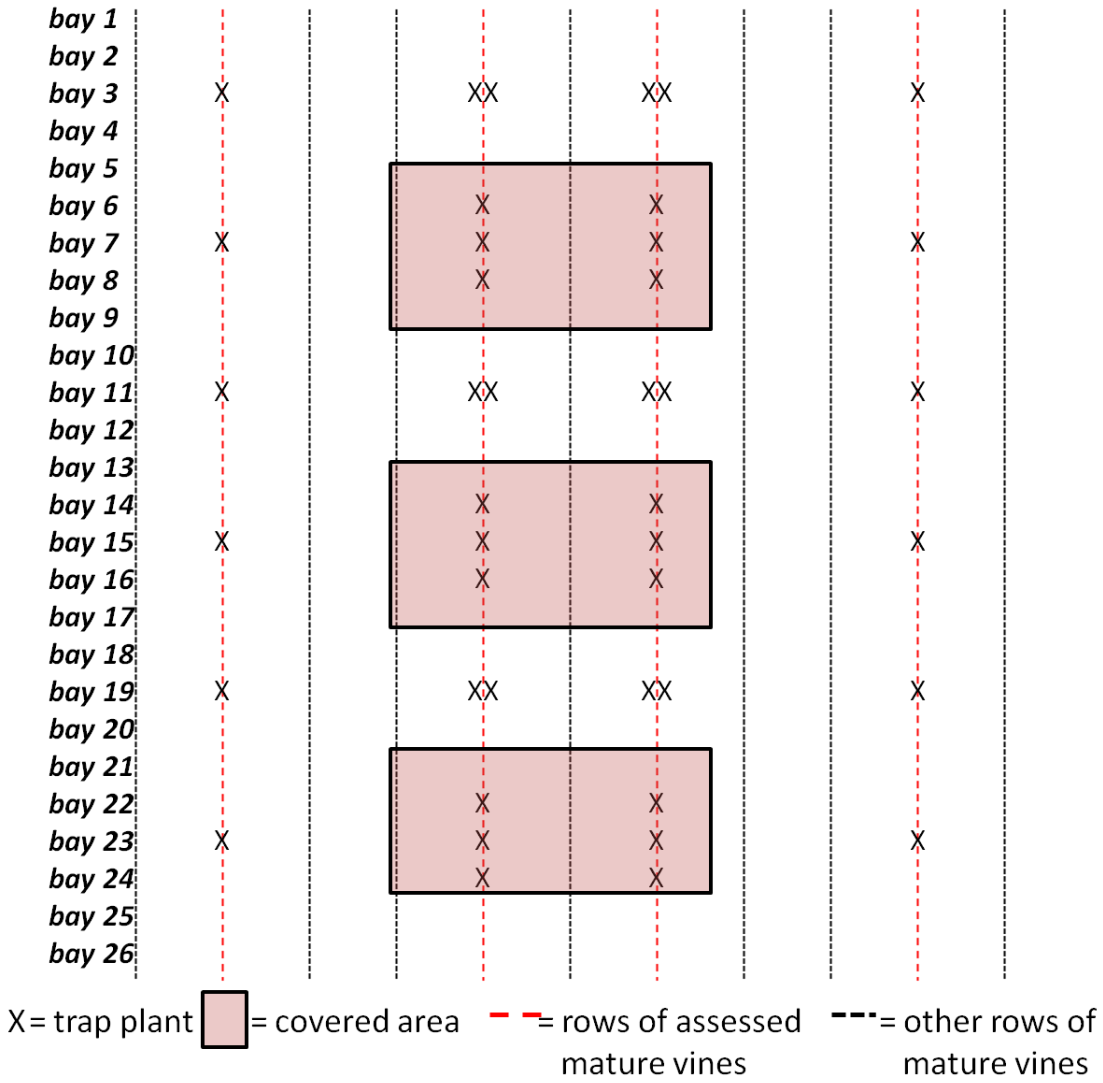

Figure 5. Tuapiro Rd block plan showing covered areas (opaque red area with dark black lines), no cover areas in-between and 'control' rows to the sides of the structures. The mature vines are *Actinidia chinensis* 'Zesy003' (Gold9) notch grafted with *A. chinensis* 'Zesy002' (Gold3). Trap plant (*A. chinensis*) plantings are also depicted (marked with X). Trap plants were located in the rows in covered and no cover areas, with two further "control" rows not in the vicinity of the covered area.

2.1.3 Maungarangi Rd, Paengaroa

Plastic covers were erected in three areas over one block. Each covered area was five rows wide and 12–13 bays long. Mature Green14 and Gold3 were growing on the rootstock (Figure 6). Artificial shelters made of shade cloth were directly adjacent to the Green14 plants and the 'Hort16A' grafted seedlings

In December 2012, 60 'Hort16A' and 60 Gold3 grafted seedlings obtained from a Psa-V-free area were planted within each bay underneath the canopy of the mature vines (Figure 6). The covers had been erected prior to the planting of the vines.

In winter of 2013 the trial was compromised by cattle being placed in the trial area. Some of the plants were trodden on and also eaten. Therefore these plants had to be removed from

assessments. In summer 2014 the orchardist cut back and removed Psa infected parts of the 'Hort16A' and Gold3 vines.

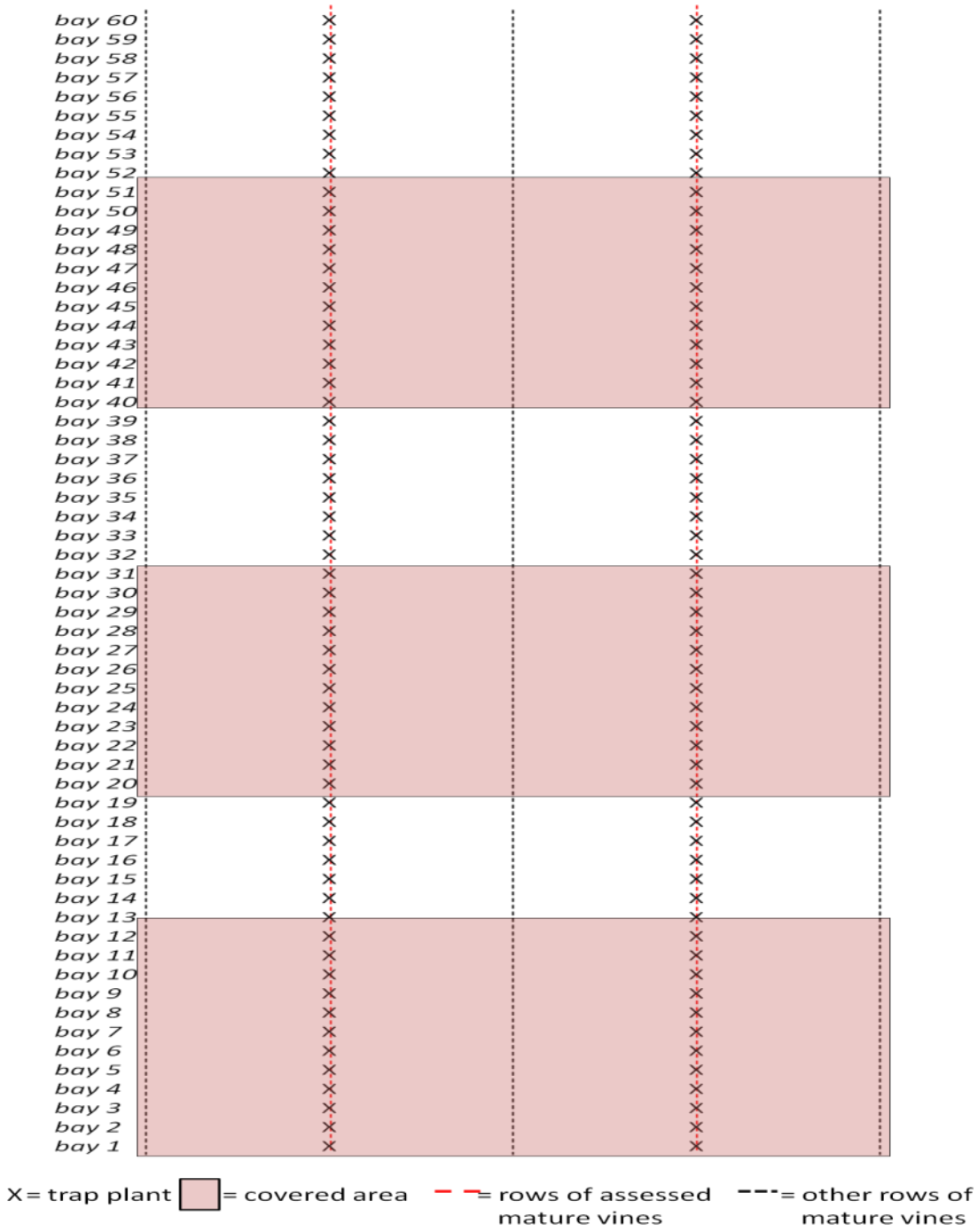

Figure 6. Placement of the three covered areas over a mature kiwifruit block at Maungarangi Rd. The existing *Actinidia deliciosa* x *A. chinensis* 'Zesh004' (Green14) and *A. chinensis* 'Zesy002' (Gold3) were in separate rows and underneath these mature and Psa-V infected vines newly grafted *A. chinensis* 'Hort16A' and Gold3 were placed.

2.2 Data collection

At Canon Rd assessments of 'Hort16A' leader and canes were made on 5 September 2013, 19 September 2013, 4 October 2013, 18 October 2013, 20 November 2013 and 27 November 2013. For each bay the number of canes emerging from the leader and the number of canes crossing the supporting wires in the bay were counted. A note was taken of cane secondary symptoms of dieback or ooze.

In vines at all three orchards, the scions (Gold3 at Canon Rd and Tuapiro Rd; Green14 and Gold3 at Maungarangi Rd) were assessed for Psa-V using the following categories:

0 = the scion is intact and clean

2 = the scion is intact but dying back due to Psa

5 = the scion is intact but dying back and has visible ooze from Psa

10 = the scion is absent following removal due to Psa.

At Maungarangi Rd, assessments of the newly grafted vines of 'Hort16A' and Gold3 were undertaken with particular emphasis on the overall health of the grafted vines on 12 November 2013 and 3 March 2014. The percentage of leaves with leaf spot was estimated, with 100% given when all the leaves on the plant had leaf spots. The percentage of leaf area with spots gives an indication of the coverage by the spots and the severity of the disease as expressed on the leaves. Secondary symptoms were also observed with a note whether there was dieback or ooze present and the proportion of the plant affected.

2.2.1 Trap plants at Canon Rd and Tuapiro Rd orchards

Actinidia chinensis (diploid red; Family A and Family B) seedlings were used at Canon Rd and Tuapiro Rd orchards as Psa-V trap plants. They were planted in both the covered and uncovered areas of the trial (Figures 1 & 5). Trap plants were assessed for the approximate percentage of leaf and woody tissue of each plant infected with Psa-V. Leaf spots were recorded as a proportion of leaf area infected, giving a measure of the proportion (%) of leaf area infected with Psa. Woody tissue symptoms were recorded as the proportion (%) of cane/stem dieback and visible ooze production. Scores for leaf spotting, dieback and death were combined to give an indication of the overall plant health. A score of 10 indicates the plant is dead as a result of Psa while a score of zero indicates a symptomless plant. Overall plant health was compared on the trap plants from covered and non-covered areas.

2.3 Summary of assessments

Table 1 gives an outline of the various assessments made at the three orchards. Greater detail has been described above, where necessary.

Table 1. Summary of assessments undertaken for scion symptoms and seedling symptoms at Canon Rd, Tuapiro Rd and Maungarangi Rd trial sites.

	Mature scions			Clean seedlings/grafted seedlings		
	Canon Rd *Actinidia chinensis* 'Hort16A' and *A. chinensis* 'Zesy002' (Gold3)	**Tuapiro Rd** *A. chinensis* 'Zesy002' (Gold3)	**Maungarangi Rd** *A. deliciosa* x *A. chinensis* 'Zesh004' (Green14) & *A. chinensis* 'Zesy002' (Gold3)	**Canon Rd** *A. chinensis* (diploid red)	**Tuapiro Rd** *A. chinensis* (diploid red)	**Maungarangi Rd** *Actinidia chinensis* 'Hort16A' and *A. chinensis* 'Zesy002' (Gold3)
Canes/ dieback	Actual number affected; note whether in leader affected; dieback and ooze recorded	Actual number affected; 4 point scoring system	Actual number affected; 4 point scoring system	% of the total plant affected, % of incidence leaves	% of the total plant affected,% of incidence leaves	% of the total plant affected, % of incidence leaves

2.4 Psa confirmation

At all trial sites, when necessary, samples were taken back to the laboratory to confirm the visual diagnosis of Psa in the orchard. When necessary, qPCR was used to confirm the presence of Psa.

2.5 Statistical analysis

Due to the setup of the trial, there were only three replicates for each treatment: three uncovered and three covered areas for each trial. The vines within the bays under the cover were pseudoreplicated and could not be included in any analysis.

All analysis was undertaken in Genstat (VSN International 2011). Statistical analysis of Psa-V symptom expression was carried out for each cultivar in covered and non-covered areas. REML analysis was performed and predicted means were obtained. In some instances an unbalanced ANOVA was used.

3 Results

3.1 Canon Rd

On 18 October 2013 the removal of the covered structures began at Canon Rd. The vines remained intact until January 2014 when the 'Hort16A' leaders were removed (Figure 7) and only the Gold9 notch grafts were retained.

Figure 7. In January 2014 *Actinidia chinensis* 'Hort16A' vines from Canon Rd were removed due to the large number of vines expressing infection by *Pseudomonas syringae* pv *actinidiae* (Psa), particularly in the non-covered area. This photograph shows the pile of plants in March 2014.

3.1.1 Mature vines

The extensive assessment undertaken in November 2013 indicated there was less secondary infection caused by Psa in the covered area (Figure 8). Approximately 10% of the canes were infected in the covered area compared with 34% in the non-covered area. The number of canes where the infection had progressed to the leader differed substantially between the two areas; there was nearly 10 times more infection in non-covered areas. In the non-covered area 10% of the canes were infected all the way to and including the leader compared with 1.5% in the covered areas. There were no statistically significant differences ($P > 0.05$) for either of the variables measured but this was the result of the limited power of the analysis with only six areas in total able to be analysed.

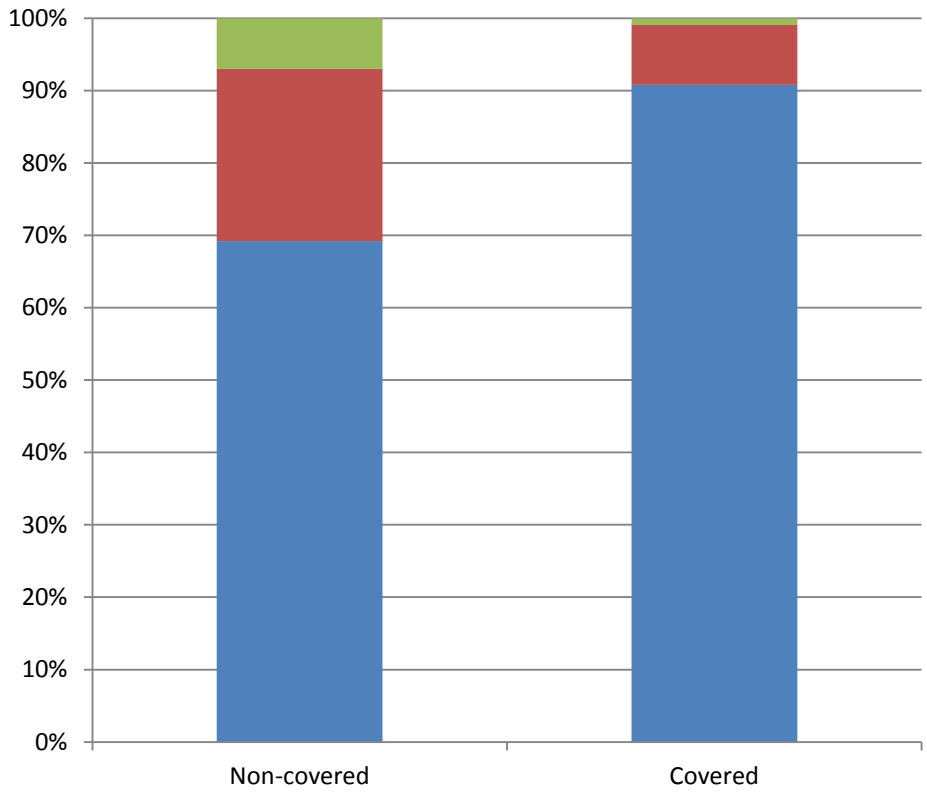

Figure 8. The percentage of *A. chinensis* 'Hort16A' canes (n=810) in uncovered (left) and covered (right) plots at Canon Rd, Katikati, showing three categories of Psa infection: 1) no Psa symptoms (blue), 2) secondary symptoms of dieback and ooze (red) and 3) secondary symptoms of dieback and ooze with the infection extending up to and into the leader (green).

Statistically there were no differences ($P > 0.05$) in the number of canes retained in a bay, after canes expressing Psa symptoms were removed from the orchards, over the duration of the trial. In addition, the mean number of infected canes in both covered and uncovered areas remained steady throughout the sampling period from September to November 2013 (Table 2).

Table 2. The average number of canes per bay and the average number of canes per bay expressing *Pseudomonas syringae* pv. *Actinidiae* (Psa) symptoms in covered (cover in table) and non-covered (none in the table) areas in *A. chinensis* 'Hort16A' plants at the Canon Rd orchard, Katikati.

	05 Sep 2013		19 Sep 2013		04 Oct 2013		18 Oct 2013		27 Nov 2013	
Ave/bay	None	Cover	None	Cover	None	Cover	None	Cover	None	Cover
Canes	8.8	8.9	8.8	8.9	8.8	8.9	7.6	8.8	7.7	9.1
Expressed symptoms	1.5	1.3	1.5	1.3	1.1	1.3	1.1	0.9	1.7	1.2

Maps of the proportion of canes (Figure 9) and leaders (Figure 10) showing Psa infection in the vines in the covered and uncovered plots show that the greatest infection occurs in uncovered areas. However, vines in the middle area under the covers showed symptoms of Psa infection on nearly all of the vines (Figure 9). Covered areas adjacent to a heavily infected uncovered area appear to have more Psa infection (Figures 9 & 10).

Uncovered	0.0	0.0	0.0	0.0	Uncovered
Uncovered	0.3	0.0	0.0	0.0	Uncovered
Uncovered	0.3	0.3	0.0	0.7	Uncovered
Uncovered	0.0	0.0	0.1	0.1	Uncovered
Uncovered	0.6	0.5	0.2	0.2	Uncovered
Uncovered	0.7	0.4	0.2	0.1	Uncovered
Uncovered	0.1	0.3	0.2	0.4	Uncovered
Covered	0.1	0.1	0.0	0.0	Covered
Covered	0.1	0.0	0.0	0.2	Covered
Covered	0.0	0.0	0.1	0.0	Covered
Covered	0.0	0.0	0.0	0.1	Covered
Covered	0.0	0.0	0.4	0.3	Covered
Uncovered	0.5	0.5	0.5	0.8	Uncovered
Uncovered	0.7	1.0	1.0	1.0	Uncovered
Uncovered	1.0	0.6	0.9	0.8	Uncovered
Covered	0.5	0.5	0.6	0.3	Covered
Covered	0.4	0.1	0.3	0.5	Covered
Covered	0.4	0.4	0.3	0.4	Covered
Covered	0.4	0.1	0.2	0.3	Covered
Covered	0.1	0.0	0.1	0.0	Covered
Uncovered	0.5	0.3	0.4	0.4	Uncovered
Uncovered	0.1	0.3	0.2	0.2	Uncovered
Uncovered	0.0	0.0	0.0	0.5	Uncovered
Covered	0.0	0.1	0.1	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered

Figure 9. Proportion of infected *A. chinensis* 'Hort16A' canes with secondary symptoms, of *Pseudomonas syringae* pv *actinidiae* (Psa) including dieback and ooze. Each number represents a vine.

Uncovered	0.0	0.0	0.0	0.0	Uncovered
Uncovered	0.2	0.0	0.0	0.0	Uncovered
Uncovered	0.1	0.1	0.0	0.0	Uncovered
Uncovered	0.0	0.0	0.0	0.0	Uncovered
Uncovered	0.4	0.3	0.1	0.0	Uncovered
Uncovered	0.3	0.0	0.0	0.0	Uncovered
Uncovered	0.0	0.0	0.0	0.0	Uncovered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.1	0.0	Covered
Uncovered	0.1	0.1	0.3	0.2	Uncovered
Uncovered	0.2	0.8	0.5	0.1	Uncovered
Uncovered	0.1	0.2	0.5	0.4	Uncovered
Covered	0.0	0.0	0.1	0.3	Covered
Covered	0.1	0.0	0.0	0.2	Covered
Covered	0.0	0.0	0.0	0.1	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Uncovered	0.0	0.0	0.2	0.1	Uncovered
Uncovered	0.0	0.0	0.2	0.1	Uncovered
Uncovered	0.0	0.0	0.0	0.0	Uncovered
Covered	0.0	0.1	0.1	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered
Covered	0.0	0.0	0.0	0.0	Covered

Figure 10. Proportion of canes that have signs of secondary Psa infection extending up to and into the leader, including dieback and ooze.

Anecdotal evidence suggests that vines under the covered area appear to produce more callus in response to Psa infection. Callus was noted in both the mature vines and the grafted scions. There were situations when callus had developed when the cane had died back from Psa infection and appeared to form callus to halt the progression of the Psa (Figure 11).

Figure 11. *Actinidia chinensis* 'Hort16A' canes with visible dieback caused by *Pseudomonas syringae* pv *actinidiae* (Psa) and the development of callus that has halted the progression of the bacteria into the older cane on the vine.

3.1.2 Canon Rd trap plants

There were fewer Psa-symptomatic vines in the covered areas than the uncovered areas (78% in covered compared with 65% in uncovered). There was no statistical (P = 0.814) difference in the amount of Psa expressed on the trap plants between the covered (n = 18) and non-covered (n = 16) areas of the trial (Table 3). Although there was no significant difference in infection between the covered and uncovered areas; the results indicate a difference in infection between

the rows (Table 3). For example, there is far more Psa expressed in vines in Row 2 than Row 3, which is closer to an artificial shelter.

Table 3. The predicted overall score after analysis for the *A. chinensis* trap plants at Canon Rd, Katikati. The higher the score, the more infected the vine. A score of 10 indicates the plant is dead due to Psa and score of zero the plant is symptomless.

	Predicted mean	Row 2	Row 3
Non-covered	1.4	2.2	0.6
Covered	1.0	1.1	0.9

3.1.3 Canon Rd Gold3 notch grafted scions

The majority of the grafted scions, whether under cover or in the non-covered area, appeared to have established well, with many being asymptomatic for Psa. Of the scions that had been removed because of Psa, there was no statistical difference (P = 0.581) between the covered (16 out of 52 removed) and non-covered (14 out of 68 removed) areas.

3.2 Tuapiro Rd

At the end of harvest in 2013 the Gold9 vines were removed. Only the Gold3 notch grafts remained. The notch grafts were progressing well with orchard management removing scions with any visible signs of Psa infection (Figure 12).

Figure 12. *Actinidia chinensis* 'Zesy002' (Gold3) notch grafts at Tuapiro Rd. The graft on the right hand side of the rootstock is not displaying symptoms of *Pseudomas syringe* pv. *actindiae* (Psa) infection. On the left hand side the graft has been removed due to Psa infection.

3.2.1 Gold3 scions at Tuapiro Rd

At the beginning of the 2013–14 season the plastic covers in some areas had holes resulting from environmental stress (Figure 4) and were subsequently removed. By December 2013 all of the covers had been removed and the orchardist had revised the structure of the canopy and a new prototype was being developed to erect over the orchard in the near future. Despite the removal of the covers, the incidence of Psa remained low in both plots and there was no difference ($P > 0.05$) in Psa symptom expression between the covered and non-covered areas (Table 4).

Table 4. The presence of *Actinidia chinensis* 'Zesy002' (Gold3) notch grafts at Tuapiro Rd orchard in February 2014 when under cover, no cover and control areas. The number of the grafts remaining exhibiting Psa symptoms is presented. The score of 10 indicated the graft has been removed due to it being dead from Psa and a 0 is no visible symptoms. Note: the cover was completely removed from the 'covered' plot by December 2013.

	14 November 2013	17 February 2014
Covered	2.79	2.89
Non-covered	3.47	3.64

3.2.2 Trap plants

There was no difference in the health of the trap plants between the covered and non-covered areas. There were greater numbers of dead plants (58%) in the non-covered areas than in covered areas (44%). The overall health score of 6.8 in non-covered plants was not significantly different ($P = 0.641$) from the overall health score of 5.4 in covered plants, whereby an overall health score of 10 indicates a dead plants and 0 is an asymptomatic plant. The plants that were alive looked in equally good health (Figure 13). There appeared to be no difference between the two families used as trap plants. When dieback did occur some plants formed calluses, restricting the movement of the Psa.

3.3 Maungarangi Rd

There were considerable problems with this site and some of the covers were removed with only one covered area retained. Artificial shelters belts in some areas were removed and those plants on the edge were exposed. Over winter several of the Green14 and Gold3 vines were removed and new scions re-grafted on the rootstock (Figure 14).

Figure 13. *Actinidia chinensis* (diploid red) seedling trap plants at Tuapiro Rd, Katikati. There are no visible signs of infection; leaves were symptomless and no dieback is present.

Figure 14. Older grafts were removed during winter 2013 and were replaced. There was damage to some of the rootstocks.

There was no difference ($P > 0.05$) in the incidence of Psa in the scion between the Green14 and the Gold3 scions. There was no statistical difference ($P > 0.05$) between the covered and non-covered areas partly due to the lack of statistical power as there were only three replicate areas in both the covered and non-covered areas. The analysis tends to indicate a separation of the data between covered and non-covered with the non-covered areas having greater symptoms of Psa infection (Tables 5 & 6).

Table 5. The presence of *Actinidia chinensis* 'Zesy002' (Gold3) notch grafted scions and *A. deliciosa* x *A. chinensis* 'Zesh004' (Green14) notch grafted scions at Maungarangi Rd orchard, Paengaroa. The number of scions present in covered and non-covered areas, with reference to the health of the graft. Numbers in () indicate the percentage of the grafts out of the total that expressed that symptom.

	Green 14 (%)		Gold3 (%)	
	Graft 1	Graft 2	Graft 1	Graft 2
Vine totally dead and removed	3	3	1	1
Clean and free of Psa	46 (79%)	54 (93%)	52 (88%)	54 (91%)
Graft dieback	1 (2%)	2 (3%)	0 (0%)	0 (0%)
Graft dieback & ooze present	0 (0%)	0 (0%)	2 (3%)	4 (7%)
Graft removed due to Psa	11 (19%)	2 (3%)	5 (8%)	1 (2%)

Table 6. The mean Psa infection score of notch grafts of *Actinidia chinensis* 'Zesy002' (Gold3) and *A. deliciosa* x *A. chinensis* 'Zesh004' (Green14) at Maungarangi Rd orchard, Paengaroa. A score of 10 means the scion has been removed due to Psa infection and a score of zero indicates the scion is clean and appears free of Psa. Green 14 n = 238, Gold3 n = 239

	Graft 1		Graft 2	
	Cover	No cover	Cover	No cover
Green 14	0.38	1.73	0.39	0.58
Gold3	1.75	2.17	0.40	0.42

There is evidence to suggest that leaves under the covered areas of the breathable plastic were larger than those in the non-covered areas. This was particularly evident in Gold3 vines. The consequence of the larger leaf development is unknown (Figure 15). There also appeared to be a greater incidence of "fresh" ooze being produced in the non-covered areas (Figure 16). The ooze droplets were not evident for the majority of the vines in covered areas.

Figure 15. *Actinidia chinensis* 'Zesy002' (Gold3) notch grafts at Maungarangi Rd orchard, Paengaroa. Enlarged leaves under the cover were evident at the trial site.

Figure 16. Ooze caused by *Pseudomonas syringae* pv *actinidiae* on an *Actinidia chinensis* 'Zesy002' (Gold3) notch grafted scion at Maungarangi Rd, Paengaroa. This vine was not under breathable plastic covers.

3.3.1 Grafted 'Hort16A' and Gold3 seedling trap plants

At the end of the autumn 2013 the 'Hort16A' plants were more susceptible to infection than the Gold3 seedlings when grown under previously infected mature vines. Both 'Hort16A' and Gold3 grew vigorously and had an extremely low incidence of Psa expression when grown under cover. However, in the 2013–14 season, because of a change in management, the results were compromised due to animals freely roaming in the trial area and the grower pruning back some of the seedling trap plants.

The Gold3 plants were more resistant to infection from Psa and the covers meant there was less infection. Despite some covers at this site being removed, there was still a low incidence of disease in these grafted seedling trap plants. By the end of the 2013–14 growing season the surviving plants had established well (Figure 17).

Figure 17. Healthy leaves on *Actinidia chinensis* 'Zesy002' (Gold3) trap plants at Maungarangi Rd, Paengaroa with no visible signs of infection caused from *Pseudomonas syringae* pv. *actinidae* (Psa).

Many of the traps plants under the cover remained free of Psa, despite some of the covers being removed during the course of the trial. There was a significant ($P < 0.05$) difference in the expression of secondary symptoms (%) between the covered and non-covered area. There were more secondary symptoms, including dieback and ooze, in the non-covered areas in both the Gold3 and the 'Hort16A' (Table 7). The first assessment (12 November 2013) highlighted that 'Hort16A' was more susceptible to Psa infection than Gold3, with the covers providing some protection. By 3 March 2014 the 'Hort16A' plants had significantly less ($P < 0.05$) secondary symptom expression than in the November assessment resulting from the grower removing stems with secondary symptoms (Figure 18A & B).

Table 7. The percentage of *Actinidia chinensis* 'Zesy002' (Gold3) and *A. chinensis* 'Hort16A' grafted seedling trap plants at Maungarangi Rd orchard, Paengaroa, with secondary symptoms of Psa, including dieback and ooze.

	Non-covered		Cover	
	Gold3	'Hort16A'	Gold3	'Hort16A'
12 November 2013	6.56	23.08	0.97	14.21
3 March 2014	3.85	1.29	2.00	1.25

Figure 18A & B. An *Actinidia chinensis* 'Hort16A' grafted seedling at Maungarangi Rd under plastic covers. The vine is healthy and is not showing any signs of infection from Psa. B. Closeup of the new leaves emerging from the grafted 'Hort16A' seedlings in Figure 16A.

The percentage of the plants expressing leaf symptoms caused by Psa was far greater ($P > 0.05$) in 'Hort16A' plants than Gold3 (Table 8; Figure 19). The cover provided greater protection from Psa in the Hort16A and Gold3 plants as fewer leaves were infected by Psa in the covered plants than the non-covered plants of the same variety. The greatest amount of infection of leaves occurred in the spring assessment, particularly with 'Hort16A' where there was a high incidence of leaf symptoms, with nearly all plants expressing leaf spots. The 'Hort16A plants that expressed the greatest incidence of Psa leaf symptoms were near the artificial shelter that had collapsed and was providing no protection.

Table 8. Leaf symptoms on Actinidia chinensis 'Zesy002' (commonly known as Gold3) and Actinidia chinensis 'Hort16A' grafted seedling trap plants at Maungarangi Rd orchard, Paengaroa caused by Pseudomonas syringae pv actinidiae (Psa). Leaf symptoms are expressed as the mean percentage of the plants expressing symptoms.

	Non-covered		Cover	
	Gold3	'Hort16A'	Gold3	'Hort16A'
12 November 2013	35.7	97.5	9.6	58.3
3 March 2014	12.5	65.1	21.2	62.2

Figure 19. A. A healthy *Actinidia chinensis* 'Hort16A' grafted seedling with no visible leaf symptoms. B. Expression of *Pseudomonas syringae* pv *actinidiae* leaf spot on an *Actinidia chinensis* 'Hort16A' grafted seedling.

4 Discussion

The trials undertaken post-harvest in 2013-2014 indicated that the covers reduced the progression of Psa into the leaders of 'Hort16A'. There appeared to be other advantages, with the protected plants producing more callus, which could be a mechanism to stop or slow the progression of Psa throughout the plant. There was also less fresh ooze of Psa under the covered areas. Results have definitively shown that ooze production is substantially less in covered areas and this should reduce the spread of the disease in a covered orchard situation.

When the covers are removed from an already infected vine, the disease can progress rapidly. This was evident after the covers were removed from the 'Hort16A' vines and the disease progression so rapidly that the orchardist decided to remove all vines.

The covers offer protection for the Gold3 and 'Hort16A' grafted seedling trap plants, suggesting that the growth of seedlings under covers for cultivars that have a high monetary value, such as the *A. chinensis* varieties, may be warranted. If the coverage can be maintained throughout the life of the plant (or at least while it is actively growing) there is a likelihood that disease in the vines caused by Psa will be kept to a minimum.

Shelter belts, either artificial or natural, may play an important role in slowing the dissemination of Psa. In instances where the vine was protected by a cover and the artificial shelter was removed, there was often infection of the plant from Psa. This needs to be investigated further.

The *A. chinensis* diploid red seedlings used as trap plants in this study have shown there is some tolerance in this variety. The vines were able to callus when under covered conditions.

This project has given scientific evidence to justify the implementation of crop covers for Psa protection. If they can be erected and maintained economically, crop covers may become an important part of kiwifruit culture.

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