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1 Acknowledgments

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2 Executive summary

Fruit flies (Tephritidae: Diptera) are recognised as the most serious impediment to fruit and vegetable industries in the Asia-Pacific region. In Indonesia, two species, the Oriental fruit fly, *Bactrocera dorsalis* and the Carambola fruit fly, *B. carambolae* not only cause significant yield losses in the field, but also limit export and international trade of mango because of stringent quarantine regulations. In Australia, the Queensland fruit fly, *B. tryoni* and another species *B. jarvisi* infest mango and pose similar problems to the industry.

To assist the mango industries in Indonesia and Australia with their fruit fly problems, project HORT/2008/041 "Area-wide management of pest fruit flies in an Indonesian mango production system" was implemented over the period 2010 – 2015. The two primary objectives of the project in Indonesia were: 1) To evaluate the ability of area-wide control treatments to reduce fruit fly infestation levels in mango crops; and 2) To introduce fruit fly monitoring techniques to provide data in support of the area-wide management program**.** This area-wide management (AWM) program was implemented in a coordinated program in two typical mango smallholder production areas covering 40 and 60 ha in the district of Indramayu in West Java. A number of environmentally friendly control methods were applied to these areas in a coordinated program. The control methods included male annihilation using blocks impregnated with methyl eugenol and insecticide and applied in a grid, weekly application of protein bait sprays during the fruiting season, culling and removal of alternate fruit fly host plants, and sanitation to remove and destroy unwanted fallen fruit. The entire community of growers in the two treatment areas were provided with extensive training and engaged in implementing the control operations in a well-coordinated program over 5 years. In Australia the objective was to determine the relationship between mango crop maturity and fruit fly infestation and enhance fly control through acceptable protein bait sprays and traps or bait stations targeting females**.** The research was carried out at the Department of Agriculture and Fisheries at Mareeba in Queensland.

Project HORT/2008/041 was successful beyond expectation with fruit fly populations in both trial areas in Indramayu being suppressed and maintained at near eradication levels according to internationally accepted Area Indices for Fruit Flies. Following AWM implementation, farmers have reported significant improvements along the mango value chain in Indramayu. Mango fruit produced within the two AWM sites has gained a reputation of being free of fruit fly infestation and also being fruit that has been produced with very little pesticide application. Importantly, the project has demonstrated for the first time that highly effective fruit fly suppression can be achieved in a non-isolated cropping area through a well-coordinated area-wide management program. The AWM program serves as a model of fruit fly management that can be expanded and implemented across the mango industry not only in Indonesia, but across other countries in the south-east Asian region where smallholder cultivation is the norm and where the Oriental fruit fly and the Carambola fruit fly are major pests of mango. With such an effective solution to the fruit fly problem, mango and other fruit industries in the region need no longer remain restricted by fruit flies.

In Australia all protein baits that were tested caused a phyto reaction to the fruit. The protein component caused the reaction to the fruit. None of the commercial protein baits that were tested are suitable for the Australian mango varieties that were tested. Fruit fly population pressure was the most significant driver for fruit fly susceptibility in Australian mangoes. The female lures tested attracted significantly more female fruit flies than male fruit flies. The fruit volatile odour lures could not compete with the natural fruit odours of ripening fruit. The protein solution, Cera trap® attracted the most female fruit flies. Bait stations based on Cera trap solution warrant further testing.

The AWM program should now be ideally implemented in more commercially oriented and higher value mango production area in Indonesia with the objective of improving market access through compliance with International Standards for Phytosanitary Measures (ISPMs). Training programs for other mango growing countries in the region can also be conducted to introduce the AWM model that has been developed by the project.

3 Background

Mango is an important commodity in the Indonesian economy and with an annual production of over 1.3 million tonnes it ranks sixth in the world, contributing 4.1 per cent of global production (FAOSTAT DATABASE, 2012). The mango sector is dominated by small farms owned by rural families. Consequently, mango has been identified as the second most important agricultural commodity out of 16 identified nationally as having the most potential to increase the incomes of the poor (Collins-Higgins Consulting 2013). However, the mango industry in Indonesia suffers from poor quality management at the farm level and along the value chain that limits the industry from realising its full potential. One of the key limiting factors along the value chain is infestation of the fruits by two species of endemic Tephritid fruit flies (the Oriental fruit fly, *Bactrocera dorsalis* and the Carambola fruit fly, *B. carambolae*).

Both the Oriental fruit fly and the Carambola fruit fly are widespread in the Southeast Asian region and infest almost all fruits and fruiting vegetables, and mango is no exception. If left uncontrolled, fruit flies can cause yield losses ranging from 40 to near 100 per cent. Besides such heavy losses to production, infestation by fruit flies also severely limits the export potential of Indonesian mangoes because of strict international quarantine regulations. Thus effective control of fruit flies is of utmost importance in mango and other fruit industries in the region. In Indonesia as well as in other countries in Southeast Asia, mango growers manage their fruit fly problem by applying control measures in their individual farms. These control measures rely heavily on cover sprays of insecticides which not only often result in undesirable residues in harvested fruits, but are also highly detrimental to beneficial organisms like pollinating insects, parasitoids and predators of crop pests. Additionally, insecticide cover spraying when carried out in individual farms, has little effect in reducing the overall fruit fly populations in the wider cultivation area and the fruit fly problem continues to persist despite these control efforts.

Pest fruit flies are most effectively managed in an area-wide approach where a number of control methods are combined and applied in a coordinated manner to suppress or eliminate populations of adult fruit flies over a large area of the crop. Such an area-wide approach has been attempted in Thailand on mango (Orankanok *et al*., 2007) but has not been properly tested and developed in Indonesia and elsewhere in Southeast Asia. To assist the mango industry with their fruit fly problem, HORT/2008/041 “Area-wide management of pest fruit flies in an Indonesian mango production system” was implemented over the period 2010 – 2015. This project evaluated the impact of controlling fruit flies in a coordinated program in two typical mango smallholder production areas covering 40 and 60 ha in the district of Indramayu in West Java. A number of environmentally friendly control methods were applied to these areas in a coordinated program. The control methods included male annihilation using blocks impregnated with methyl eugenol + insecticide and applied in a grid, weekly application of protein bait sprays during the fruiting season, culling and removal of alternate fruit fly host plants, and sanitation to remove and destroy unwanted fallen fruit. The entire community of growers in the two treatment areas were provided with extensive training and engaged in implementing the control operations in a well-coordinated program over 5 years.

Project HORT/2008/041 has been highly successful with fruit fly populations in both trial areas being suppressed and maintained at near eradication levels. Following AWM implementation, farmers have reported significant improvements along the mango value chain in Indramayu. Mango fruit produced within the AWM sites in Krasak and Sliyeg has gained a reputation of being free of fruit fly infestation and also being fruit that has been produced with very little pesticide application. The growers have reported yield increases of up to 72% and have also improved other agronomic aspects of mango growing as profits have increased. The community within the treatment area has also benefited with close collaboration resulting in better relationships between neighbours. The collaborative work between farmers has also benefited the wives of farmers as there has been less requirement for their labour in mango production leaving more time to attend to children and household activities.

Project HORT/2008/041 also addressed the critical need for an effective and workable model of fruit fly management that can now be tested and applied to other areas that cultivate mango in Indonesia. Such an AWM model is also applicable to other countries in Southeast Asia where the Oriental fruit fly and the Carambola fruit fly are major pests of mango.

In Australia, the mango industry relies almost totally on insecticidal cover sprays for in-field control of fruit flies. This is because protein bait sprays to date have caused blemishes on fruit, significantly reducing their marketability. In addition, there is a need to reassess when mangoes become susceptible to fruit fly attack in relation to crop maturity and when bait sprays need to be applied to counteract it. Female traps or bait stations are seen as potentially valuable in crops where insecticides cannot be used or as a targeted control method for gravid female fruit flies as an adjunct to bait sprays. Research to date on fruit volatiles indicates that their combination with ammonia and protein will enhance gravid female attractancy. However bait stations containing a protein source proved more efficacious, particularly close to harvest when synthetic fruit volatile odours could compete with natural fruit volatiles. This approach should be pursued.

4 Objectives

The primary objective of the project was to trial an area-wide field control program for pest fruit fly species over a large area of mango production in Indonesia. After a scoping study and in consultation with the Directorate General of Horticulture and the Centre for Plant Quarantine in Indonesia the Indramayu region of west Java was deemed the most suitable.

The project objectives were as follows:

1. To evaluate the ability of area-wide control treatments to reduce fruit fly infestation levels in mango crops.

Activities

1.1. Conduct a project implementation workshop involving all key stakeholders to define the treatment area, evaluate current practices, discuss treatment supplies, plan the application of treatments and consider the community engagement required to ensure the project's acceptance.

1.2. Instigate Male Annihilation (MA) across the designated area using appropriate attractants and toxicants, distribution rates and a three to four monthly replacement cycle of 'blocks'.

1.3. Introduce protein bait spray applications on a weekly cycle. These treatments need to target host fruit trees during maturation of fruit, the stage which is known to be susceptible to fruit flies.

1.4. Encourage orchard hygiene to reduce potential sources of flies.

1.5. Undertake capacity building by training farmers and DINAS workers in the appropriate establishment of area wide control techniques, bait spray application and orchard hygiene practices to ensure the dissemination of AWM techniques to the major mango growing regions in Indonesia.

2. To introduce fruit fly monitoring techniques to provide data in support of the area-wide management program.

Activities

2.1. Conduct a project implementation workshop (see activity 1.1) to define the monitoring requirements appropriate for the fruit fly species involved and to map the fruit fly susceptible host fruits within the treatment area.

2.2. Introduce a monitoring program prior to the commencement of the control treatments to continue for the duration of the project. This will involve an extensive network of traps with male lures and a fruit collection program to assess infestation levels and define problem areas.

2.3. A workshop on fruit fly identification for key Directorate General of Horticulture and Centre for Plant Quarantine staff to refine their taxonomic skills.

2.4. Data-basing and evaluation of the monitoring data to assess the effectiveness of the control treatments and to adjust them if necessary.

2.5. Liaise with the local community to guarantee the integrity of the monitoring program.

3. To determine the relationship between mango crop maturity and fruit fly infestation and enhance fly control through acceptable bait sprays and traps or bait stations targeting females

Activities

3.1. Re-assess fruit fly infestation levels in relation to crop maturity, particularly in the major mango varieties.

3.2. Undertake research trials on protein bait sprays and application methods in mangoes in Australia designed to overcome fruit blemishing.

3.3. Optimise the attractants for gravid female flies to enhance bait treatments or, further reduce insecticide use and to provide trapping or bait station options as additional biosecurity tools.

5 Methodology

Objective 1: To evaluate the ability of area-wide control treatments to reduce fruit fly infestation levels in mango crops.

Indonesia

The strategy and plans to implement fruit fly Area-wide management techniques were developed.

This work was conducted by Dr Harry Fay (DAF) and Dr Vijay Shanmugam (consulting entomologist)

1.1 Conduct a project implementation workshop involving all key stakeholders to define the treatment area, evaluate current practices, discuss treatment supplies, plan the application of treatments and consider the community engagement required to ensure the project's acceptance.

The project inception meeting was held in Jakarta on 14-15 April 2010, with 5 delegates from Australia and 12 from Indonesia. Discussions and outcomes evolved around the following topics:

- Selection of treatment areas

The two selected trial sites were located at Krasak (40 ha) and Sliyeg Lor villages (60 ha) in the District of Indramayu, Province of West Java. The standard insecticide treated area was located at Cikedung (40 ha), also in the District of Indramayu, Province of West Java and approximately 25 km from the trial sites. The orchards were surrounded mainly by rice fields, with dwellings and the village located at one side with a variety of other fruit fly hosts present within the village.

- Current practices for fruit fly control

Currently individual growers apply ad-hoc insecticide treatments to control fruit fly. Losses of up to 80% have been claimed by the growers

- Treatment supply discussions

The methyl eugenol (ME) was sourced from the Indonesian company PT. Ragam Mandiri and sold as Petrogenol® (80% ME). This product was later replaced by a cheaper locally sourced product (Indesso 98% ME). It was decided that the chipboard would be used for the male annihilation (MA) blocks. The blocks were cut to size by a commercial enterprise. The protein bait based on beer yeast waste was supplied by the Malaysian company Pupuk Alam SDN and sold as Prima®. The Malaysian supplier is the only supplier in Southeast Asia following the closure of the Indonesian plant in 2009. Australian products were five times more expensive. Monitoring traps were sourced from Australia but later were manufactured by the Krasak farmer group.

- Treatment application planning

The annual estimated treatment requirements were:

➢ 1000 blocks/cycle
➢ 100l Petrogenol annually
➢ Fipronil to be used as toxicant in traps and blocks due to rain fastness
➢ 4000l protein bait annually
➢ Maldison toxicant mixed with protein baits
➢ Protein baiting to commence at fruit set and continue until harvest is completed

- Community engagement plans

Annual farmer field days were planned. Socialisation meetings conducted by the Directorate General Horticulture (DGH), Directorate of Horticulture Protection (DHP), and attended by the pest forecasting centres (DGH), DINAS and key farmers were planned. Annual co-ordination meetings were also planned and the development of extension material.

1.2. Instigate Male Annihilation (MA) across the designated area using appropriate attractants and toxicants, distribution rates and a three to four monthly replacement cycle of 'blocks'.

This work was conducted in Indramayu and Jakarta by Dr Harry Fay (DAF), Dr Vijay Shanmugam (consulting entomologist), Stefano De Faveri (DAF) Anik Kustaryati (DHP), Dr Dwi Iswari (DHP), Cahyaniati (DHP), Arif Akbar M (DHP), Benny F Maarisit (DHP) and Mahmud (DHP).

Chipboard Male Annihilation blocks (50 mm X 50mm X 15 mm) supplied and cut to size by a private contractor were used. Initially blocks were nailed to trees and left to biodegrade. Later blocks were suspended from branches by wire following an incident where a mango picker cut his foot on nail. As discussed in 1.1, ME (Petrogenol) was used as the male attractant. This was later exchanged for a cheaper more pure product supplied by Indesso. Fipronil was used as the toxicant due to its rain fastness. Blocks were placed in a woven sack and soaked in a mixture of 4 ME:1 fipronil for 24 hours contained in a large tub. The sack was then suspended above the tub and excess chemical drained. Blocking commenced in April 2011 and new blocks installed approximately every two months. Old blocks remained on trees to break down naturally. Residual activity, even though reduced lasted longer than two months. The blocking rate was 6 blocks per hectare.

A field trial compared Petrogenol (80% ME) with a more pure product (Sigma Aldrich 98% ME). The trial was conducted in Depok, West Java. Ten traps of each treatment were placed in individual guava trees with one trap of each treatment in trees approximately 20 m apart. Pairs of traps were at least 50 m apart from another replicate pair. Ten pairs (or replicates) were placed out each week.

Fruit fly counts were recorded at the end of each week and newly aged traps put out in the field. This was continued for 14 weeks. The trial was conducted at two properties, with the first 7 weeks at one location, and the second 7 weeks at a different location.

Analysis of variance (ANOVA) were conducted to compare the two treatments at each week.

1.3. Introduce protein bait spray applications on a weekly cycle. These treatments need to target host fruit trees during maturation of fruit, the stage which is known to be susceptible to fruit flies.

This work was conducted in Indramayu by Dr Harry Fay (DAF), Dr Vijay Shanmugam (consultant entomologist), Stefano De Faveri (DAF), Anik Kustaryati (DHP), Dr Dwi Iswari (DHP), Cahyaniati (DHP), Rifki Kadarachman H (Crop protection field laboratory).

A field day was conducted to teach farmers how to apply protein baits. The training included mixing instructions, safety training, calibration of sprayers and application methodology. Further training was undertaken to train DINAS and crop protection staff from other provinces.

Protein baiting was based on the beer yeast by-product Prima®. Protein bait was diluted with water and a toxicant added.

Dilution rates based on 10l solution:

Prima 1l

Water 8.95 l

Maldison (Fyfanon) 50ml

Four spot sprays of 25ml each were applied per tree (100ml/tree) / week. Applications of 10 l/ha were based on 100 trees/ha. Protein baiting commenced in 2011. Protein baits were applied at fruit set and continued until harvest up to 2013. In 2014 and 2015, protein baiting continued until all fruit residues were removed from the orchard. Growers were reluctant to apply baits in 2011 resulting in only nine applications in the first year. However protein baiting applications increased in subsequent years as growers witnessed the results of the treatments. Generally treatments were applied between July-December. No protein baiting occurred during the Moslem holy period of Ramadan.

The project purchased backpack sprayers for the growers to ensure uniform spray coverage was applied by all growers. The project also provided protective safety equipment for the spray applicators.

1.4. Encourage orchard hygiene to reduce potential sources of flies.

This work was conducted in Indramayu by Dr Harry Fay (DAF), Dr Vijay Shanmugam (consulting entomologist), Stefano De Faveri (DAF), Anik Kustaryati (DHP), Dr Dwi Iswari (DHP), Cahyaniati (DHP).

Fruit collection bins were provided. Training was undertaken to educate growers on the alternate fruit fly hosts and the importance of maintaining hygiene in the orchard. The farm leader at Krasak village ensured some alternate hosts were removed to reduce the risks of fruit fly infestation from these sources. Growers collected fallen fruits and disposed of them in the bins provided. The collected fruits were then collected and disposed regularly.

1.5. Undertake capacity building by training farmers and DINAS workers in the appropriate establishment of area wide control techniques, bait spray application and orchard hygiene practices to ensure the dissemination of AWM techniques to the major mango growing regions in Indonesia.

This work was conducted in Indramayu by Anik Kustaryati, Dr Dwi Iswari and Cahyaniati all from DHP and conducted at Indramayu.

Approximately three co-ordination meetings were held annually with the Australian project team, DHP, the Indramayu pest forecasting centre, DINAS staff and key farmers. Approximately three socialisation meetings conducted by DHP staff for pest forecasters and DINAS staff from other provinces were conducted annually. Field days for farmers were also conducted annually. Posters, pamphlets and pocket guides on Area-wide management implementation were produced.

Objective 2: To introduce fruit fly monitoring techniques to provide data in support of the area-wide management program.

Indonesia

2.1. Conduct a project implementation workshop (see activity 1.1) to define the monitoring requirements appropriate for the fruit fly species involved and to map the fruit fly susceptible host fruits within the treatment area.

This work was conducted in Jakarta by Dr Harry Fay (DAF), Dr Vijay Shanmugam (consultant entomologist), Cahyaniati (DHP) and Anik Kustaryati (DHP).

As in 1.1 above the inception meeting was conducted in Jakarta on 14-15 April 2010. Plans to produce and deploy monitoring traps and contingencies for missing traps and data were discussed. Discussions included trap layout, trap type and number at each location. Data collection, collation and analysis were also discussed. Plans for mapping of trap and MA block locations were discussed. GPS devices would be used to locate all traps and MA blocks. Plans were also in place to map fruit fly susceptible hosts near the trap locations at Krasak.

2.2. Introduce a monitoring program prior to the commencement of the control treatments to continue for the duration of the project. This will involve an extensive network of traps with male lures and a fruit collection program to assess infestation levels and define problem areas.

This work was conducted in Indramayu by Dr Harry Fay (DAF), Dr Vijay Shanmugam (consulting entomologist), Stefano De Faveri (DAF), Anik Kustaryati (DHP), Dr Dwi Iswari (DHP), Cahyaniati (DHP), Arif Akbar M (DHP), Andi Abdurahim (DHP), Mulyanto (crop protection field lab), Suripudin (crop protection field lab), Gischa (crop protection field lab) and Rifki Kadarachman H (crop protection field lab).

Steiner traps were produced in Australia and sent to Indonesia. The Steiner traps were based on "Trapping Guidelines for Area-wide Fruit fly Programmes" (IAEA 2003). Replacement Steiner traps were produced by the Krasak farmers group. Twelve ME Steiner traps were strategically placed at each treatment site (Krasak and Sliyeg Lor). Six ME traps were strategically placed at the conventionally treated site at Cikedung. A further three traps were introduced at Krasak in December 2012. Three Cue lure traps were also placed at Sliyeg Lor and Cikedung and two at Krasak. These traps were removed in September 2013 following a contamination issue. Lures were replaced every two months. Traps were cleared and counted weekly. In the first year of the project traps were stolen regularly, mainly at Cikedung. These traps were replaced, but at times replacement was not immediate and data were missing as a result.

2.3. A workshop on fruit fly identification for key Directorate General of Horticulture and Centre for Plant Quarantine staff to refine their taxonomic skills.

This work was conducted in Brisbane by Dr Richard Drew and Meredith Romig from Griffith University.

A fruit fly identification workshop was conducted by Professor Richard Drew at the Griffith University Nathan Campus, Brisbane on 5-8 November 2012. One staff from DHP and three from the Indonesian Agricultural Quarantine Agency attended the four day course. One DAF Queensland staff also attended the training. Two staff from DHP attended field control training facilitated by Stefano De Faveri in South East Queensland over the same period.

2.4. Data-basing and evaluation of the monitoring data to assess the effectiveness of the control treatments and to adjust them if necessary.

This work was conducted by Dr Harry Fay (DAF), Dr Vijay Shanmugam (consultant entomologist), Stefano De Faveri (DAF), Anik Kustaryati (DHP), Dr Dwi Iswari (DHP), Cahyaniati (DHP), Andi Abdurahim (DHP), Arif Akbar M (DHP), Mulyanto (crop protection field lab), Suripudin (crop protection field lab), Gischa (crop protection field lab), and Rifki Kadarachman H (crop protection field lab) at Indramayu and Jakarta.

Weekly trap catch data and rearing data were recorded and analysed in an Excel spreadsheets. Data were transferred from data sheets into the worksheets. Data included trap ID and trap catch expressed as fruit flies per trap per day (FTD). Fruit infestation data were expressed as percentages. Data were analysed and presented as graphs to Indonesian and Australian project leaders on a semi regular basis. Data were checked periodically to ensure the accuracy of transcription. The data were scrutinised to evaluate the efficacy of the treatments and to identify problem areas such as hosts, hygiene and resulting in population peaks.

2.5. Liaise with the local community to guarantee the integrity of the monitoring program.

This work was carried out in Indramayu by DHP staff Anik Kustaryati, Dr Dwi Iswari, Cahyaniati, Issusilaningtyas UH, Andi Abdurahim, Evey Octavia, Nelly Saptayanti, Ami Cahyani R, Mahmud, Arif Akbar M, Cacap Rahmad H crop protection filed lab staff Rifki Kadarachman H, Mulyanto, Suripidin Gischa and DINAS staff Tin Setiatin and Alih Yulia.

Regular socialisation meetings and field days for growers, crop protection and DINAS staff were conducted annually to provide information on monitoring and treatments. Several extension materials such as posters, pamphlets and field guides were produced.

Objective 3: To determine the relationship between mango crop maturity and fruit fly infestation and enhance fly control through acceptable bait sprays and traps or bait stations targeting females

Australia

3.1. Re-assess fruit fly infestation levels in relation to crop maturity, particularly in the major mango varieties.

This work was carried out in north Queensland by Stefano De Faveri, Dr Harry Fay and Gail Lowe from DAF.

Trials were set up in blocks of mango trees at the Southedge Research Station near Mareeba north Queensland. Male lure traps were maintained through the trial site to determine the level of fruit fly activity during fruit maturation. Mango fruits were randomly sampled every week from 8 weeks prior to harvest in 3 major mango varieties (spread across the mango season). Fruit were collected from a number of positions on each tree to account for differences in oviposition preferences.

Fruit maturity was measured with a hand-held spectrophotometer to measure skin and flesh colour, a refractometer to estimate % Brix and through flesh subsampling to calculate dry weight. Fruit were examined for fruit fly stings and suspect fruit were held to rear any fruit flies through.

The numbers of fruit flies emerging, the species recovered and the oviposition damage recorded were statistically evaluated in relation to fruit maturity.

3.2. Undertake research trials on protein bait sprays and application methods in mangoes in Australia designed to overcome fruit blemishing.

This work was carried out in north Queensland by Stefano De Faveri, Dr Harry Fay and Patrick O'Farrell from DAF.

A series of field and laboratory trials were conducted in north Queensland to examine the physical impact on fruit of different protein baits, their efficacy for controlling fruit flies and the timing of applications.

Phytotoxicity trials

Different protein baits were sprayed onto fruit on a weekly basis at least four weeks prior to harvest. Fruit were collected at harvest and rated for phytotoxicity damage. Fruit were sprayed at four aspects of the tree (N, S, E, W). Five fruit were collected at each replicate for rating. Treatments were trialled in a randomised complete block design with four or five replicates. Other non-replicated trials included manipulating Ph to determine whether acidity of protein baits had an effect on phytotoxicity.

Products tested were:

- Yeast autolysate
- Natflav
- Prima
- Buminal
- Cera bait
- Maurimos
- Naturalure
- XXXX Lion Nathan
- Dehydrated yeast autolysate
- Hymlure
- DacGel
- Anamed

Laboratory and glasshouse trials evaluated the least phytotoxic protein baits for efficacy against the Queensland fruit fly, *B. tryoni* and Jarvis's fruit fly, *B. jarvisi*. The treatments were:

CERABAIT™

Natflav500™

HYM-LURE™

These were compared with the most commonly used protein bait in Queensland, Fruit Fly Lure™.

3.3 Optimise the attractants for gravid female flies to enhance bait treatments or, further reduce insecticide use and to provide trapping or bait station options as additional biosecurity tools

This work was carried out in north Queensland by Stefano De Faveri, Dr Harry Fay and Gail Lowe from DAF.

A series of field and glasshouse trials compared ammonia, protein, fruit volatiles separately and combined as attractants for gravid female fruit flies. Different means of dispensing these compounds and various trap types were investigated.

Initial trials compared fruit volatile odours, protein (torula yeast) and ammonium bicarbonate individually and in combinations. The solutions were contained in a small centrifuge tube with a hole in the lid for volatile emission (figure 1). Lure dispensers were placed in prototype traps (figure 2). The female lures were compared with Cera trap® solution which was contained in its own trap.

In further trials the lure combinations were incorporated in a wax matrix and placed in the prototype traps and yellow Probodelt cone traps. Further trials compared the wax matrix lures (figure 3) against protein baits, toxicants and trap types (figure 4).

The Cera trap® solution was also tested in a wax matrix and as gel solution in synthetic membrane. Field trials compared the wax matrix and synthetic membrane with the best toxicants in Biotrap globe traps. The gel synthetic membrane version was used in the female traps in Indonesia.

Figure 1. Dispensers containing protein (left) and fruit volatiles (right).

Figure 2. Prototype trap developed for female lure trials.

Figure 3 Wax matrix lures

Figure 4 Yellow cone traps tested with wax matrix lures

6 Achievements against activities and outputs/milestones

Objective 1: To evaluate the ability of area-wide control treatments to reduce fruit fly infestation levels in mango crops.

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1	Conduct project implementation workshop in Indonesia (PC)	Roles of participants identified Treatment area defined Current practices identified Training required by local participants identified	April 2010	Project implementation meeting was conducted 14-15 April 2010. Work plans were developed for 2010 and 2011and key personnel in DHP and DINAS identified. Treatment and control areas in Indramayu suggested for verification in July 2010. Yearly treatment needs for blocking (up to 1000/cycle) and baiting (4000L/year) calculated to facilitate chemical/bait ordering. Current fruit fly controls outlined. Training for trainers (ca. 20) and farmers (ca. 200) outlined and scheduled for around mango flowering.
1.2	Instigate male annihilation across the treatment area (PC)	Male annihilation treatments successfully established	Dec 2015	The number of male annihilation blocks and installations increased annually until 2014 and 2015 when blocking frequency and numbers remained consistent. Overall the blocking had progressed well and provided a constant reliable barrier to male fruit flies.
1.3	Introduce bait spray application (PC)	Bait spray program entrenched	Dec 2015	The total number of protein bait applications at both sites had increased and growers had taken heed of the 2014 recommendation to continue treating post-harvest. This action had partly been responsible for avoiding the January population spike that occurred in 2014.
1.4	Promote crop hygiene (PC)	Crops kept clean of residual fruit and discarded fruit disposed of appropriately	Dec 2015	There were ongoing meetings with and training of farmers where this concept was promoted. A concerted effort to remove residual fruit post-harvest had contributed to avoiding population spikes.
1.5	Capacity building of farmers and DINAS workers (PC)	Farmers and DINAS workers trained in establishment of area wide control techniques, bait spray application and orchard hygiene practices	Dec 2015	Co-ordination meetings involving provincial and directorate staff and key farmers were held about three times per year. Socialisation meetings for farmers and DINAS staff were also held regularly.

PC = partner country, A = Australia

Objective 2: To introduce fruit fly monitoring techniques to provide data in support of the area-wide management program.

No.	Activity	Outputs/ milestones	Completion date	Comments
2.1	Conduct a project implementation workshop in Indonesia (PC)	Monitoring requirements for fruit fly species identified Relevant species of fruit flies mapped within the treatment area	April 2010	Completed in 2010.
2.2	Implement the fruit fly monitoring program (PC)	GPS used to identify trap sites and fruit collection locations Traps checked regularly to ensure the success of the program Fruit fly identification completed in the laboratory Further fly identification training conducted	Dec 2015	All traps were mapped and checked regularly. All identification training was completed. There were mainly two species of fruit fly present, B. dorsalis and B. carambolae. Both are very similar morphologically and also biologically. Due to the large numbers of fruit flies that were collected at times and the work load of collection staff it was deemed unnecessary to identify fruit flies.
2.3	Monitoring database established to assess the effectiveness of control treatments and adjust if necessary(A&PC)	Database up and running Database checked for anomalies Effectiveness of treatments determined	Dec 20105	Collation of the data was adequate. However data entry and reporting was slow. As a result, there was limited review which could have resulted in undetected population spikes within the treatment area. This area could have been improved dramatically.
2.4	Liaise with the community to guarantee the integrity of the monitoring program (PC)	Extension material provided which explains the monitoring, treatments and project benefits	Ongoing	Socialisation meetings involving farmers, DGH and DINAS staff from West Java were held regularly. Pocket guides, articles, and pamphlets were produced regularly.

PC = partner country, A = Australia

Objective 3: To determine the relationship between mango crop maturity and fruit fly infestation and enhance fly control through acceptable bait sprays and traps or bait stations targeting females.

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	Re-assess crop maturity vs. fruit infestation in major mango varieties (A)	Definitive relationship established between fruit maturity and fly infestation	March 2013	In ripening Kensington pride mangoes, there was a reasonable correlation between high % Brix (>12%), prominent skin colour (> 90% yellow) and fruit fly stings. This was in the presence of low-moderate fruit fly pressure (10-15 Flies/Trap/Day). In the later varieties including Keitt, under substantially higher fly pressure (up to 100 FTD), there was no significant relationship between % Brix, skin colour or fruit fly stings. This suggests that fruit fly population pressure is the significant driver in the relationship between mango maturity and fruit fly infestation.
3.2	Research trials on bait sprays and application methods in mangoes (A)	Baiting technique devised	Ongoing	12 commercial protein baits were tested for phytotoxicity. Trials also tested varietal susceptibility to protein baits. All varieties tested showed phyto-blemish symptoms. Hymlure caused the least blemish.
3.3	Enhance female attractants (A)	Attractants optimised for field use	Ongoing	The combination of fruit volatile odour, ammonium bicarbonate and torula yeast in a wax matrix Further data have been collected on the efficacy of ammonium bicarbonate and torula yeast as female attractants, and a comparison made with a commercial liquid (Cera) trap. The liquid trap caught significantly more flies than the dry traps. Protein bait stations containing Ceratrap® gel were tested. Lab trials elucidated the efficacy of several toxicants added to wax matrix Ceratrap® bait stations. Following the lab experiments, the most efficacious toxicants were added to wax matrix and membrane (dialysis tubing) at 50 and 100 ml Ceratrap® solution. The membrane containing 100 ml gel solution and maldison toxicant captured the most fruit flies.

PC = partner country, A = Australia

7 Key results and discussion

Objective 1: To evaluate the ability of area-wide control treatments to reduce fruit fly infestation levels in mango crops.

Activities

1.1. Conduct a project implementation workshop involving all key stakeholders to define the treatment area, evaluate current practices, discuss treatment supplies, plan the application of treatments and consider the community engagement required to ensure the project's acceptance.

The project implementation workshop (inception meeting) was held at Jakarta on 14-15 April 2010. The inception meeting agenda is attached in Appendix 1. Five Australians, three representing the project team included Dr Harry Fay previous project leader and DAF Entomologist (now retired); Dr Vijay Shanmugam, consultant entomologist and Dr Hainan Gu, former DAF Entomologist and two representing ACIAR, Les Baxter RPM Horticulture and Felicity Muller, both previous employees. Twelve Indonesian staff represented the Directorate of Horticulture protection and the Indonesian Agricultural Quarantine Agency. Key DHP staff included the Director of DHP, Mr Soekirno (now retired) and key project staff Dr Dwi Iswari (former staff member) and Ms Anik Kustaryati, both from DHP.

Delegates at the meeting agreed on the selected treatment and conventionally treated sites. The major mango producing district of Indramayu was selected as the district to test the Area-wide management system. The area has a flat landscape making it relatively easy to deploy fruit fly control treatments. A 40ha area of mangoes at Krasak and 60 ha area in Sliyeg Lor villages were identified as the prospective area-wide Management treatment sites. A 40 ha area of mangoes at Cikedung was selected as the conventionally treated site.

Fruit fly control at all sites ranged from doing nothing to applying insecticide treatments at the individual farm level. Damage levels were quite high, particularly at the two treatments sites.

The delegates agreed to purchase ME from company PT. Ragam Mandiri and sold as Petrogenol® (80% ME). PT Ragam Mandiri was the only known supplier of ME at the time of the inception meeting. The protein bait based on beer yeast waste supplied by the Malaysian company Pupuk Alam SDN and sold as Prima® was selected as the protein bait source. The Malaysian company is the only supplier in Southeast Asia following the closure of the Indonesian plant in 2009.

Treatments were planned to commence in 2010, however due to changes in the Indonesian financial regulations, the project start date had to be delayed until 2011.

At least three co-ordination meetings per year involving major stakeholders and to plan activities and discuss progress and issues with the program were planned. Farmer and officer training in treatment application was planned. Annual field days to demonstrate the program were also planned.

Agreement was reached on the roles and responsibilities of key staff.

1.2. Instigate Male Annihilation (MA) across the designated area using appropriate attractants and toxicants, distribution rates and a three to four monthly replacement cycle of 'blocks'.

MA blocks were initially installed in April 2011 and new blocks deployed approximately every two months. The number of blocks per cycle had increased from the initial 500 up to 700 at the completion of the project. New blocks were deployed roughly every two months at the rate of 6/ha. However in the first and second year this was not consistent due to other commitments and timing of religious events such as Ramadan. However by about the third year of treatments the cycle was consistently every two months. Blocking had the desired effect of reducing the male fruit fly populations to very low levels. Unfortunately there were issues with traps being stolen and poor understanding of the trap collection requirement that monitoring for male fruit flies did not commence until August 2011, five months after blocking had commenced. Results of monitoring are presented in activity 2.4.

1.3. Introduce protein bait spray applications on a weekly cycle. These treatments need to target host fruit trees during maturation of fruit, the stage which is known to be susceptible to fruit flies.

Protein baiting commenced in July 2011 and continued until September during the first year. Protein baiting was not regular and only nine applications were made in 2011. Growers were reluctant to apply protein bait sprays in the initial year of the project as they could not see the visual effects of the treatment. However the proportion of infested fruit had decreased following the first season and the growers were convinced that protein baiting was effective. Growers were instructed on the importance of consistent and regular protein baiting. The project also purchased new sprayers for the growers in 2012 as there were complaints that most sprayers were poorly maintained. In subsequent years the number of applications had increased up to 20 in some years. Protein baiting did not occur when Ramadan coincided with the fruiting period.

Ramadan is a holy period in the Muslim calendar during which Muslims worldwide observe a month of fasting during which they are not permitted to consume food or drink liquids from sunrise to sunset daily. Understandably during this fasting period, farming activities in the field are extremely difficult for farmers and workers to undertake and are thus kept to a minimum. Ramadan had occurred during critical periods however the overall effect of not baiting was minimal.

Initially protein baiting ceased once the majority of the crop was harvested. During 2013 a small peak in trap catches occurred at the end of the season. According to internationally accepted Area Indices for Fruit Flies (IAEA manual 2003) the populations of fruit flies have been at eradication levels (FTD 0.1-0) at Krasak for most of 2013/14. Apart from post-harvest in January 2014 where the population increased to suppression levels (FTD 1-0.1). The population levels were at suppression levels (FTD 1-0.1) at Sliyeg, however they increased to infestation levels (FTD >1) during January 2014. Peaks at both sites were attributed to the cessation of protein baiting and poor end of season hygiene. A concerted effort to continue protein baiting and improve sanitation over this period resulted in maintaining eradication levels at both sites.

1.4. Encourage orchard hygiene to reduce potential sources of flies.

Orchard hygiene improved throughout the project. There were ongoing meetings with and training of farmers where this concept was promoted and disposal bins were provided to assist farmers to undertake this task. Consistently high trap catches in particular traps at Krasak in 2011 and 2012 were attributed to the occurrence of alternative hosts adjacent to the traps. Subsequently the farm leader at Krasak removed certain hosts and ensured that fruit residues were eliminated. The peaks in fruit fly populations that occurred in 2013/14 were partly attributed to poor sanitation at the end of harvest. In subsequent seasons sanitation, along with continued protein baiting resulted in the elimination of the end of season peaks.

1.5. Undertake capacity building by training farmers and DINAS workers in the appropriate establishment of area wide control techniques, bait spray application and orchard hygiene practices to ensure the dissemination of AWM techniques to the major mango growing regions in Indonesia.

Up to three co-ordination meetings involving provincial and directorate staff, farmers and Australian project members were held annually. Annual Socialisation meetings and field days directed at farmers, DINAS staff and Horticulture protection staff from other provinces in Indonesia. Capacity impacts are discussed in 8.2.

Objective 2: To introduce fruit fly monitoring techniques to provide data in support of the area-wide management program.

2.1. Conduct a project implementation workshop (see activity 1.1) to define the monitoring requirements appropriate for the fruit fly species involved and to map the fruit fly susceptible host fruits within the treatment area.

The inception meeting was held in Jakarta on 14-15 April 2010. Details of attendees is in 1.1 above. Delegates agreed that the major pests were the Papaya fruit fly, *Bactrocera* papayae which is now called Oriental fruit fly, *Bactrocera dorsalis* and the Carambola fruit fly, *Bactrocera carambolae*. Both species are attracted to ME. It was also agreed that a small number of traps containing Cue lure would be deployed to monitor the Cucurbit fly, *Bactrocera cucurbitae*. Plans for mapping were agreed upon. Initial mapping included site, trap and block locations. Trapping protocols such as number of traps and their location, trap clearance frequency and lure change frequency were finalised. Data recording and

Agreement was reached on the roles and responsibilities of key monitoring staff.

2.2. Introduce a monitoring program prior to the commencement of the control treatments to continue for the duration of the project. This will involve an extensive network of traps with male lures and a fruit collection program to assess infestation levels and define problem areas.

Monitoring traps and their location were deployed on the 23rd of February at Cikedung and on the 2nd of March 2011 at the treatment sites of Krasak and Sliyeg Lor, approximately one month prior to the initiation of MA. All trap locations were mapped. Initial trap clearance was sporadic with inconsistencies in the intervals between clearances. However from early 2012 the trap clearance intervals were more consistent at approximately seven day intervals.

In 2011 several traps, particularly from Cikedung were regularly stolen. Initially, replacement of stolen traps was delayed however following a coordination meeting where the importance of consistent trapping data was discussed, the trap clearance staff always carried replacement traps and delays were reduced. Also socialisation meetings were held with growers in the treatment sites and the importance of the monitoring traps was discussed. Trap theft was rare following the public meetings.

Fruit sampling to determine levels of infestation commenced in 2011. The understanding and execution of this concept proved difficult. Initial fruit collections and observations were minimal and handling procedures not standardised. Fruit collection in 2011 was limited to the conventionally treated area of Cikedung. The staff were not abreast of harvesting times, therefore collection was limited by number and site due to harvest completion. Staff improved fruit collection and handling procedures with increased numbers of fruit being sampled every subsequent year. The annual number of fruit sampled per year ranged from 405 in 2011 up to 26500 in 2015 (Table 1). Infestation levels at all sites were very low at all sites. The low infestation levels at the conventionally treated site are attributed to the heavy cover sprays that are applied by contractors at this site.

Table1. Infestation levels from fruit sampling (2015)

Site	Fruit sample	Infested by fruit fly	% infestation
Krasak	15,000	23	0.15
Sliyeg Lor	3,000	0	0.0
Cikedung	8,500	38	0.44

In 2015 alternate host fruit were collected for rearing of possible fruit flies. There were four infested fruit in total from Sliyeg. The fruit fly species was *Bactrocera albistrigata*, a major pest of Rose apple and not a target for AWM. This species is attracted to Cue lure and would not have been effected by the MA block treatments.

2.3. A workshop on fruit fly identification for key Directorate General of Horticulture and Centre for Plant Quarantine staff to refine their taxonomic skills.

One DHP and three IAQA staff attended the fruit fly identification workshop conducted by Professor Dick Drew at the Griffith University Nathan Campus, Brisbane on 5-8 November 2012. Workshop topics included phytosanitary standards for fruit flies, biology of fruit flies, morphology and diagnostic characters for fruit flies and practical identification of Indonesian fruit flies.

Two staff from DHP attended a study tour of Queensland research in South East Queensland hosted by DAF Senior Entomologist Mr Stefano De Faveri. The group visited the DAF Granite Belt Research station at Applethorpe in Southern Queensland. Mr Brendan Missenden, Entomologist DAF Brisbane discussed chemosterilant trials that were conducted at the research station and demonstrated the attributes of the fruit fly exclusion netting structure on the station. Station Manager Peter Nimmo led a tour of the research station, and discussed fruit fly management in the Granite Belt. The group also visited the DAF Redland Bay facility where Mr Ed Hamacek discussed fruit fly research that was being conducted at the field station.

2.4. Data-basing and evaluation of the monitoring data to assess the effectiveness of the control treatments and to adjust them if necessary.

Data were entered into the database regularly. The data-basing commenced in 2011 and continued until the completion of the project in December 2015. Figures 5 shows the results of the male fruit fly trapping data at the two treatment sites of Krasak and Sliyeg Lor. Figure 6 shows the population levels at the conventionally treated site of Cikedung. Population levels are represented as flies per trap per day (FTD). Unfortunately due to the constant theft of traps early in 2011 and the difficulties in understanding the monitoring concept by local staff, pre-treatment data were not captured. The first reliable data were captured in August 2011, this was four months after initial MA treatment and one month after protein baiting commenced. Therefore it is not possible to illustrate the population levels prior to treatment application. In 2011 fruit fly populations within the treated areas fluctuated and FTD's of 15, 18 and 8 occurred at Krasak between Oct-Dec. The populations decreased further in 2012 but occasionally crept over the infestation level of 1 (IAEA 2003). Figure 3 shows the male fruit fly populations between August 2011 and December 2015 at the two AWM treatment sites.

In 2013 according to internationally accepted Area Indices for Fruit Flies (IAEA manual 2003) the populations of fruit flies had been at eradication levels (FTD 0.1-0) at Krasak for most of 2013/14. Apart from post-harvest in January 2014 where the population increased to suppression levels (FTD 1-0.1). The population levels were at suppression levels (FTD 1-0.1) at Sliyeg Lor, however they increased to infestation levels (FTD >1) during January 2014. Peaks at both sites were attributed to the cessation of protein baiting and poor end of season sanitation.

Following more rigorous sanitation and protein baiting late in the season of 2014 and 2015 populations at both treatment sites were maintained at suppression levels (FTD 1-0.1) at Sliyeg and eradication levels (FTD 0.1-0) at Krasak.

In contrast with the AWM treated sites the population levels at the conventionally treated site regularly peaked at over 50 FTD with a major peak at over 400 FTD (figure 6). Figure 6 also illustrates the peak populations occurring around peak and post-harvest time harvest time around October to December.

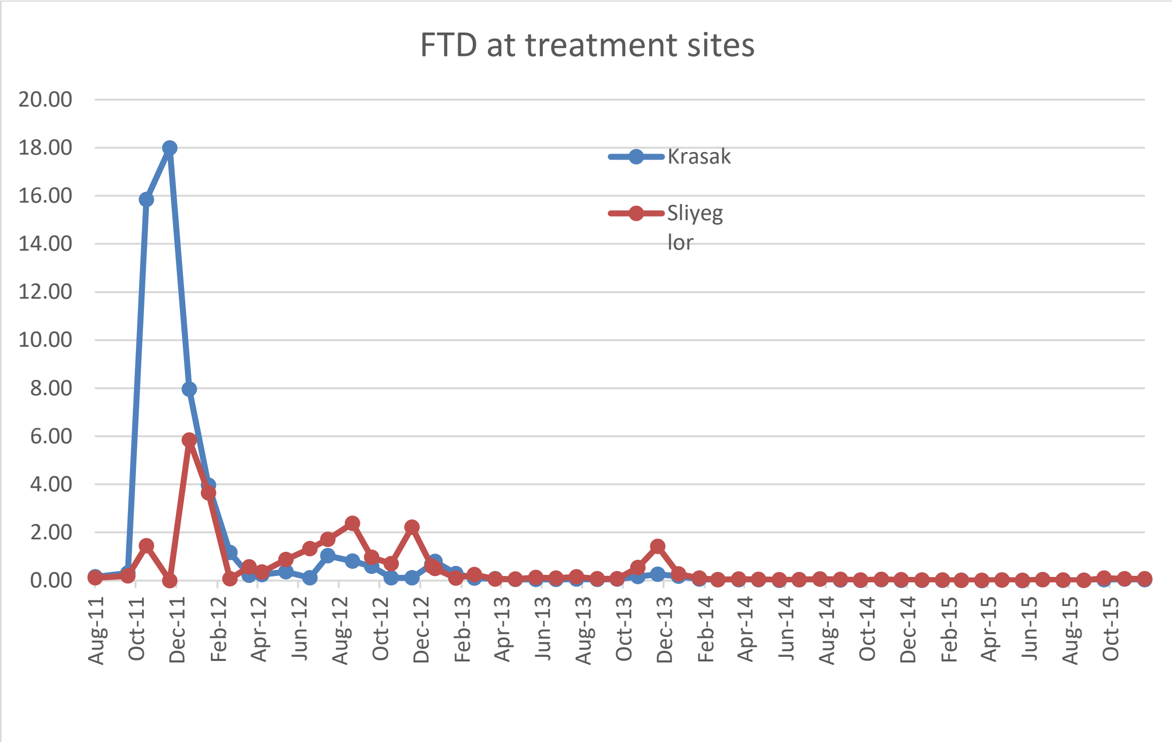

Figure 5. FTD of male fruit fly catches at the AWM treatment sites of Krasak and Sliyeg Lor

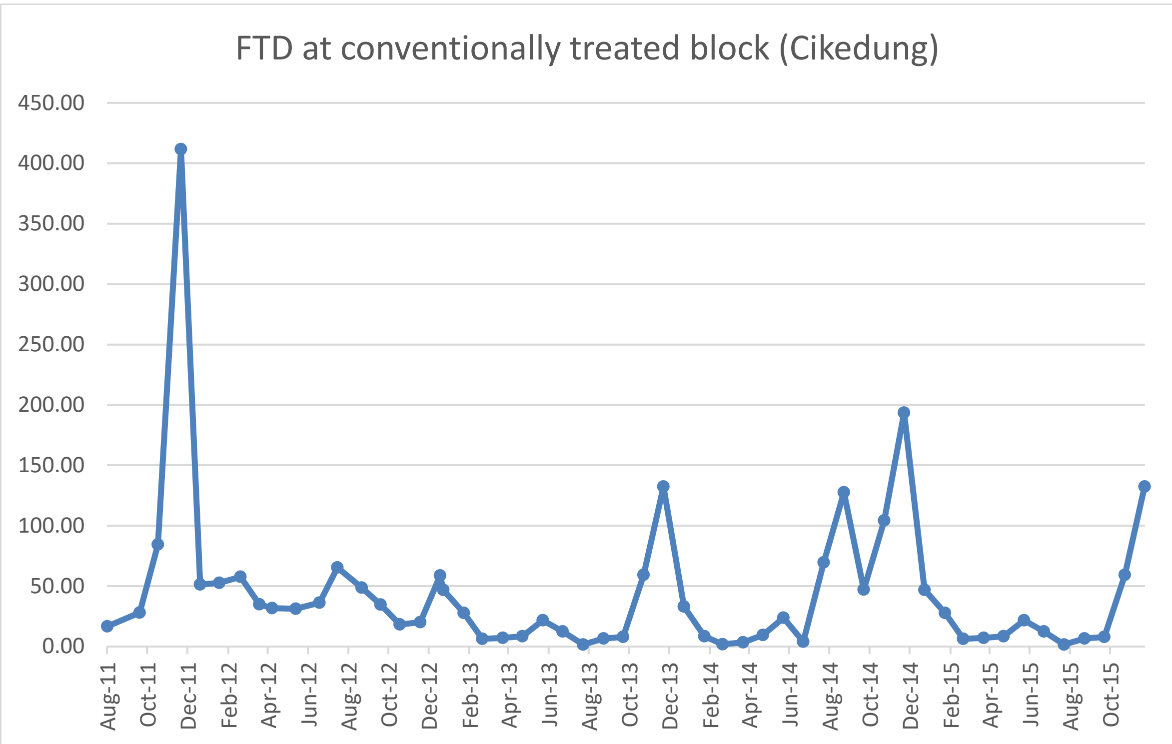

Figure 6. FTD of male fruit fly catches at the conventionally treated site of Cikedung.

Monitoring traps were also established at regular (500M) intervals away from the central trap at Krasak to determine the fruit fly population levels surrounding the treatment area. This activity was implemented in SRA project HORT/2014/026. Monitoring continued after the termination of the SRA. Figure 7 shows populations generally increasing the further the trap is from the treatment area. The traps at 2000m east and west captured the most fruit flies. There was a trend for the 1500m traps at four orientations to capture less fruit flies than traps at 1000m from the central trap. The central trap which was located in the centre of the treatment area did not capture any fruit flies. However traps to the north show a decrease. This was probably due to the Sliyeg treatment site being to the north of the trap. There appears to be an effect from the treatment area on the traps located 500m from the central trap. It is likely that the AWM zone treatments have had a population reduction effect on the fruit fly populations adjacent to the zone rather than the populations outside the zone impacting on the treatment zone.

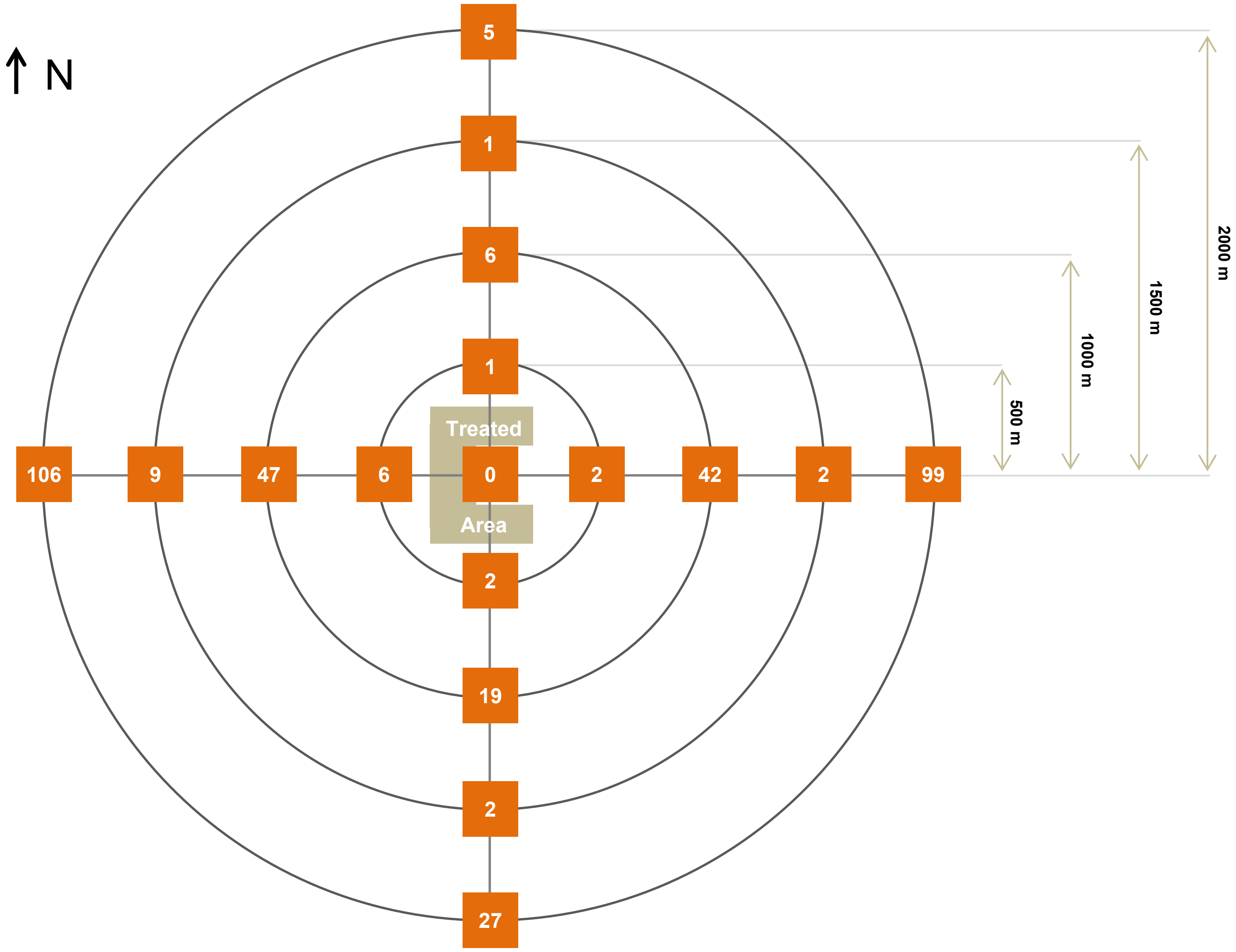

Figure 7. Average fruit flies captured/trap/day (FTD) at Krasak suppression zone and at locations 0.5, 1, 1.5 and 2 kilometres from the central trap (July 2014-Dec 2015).

The concept of female trapping was also introduced in 2014. Original guava/ammonia McPhail traps did not capture fruit flies and these traps were abandoned. The introduction of protein (Cera Trap® gel solution) based dry traps however resulted in significant trap captures. Figure 8 shows the female trap capture data. The results show the increased activity of female fruit flies during the fruiting season. There were less fruit flies captured in the treatment zone traps compared to the control area traps. However female fruit flies were present in the treated orchard even though the male fruit fly trapping indicated very low population levels. However specimens were poorly stored and species determination was not possible. Therefore captured species were not identified.

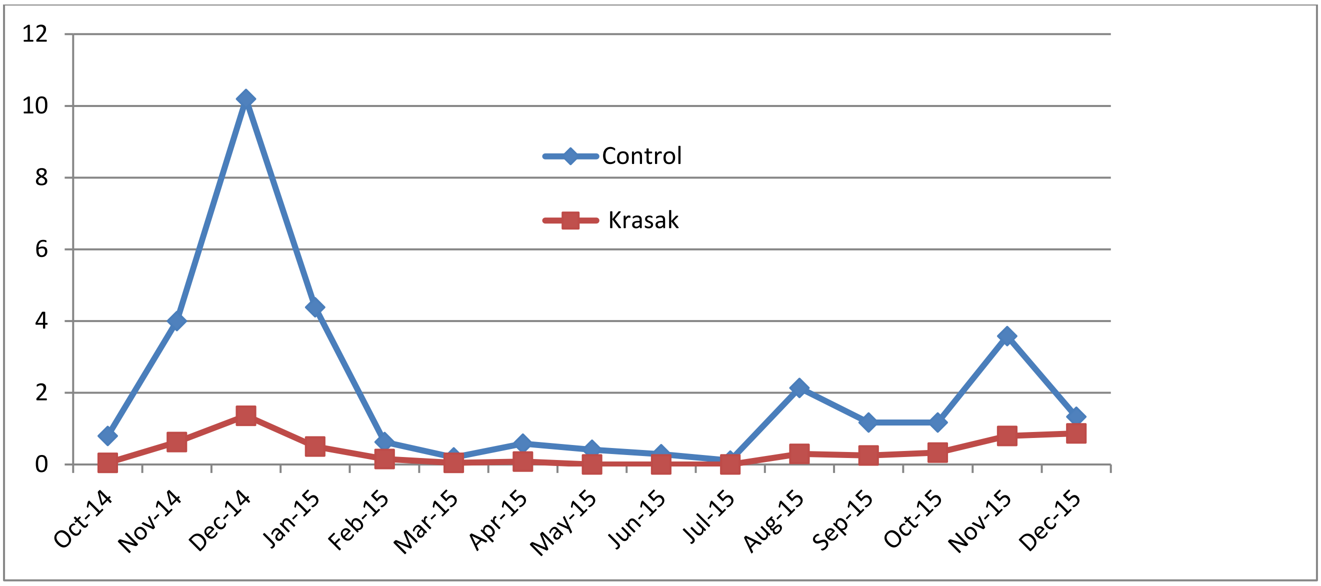

Figure 8. FTD of female trap catches at Krasak and at a neighbouring control area.

2.5. Liaise with the local community to guarantee the integrity of the monitoring program.

Field days were held annually to demonstrate the results of the AWM program and to educate the community about the monitoring program. There were initial issues as discussed above regarding trap theft. Thieves falsely believed the traps would control fruit fly on their properties. Following several meetings with the local community, theft of traps was no longer an issue. However theft of the male trapping outside the treatment zone and female traps occurred as these were new areas that traps were installed.

Objective 3: To determine the relationship between mango crop maturity and fruit fly infestation and enhance fly control through acceptable bait sprays and traps or bait stations targeting females

Activities

3.1. Re-assess fruit fly infestation levels in relation to crop maturity, particularly in the major mango varieties.

The first season's work on the relationship between fruit maturity and fruit fly infestation examined early season Kensington Pride (KP) types and later maturing Keitts and other varieties. There were no fruit fly control treatments in place. No fruit fly stings or infestation could be ascertained in the KP type fruit. However, in the Keitts and later varieties there were fruit fly stings on and flies reared from both maturing and ripe fruit. Most were in ripe fruit with a reasonable correlation between the numbers stings and increasing Brix. The later varieties are subject to greater fruit fly pressure than the KP types.

In ripening Kensington pride mangoes, there was a reasonable correlation between high % Brix (>12%), prominent skin colour (> 90% yellow) and fruit fly stings. This was in the presence of low-moderate fruit fly pressure (10-15 Flies/Trap/Day). In the later varieties including Keitt, under substantially higher fly pressure (up to 100 FTD), there was no significant relationship between % Brix, skin colour or fruit fly stings. This suggests that fruit fly population pressure is the significant driver in the relationship between mango maturity and fruit fly infestation.

During the 2012/13 mango season there were four fruit infested in the fruit maturity versus fruit fly infestation trials. All infested fruit had a high brix level (10 – 15% Brix) prominent skin colour (rated 5-6) and were soft (9 -20 Newtons penetrometer readings). The fruit fly pressure was moderate to high at 23-60 Flies/Trap/Day compared to 10-15 in 2011. The data suggest Kensington Pride mangoes may not be susceptible to *Bactrocera tryoni* when picked green mature even under reasonably high population pressure. The data do not reflect this relationship in other varieties or to infestation by *Bactrocera jarvisi. B. jarvisi* has a later population peak that does not coincide with the Kensington Pride harvest.

As fruit fly population pressure appears to be the significant driver in fruit susceptibility it is important to implement protein baiting early to reduce populations to low levels rather than waiting until fruit become susceptible.

3.2. Undertake research trials on protein bait sprays and application methods in mangoes in Australia designed to overcome fruit blemishing.

All proteins assessed in North Queensland, irrespective of formulation, caused phytotoxic fruit blemish. Most severe blemish was associated with baits applied as a paste or gel (ANAMED™ SPLAT (protein), DacGel™). Natflav 500™, HYM-LURE™ and CERABAIT™, at the same (recommended) protein concentration as for Fruit Fly Lure™ (0.84%), were relatively less ($p<0.05$) phytotoxic to mango (cv. R2E2) than Fruit Fly Lure™ (Table 2).

The protein component of the bait solution (not the toxicant) was shown to be responsible for causing blemish. Bait solution pH had no apparent influence on blemish expression when KOH modified Fruit Fly Lure™ solutions were applied to cv. Calypso. In other assessments, blemish symptoms were slight and obscure, and did not clarify the influence of Natflav 500™ solutions (borax modified) applied to cv. Kensington Pride.

Table 2. Phytotoxic response of mature mango fruit (cv. R2E2) to protein treatments at Mareeba, North Queensland.

Treatment		Mean phytotoxic blemish rating	
Protein	*Concentration (%)*		
CERABAIT™	0.36	0.46	a
CERABAIT™	0.84	0.56	a
HYM-LURE™	0.42	0.49	a
HYM-LURE™	0.84	0.66	ab
Natflav 500™	0.84	1.00	b
Fruit Fly Lure™ (control)	0.84	2.15	c
5% LSD		0.43	

Phytotoxic blemish ratings with a letter in common are not significantly (p<0.05).

Significant differences (p<0.05) in attraction counts were found for both *B. tryoni* and *B. jarvisi* at various count times which described a trend of greater numbers of flies attracted to HYM-LURE™ 0.84% concentration (data not presented). Across times, HYM-LURE™ (0.84%) attracted greater (p<0.001) numbers of *B. tryoni* and *B. jarvisi* than the other protein treatments (Table 3).

Laboratory and efficacy trials were conducted on the least phytotoxic protein baits and these were compared with the most used protein bait in Queensland.

Table 3. Mean numbers of *B. jarvisi* and *B. tryoni* attracted to different proteins over a 4.5 hour monitoring period in laboratory cage trial 1.

Protein treatment	Mean *B. tryoni* attraction				Mean *B. jarvisi* attraction			
				BT[1]				BT[1]
CERABAIT™ 0.36%	0.00	a	*0.00*	1.30	0.00	a	*0.00*	1.00
CERABAIT™ 0.84%	0.10	a	*0.68*	1.40	1.51	b	*0.49*	2.51
HYM-LURE™ 0.42%	1.19	a	*0.68*	2.49	3.67	c	*0.49*	4.67
HYM-LURE™ 0.84%	2.88	b	*0.68*	4.18	6.47	d	*0.49*	7.47
Fruit Fly Lure™ (control)	0.05	a	*0.68*	1.34	2.03	b	*0.49*	3.03

Means not followed by a common letter within a column differ significantly p<0.001. Values in italics are standard errors of the transformed means. [1]Back-transformed means.

Protein bait efficacy trial

Significant differences (p<0.05) in attraction counts at various count times were found only for *B. jarvisi*; however for both *B. tryoni* and *B. jarvisi* there was trend of greater numbers of flies attracted to HYM-LURE™ 0.84% concentration (data not presented). Across times, *B. tryoni* attraction to protein treatments was not significantly different, but HYM-LURE™ (0.84%) attracted greater (p<0.001) numbers of *B. jarvisi* than the other protein treatments (Table 4).

Table 4. Mean numbers of *B. jarvisi* and *B. tryoni* attracted to different proteins over a 4.5 hour monitoring period in laboratory cage trial 2.

Protein treatment	Mean *B. tryoni* attraction				Mean *B. jarvisi* attraction			
				BT[1]				BT[1]
Natflav 500™ 0.42%	0.84	a	*0.22*	2.31	0.87	a	*0.22*	2.38
Natflav 500™ 0.84%	0.40	a	*0.27*	1.48	1.44	b	*0.17*	4.23
HYM-LURE™ 0.42%	0.97	a	*0.20*	2.63	1.52	b	*0.16*	4.56
HYM-LURE™ 0.84%	1.22	a	*0.18*	3.39	2.49	c	*0.10*	12.07
Fruit Fly Lure™ (control)	0.62	a	*0.24*	1.86	1.48	b	*0.16*	4.38

Means not followed by a common letter within a column differ significantly p<0.001. Values in italics are standard errors of the transformed means. [1]Back-transformed means.

Flight cage efficacy trials

Dead female and male *B. jarvisi* and *B. jarvisi* of both age groups (7–10 and 14–17 days old) were retrieved from catching sheets of both protein treatments. Treatments did not influence (p>0.05) the number of dead *B. tryoni* of either sex or age group (Table 5), and only influenced the number of dead 7–10 day old *B. jarvisi* males; the number of dead males was higher (p<0.028) for HYM-LURE™ compared with Fruit Fly Lure™ (Table 6). While not significant, there was a consistent trend of higher fly death associated with HYM-LURE™ compared with Fruit Fly Lure™ for both fly species sex and age.

Table 5. Mean number of dead *B. tryoni* of two age groups retrieved from catching sheets of protein treatments four hours after release within flight cages.

Protein treatment	Total males and females		Total females		Total males	
	7–10 day old fruit flies					
HYM-LURE™	90.5	a	45.5	a	45.0	a
Fruit Fly Lure™ (control)	59.0	a	29.2	a	29.8	a
	14–17 day old fruit flies					
HYM-LURE™	63.8	a	36.0	a	27.8	a
Fruit Fly Lure™ (control)	48.0	a	30.2	a	17.8	a

Means not followed by a common letter within a column differ significantly p<0.05.

Table 6. Mean number of dead *B. jarvisi* of two age groups retrieved from catching sheets of protein treatments four hours after release within flight cages.

Protein treatment	Total males and females		Total females		Total males	
	7–10 day old fruit flies					
HYM-LURE™	143.2	a*	77.2	a	66.0	b
Fruit Fly Lure™ (control)	119.2	a	66.2	a	53.0	a
	14–17 day old fruit flies					
HYM-LURE™	129.5	a	70.8	a	58.8	a
Fruit Fly Lure™ (control)	88.8	a	39.2	a	49.5	a

Means not followed by a common letter within a column differ significantly p<0.05.

3.3. Optimise the attractants for gravid female flies to enhance bait treatments or, further reduce insecticide use and to provide trapping or bait station options as additional biosecurity tools.

Data were collected on the efficacy of ammonium bicarbonate, torula yeast and fruit volatiles as female attractants. These were tested in both early and late mango varieties. During KP mango maturation, 96.7% of flies caught in traps with attractants were females and 98.4% of these were pest species. The results for the fruit volatiles were varied and confirmed that they perform best when they do not have to compete with the odours produced by a large amount of ripe fruit.

The efficacy of the ammonium bicarbonate, torula yeast and fruit volatile lures were compared with a commercial liquid Cera Trap®. The liquid trap caught significantly more fruit flies (including 83.6 % females) than the dry traps. However there was a high bi-catch of other blow flies and the decaying flies went rank in the solution.

Wax based lures containing ammonium bicarbonate and torula yeast were also tested to improve field longevity. In cage trials the addition of fruit volatiles to the torula yeast and ammonium bicarbonate wax matrix attracted more gravid female fruit flies than the yeast/ammonia combination alone. In a field trial there was no significant difference in number of female fruit flies caught in wax matrix lures in yellow cone traps containing maldison compared with the panel trap containing Fruit Fly Lure™ but both treatments caught significantly more female fruit flies than the other treatments. The Lion Nathan protein panel was not significantly different to the control panel trap and the Steiner trap containing the wax matrix blend caught significantly less female fruit flies than any other treatment. (Table 7).

Table 7. Mean female fruit fly catch (*B. jarvisi* and *B. tryoni*) over the 5 week collection period as influenced by lure/protein/trap treatments at Mareeba.

Treatment	Total female fruit fly catch (*B. jarvisi* and *B. tryoni*)			BT[1]
Wax+maldison wick (Steiner)	0.69	a	*0.65*	2.00
Wax + maldison wick (cone trap)	3.21	c	*0.19*	24.8
Lion Nathan Protein on panel	2.46	b	*0.27*	11.8
Fruit Fly Lure™ Protein on panel	3.20	c	*0.32*	13.5
Panel control	2.44	b	*0.27*	11.5

Means not followed by a common letter differ significantly ($p<0.05$). Values in italics are standard errors of the transformed means. [1]Back-transformed means.

A further field trial compared wax matrix lures containing fruit volatiles, protein and ammonia bicarbonate and different toxicants. The wax matrix dichlorvos strip treatment caught more female fruit flies than the wax matrix maldison wick and wax matrix dichlorvos wick treatments which captured significantly more female fruit flies than the maldison incorporated in the wax matrix treatment. The control treatment (cone trap + maldison wick) caught significantly less female fruit flies than all other treatments (Table 8). There appears to be an effect on the volatility of the female attractants when maldison is incorporated with the lures. Another explanation could be that maldison alters one or more lure components when they are combined.

Table 8. Mean female fruit fly catch (*B. jarvisi* and *B. tryoni*) over the 8 week collection period as influenced by lure/toxicant treatments at Mareeba.

Treatment	Total female fruit fly catch (*B. jarvisi* and *B. tryoni*)			BT[1]
Wax + maldison incorporated	1.91	b	*0.19*	6.8
Wax + maldison wick	2.55	c	*0.15*	12.7
Wax +dichlorvos strip	3.66	d	*0.10*	39.0
Wax + dichlorvos wick	2.70	c	*0.14*	14.7
Control (maldison in trap)	-1.61	a	*1.06*	0.2

Means not followed by a common letter differ significantly ($p<0.05$). Values in italics are standard errors of the transformed means. [1]Back-transformed means.

Comparison of bait stations in field trials

Bait stations containing different rates of Cera Trap® solution, different rates of toxicants and either incorporated in the wax matrix or a synthetic membrane were compared with the commercial Cera Trap® product in trials at Mareeba and Dimbulah. Weekly fruit fly catches of treatments followed similar trends at Mareeba and Mutchilba for the respective collection periods of each trial (data not presented). At Mareeba, highest catches of both fruit fly species (*B. jarvisi* and *B. tryoni*) were collected over a 35 day period from 13 January to 17 February 2015 (80% of the total of each species caught) (Figure 9).

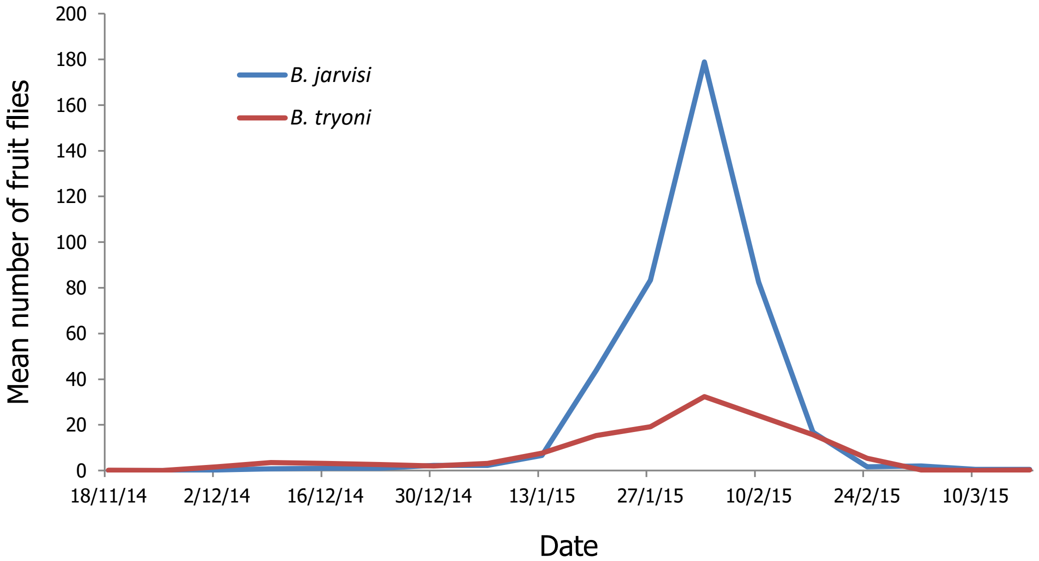

Figure 9. Distribution of weekly fruit fly catches (male and female flies) at Mareeba.

Significantly higher ($p<0.001$) total catches were collected from Cera Trap® at both trials (Tables 9 and 10). While differences in total catches amongst the wax matrix and synthetic membrane treatments were not consistent at the two trials, catches tended higher for synthetic membrane (100 ml protein and 5 ml maldison) at both locations.

Table 9. Mean fruit fly catch (*B. jarvisi* and *B. tryoni*) over the 68 day collection period as influenced by bait/toxicant treatments at Mutchilba.

Treatment	Total fruit fly catch (*B. jarvisi* and *B. tryoni*)			
				BT[1]
Wax Maldison 100/5	1.33	ab	*0.47*	3.79
Wax Maldison 50/2.5	0.49	a	*0.65*	1.62
Wax Spinetoram 100/2	0.93	ab	*0.54*	2.53
Synthetic Mal 100/5	2.61	c	*0.32*	13.54
Synthetic Mal 50/2.5	1.95	bc	*0.38*	7.04
Cera Trap®	3.62	d	*0.279*	37.19

Means not followed by a common letter differ significantly ($p<0.001$). Values in italics are standard errors of the transformed means. [1]Back-transformed means.

Table 10. Mean fruit fly catch (*B. jarvisi* and *B. tryoni*) over the 125 day collection period as influenced by bait/toxicant treatments at Mareeba.

Treatment	Total fly catch (*B. jarvisi* and *B. tryoni*)				Proportion *B. jarvisi*			
				BT[1]				BT[1]
Wax Mal 100/5	1.27	b	*0.27*	58.6	0.78	a	*0.21*	0.69
Wax Mal 50/2.5	1.56	b	*0.23*	78.2	1.07	a	*0.19*	0.74
Wax Spin 100/2	0.00	a	*0.51*	16.4	0.77	a	*0.39*	0.68
Synthetic Mal 100/5	1.92	b	*0.20*	111.6	1.11	a	*1.16*	0.75
Synthetic Mal 50/2.5	1.39	b	*0.26*	65.8	1.04	a	*0.21*	0.74
Cera Trap®	3.04	c	*0.11*	313.0	1.26	a	*0.10*	0.78

Means not followed by a common letter within a column differ significantly ($p<0.001$). Values in italics are standard errors of the transformed means. [1]Back-transformed means.

At Mareeba, both *B. jarvisi* and *B. tryoni* were collected from all treatments (Table 10). *B. jarvisi* were caught in greater numbers (75% of the total caught); however the number, as a proportion of the total *B. jarvisi* and *B. tryoni* caught, was not influenced ($p>0.05$) by treatments. The proportion of the total number of each fruit fly species caught that were female was also not influenced ($p>0.05$) by treatments (Tables 11 and 12). Averaged across treatments, 82% of the total *B. jarvisi* caught were females, while only 18% of the total *B. tryoni* caught were female.

Gravid (egg carrying) females of both fruit fly species were caught by all treatments. Differences amongst treatments for the proportion of the total females caught that were gravid were only significant for *B. jarvisi* however, Cera Trap® and synthetic membrane (100 ml protein and 5 ml maldison) caught proportionally higher ($p=0.005$) numbers than wax matrix and synthetic membrane both with 50 ml protein and 2.5 ml of maldison. Averaged across treatments, 63% of the total numbers of *B. jarvisi* females were gravid, while only 36% of *B. tryoni* females were of this condition.

Table 11. Mean fly catch (*B. jarvisi*) over the 125 day collection period as influenced by bait/toxicant treatments at Mareeba.

Treatment	Total *B. jarvisi* catch				Proportion female				Proportion of females gravid			
				BT[1]				BT[1]				BT[1]
Wax Mal 100/5	3.69	ab	*0.29*	40.2	1.54	a	*0.27*	0.82	0.43	ab	*0.17*	0.61
Wax Mal 50/2.5	4.06	bc	*0.24*	58.2	1.53	a	*0.23*	0.82	0.15	a	*0.14*	0.54
Wax Spinetoram 100/2	2.42	a	*0.55*	11.2	1.37	a	*0.46*	0.80	0.61	ab	*0.30*	0.65
Synthetic Mal 100/5	4.43	c	*0.20*	84.0	1.62	a	*0.20*	0.83	0.82	b	*0.13*	0.70
Synthetic Mal 50/2.5	3.88	bc	*0.26*	48.6	1.36	a	*0.24*	0.80	0.33	a	*0.15*	0.58
Cera Trap®	5.59	d	*0.11*	267.2	1.65	a	*0.13*	0.84	0.69	b	*0.09*	0.67

Means not followed by a common letter within a column differ significantly (p=0.005). Values in italics are standard errors of the transformed means. [1]Back-transformed means.

Table 12. Mean fly catch (*B. tryoni*) over the 125 day collection period as influenced by bait/toxicant treatments at Mareeba.

Treatment	Total *B. tryoni* catch				Proportion female				Proportion of females gravid			
				BT[1]				BT[1]				BT[1]
Wax Mal 100/5	2.91	b	*0.28*	18.4	-1.54	a	*0.27*	0.18	-0.62	a	*0.38*	0.35
Wax Mal 50/2.5	2.98	b	*0.28*	19.6	-1.55	a	*0.22*	0.18	-0.25	a	*0.29*	0.44
Wax Spinetoram 100/2	1.65	a	*0.53*	5.2	-1.36	a	*0.45*	0.20	-0.59	a	*0.64*	0.36
Synthetic Mal 100/5	3.32	b	*0.23*	27.6	-1.62	a	*0.20*	0.17	-0.51	a	*0.27*	0.38
Synthetic Mal 50/2.5	2.85	ab	*0.29*	17.2	-1.35	a	*0.23*	0.21	-1.67	a	*0.42*	0.16
Cera Trap®	4.33	c	*0.14*	75.8	-1.65	a	*0.13*	0.16	-0.16	a	*0.15*	0.46

Means not followed by a common letter within a column differ significantly (p<0.001). Values in italics are standard errors of the transformed means. [1]Back-transformed means.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Managing pest fruit flies through a program of population suppression over a wide area of fruit cultivation has many benefits but has seldom been attempted or demonstrated to be successful, especially with smallholder fruit farmers in Southeast Asia. The major scientific impact of this project has been to convincingly demonstrate and provide data that an Area-Wide fruit fly population suppression program is technically feasible to the point where suppression can be achieved and maintained at near eradication levels according to International Standards for Phytosanitary Measures (ISPM) in a relatively small area of mango ranging from 40 – 60 ha in size. Importantly, this project has also demonstrated that an area of suppression can be created in a relatively non-isolated environment where fruit flies are abundantly distributed both within and in the areas immediately surrounding the suppression zone. Migration of adult fruit flies from outside into the suppression zone is not a limiting factor as has been previously considered to be so.

The scientific data provided by this project will undoubtedly stimulate more research activities to be undertaken in the region within the next 5 years to expand the AWM model to other mango growing industries in the region. Besides mango, the AWM model should also encourage similar research to be conducted in other crops and with other species of pest fruit flies.

The development of improved baits and lures for female fruit flies is a major and very important challenge in fruit fly research. The use of female fruit fly traps provides a better indication of fruit fly activity in a region or an orchard as it is the females that oviposit in fruits. Currently population monitoring is mostly conducted by trapping male fruit flies, for which there have been powerful lures in use for many years. The research conducted in Australia is ongoing and has identified some compounds that have shown increased attractancy over the conventional protein baits in use now. When an improved female lure in conjunction with an appropriate trapping mechanism is eventually developed, it will provide a significant improvement to the control systems that are used in an Area-Wide program. The use of female fruit fly monitoring would also be a valuable tool in market access negotiations to prove either low pest prevalence or pest freedom.

8.2 Capacity impacts – now and in 5 years

Smallholder farmers together with staff from the Department of Horticulture Protection (DHP) and DINAS have successfully collaborated over 5 years to implement the Area-Wide program in Indramayu. With the initial training carried out by Australian project staff, and subsequently continued by DHP and DINAS, the knowledge base and capacity to recognize fruit fly damage, understand the key ecological and biological parameters, and institute the various control actions in a coordinated area-wide program has been successfully achieved at all levels in Indonesia.

The smallholder farmers in the two project sites of Krasak and Sliyeg now have the capacity and confidence to expand the AWM program to neighbouring farms. Both DHP and DINAS staff also now have the required knowledge and capacity to design and implement area-wide fruit fly management programs in other mango growing areas as well as in fruit and vegetable crops other than mango. This enhanced capacity and knowledge will expand well within the next 5 years and beyond in Indonesia with The Agriculture Ministry in Indonesia taking a keen interest in implementing fruit fly AWM in other crops and regions in Indonesia.

Three staff from the Indonesian Agricultural Quarantine Agency (IAQA), one staff from DHP and one DAF employee attended specialised fruit fly identification training by Dr Richard Drew from Griffith University. This training has increased the biosecurity capacity of the Indonesian agencies, particularly in regards to quarantine detection.

Fruit fly field management training for four DGH staff in Australia focused on north Queensland research including assessment of farm-wide management of Queensland fruit fly, alternative technologies for fruit fly control and other pests in north Queensland. This training has increased Indonesia's research capacity to control fruit flies and other pests. The visit also introduced the group to other researchers from north Queensland and therefore increased Indonesia's access to Australian expertise.

8.3 Community impacts – now and in 5 years

Prior to the implementation of the project and the AWM program, the smallholder mango farmers in Indramayu were a fragmented bunch of low-grade mango producers who rarely worked together and largely contracted out their trees to contract buyers. The quality of fruits produced was inferior and the prices obtained were low. With the introduction of the AWM program, the entire community of smallholder farmers in both trial sites of Krasak and Sliyeg Lor have begun to work harmoniously together to tackle the common fruit fly problem. A strong spirit of community participation, discussion and sharing of experiences and ideas has been fostered in the community. Aided by higher prices and demand for the better quality fruit they were producing through the AWM program, the farmers in Krasak and Sliyeg Lor have now been recognised across the province as progressive and productive. This has given the community a new sense of pride and achievement that was not present before. Such a community spirit will develop further and flourish into the future.

8.3.1 Economic impacts

Improvements in fruit quality, yield and incomes were realised following implementation of fruit fly area-wide management in project HORT/2008/041. Farmers reported that prior to AWM, only 20 per cent of their fruit was saleable. However after the AWM program, the amount of saleable fruit increased to 90 per cent. Prior to the AWM program, farmers used to lease all their mango trees to contract buyers and obtained an income of IDR 30 million/ha (AUD 3,000/ha). Following AWM, however, farmers were able to market the higher quality fruit to wholesale buyers and obtained an income in excess of IDR 70 million (AUD 7,000) per hectare.

Some mangoes are now being sold directly to wholesalers rather than to traders and smallholders are receiving IDR15, 000/kg (AUD 1.50/kg) compared to IDR 10,000/kg previously. A study by Maghraby and Gandasoemita (SRA HORT/2016/001 preliminary results) has shown that yields within the treatment areas have increased by 72% at Krasak and by 57% at Sliyeg Lor. This has translated to increased profits of 6% at Krasak and 21% at Sliyeg Lor. However other expenses for inputs such as fertilizers and pesticides have increased as the farmers are paying more attention to their crops. Growers have increased the amount of the new inputs or have purchased more expensive brands. Some of these extra input costs may not be necessary as they may not result in yield or quality improvements. However this project does not have the scope or personnel to conduct this work.

There has also been an increase in the average number of trees grown per farmer from 195 to 214 at Krasak. Seventy five percent of farmers in the treatment areas claim their standard of living has improved after the implementation of AWM.

Additionally, mango fruit from the AWM zone was also sought out by consumers as high quality, low pesticide residue fruit, and in one season growers received an IDR 30,000 premium for such fruit. Prior to the AWM program the mangoes were only sold to the local market, but after AWM implementation fruit from the AWM zone was sought by wholesale buyers and delivered for the first time to other markets in Indonesia. The prices for peak season fruit have increased since the implementation of AWM (table 13) in comparison to the control site. However the off season fruit prices have decreased. These are preliminary data and it is uncertain whether the increased prices are due to normal market fluctuations.

Table 13. Average prices per kilogram paid to growers.

Village	Price (Rp/kg) pre AWM	Price (Rp/kg) during AWM
Cikedung		
Peak season	6, 678*	
Off-season	8,991*	
Sliyeg Lor		
Peak season	12, 845	45, 255
Off-season	16, 931	9, 841
Krasak		
Peak season	10, 907	34 889
Off-season	45, 303	13, 428

*Cikedung prices are current returns.

In summary there has been a positive economic impact from the AWM program. Costs have increased due to the implementation of AWM and increases in other inputs due to growers aims at producing better quality fruit. Growers at Krasak have increased their plantings of mangoes and growers who contracted their crop previously are now growing and selling their own fruit. Further gains may be achieved by improving the marketing value chain. Collective action by growers could result in bargaining power with traders.

8.3.2 Social impacts

Implementation of an Area-Wide Management program requires collective action by a majority of participants within an area. In the case of fruit fly area-wide management most growers and village inhabitants must co-operate to implement the required measures to reduce fruit flies over a determined area. Strong leadership is required by farm leaders to implement and facilitate activities. The farm leaders at Sliyeg Lor and Krasak were proactive in leading and implementing this AWM program with strong co-operation by all participants. As a result of the collective actions the farmer groups at both treatment villages have strengthened considerably and this has been the greatest social impact of the project.

As a result of the co-operative actions growers have improved relationships with neighbours and farmers discuss issues within the group and therefore help solve problems amongst the group rather than bearing issues individually. This has also resulted in improved production due to the shared knowledge within the groups.

The wives of farmers are required to do less labour within the farm due to the collective action of the farmer groups. This leaves more time for housework, more time to interact with children and more social activities. Females within the community also interact more closely with each other and have formed closer bonds.

A study by Maghrabi and Gandasoemita has shown that 75% of growers feel that their standard of living has improved after implementing AWM. 95% of growers also feel they have more time for socialisation now that they are involved in the farmer group and this is due to the collective action of the group. Twenty-five percent of growers feel that their health status has improved. This is either due to better health care resulting from increased profits or due to less use of cover sprays for fruit fly control. Twenty percent of growers claim their children’s education has improved due to less requirement for children to working the orchard.

8.3.3 Environmental impacts

Fruit flies have traditionally been managed and still are in most parts of Indonesia as well as in many other countries in the region with cover sprays of insecticides on the fruiting crop. These cover sprays require large volumes of water and multiple applications of insecticides starting from fruit set and often applied weekly until harvest. Such a practice is highly polluting to the environment, is broad spectrum and damaging to beneficial and other non-target organisms, as well as often leaving undesirable residues of pesticides in harvested fruit.

The AWM program overcomes all these problems by utilizing a combination of individual control technologies such as male annihilation using lure-impregnated blocks and protein bait spot spraying, both of which require extremely low levels of pesticides that have been selected for their lower toxicity and safety profile. Being attract and kill technologies and being specific to fruit flies, these control methods are also non-polluting and do not affect beneficial and other non-target organisms. The major reduction in pesticide volume and its use in a targeted manner in the AWM program has had a major positive environmental impact.

8.4 Communication and dissemination activities

Co-ordination meetings involving Female farmers have more time to allocate to children education and domestic chores as they are required less for manual labour of farm activities provincial and directorate staff were held 4 times a year to discuss project activities including timelines. Field staff also met weekly with farmers in the treatment areas. Mr Stefano De Faveri (DAF Qld) and Dr Vijaysegaran and Dr Fay prior to retiring travelled to Indonesia up to three times annually to attend co-ordination meetings, observe field activities and implement new concepts when scheduled. They reviewed the blocking and bait-spraying and monitoring, discussed progress with project staff and farmers. The first of the year included planning activities for the new season. The final trip of the year acted as a review of the completed fruiting season.

DHP staff conducted annual Area-Wide Management Implementation training workshops for Directorate of Horticulture and Food and crop protection centres staff. These workshops were conducted in Indaramayu 2011 and 2012, 2013 and 2015; Cirebon 2014 and South Sumatera 2011crop protection and DINAS staff from other provinces in Indonesia. There were approximately 50 participants at each workshop.

DHP staff produced manuals, pocket guides and pamphlets. The list of extension material included:

1) Manuals (AWM implementation)

    Area-wide management of fruit fly. DHP/DGH, 2012, 24 pp.

2) Brochures

    Petunjuk Pembuatan dan Pemasangan Wooden Block (Manufacture and deployment of wooden blocks)

    Penggunaan Umpan Protein (Guidance on application of Protein Bait)

    Pengelolaan Hama Lalat Buah Skala Luas Pada Tanaman Mangga (Large scale management of pest fruit flies in mango crops)

    Hama dan Penyakit Pada Buah Mangga (Pests and diseases of mango fruit)

    Hama dan Penyakit pada Buah Mangga (Pest and Disease Management on Mango Fruit)

3) Pocket guides

    Guidance on Implementation of Area Wide Management of Fruit Fly on Mango

    Guide to Implementing ALPP for Fruit Fly on Mango Farms

    Checklist Implementation of Area Wide Management of Fruit Fly on Mango

4) Indonesian Agriculture magazine (*Sinartani Tabloid*)

    “Pengelolaan Hama Lalat Buah Skala Luas PadaTanaman Mangga” September 2014 edition (Area-Wide Management of Fruit Fly in Mango)

Mr Stefano De Faveri, presented a poster “Area-Wide Management of Pest Fruit Flies in Smallholder Mango Farms in Indonesia” at the 9th International Symposium on Economic Fruit Flies of Economic Importance held at Bangkok on 12-16 May 2014. Co-authors Dr Vijaysegaran and Dr Harry Fay also attended the symposium. Dr Dwi Iswari, Ms Anik Kustaryati and Mr Soesilo were co-authors but did not attend the symposium.

Mr Stefano De Faveri, delivered an oral presentation “Area-Wide Management of Pest Fruit Flies in Smallholder Mango Farms in Indonesia” at the 29th International Horticulture congress, Symposium 18, Pest and Disease Management in Developing Countries. Brisbane, 17-22 August 2014. Co-authors did not attend the congress.

Mr Stefano De Faveri, delivered an oral presentation “Area-Wide Management of Endemic Pest Fruit Flies in Smallholder Mango Farms in Indonesia” at the 11th International Symposium on Economic Fruit Flies of Economic Importance held at Bangkok on 28 September - 2 October 2015. Co-authors Dr Vijaysegaran and Ms Anik Kustaryati also attended the symposium. Other co-authors but did not attend the symposium.

Mr Stefano De Faveri also delivered an oral presentation at the Australian Mango Industry Field Day held at Walkamin Research Station on 30 July 2014.

An article was prepared for the December 2011 ACIAR Indonesia Newsletter on ‘Reducing the impact of fruit flies in mangoes’.

9 Conclusions and recommendations

9.1 Conclusions

The major objective of this project was to trial MA, protein bait spraying and crop hygiene in combination to reduce pest fruit fly problems over a specific mango production area in Indonesia. All components of the system were implemented diligently. However there were aspects such as protein bait spraying that the growers were initially reluctant to implement as this was a labour intensive task. It wasn't until the growers witnessed the results of protein bait spraying that sufficient applications of protein baits were applied. Another issue that was faced was the belief that MA would be sufficient to control fruit flies. Several coordination meetings were required to convince farmers and pest departmental staff that all components of the system were required to achieve adequate suppression.

Monitoring time between data collection, collation and reporting was too slow. Delays in reporting had in one instance resulted in increases (spikes) over a two month period not being reported. More rapid reporting would have indicated a possible spike before it occurred and corrective action applied. The reporting of monitoring data must be streamlined in a future project. The inclusion of ACIAR tested tablet technology where real time analysis/auditing/access by project members should be considered.

There was a progression of technology research in relation to female lures. Original research was based on fruit volatile odours, protein and ammonia. This then progressed to protein baits as bait stations rather than applied to fruit. The commercial product Cera Trap® presented in a synthetic membrane provided the best results. However this technology requires more research to attain a product that is inexpensive and as efficacious as protein bait spraying.

The AWM model that was trialled at Indramayu was successful beyond expectations at reducing pest fruit fly populations to extremely low levels and reducing infestations to virtually zero. The project proved that pest fruit flies can be controlled in relatively small areas where the endemic population is extremely high. Initial economic analyses have also shown that the program is economically viable.

9.2 Recommendations

1. Develop a new project that implements AWM of fruit fly in a commercially orientred mango production area that produces high yielding, high quality fruit suitable for export. The objective of the project should be to improve market access through compliance with relevant International Standards on Phytosanitary Measures (ISPM).

2. Continue to support and monitor the AWM program at Indramayu and document socio-economic impact of the program. Evaluate the value chains and determine whether improvements can be made to marketing of the highly sought low pesticide fruit. Socio-economic and value chain research in the new area should be initiated at the start of the project establishing the baseline data and tracking progress throughout the project.

3. The procurement of protein bait in the future could become an issue for AWM programs in Indonesia. Establishing a new plant in Indonesia is not feasible based on the current market demand for the product. It is recommended that product continue to be procured from Malaysia, however an agent would be required to import and market the product to framers. It is also recommended that fruit fly AWM be expanded throughout Indonesia and thus creating sufficient demand for an Indonesian plant to be viable.

4. There may be an opportunity to reduce the required number of blocks. Current rates are 1 bock/100m in a grid. It may be possible to reduce to 1 block/100m. However research is required.

5. The current issues with timeliness of data collation, analysis and review could be overcome to some extent by introducing tablet technology enabling real time access to data by project personnel.

6. Research on female lures should continue. Initial results based on the Cera Trap® protein dry traps were encouraging. Research should also aim to link the female trap catch data to a monitoring outcome such as economic injury levels. The information on female trap catch could then be linked to internationally accepted Area Indices for Fruit Flies as is the case for male fruit flies (IAEA manual 2003). Documentation of such results would aid in trade negotiations.

7. Alternatives to protein baiting for mangoes in Australia must continue. It appears that protein baiting options are not suitable following the evaluation of a large number of commercial protein baits within this project. Protein bait stations should be explored further. Commercial female lures for the Mediterranean fruit fly based on attractive volatiles have been produced Epsky et al (2014). This avenue should be explored for Queensland fruit fly.

8. Improve male lures for Queensland fruit fly should be explored. The male lure for Queensland fruit fly (cue lure) is not as effective as the male lure for Oriental fruit fly (methyl eugenol) catching a much reduced rate in comparison. An improved lure has been developed with up to tenfold increases in capture rates (Siderhurst et al 2016). However the lure hydrolyses rapidly and is therefore only attractive for a very short period (Park et al 2016). This lure should be evaluated further and methods to reduce hydrolysis to be evaluated.

9. Training programs for other mango growing countries in the region can also be conducted to introduce the AWM model that has been developed by the project.

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Siderhurst, M., Park, S., Buller, C., Jamie, I., Manoukis, N, Jang, E. and Taylor, P. (2016) Raspberry ketone trifluoroacetate, a new attractant for the Queensland fruit fly, Bactrocera tryoni (Froggatt). *Journal of Chemical Ecology.* **42**, pp: 156-162.

10.1 List of publications produced by project

Mr Stefano De Faveri delivered an oral presentation, “Area-Wide Management of Pest Fruit Flies in Smallholder Mango Farms in Indonesia” at the 29th International Horticulture Congress held at Brisbane on 17-22 August 2014. Co-authors Dr Vijaysegaran, Dr Harry Fay, Dr Dwi Iswari, Ms Anik Kustaryati and Mr Soesilo did not attend the conference.

Mr Stefano De Faveri delivered an oral presentation, “Area-Wide Management of Pest Fruit Flies in Smallholder Mango Farms in Indonesia” at the 11th International Mango Conference held in Darwin on 28 September-02 October 2015. Co-authors Dr Vijaysegaran, Dr Harry Fay, Ms Cahyaniati, Ms Anik Kustaryati and Mr Soesilo and Dr Dwi Iswari

A Guide Book “Checklist Implementation of Area Wide Management of Fruit Fly on Mango” was produced.

A Publication in Sinar Tani Tabloid was published in the September 2014 edition.

11 Appendixes

11.1 Appendix 1:

Inception meeting agenda, 14-15 April 2010

Inception Meeting Workshop for

HORT/2008/041 Area-wide management of pest fruit flies in an Indonesian mango production system

The Grand Kemang Hotel

Wednesday and Thursday, 14–15 April 2010

Day 1- Inception Workshop	
08:30-10:30	Opening program Welcome remarks *Soekirno – Directorate General of Horticulture* *Felicity Muller – ACIAR* Role of the Country Office *TBA* Review of the project aims, objectives and activity plan *Harry Fay*
10:30-11:00	Coffee Break
11:00-12:30	Discuss current fruit fly project, issues/problems, funding role over into new project, lessons that could be applied to new project, alternative strategies to move new project forward if funds an issue.
12:30-13:30	Lunch
13:30-15:15	Discuss monitoring requirements: Supplies, activities, responsibilities, equipment, facilities, personnel, fly IDs, training requirements, data recording.
15:15-15:45	Coffee Break
15:45-17:00	Discuss/define Indramayu treatment area and untreated (monitoring) area. Brief overview of how day 1 went.
Day 2- Inception Workshop	
08:30-10:30	Brief review of day 1 outcomes and aims for day 2 Discuss treatments: Bait supply, requirements, insecticides, MA supplies, transport, authorisations, bait and MA application, equipment, roles and responsibilities, training.
10:30-11:00	Coffee Break
11:00-12:30	Discuss communication/extension requirements: For community, villages, farmers, extension personnel and project generally.
12:30-13:30	Lunch
13:30-15:15	Discuss funding issues, travel plans and collaborator communication. Start on finalising work plan from all the above discussions.
15:15-15:45	Coffee Break
15:45-17:00	Finalise work plan, for the next 6 months particularly, including roles, responsibilities and timelines. Close meeting.