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Contents

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2 Executive summary

Mangoes are an economically important crop in the Philippines and Australia. However, in the Philippines declining production yields and poor quality fruit has been attributed to high pest and disease pressure, unproductive poorly nourished trees and high costs of inputs. The project objectives were: To improve mango fruit quality by developing cost effective insect control and IPM solutions; To improve fruit quality through developing effective solutions to mango pre- and postharvest fungal diseases; To improve fruit quality, size and yields by optimising nutrition and canopy management; To improve mango farmer livelihoods and profits through, developing and implementing an integrated management package of "best practices" with mango farmers.

Insecticide resistance studies proved that Mindanao thrips populations were resistance to profenofos and cypermethrin. These chemicals are no longer effective and the continued misuse of such pesticides is likely exacerbating the problems. These findings have important policy implications, which will influence pesticide regulation and labelling. In field trials, Clothianidin, Spinosad and Cartap Hydrochloride gave effective control of thrips, whereas deltamethrin performed no better than the unsprayed controls. An IPM & resistance management program was developed and implemented with a selected farmer group, but further extension work is required. *Lantana camara* and other weeds were found to be important alternative host sources for mango thrips. With further research, strategically timed removal or spraying of weeds may be a way to manage thrips. A parasitoid wasp (*Synopeas mangiferae*) has been found attacking mango cecid flies. This is of significant importance for future biological control programs in both the Philippines and Australia, as the same species of cecid fly has invaded Torres Straight and threatens Australian mango production. In Australia, a number of parasitoid species were identified attacking mango planthoppers, and were thought to have a significant effect on these planthopper populations. The new pesticide Sulfoxaflor appeared to work at managing Banana Spotting Bugs; however, it is not as effective for the control of planthoppers. A lure and kill system was also developed for managing Spotting Bugs.

In plant pathology trials in the Philippines, Serenade™ (*Bacillus subtilis*), Timorex Gold™ (a tea-tree extract) and a chemical fungicide (ionic copper concentrate) were the most effective for control of pre and post-harvest fungal diseases. Other endophytes and using a combination of plant growth regulators with fungicides showed some positive results.

In the Australian canopy management research, high density trellised training systems produced early yield improvements for newly established orchards compared to conventional training systems. In the Philippines most farmers do not actively manage their tree canopies, but only carry out minimal pruning (mostly dead/dying under-canopy limbs). Consequently, trees are largely unpruned and canopies are allowed to close-over, grow to unmanageable heights and became unproductive; leading to widespread yield decline. Through the extension program, farmers learned how trees could be maintained and pruned to produce higher fruit yields, whilst preventing canopy closure and subsequent yield declines. An income assessment showed that undertaking selective pruning produced increased income with a 48% reduction in expenses per tree.

The farmer-cluster extension model has proved highly successful with over 670 growers, contractors and extension staff having undertaken training within this project. 50 extension officers were trained in extension methods, training techniques, best practices and new R&D innovations. 185 mango growers have completed farmer field school season-long training and adopted best management practices, which has resulted in at least 115% increase in yields and net profit increases from 43% up to an 11-fold increase.

In the Philippines declining mango production yields and poor quality fruit issues could largely be addressed through the implementation of a strategic extension and demonstration program which promotes improved canopy management and pesticide resistance management practices.

3 Background

Mangoes are an economically important crop in both the Philippines and Australia. The Philippines produces approximately 820,000 to 885,000 tonnes of mangoes per year from around 188 000 ha (4-4.t T/ha), with 36,000–40,000 tonnes exported (FAOSTAT 2016). In 2015, the Philippines was placed seventh amongst exporters of fresh and dried mango, with US$91 million in exports and 4% of the global market (Fernandez-Stark *et al.* 2017). The Philippines produces approximately 10% of world fresh and dried mango exports (FAOSTAT 2016). The Philippines is the 8th biggest mango producer in the world, however mango exports are declining. Approximately 90% of mangoes produced in the country are consumed as fresh fruits. Currently, mango production lags behind population growth in the Philippines and it is likely that domestic and export demand for mangoes will continue to grow. However, despite increases in area from new mango plantings, yields are declining. The Philippines has a predominance of smallholder mango farmers (2.5 million), which significantly contribute to production (PCARRD-DOST 2011). In 2015, the average farm size of mango producers was only 1.34 ha (Fernandez-Stark *et al.* 2017). Almost 73% of mango farms are under 3 ha and smallholder production (from farms under 3 ha) account for almost 48% of the total production (Buguis 2014). There is an active network of provincial agriculturists fostering improvement of crop management. However, their resources and integrated crop management (ICM) skills are limited.

The DOST-PCAARRD Industry Strategic S&T Plan for Mango (2012), aimed to increase yields by 90% (to 11 T/Ha) and reduce postharvest losses to 15%. In the Philippines there have been increased areas planted with mangoes, however the total volume of fruit production is decreasing.

In February 2013, a workshop was organised in Davao city, the "ACIAR-PCAARRD southern Philippines New Mango R&D Program Planning Workshop (Oakeshott *et.al.* 2013). The workshop was organised so that growers and provincial agricultural extension staff could participate in the priorities of future mango research and extension in the Southern Philippines. During this meeting it was recognized that declining fruit yields and quality in the Southern Philippines is primarily due to high pest and disease pressure, unproductive poorly nourished trees and the high costs of inputs (mostly pesticides and fertilisers). Export market access is constrained by ongoing pesticide residue problems.

Pesticide misuse continues to be a major problem in the Philippines and is thought to have led to a number of production and postharvest issues, including: pesticide resistance build-up, a major disruption of natural enemies (and subsequent chemical flare of secondary pests), and pesticide residue problems (particularly for export markets). Other issues include incompatible tank mixes "chemical cocktails", as well as poor chemical handling and OH&S issues.

The primary target for this research and extension was aimed at mango growers in Region XI of the Southern Philippines (Mindanao) in the areas of Davao del Norte and Davao del Sur. These locations contain large numbers of poor small-holder mango farmers, generally of less than 3ha in size. Many of these farmers have a limited education and have limited resources, often relying on chemical resellers for advice or leasing their trees to contractors to obtain an income. Trees are usually induced to flower, but are often poorly managed with insufficient fertilizer and a general overuse of older broad-spectrum pesticides. Contractors will usually repeatedly spray all their orchards with the same pesticide, usually one of the cheapest broad-spectrum pesticides available. There are no co-ordinated pesticide management plans between neighbouring farmers and contractors, which is thought to have resulted in widespread insecticide resistance build-up in pest populations (Newton *et al.* 2013). Contractors (and some growers) are short-term investors and will not invest in fertilizers or long term crop management, which ultimately results in yield declines. Spray technology is rudimentary and usually involves a handheld hose and often the operator will climb into the tree to get better penetration (often with little or no personnel protective safety equipment). The trees are usually kept very large with limited hand pruning. There is generally a low investment in fertilizers and crop management because input costs are too high and investment return times too slow. The project's targeted areas are serviced by district agricultural extension staff, who are experienced and reasonably well trained. However, the extension staff have limited resources and service a very large number of growers. With the assistance of the district agricultural extension staff, coordinated mango grower groups have recently formed. The Samal Island Mango Marketing Co-operative Association (Davao del Norte) has approximately 3000 smallholder farmers and they are now starting to adopt a more coordinated approach, which has recently involved building a packing shed and gaining new overseas export market access. This project aimed to target these 3000 smallholder farmers and a similar number from Davao del Sur.

Australia produces over 60,000 tonnes of mangoes per annum from approximately 10,000 ha of which 94% is for the fresh market and 6% for processing (Hort Innovation 2018). Exports have risen to over 7,000 tonnes, representing 0.5% of global export trade.

The gross value of production (GVP) at farm gate is approximately $196 million per annum (Hort Innovation 2018). Production volumes from the Northern Territory equals production from Queensland, which together produce 95% of the national crop. Domestic demand for mangoes is growing and there are prospects for expansion of export markets. However, labour costs are high and fruit is often left unharvested if market prices are too low. In Australia, fungal diseases and insect pests cause fruit losses (both pre and post-harvest), reduce market quality and inhibit export market access. The Australian Mango Industry Association have identified a number of insect pests and fungal diseases that currently limit export potential (Dunmall 2013). The key market access insect pests include mango seed weevil and fruit fly. The previous ACIAR mango Philippines project – HORT/2007/067/4 (Newton *et al.* 2013) provided some solutions to the seed weevil problem, whilst other ACIAR (Indonesia HORT/2008/041) and Horticulture Australia projects (Farm-wide fruit fly management systems for the east coast of Australia HAL project Number MT12050) have been researching fruit fly control solutions. The increased regulation and removal of pesticides (e.g. the recent removal of endosulfan) have proved new challenges in controlling sucking bugs (particularly fruit spotting bugs, mango planthoppers and tea mosquito bugs) in mangoes and there are few effective IPM compatible control solutions. The few remaining effective insecticides are older broad-spectrum chemicals, which are not IPM compatible, because they are known to kill beneficial insects and cause flare of secondary pests such as thrips, mites and scale. Fungal diseases such as anthracnose and stem end rot are also major problems limiting both domestic and export market quality and shelf life.

The project aimed to address the R&D priorities identified within the mango industry strategic plans of the Philippines and Australia, and has the support of industry and R&D agencies in both countries. This project also complemented a number of other mango production and postharvest projects in the Philippines and Australia. ACIAR has funded a significant amount of innovative scientific research, which has benefits across many other cropping systems. However, this research is often considered high risk by industry, and as such they are often reluctant to fund such research activities.

Previous ACIAR mango projects have led to improved management methods of key mango pests and diseases, resulting in reduced losses, reduced input costs and improved farmer profits (Newton *et.al*. 2013). A system of using “farmer clusters” and selecting and training key growers within each cluster, was developed and could provide a superior system of extension, reaching more farmers. However, the previous project also identified research and management gaps, where future project work was required. These included:

- More farmers need to reduce their insect pest pressure (in particular thrips, cecid flies and fruit fly), disease incidence (and increase shelf life) and reduce the risk of pesticide residues.

- Developing IPM compatible inputs, pesticide resistant management plans, and Area Wide Management strategies that engage not only the farmers, but also the contractors.
- Improving pest monitoring methods and economic thresholds.
- Research into organic inputs that could provide some cost effective solutions, but more research with conventional chemicals and residue management is also required.
- Research into nutrition and canopy management.
- Extending the farmer cluster model so as to reach more farmers and perhaps more importantly to include contractors.

This project was designed to address these gaps. It aimed to build on the research results and extension systems from the previous project and deliver a more efficient Integrated Crop Management system, which could be rolled out to a greater number of growers.

The project was designed to address the following research questions:

- How do we reduce fruit damage and economic losses caused by insect pests?
- How do we reduce losses due to diseases and thus improve shelf-life?
- How can we manage trees and inputs to further improve fruit quality, size and yield?
- How do we deliver the best overall farm management package with mango farmers?

4 Objectives

The project contributes to improving the livelihood of smallholder mango farmers and other stakeholders in the value chain by: reducing product losses due to pests and diseases, decreasing inputs costs and improving quality and yield, thus increasing grower profit margins.

The projects objectives and activities were:

1. To improve mango fruit quality by developing effective insect control and IPM solutions.

- Studies were conducted on the ecology and management of thrips and cecid flies
- A trial was to be conducted on Area Wide Management (AWM) of Fruit Fly.
- Studies were undertaken of the biology and control options for managing sucking hemipteran pests in Australia
- IPM compatible control solutions and an insecticide resistance management program was developed with famers.

2. To improve fruit quality through developing effective solutions to mango pre and postharvest fungal diseases.

- Investigated economical alternatives to conventional chemical disease control.
- Explored the potential of plant growth regulators for the control of pre and postharvest diseases of mango.
- Investigated the efficacy of endophytes against anthracnose and stem end rot.
- Developed an economically viable integrated disease management program with farmers.
- In collaboration with farmers, developed a best practice economically viable disease control package aimed at the southern Philippines.

3. To improve fruit quality, size and yield by optimising nutrition and canopy management

- Field trials were conducted to optimise nutrition and canopy management techniques with the aim of improving fruit quality, size and yield.
- In collaboration with farmers we developed a nutrition, and canopy management package that aims to improve fruit quality, size, yield and efficiency of harvest.
- Investigated harvesting tools and operations to maintain fruit physical appearance.
- Investigated the effects of early establishment training frameworks on tree architecture, growth and yield.

4. **To improve mango farmer livelihoods and profits through, developing and implementing an integrated management package of "best practices" with mango farmers.**
   - Developed a communication and research adoption plan. This plan included how extension was to be delivered to clusters (farmer to farmer) and to the private sector.
   - Developed and documented a best practice management package with farmers and contractors. Implemented the best bet package with farmer clusters.
   - Developed capacity and trained extension and scientific staff to deliver best practice packages.
   - Investigated options for a repository of advisory and extension information for mango farmers and others.
   - Developed electronic delivery options of information for the Australian mango industry.

5 Methodology

Objective 1: To improve mango fruit quality by developing effective insect control and IPM solutions

Activity 1.1 Studies will be conducted on the ecology and management of thrips and cecid flies (Philippines)

Population Dynamics and Ecology of Thrips and Cecid Flies

Dr Celia Medina UPLB.

Population dynamics of thrips in mango and in non-cultivated plants in a mango orchard were studied in selected mango orchards in Davao Region, namely: Magsaysay, Bansalan, Matanao, Digos City in Davao del Sur and Island Garden City of Samal in Davao del Norte. In each orchard, different species of non-cultivated plants were monitored weekly for the presence of *Scirtothrips dorsalis* and *Thrips hawaiiensis* during and after mango fruiting season. Destructive sampling of flowers and/or shoots was undertaken. Sample shoots comprised the first three bipinate, trifoliate and compound leaves while sample flowers comprised one single and/or compound inflorescence. In insecticide treated mango orchards, flowers and shoots of non-cultivated plants were collected at the edge or border of the area because they were less exposed to chemicals during spraying. While in non-treated orchards, shoots and flowers of non-cultivated plants were taken anywhere inside the orchard. Collection of shoots and flowers was done by carefully by enclosing the plant part inside a plastic bag before detaching. Prior to processing of the plant samples, the biomass of the samples was recorded. Thrips collected from the samples were counted and classified according to species, sex and growth stage. Other insects found in these samples were also recorded.

Ecological studies on cecid flies were limited to opportunistic sampling of mango shoots due to the very low incidence of the pest in the study sites. Infested shoots were collected whenever possible in the orchards that were being monitored. The collected shoot samples were kept in self sealing plastic bags until larval emergence. Larvae were reared to adult in petri dishes lined with peat moss. Parasitoids collected were preserved and sent for taxonomic identification to Dr Andrew Polaszek of the Natural History Museum in London.

Documentation on the management of thrips including having effective chemical control tactics.

Dr Conrado Evangelista and Mr Jayson Suhayon USM Entomology

The organophosphates (profenofos in particular) and synthetic pyrethroids (cypermethrin in particular) have been misused and over used in Mindanao, which has lead to insecticide resistance. The aim of these trials was to provide effective alternative pesticide treatments for mango thrips as part of an integrated pest management program. Several field trials were conducted in Davao del sur at different locations (Matanao, Padada and Digos City respectively). A Randomized complete block design (RCBD) was used in each trial with different insecticides as treatments and with three replications, using one (1) tree per treatment. In the first trial, the evaluation of insecticides against mango thrips was conducted in the Municipality of Matanao from January to June 2015. The Insecticides treatments were: Spirotetramat, Avermictin, Profenofos, Spinosad, Clothianidin, Azadirachtin, Indoxacard and Chlorantraniliprole. In a second trial, the evaluation of promising insecticides was conducted in Barangay Sergio Osmeña, Padada, Davao del Sur from August to December 2016. The treatments used were: Cartap hydrochloride, Clothianidin, Profenofos + Cartap hydrochloride (mixed formula), Spinosad,

Imidacloprid and Avermictin. In a third trial, the verification of selected insecticides for the control of mango thrips was conducted in Brgy. Colorado, Digos City, The treatments used in this trial were: Cartap hydrochloride + Profenofos (mixed formula), Cartap hydrochloride, Clothianidin, Fipronil, Deltamethrin.
The assessment was undertaken by counting the thrips present in the inflorescence of 20 panicles. Observations were made a day before (pre spray), a day after (post spray) until 55 DAFI. Fruit set and retention was assed by recording the number of fruitlets at 45 DAFI (fruit set) and the remaining fruits at 55 DAFI (fruit retention), which were counted based on 20 panicles per tree. Marketable and non-marketable fruits and fruit yield (kg/tree) was recorded during harvest. At fruit maturity, all fruits from the treated trees were harvested and the number of marketable fruit (without damage or deformities) and non-marketable fruits (damaged or with deformities) and their corresponding weight was recorded. Data was analyzed using ANOVA. Means were separated using a Tukey test.

Activity 1.2. A trial will be conducted on Area Wide Management of Fruit Fly

Dr Ana Notarte PAGRO (Philippines)

Baseline study complete, showing initial fruit fly population before AWM. *A Notarte.*

To determine the baseline population data and determine typical fruit fly pressure on mango farms, fruit fly trapping was undertaken in three farm districts of the Island Garden City of Samal, Davao del Norte, from January to December 2015. Methyl eugenol traps (attract male Oriental fruit flies) were placed in 16 different sites on the island. Further trapping was undertaken to counter check the fruit fly population in the urban areas, three sites were strategically established: Toril, Anonang and San Isidro, Kaputian.

AWM intervention trial, documentation of efficacy and economics.

It was agreed with the program manager that this milestone could not be achieved within the budget of this project, as outlined in the 2015 annual report. An AWM trial is planned for a new ACIAR project (HORT/2015/042), starting in late 2018 under Stefano De Faveri DAF. The baseline studies will be of use for the new project.

Activity 1.3. Studies will be undertaken of the biology and control options for managing sucking hemipteran pests in Australia

Dr Ian Newton and Ms Donna Chambers DAF (Australia)

Taxonomy status of sucking bugs is determined.

A comprehensive literature review of Australian sucking mango pests was conducted; it concentrated on planthoppers (*Colgaroides acuminata*), Tea Mosquito Bug (*Helopeltis* sp.) and Banana Spotting Bugs (*Amblypelta l. lutescens*), appendix 1.3-A.

Documentation of the biology and control options for managing sucking hemipteran pests in Australia.

Biology Studies

Biology work concentrated on the mango planthopper *Colgaroides acuminata* (Walker) (Hemiptera: Flatidae), also commonly known as “flatids”, is a pest of mangos in North Queensland. This insect sucks the sap from shoots, flowers and fruit and causes the growth of sooty mould. In this study, field surveys were conducted to establish baseline abundance data of natural enemies associated with mango planthoppers in north Queensland and confirm the identity of several mango leafhopper egg parasitoids.

Field collections and observations were made of Mango planthopper adults, nymphs and egg masses, as well as Dryinid pupal cases. The insects were collected from Southedge (SRS) and Ayr Research Stations (ARS), north Queensland between October 2014 and January 2016, appendix 1.3-B.

Pesticide Trial with sulfoxaflor (Transform™) as an IPM alternative for control of Mango Planthoppers (*Colgaroides acuminate*) and Bananaspotting bugs (*Amblypelta lutescens lutescens*).

A field trial was set up to test if the new pesticide sulfoxaflor (Transform™) was effective at controlling Mango Planthoppers (*Colgaroides acuminate*) and banana spotting bugs BSB (*Amblypelta lutescens lutescens*). Details of the methods can be found in appendix 1.3-C.

Monitoring Integrated Lure and Kill (MILK): A method of managing *A. lutescens lutescens* using an aggregation pheromone combined with limited pesticide use.

In this study we trialed a new system of controlling Banana Spotting Bugs *A. lutescens lutescens* with an aggregation pheromone, using a Monitoring Integrated Lure and Kill (MILK) approach. The MILK system would work by monitoring pheromone traps and spraying only the trap-trees with an insecticide when a threshold is reached. The treatments consisted of 4 sprayed trap-trees which surrounded the 4 unsprayed test trees (being protected) against and a matching control block which consisted of 4 sprayed non-trap trees that surrounded the unsprayed negative control trees. Further Details of the methods can be found in appendix 1.3-C.

Transmission of *Beauveria bassiana* and *Metarhizium anisopliae* to male *Bactrocera tryoni* via para-pheromone lures and subsequent transmission to females

Queensland fruit fly (*Bactrocera tryoni*) is a major pest of mangos in Australia. It is a significant market access and trade barrier for many exporting fruit. In caged laboratory experiments, we examined novel ways to lure and kill male *B. tryoni* with male lures impregnated with *Beauveria bassiana* or *Metarhizium anisopliae*. The aim was to determine if we could attract and contaminate male flies with entomopathogenic fungi, and then use those male flies to transmit the fungi to females. Further Details of the methods can be found in appendix 1.3-C.

Activity 1.4. IPM compatible control solutions and an insecticide resistance management program will be developed (Philippines)

Farmer survey complete, IPM & resistance management program designed and implemented with selected farmer groups. C Medina.

To understand the insecticide practices of farmers, a survey interview was conducted in Davao del Norte and Davao del Sur that covered a total of 65 farmer respondents. The questionnaire was designed not only to document the insecticide application practices but also to measure their particular knowledge on and attitude towards pests and pesticides.

The results of the survey interview was used as a basis in drafting an insecticide resistance management training module. Aspects in the knowledge that were found lacking in farmers were given emphasis in the content of the training. Training tools were used to enhance the participants understanding of insecticide mode of action and insecticide resistance management strategies. Several training sessions were conducted to pre-test the modules and tools. Pre and post assessments were conducted to measure the learnings of the participants in the training.

Due to the farmers' practice of tank-mixing different insecticides as well as the frequent spraying schedules, it was difficult to look for an insecticide mode of action that could be alternated in the conventional farmers system. Field and laboratory toxicity trials of insecticides with new modes of action were therefore conducted to determine their effectiveness against the Davao thrips population. These included insecticide formulations such as spirotetramat, avermectin and spinosad that were available in the Philippines but not registered for use in mango. Profenonfos and no insecticide treatment served as a comparison.

IPM package testing complete & documented with farmer groups. C Evangelista.
The IPM package was developed from the results from activities 1.1. These trials were verified with participatory on-farm trials (results 1.1) and the insecticide resistance management strategies were developed and integrated from activities 1.1, which were also tested on-farm. This information was also delivered to extension teams for adoption.

Objective 2: To improve fruit quality through developing effective solutions to mango pre and postharvest fungal diseases

Activity 2.1. Investigate economical alternatives to conventional chemical disease control

Dr James Silvestre and Ms Edralyn Catubay USM Pathology

A one hectare mango farm in the Island Garden City of Samal, Davao del Norte was identified and used for the 1st trial. A total of 120 Carabao (var.) mango trees aged 15 years were sprayed. The farmer used chicken dung as organic fertilizer, which he applied three months before the application of paclobutrazol. Similarly, in the 2nd and 3rd trial another one hectare mango farm in Barangay Sergio Osmeña, Padada, Davao del Sur was used. All Carabao mango trees (aged 18 years) were fertilized with a combination of complete fertilizer (14-14-14) and potassium nitrate (1:1 ratio) at 1 kg per tree, which was applied before and after harvest.

The first trial was conducted in a randomized complete block design with four replications from January to June 2015. The following fungicides (biological and chemical) treatments were applied in five cycles at 10 day intervals: Serenade (*Bacillus subtilis*), Timorex Gold (Tea-tree extract), Ion Copper Concentrate (ICC), Bioway Organic Germ (unknown active ingredient), Marvelous Premium Quality MPQ (Seaweed Extract), *Trichoderma harzianum*, DQBac (unknown active ingredient) + Mancozeb, Propineb (Chemical check), and Mancozeb (Chemical check). Four postharvest experiments were conducted by plant pathology (major) students to further evaluate the efficacy of the same fungicides (chemical and biological); they were:

1. Management of stem- end rot and anthracnose of mango applied with five pre-harvest biofungicides (Charlene C. Malacad);
2. Management of postharvest diseases of carabao mango applied with five biofungicides (Ravin M. Hermida);

3. Efficacy evaluation of hot water treatment plus biofungicides against postharvest diseases of carabao mango (Anthony James B. Valdez); and
4. Evaluation of two formulations of marvelous premium quality (MPQ) at various rates for the control of post- harvest diseases of mango (Lawrence Kent T. Modesto).

The second trial was a verification (repeated with modifications) of the first trial, of different fungicides (chemical and biological) for the control of pre- and postharvest fungal diseases. It was was conducted in a randomized complete block design with four replications. The fungicides that were used in Samal were further evaluated in the second trial, except without Bioway, DQBac and Serenade 500 and with addition of AZ41 (Aloe vera, Tea tree, D-Limonine blend), which were applied in six cycles at eight-day intervals.

The third trial evaluated different rates of fungicides (Serenade, Timorex Gold, ICC, and MPQ) including a biological check (*T. harzianum*) and a chemical check (Propineb) for the control of pre and postharvest fungal diseases of mango. The pre-harvest trial design used a randomized complete block design with 16 treatments and was replicated three times, while the postharvest design used a completely randomized design with 16 treatments and was replicated four times. In the pre-harvest component, data was collected for severity of infection, infection of blossom/panicle blight, fruit set and fruit retention. Postharvest data was collected for severity of disease infection (for anthracnose and stem-end rot of fruit), visual quality, weight reduction and storage life.

Activity 2.2. Explore the potential of plant growth regulators for the control of pre and postharvest diseases (Philippines)

Dr Virgie P Ugay, V.P. and Cesar A. Limbaga Jr.

The experiment aimed to determine if plant growth regulators (PGR) can be used as an alternative to fungicides in order to reduce the frequency and volume of fungicide use. This was conducted at a cooperator's farm at Mabuhay, Bansalan, Davao del Sur on trees that were 20-23 years old. It has the following specific objectives: 1) assess the efficacy of PGRs against blossom blight and fruit drop; 2) evaluate the efficacy of field applications of PGRs to postharvest diseases, fruit anthracnose and stem end rot of mango.

The trial used a random complete block design with 6 trees per treatment. Trees were prepared using best practices. Paclobutrazol was applied a month after flushing. Trees were sprayed with Calcium Nitrate at 8kg/200L water to induce flowering and were fertilized with 6 kg of mixed fertilizer at a ratio of 2:1:1, NPK(18-18-18), Urea and muriate of potash. The treatments were:

T1 - Control (No treatment at all)

T2 - Mancozeb at bud break, full bloom and 50DAFI, Propineb at panicle elongation, Difenoconazole at pre-bloom, Benzimidazole at fruit set, Carbendazim at 42DAFI

T3 - Mancozeb at bud break and 50 DAFI, Benzimidazole at fruit set, Carbendazim at 42DAFI, (Aux+Cyt+GA): 0.3% at panicle elongation, 0.5% at pre-bloom and full bloom

T4 - Mancozeb at bud break and 50 DAFI, Benzimidazole at fruit set, Carbendazim at 42DAFI, (Aux+Cyt+GA+CaB): 0.3% at panicle elongation, 0.5% at pre-bloom and full bloom

T5- Mancozeb at bud break and 50 DAFI, Benzimidazole at fruit set, Carbendazim at 42DAFI, (SA+GA+CaB): 0,5% at panicle elongation and 1% at pre-bloom

T6- Mancozeb at bud break and 50 DAFI, 0.3% (Aux+Cyt+GA) at panicle elongation, 1% (Aux+Cyt+GA+CaB) at pre-bloom, 0.2% (Aux+Cyt+GA) at full bloom, 1.0% Cyt+CaB at fruit set and 42DAFI

T7- Farmer's practice: Mancozeb at bud break, panicle elongation, and fruit set, Difenoconazole at pre-bloom, propineb at 42DAFI and 70DAFI

Pre-harvest data gathered were % flowering, % blossom blight, fruit set per panicle, fruit retention per panicle and yield per tree.

Assessment of postharvest diseases of mango fruits applied with PGRs at preharvest stages. Thirty (30) fruits per treatment per replicate were randomly selected and set up in the laboratory for assessment of anthracnose and stem end rot. Treatments were arranged in Completely Randomized Design (CRD) with five replicates. The same number of fruits from each treatment per replicate were subjected to a hot water dip (59°C) for 1 minute (effective control treatment) before setting up the experiment (using a CRD in the same room as the arrangement above). Fruits were allowed to ripen naturally at ambient temperature (28-30°C).

The proportion (%) incidence of SER and anthracnose and proportion (%) severity of anthracnose were determined at full ripe stage. Data were transformed (when necessary) before analysis of variance, and means were compared using $HSD_{0.05}$.

Activity 2.3. Investigate the efficacy of endophytes against anthracnose and SER

Ugay, V.P. and Limbaga, C. Jr. A. (Philippines)

This study aimed to find effective endophytic fungi from mango tissues for use as biological control of pre and postharvest diseases of mango. It had the following objectives: 1) to isolate endophytic fungi from healthy mango tissues, 2) to evaluate the endophytes for antagonism to *Colletotrichum gloeosporioides* (*Cg*) and *Lasiodiplodia theobromae* (*Lt*) 3) to test the efficacy of endophytic fungi against blossom blight and fruit drop, 4) to determine the efficacy of endophytic fungi applied as a field spray against anthracnose and stem end rot (SER), and 5) to assess the efficacy of endophytic fungi applied at postharvest against anthracnose and SER.

Isolation and screening of endophytic fungi. Endophytic fungi were isolated from freshly collected healthy flowers, stems, leaves, peduncle and developing fruit of 'Carabao' mango detached from trees in the locality. Isolation on potato dextrose agar (PDA) was conducted in the laboratory.

Non-pathogenic endophytes were determined by inoculating spores (10^6 spores ml^{-1}), or mycelial suspensions, prepared from 7-day old pure culture of each endophyte to pricked mango fruit peel, then incubated in a humid chamber to favour its establishment in the tissues. Control fruits were applied with sterile distilled water. Inoculated peel that did not develop symptoms indicate that the endophyte is non-pathogenic.

Test for antagonism of endophytic fungi to *C. gloeosporioides* and *L. theobromae*. The test of antagonism to the two pathogens was conducted only with the non-pathogenic endophytes. The co-culture method of 7-day old cultures of each pair was conducted on PDA. Plates were incubated at 30°C and observed for antagonism for 7 days.

Mass production of endophytic fungus. For the field spray, the endophyte (coded FSLDf) was mass-produced using a medium of mature mango leaves. Leaves freshly gathered from unpruned and unsprayed mango trees were washed, weighed (100g leaves/bag) and sterilized (30 minutes at 15PSI). The 7-days old pure culture of FSLDf was aseptically inoculated on the prepared leaves and incubated at ambient condition. Mycelial suspension of FSLDf was prepared by washing the colonized leaves on clean tap water then strained prior to immediate use.

Field application of FSLDf against pre-harvest diseases of mango. The field experiment was conducted on 15 year old mango trees on the USEP Mabini Campus, Compostela Valley Province, using mango trees planted in a single row. Each treatment had three replicates. Best practices were followed in preparing the trees for the experiment. Paclobutrazol was applied three months before flower induction. Calcium nitrate at the rate of 8kg/200L water was sprayed to induce flowering. The treatments were: T1 – positive control (with insecticides); T2 - fungicides, with insecticides; T3 –

FSLDf with insecticides. The treatments were applied at bud break, panicle elongation, pre-bloom, full bloom, fruit set, 42 and 50 DAFI. The following insecticides were used in all treatments: Dantop™ (clothianidin) at 13 DAFI, Selecron™ (profenofos) at panicle elongation (20DAFI), Dantop™, Selecron™ and Actara™ (thiamethoxam as root zone drench) at fruit set (34 to 35 DAFI), Cartap and Actara™ at 48DAFI. Fungicides applied were: Amistar™ (Azoxystrobin) at 13, 20 and 23 DAFI, Amistar™ + Mancozeb at 27, 35, 42 and DAFI. The schedule of spraying FSLDf was synchronized with fungicide applications. FSLDf was initially applied separately before insecticide spray but after determining *in vitro* that it is not sensitive to the insecticides listed above, in the succeeding treatments, it was added as tank mix to the insecticides to minimize labour costs. Fruits were bagged at 55-60 DAFI and harvested at 125 DAFI. Data gathered were proportion (%) of blossom blight, fruit set, fruit retention and fruit yield.

Field application of endophytic fungus against postharvest diseases of mango. Thirty (30) randomly selected fruits per treatment per replicate were brought to the laboratory for the postharvest evaluation of anthracnose and SER. The experiment was set up in a complete random design. Fruits were induced to ripen using ethrel. After three days of incubation to enhance ripening, fruits were set up at ambient condition with temperature ranging from 28-30°C. Anthracnose and SER incidence and the severity of anthracnose infection were rated at the full ripe stage.

Efficacy evaluation of FSLDf applied as postharvest treatment against anthracnose and SER. Fruits for the postharvest experiment were sourced from a single mango tree in Davao Oriental. Clean fruits were selected from a fresh harvest and brought to the laboratory for immediate use. Thirty fruits were provided for each treatment per replicate. Treatments were: T1 – Positive control (untreated), T2 - *Bacillus subtilis*, T3- FSLDf. Fruits were washed of dirt, surface moisture allowed to air dry before spraying the treatments. The commercially available product containing *B. subtilis* (at recommended rate) and FSLDf aqueous mycelial suspension were applied to fruits by spraying. Fruits were induced to ripen using ethrel, incubated for three days then set up using a complete random design at ambient conditions (28-30°C) for observation. Anthracnose and SER incidence, and the severity of anthracnose were rated. Data were subjected to analysis of variance and T-test, means were compared using $HSD_{0.05}$.

Mr Peter Trevorrow DAF (Australia).

Selection and Isolation of endophytic fungi: Clean (symptomless) flowering panicles of *Mangifera indica* cultivars (Kensington Pride, Keitt, R2E2 and *M. laurina*) were subject to a rigorous sterilisation procedure to recover endophytic fungi from the tissue. Panicles were washed in 70% ethanol (1 min), 1% sodium hypochlorite (2 min), 90% ethanol (30 sec) and 0.3% sodium chlorate (45 sec). Tissue sections were plated onto ½ potato dextrose agar with the addition of the antibiotic, streptomycin sulphate (½ PDA+S). Cultures recovered were identified to at least genus level and deposited into the DAF herbarium (BRIP). Isolates used in the fruit bioassay were also obtained from diseased fruit and stem specimens.

Bioassay for screening endophyte activity: A mango fruit bioassay was developed to determine if fruit could be protected from anthracnose by inoculation with endophytic fungi. Mangoes cultivars (Kensington Pride, Keitt and *M. laurina*) at hard green maturity were de-sapped and the stem end of fruit dipped in a known concentration (1×10^6 spores/ml) of *Colletotrichum asianum* (previously known as *C. gloeosporioides*) and allowed to dry. Fruit pedicles were freshly cut and plugs of actively growing endophyte fungi (*Colletotrichum* sp., *Pestalotiopsis* sp., *Diaporthe* sp. and *Neofusicoccum* sp.) were applied to the pedicle. Fruit was incubated under high humidity for 48 hours prior to disease observations.

Activity 2.4. Develop a best practice economically viable disease control package

Potential chemical and biological fungicides were documented and delivered to Dr Notarte and extension teams to be used in the update of their best bet package.

Objective 3: To improve fruit quality, size and yield by optimising nutrition and canopy management.

Activity 3.1. Field trials will be conducted which will optimise nutrition and canopy management techniques with the aim of improving fruit quality, size and yield.

Ms Graciela L. Caballero and Mr Eddie Batoctoy SPAMAST (Philippines).

Benchmarking

A visit to the Provincial/Municipal Agricultural Offices of the provinces of Davao del Sur and Davao del Norte was undertaken initially for research project orientation and benchmarking of the mango growing areas. Briefing of the project concept was undertaken with the Local Government Units to familiarize them on the purpose of the research project. As baseline information, a survey on the status of the mango orchards in the region completed. This included the identification of the mango canopy condition, which was completed primarily in Davao del Sur by two undergraduate Agriculture students of SPAMAST. With the support of the Provincial/Municipal Agricultural Office and the High Valued Crop Coordinator, the survey was conducted on the status of mango orchards in the region, which included cultural management practices and canopy condition.

Establishment of the Research Trial Areas

Two research sites were in Davao del Sur and one was on Samal Island, Davao del Norte and three sets of trials were conducted. All trials were carried out in a randomized complete block design.

Study 1: Effect of light interception under pruned trees. The following treatments were undertaken: T1 – with Light Interception, T2 - no Light Interception.

Study 2: Canopy Management versus No Canopy Management. Treatments were: T1 – Pruned trees, T2 – Unpruned Trees.

Study 3: Performance of Canopy Managed trees under Optimized Nutrient supply. Treatments were: T1 – Soil Analysis (intervention), T2 - Recommended Fertilizer based on the Package of Technology (5 kg complete fertilizer/tree for over 12 year-old trees), T3 - Farmer's/Contractor's Practice (1kg/tree mixture of complete and potassium nitrate 1:1 ratio.

Research Protocol

1. Canopy management protocol included: open centre method, formative/corrective pruning and sanitary pruning. These methods were applied as part of the tree management to attain a "well-groomed" canopy exposing more or less the majority of leaves to sunlight. Tip pruning was done on the second stage to maintain canopy shape and prevent future overlapping canopies.

2. Fertilizer was applied after pruning by placing in a 25 cm^2 wide and 25 to 30 cm deep trenches dug around the tree 2m away from the trunk.

3. Application of Paclobutrazol was undertaken following the rate stipulated on the label.

4. Flower induction was carried out following the usual practice.

5. Chemical control was applied based on pest monitoring. Fruit bagging was done using ordinary newspaper.

6. The data gathered were:

- Study 1 (number of shoots per tree, number of days to shoot emergence and average length of shoots (cm))
- Study 2 (yield, number of marketable fruits, and disease infection rate)
- Study 3 (number of shoots/tree, shoot length, days to shoot emergence, fruit size (length & width), fruit weight, number of fruits/tree, percent/ number of fruits based on

recommended classification, average yield per tree, visual quality rating, number of days to ripening, and cost analysis).

7. Manual harvesting was carried out. Harvested fruits were washed and air dried.

8. Statistical analysis used a T-test for unequal variances for Study 1 and 2; analysis of variance for randomized complete block design for study 3.

Activity 3.3. Investigate harvesting tools and operations to maintain fruit physical appearance (solutions to control sap burn).

Dr Ana Notarte PAGRO (Philippines)

Two types of harvesting tools developed by the USeP were tested for the maintaining quality of fruit and physical appearance (cracks due to fall and sap burn): a harvesting tool with a blade and cable (Tool A) and the other with a blade alone. (Tool B). They were tested against a control and a conventional harvesting tool (Tool C). Six (6) trees per harvesting tool were used on two farms.

Activity 3.4. Investigate the effects of early establishment training frameworks on tree architecture, growth and yields (A)

Dr Paula Ibell and Dr Ian Bally DAF (Australia)

Experiment 1 – Mango alternate training systems

Four mango varieties (NMBP 1243 and 4049, Keitt and Calypso) were planted at high density (1,250 tree per ha) on trellis at Walkamin Research Station, Far North Queensland, Australia. The aim of this experiment was to compare different training systems within high density trellised mango plantings.

This experiment was designed as a split-plot with training system at the main plot level and variety at the sub-plot level. Each of 4 varieties (NMBP 1243, NMBP 4069, Keitt and Calypso) were included in each row and each row was trained with either Palmette, Cordon or Espalier trellised training systems (figure 3.4.1). Each block was replicated 4 times. Trees of NMBP 1243, Keitt and Calypso varieties were planted on the 20th of May 2015 while the NMBP 4069 trees were planted later on the 7th of November 2015. More details can be found appendix 3.4.

Experiment 2 – To prune or not to prune

A second experiment aimed to look at four unpruned varieties (NMBP 1243 and 4069, Keitt and Calypso) and compared them to a pruned and unpruned Kensington Pride (KP) as the industry standard. Variables were assessed at 3.5 years of age and assessed various tree architecture traits including counts of the number of orders, growth units, terminal growth units, flowers and fruiting. The aim of this experiment was to compare how pruning or variety influenced the orchard productivity.

(a) (b) (c)

Figure 3.4.1. The three canopy training techniques (a) Palmette, (b) Cordon and (c) Espalier or fence training techniques under investigation in experiment 1.

Objective 4: To improve mango farmer livelihoods and profits through, developing and implementing an integrated management package of "best practices" with mango farmers.

Activity 4.1. Develop a communication and research adoption plan.

Dr Ana Notarte (Philippines)

The communication and research adoption plan was developed and presented at the inception meeting.

Activity 4.2. Develop and document a best practice management package with farmers and contractors. Implement the best bet package using farmer clusters.

Dr Ana Notarte (Philippines)

A national survey was conducted in the nine major growing areas in the Philippines namely: Davao Oriental, Davao del Sur, Misamis Oriental, Sarangani Province, Guimaras, Zambales, Pangasinan and Davao del Norte. The survey aimed to document common practices being performed by the contractors and mango growers and then to come up with a "Best Practice Crop Management Package". After consolidating common best management practices from the survey data, and some refinement of the package, the best bet package was developed and implemented as detailed below (Activity 4.3).

Activity 4.3. Implement the best bet package with farmer clusters; evaluate and refine the package as required.

Dr Ana Notarte and Julia Sagolili (Philippines)

After consolidating the best management practices the "Mango Season Long Training" was conducted in Davao del Norte (February – August 2016, February - July 2017) and Davao del Sur (2017). The first training program was participated by both technical staff (Agricultural Extension) and mango growers not only in the Island Garden City of Samal but in Region XI-Davao Region namely the provinces of Davao del Sur, Davao Oriental and Region X. The second and third programs were participated by mango growers from Davaoa del Sur, Samal clusters, Panabo City, New Corella, Tagum City, Sto. Tomas, Davao City and Carmen, North Cotabato. Five Agricultural Extentionists from Samal, Provincial Agriculturist and Panabo City also participated in the season long training. Details on participant numbers are in the results section.

Part of the module included ten days of concentrated lectures explaining in detail the mango package of technology, of which the ACIAR Mango Team Leader Dr Ian Newton lectured on integrated pests management, Dr Geoff Dickinson (Extension Component

Leader) lectured on the role of extension technology and adoption and mango nutrition. Dr Celia Medina – (ULPB entomologist) delivered a lecture thrips management and Dr Emma Bayogan (UP Mindanao Campus, from ACIAR project HORT/2012/098) lectured on mango postharvest technology, emphasizing the effect of fruit dropping during harvest and exposure of fruits under the heat of the sun. Local study leader – Dr Ana Notarte lectured on the remaining modules together with the technical staff of the city Agriculturist Office of Samal.

Activity 4.4. Develop capacity and train extension and scientific staff to deliver best practice packages

Capacity has been developed through training provided to scientific and extension staff as detailed in section 8.2.

Activity 4.5. Investigate options for a repository of advisory and extension information for mango farmers and others.

Dr Geoff Dickinson DAF and Dr Ana Notarte PAGRO (Philippines)

Existing Philippines websites which may have potential as repositories of advisory and extension information for mango farmers and others were explored. The most prominent existing website is the 'Mango Information Network' constructed by the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD), Los Baños, Laguna, Philippines. This website was developed and launched 2008-2010 (http://www.pcaarrd.dost.gov.ph/home/momentum/mango/). This very well-structured website includes pages on Mango Technology, Markets, Pests, Policy, Bazaar, R&D, Statistics and a Stakeholder Directory. However due to insufficient resourcing, this website became inactive at the end of 2010 and no new posts or updates have been added since then.

The Davao del Norte and Davao del Sur provincial government websites were also investigated as repositories for mango information. However, both these sites are quite simple directories and are not designed for use as an information database. In addition there was not a designated budget for their maintenance, so the suitability of either website was not explored further. No other website platforms in the Philippines were identified that would be suitable as a publically accessible electronic repository for mango information.

Activity 4.6. Develop electronic extension delivery methods for the Australian mango industry.

Dr Geoff Dickinson (Australia)

Effective web-based delivery of electronic resources is highly dependent on the establishment of a long-term, well maintained system which is regularly updated with new and relevant information and is easily accessible to the web user. In Australia there are three websites where mango growers have traditionally turned to find information on mango production and marketing activities. These are the Australian Mango Industry Association website (http://www.industry.mangoes.net.au), the Queensland Department of Agriculture and Fisheries website (https://www.daf.qld.gov.au/plants/fruit-and-vegetables/fruit-and-nuts/mangoes) and the Northern Territory Department of Primary Industries and Resources website (https://nt.gov.au/industry/agriculture/food-crops-plants-and-quarantine/fruit-crops/mango/mango-research-results). The QDAF and NTDPIR websites are infrequently updated, have many information gaps and both have undergone significant downsizing and re-design over 2014-2018, which has resulted in the loss of significant content. The AMIA website was subsequently identified as the most suitable repository for mango information resources as it is grower managed, is updated regularly and is not restrained by government protocols which may restrict the sharing of information or the listing of external information resources. A process was designed to provide mango information resources to AMIA for inclusion on their website as an information repository for growers.

The usefulness of grower videos was also explored through analysis of the DAF “Mango-picking: How to do it right” video which was released in 2013, widely publicized and was publically available at no cost for viewing from Youtube. Viewer metrics over 4 years were assessed, analysed and published in the Mango Matters industry magazine (October 2017).

Facebook was also explored as a new tool for electronic extension communication. Over 20 mango information posts were made from 2014-2018 on the QDAF Queensland Agriculture Facebook site. This included a 7-month promotion “Queensland Mango Moments” where a monthly post was made updating the progress of the 2016 Mareeba mango season. Each monthly post corresponded to a particular operational practice (eg fertiliser, irrigation, maturity assessment) with a link provided to guide growers to the relevant electronic information resource for that practice.

6 Achievements against activities and outputs/milestones

Objective 1: To improve mango fruit quality by developing effective insect control and IPM solutions

no.	activity	outputs/ milestones	completion date	comments
1.1	Studies will be conducted on the ecology and management of thrips and cecid flies	Surveys of cecid fly natural enemies complete. Identification and documentation of the natural enemies complete. C Medina (PC)	Feb 2016	A parasitoid of *Procontarinia pustulata* was identified as *Synopeas mangiferae* PLATYGASTRIDAE. No parasitoid was found attacking thrips. Many species of predators were documented during the flowering stage of mango included mirid bugs, coccinellid beetles, and lacewings.
		Documentation of the biology of thrips including host utilization pattern and spatial and temporal distribution of thrips in mango orchard. C Medina (PC)	Feb 2016	*T. hawaiiensis* infests flowers starting at 19 DAFI earlier than *S. dorsalis* (26 DAFI). However, *T. hawaiiensis* population disappeared in mangos at 40 DAFI while *S. dorsalis* continued to infest developing fruits up to 58 DAFI. Among the various weeds, *Lantana camara* harboured the highest density per flower. The peak of the thrips population on this weed coincided with the period when thrips could no longer be found in mango.
		Documentation of the population dynamics of the 2 cecid fly species showing the patterns of annual occurrence. C Medina (PC)	May 2017	The infestation of cecid fly was very low in the study area; therefore, only opportunistic sampling could be undertaken. The annual occurrence of the 2 cecid fly species depended on the presence of shoots and developing fruits, which was highly variable and influenced by the climate and tree management practices.
		Documentation on the management of thrips including having effective chemical control tactics. C Medina (PC)	Jun 2017	Laboratory and field toxicity experiments were conducted to determine the degree of insecticide resistance of *T. hawaiiensis* and *S. dorsalis* to commonly used insecticides. Thrips were found to be highly resistant to profenofos and cypermethrin in Mindanao.
		Documentation on the management of thrips including having effective chemical control tactics. C Evangelista (PC)	Jun 2017	A number of chemical insecticides were tested as alternatives to using synthetic pryrethroids and profenofos. Cartap hydrochloride (an older carbamate) generally produced the best results; however, the newer chemicals clothianidin avermictin and spinosad were also effective. Deltamethrin was no better than the unsprayed controls.

1.2	A trial will be conducted on Area Wide Management of Fruit Fly	Baseline study complete, showing initial fruit fly population before AWM. A Notarte (PC)	May 2016	Baseline date on population of fruit fly in was determined showing the initial population of fruit fly. By June the population increased and peaked in August. From September until December, fruitfly populations in Babak and Samal districts decreased, but in the Kaputian district the population increased. When the fruitfly population increased on the farms it also increased in urban sites. These bassline studies will be of use in future area wide management trials in another project.
		AWM intervention trial compete, documentation of efficacy and economics complete. A Notarte (PC).	Not Completed	It was agreed that this milestone could not be achieved within the budget of this project, as outlined in the annual reports. An AWM trial is planned for a new project, starting in late 2018 under Stefano De Faveri DAF. The baseline studies will be of use for the new project.
1.3	Studies will be undertaken of the biology and control options for managing sucking hemipteran pests in Australia	Taxonomy status of sucking bugs is determined. I Newton (A)	May 2016	Complete. A comprehensive literature review of sucking pests, concentrated on planthoppers, Tea Mosquito Bug and Fruitspotting bugs.
		Documentation of the biology and control options for managing sucking hemipteran pests in Australia. I Newton (A).	Jul 2017	Collections of planthoppers and parasitoids from Mareeba/Ayr/ Bowen complete. Positive IDs on Planthoppers, egg and larval parasitoids. Parasitoid IDs were from obtained from overseas expert taxonomists. Investigation of new chemistry to control planthoppers and Fruitspotting Bugs was undertaken, including lure and kill approach using FSB pheromones with insecticides. Documentation of biology of Planthoppers complete.
1.4	IPM compatible control solutions and an insecticide resistance management program will be developed	Farmer survey complete, IPM & resistance management program designed and implemented with selected farmer groups. C Medina (PC).	Jun 2018	The majority of the respondents have received formal training on pests and pest control. However, the level of knowledge gained was low, leading to misuse and abuse of pesticides. An IPM & resistance management program was developed implemented and used by a select group of farmers in Davao del Sur.
		IPM package testing complete & documented with farmer groups. C Evangelista (PC)	Jun 2018	Developed from the results from activities 1.1.This information was delivered to extension teams. Farmers are now advised to avoid using pyrethroids and profenofos. An IPM & resistance management program was also developed, implemented and used by a select group of farmers in Davao del Sur.

PC = partner country, A = Australia

Objective 2: To improve fruit quality through developing effective solutions to mango pre and postharvest fungal diseases.

no.	activity	outputs/ milestones	completion date	comments
2.1	Investigate economical alternatives to conventional chemical disease control	Identify farmer co-operators and collect baseline data. J Silvestre (PC)	June 2015	Complete
		Yearly trial results reported. J Silvestre (PC)	July 2017	The biological fungicides Serenade, Timorex Gold, and MPQ and the chemical fungicide ICC were effective at reducing blossom blight, anthracnose and stem-end rot of mangos. Fruits applied with four different rates of fungicides (Serenade, MPQ, ICC, and Timorex Gold) had excellent appearance, similar to fruits from chemical control (Propineb), which was relatively more expensive.
2.2	Explore the potential of plant growth regulators for the control of pre and postharvest diseases	Determined in vitro which phytohormone inhibits germination and growth of C gloeosporioides and B theobromae V Ugay (PC).	May 2015	Plant growth regulators (Auxin-Cytokinin-Gibberellic acid at 0.3 & 0.5%), (Auxin-Cytokinin-Gibberellic acid + Calcium Boron at 0.3 & 0.5%), and (Salicylic Acid- Gibberellic acid + Calcium Boron at 0.5 &1%) did not inhibit the growth of *Colletortichum gloeosporioides* and *Botryodiplodia theobromae* , *in-vitro*.
		Established the efficacy of using phytohormone as postharvest treatment for the control of anthracnose and SER V Ugay (PC).	May 2016	Complete. In vitro tests showed phyto-hormones unlikely to work as a post harvest treatment.
		Established the efficacy of using exogenous hormones applied in the field for the control of anthracnose and SER V Ugay (PC).	May 2016	Complete. Single PGR product can replace 3 sprays of fungicide applied at panicle elongation, pre-bloom and full bloom. SER and anthracnose incidences and anthracnose severities were similar to 7 straight fungicide applications.
2.3	Investigate the efficacy of endophytes against anthracnose and SER	Collect and isolate endophytic fungi. V Ugay & P Trevorrow (PC&A).	May 2016	Collections complete. Isolated and screened 32 endophytic fungi from 'Carabao' mango (PC) and nine from Kensington Pride & other varieties (A).
		Established the efficacy of using endophytic fungi applied for the control of anthracnose and SER V Ugay & P Trevorrow (PC&A).		Laboratory experiments were complete using naturally occurring endophytic fungi (A). The EFA applied at pre-harvest showed similar efficacy with fungicides in the management of pre and postharvest anthracnose and stem end rot (PC).

		Establish efficacy of endophyte when applied as postharvest treatment against anthracnose and SER V Ugay (PC).		EFA is ineffective against stem end rot and anthracnose when applied at post-harvest.
2.4	Develop a best practice economically viable disease control package.	Best bet package documented, delivered to extension team and to 1st early adopter farmers. J Silvestre (PC)	June 2017	Potential chemical and biological fungicides were documented and delivered to Dr Notarte to be used in the implementation of their best bet package. The biological fungicides (Serenade, Timorex Gold, and MPQ) and one chemical fungicide (ICC) were effective control for the pre and post-harvest fungal diseases and were recommended for use in the extension team.

PC = partner country, A = Australia

Objective 3: To improve fruit quality, size and yield by optimising nutrition and canopy management.

no.	activity	outputs/ milestones	completion date	comments
3.1	Field trials will be conducted which will optimise nutrition and canopy management techniques with the aim of improving fruit quality, size and yield.	Benchmarking of farmers practices. Assessment and identification of research sites and co-operators. G Caballero (PC)	May 2015	Students conducted surveys on the status of the Mango Industry in Davao Region (2014), see student thesis titles in reference section
		Established research sites at Davao del Sur and Davao del Norte and Davao del Norte, tag trees. G Caballero (PC)	Feb 2016	Complete. Three farm sites were established: Farm 1 – Padada, Davao del Sur; Farm 2 – Malita, Davao Occidental; Farm 3 – Babak, Samal, Davao del Norte
		Processing of project inputs, claims and requests. Yearly trial results reported. G Caballero (PC)	Apr 2018	Complete. Some trials failed due to weather events and lack of flowers and fruit. Two areas (Farm 2 and 3), reached the stage of successful flower induction, but fruit set failed due to blossom blight, because of frequency of rain.
		Trial results reported G Caballero (PC)	May 2018	Overall most results showed no significant difference among treatments. However, the data indicated better quality & lower disease incidence from trees applied with fertilizers based on an onsite soil analysis. Canopy management improvement could increase farmer profits. Production cost were reduced from a baseline of ₱1,452/tree to ₱759/tree or 48%.

3.2	Develop a nutrition and canopy management package that aims to improve fruit quality, size, yield and efficiency of harvest	Develop and Distribute IEC materials to 200 adopters and interested mango growers, Conduct field day. G Caballero (PC)	Apr 2018	Complete. 15 mango growers trained under the Farmer's Field School adopted pruning.Field Day complete; training conducted on canopy management was done by the canopy management team in coordination with the Farmer's Field School conducted by the Extension Team in Davao del Sur.
3.3	Investigate harvesting tools and operations to maintain fruit physical appearance (solutions to control sap burn).	Report submitted on different tools and operations that were investigated or recommended. A Notarte (PC).	Jul 2015	Completed with collaboration from USeP, A more efficient and effective harvest tool is being developed, but requires further work.
3.4	Investigate the effects of early establishment training frameworks on tree architecture, growth and yields (A)	Report on the effects of different training frameworks on tree architecture, growth and yields. I Bally (A)	Jun 2018	Trees Planted and established with different architectures. Trialling trellised (Espellier orfence system) small trees against other training systems and non-trained trees. High density trellised systems produced early yield improvements for newly established orchards compared to conventional training systems.

PC = partner country, A = Australia

Objective 4: To improve mango farmer livelihoods and profits through, developing and implementing an integrated management package of "best practices" with mango farmers.

no.	activity	outputs/ milestones	completion date	comments
4.1	Develop a communication and research adoption plan (PC).	Plan is complete and is documented. A Notarte & J Sagolili (PC).	Jun 2014	Plan produced and presented at inception meeting.
4.2	Develop and document a best practice management package with farmers and contractors. Implement the best bet package using farmer clusters.	Best practice crop management package available to farmers and contractors. A Notarte & J Sagolili (PC)	Feb 2016	National survey of mango farming management practices completed. Best management practices identified for inclusion in best bet package.

4.3	Implement the best bet package with farmer clusters; evaluate and refine the package as required (PC).	An information package of all education materials available. Applied best practices assessment and evaluation. Farmer clusters adopted package. 300 to 400 farmers trained and 30 to 40 cluster leaders intensely trained. A Notarte & J Sagolili (PC).	June 2018	After consolidating best management practices from the survey data, and some refinement of the package the "Mango Season Long Training" was conducted in Davao del Norte (February – August 2016, February - July 2017) and Davao del Sur (2017). There are now 21 cluster farmer groups with 21 trained cluster leaders (10 Davao del Sur + 11 Davao del Norte). A total of 185 mango growers (75 Davao del Sur + 110 Davao del Norte) have participated in farmer field school season-long training. There are another 73 cluster groups with 73 trained leaders (51 Davao del Sur + 43 Davao del Norte) being developed, that will be up and running in the next 1-2 years.
4.4	Develop capacity and train extension and scientific staff to deliver best practice packages	Improved capacity of extension and scientific staff to deliver best practice packages. A Notarte & J Sagolili (PC).	August 2017	Capacity and training activities for extension and scientific staff are listed in detail in section 8.3 (Capacity Impacts).
4.5	Investigate options for a repository of advisory and extension information for mango farmers and others	A repository of advisory and extension information that can be accessed and used by mango farmers and others. A Notarte & G Dickinson (PC).	June 2018	3 Philippine websites investigated as formal repositories. None were found suitable. Video has been produced on the package of mango technology from pruning/canopy management, fertilization, paclobutrazol application, flower induction, pesticide use and harvesting; this has been uploaded and made publically available on YouTube.
4.6	Develop electronic extension delivery methods for the Australian mango industry	System to allow electronic delivery of extension materials for the Australian mango industry. G Dickinson (A).	June 2018	Three Australian websites investigated as formal repositories. The Australian Mango Industry Association website was identified as very suitable. Considerable extension content was sourced and loaded to this site. Ineffective website structure and insufficient resources resulted in this website being no longer effective as an information repository. Case study of mango extension videos (available via Youtube) have found them to be highly accessible and utilised by mango stakeholders. (DAF mango picking video had > 55,000 views over 5 years). Facebook identified with potential as electronic delivery method. Queensland Agriculture Facebook has >6,000 followers. Of 20 mango posts, most posts received 50 likes and 10-15 shares.

PC = partner country, A = Australia

7 Key results and discussion

Objective 1: To improve mango fruit quality by developing effective insect control and IPM solutions

Activity 1.1 Studies will be conducted on the ecology and management of thrips and cecid flies

Surveys of cecid fly natural enemies complete. Identification and documentation of the natural enemies complete. C Medina (PC).

A parasitoid of *Procontarinia pustulata* was identified by Dr Andrew Polaszek of the Natural History Museum in London, as *Synopeas mangiferae* (Platygastridae). This species has been found in other parts of Asia. No parasitoid was found attacking thrips.

Many species of predators were documented during the flowering stage of mango including mirid bugs, coccinellid beetles, and lacewings. Direct evidence of feeding on thrips was not observed. These predators were probably feeding on mango leafhopper that also occurred during the flowering stage of mango.

Documentation of the biology of thrips including host utilization pattern and spatial and temporal distribution of thrips in mango orchard. C Medina (PC).

The population dynamics of the two most dominant species of thrips - *Thrips hawaiiensis* and *Scirtothrips dorsalis* in mango and other non-cultivated plants was studied during and after the mango fruiting season. *Thrips hawaiiensis* infests flowers starting at 19 days after flower induction (DAFI) and earlier than *S. dorsalis* (26 DAFI). However, the *T. hawaiiensis* population disappeared from mangos at 40 DAFI, while *S. dorsalis* continued to infest developing fruits up to 58 DAFI. Among the various weeds where these thrips were found, *Lantana camara* harboured the highest density per flower. The peak of the thrips population on this weed coincided with the period when thrips could no longer be found in mango. This temporal pattern was particularly true if there were no flowering or flushing mango trees in the vicinity. This ecological study showed the close association of thrips in mango and in weeds. With further research, strategically timed removal or spraying of weeds may be a way to manage thrips.

Documentation of the population dynamics of the 2 cecid fly species showing the patterns of annual occurrence. C Medina (PC)

From 2014-2016, the infestation of cecid fly was very low or almost negligible in the study area. For this reason, only opportunistic sampling was done in different areas of the Southern Philippines, whenever there were mangos at the flushing or fruit-setting stages. The annual occurrence of the two cecid fly species depended on the presence of shoots and developing fruits, which was highly variable and influenced by the climate and tree management practices.

Documentation on the management of thrips including having effective chemical control tactics. C. Evangelista (PC).

Trial 1*. Evaluation of new pesticides against Mango Thrips*
In the first spray application of insecticides, population counts of thrips were evenly distributed among the treated trees. All insecticides offered effective control against thrips as reflected by significantly lower thrips counts. Notably, spinosad and clothianidin gave lower population counts which were comparable or better than profenofos and other insecticides. Furthermore, at the second application, azadirachtin and spinosad produced lower population counts, which were comparable to other insecticides used. At the third

application, the thrips populations were significantly different among treatments. Spinosad produced a lower thrips count of 304 thrips/20 panicles, which was comparable to azadiractin, indoxacard and clothianidin with the population counts of 346, 349 and 329 thrips/20 panicles respectively. The result implies that the application of newer insecticides, especially spinosad and clothianidin, offered effective control of thrips.
With regards to fruit set and retention, spinosad produced significantly higher mean fruit set (167 fruit/tree) and retention (118/tree), than the other treatments, but was comparable to avermictin (fruit set of 130/tree and retention of 91/tree). The untreated trees produced the lowest fruit set and retention with a mean count of 7.3 and 4.0 fruit per tree, respectively. The above result implies that the application of the newer insecticides, particularly, spinosad produced more fruit yields among the insecticide treatments.
Trees that were treated with avermictin and spinosad produced a significantly higher marketable yield. However, there was no significant difference among the insecticide treatments for non-marketable fruit. Finally, in terms of total fruits harvested, avermictin and spinosad gave the highest fruit yield among the other treatments. This was attributed to effective control of thrips.

Trial 2. Evaluation of promising and recommended insecticides for the control of mango thrips

Thrips *(Thrips hawaiiensis*). Pre-spray assessment at 18 and 42 days after flower induction (DAFI), the thrips population count was evenly distributed among the experimental trees. However, at 25 and 35 DAFI there was a significant difference among treatments; Profenofos + Cartap hydrochloride (mix) produced the lowest population count, but this was not significantly different than the clothianidin, spinosad and imidacloprid treatments. The post-spray application assessment at 18, 25, 35 and 42 DAFI, showed no significant difference among treatments, indicating minimal affect.
Thrips *(Scirtothrips dorsalis* Hood*).* The pre-spray assessment at 24, 34, 41 and 48 DAFI, revealed that the thrips population was evenly distributed among the experimental treatments. The post-spray assessment at 26, 36, 43 and 50 DAFI also revealed that population of thrips was evenly distributed among the insecticide treated and untreated trees.
Fruit Set, Fruit Retention and Number of fruit bagged fruit per tree. Application of insecticides did not affect the number of fruits set. Cartap hydrochloride produced the highest fruit retention. However, in terms of number of fruits bagged, Cartap hydrochloride treated trees produced the highest yield among the other insecticide treated trees.

Weight of Non-marketable, Marketable and Fruit yield. The weight of marketable, non-marketable and total fruit yield was significantly different among treatments. Cartap hydrochloride produced higher non-marketable fruits (3.67 kg / tree) marketable fruits (87.33kg / tree) and total fruit yield (91.00 kg / tree), but this was comparable with the spinosad and the Farmers practice treatments. This might be attributed to the control of thrips and possibly other insect pests such as mango leafhopper and mango seed borer (not quantified).

Trial 3. Verification trials of selected insecticides for the control of mango thrips.

Thrips *(Thrips hawaiiensis).* The population count of thrips *(Thrips hawaiiensis)* was affected by the application of selected insecticides sampled at different time points (days after flower induction DAFI) and multiple spray applications. At the pre-assessment count before the first spray application of insecticides (at 18 DAFI); the thrips population was evenly distributed among the treated trees. The mean population counts ranged from 14.7

to 38.7 thrips/20 panicles. The post-spray assessment also demonstrated no significant differences between the insecticide treatments, which ranged from 12.7 to 24.3 thrips/20 panicles. However, all trees that were treated with insecticides produced a lower thrips count than the untreated trees.
By the second spray application (at 24 DAFI); the pre-spray assessment revealed that there was a significantly difference in thrips pressure among the insecticide treatments. Cartap Hydrochloride + Profenofos (mixed formula) produced a lower thrips count (132 thrips/20 panicles) when compared to the Profenofos alone (144 thrips/20 panicles). The untreated trees produced the highest thrips count. At the post-spray assessment, all insecticide treatments produced a lower thrips count than the untreated trees. The Cartap Hydrochloride + Profenofos application demonstrated effective control against thrips as reflected by a lower count than the Profenofos alone or Deltamithrin. Cartap hydrochloride alone also produced a lower population count, which was comparable to the Profenofos and Cartap Hydrochloride + Profenofos.
By the third and fourth spray application (at 34 and 41 DAFI), there was no significant difference among the insecticide treatments. Cartap hydrochloride + Profenofos (mix) and Cartap Hydrochloride (alone) offered effective control of mango thrips. However, other work has suggested thrips are resistant to profenofos, therefore the Cartap Hydrochloride alone is the more likely the most important component.

Thrips (*Scirtothrips dorsalis*). The population of thrips *(Scirtothrips dorsalis)* appeared at the second application of insecticides. At the pre assessment population count, there was no significant difference in thrips counts between treatments and the thrips counts were evenly distributed among the treatments. All the insecticide treatments produced a lower thrips count compared to the untreated trees except the clothianidin treatment. At the post-spray assessment the thrips population count was significantly different among the treated trees. All insecticide treatments produced a lower thrips count than the untreated trees. However, Cartap hydrochloride + Profenofos (mix) and Cartap hydrochloride (alone) produced a lower thrips count compared to Profenofos (alone), Deltamethrin and the other insecticides. At third and fourth application of insecticides, both pre and post-spray results showed no significant differences among the treated trees. The population of thrips were evenly distributed amongst the treated tress. This indicates that Cartap hydrochloride (alone) has potential for reducing mango thrips.

Fruit Retention and Yield. The Cartap hydrochloride + profenofos (mixed formula) application produced the highest fruit retention compared to the other insecticide treatments. However, in terms of number of fruit harvested per tree, the Cartap hydrochloride (alone) treatment produced the higher number of fruit.

The weight of fruits and fruit yield were significantly different among treatments; Cartap hydrochloride (alone) produced the highest fruit yield of 110 kg/tree (or 11.0 tons/ha), which was higher than the profenofos treatment at 96 kg/tree (or 9.63 tons/ha), deltamethrin (50 kg/tree, 5.03 tons/ha) and untreated trees (43.57 kg/tree, 4.37 tons/ha). Cartap hydrochloride alone was comparable to cartap hydrochloride + profenofos (106 kg/tree and 10.6 tons/tree). This might be due to the insecticides reducing thrips and possibly other insect pests such as mango leafhopper, mango seed borer and fruitfly.

This result showed that Cartap hydrochloride alone provided insect produced higher yields due to the effective control for mango thrips and other insect pests, while the deltamethrin treatment was no better than the untreated controls.

Activity 1.2. A trial will be conducted on Area Wide Management of Fruit Fly

Baseline study complete, showing initial fruit fly population before AWM. A Notarte (PC)

Figure 1.2.1. shows the summary of mango fruit fly trapping by each month in the three districts of the Island Garden City of Samal, Davao del Norte, January – December 2015. From January to June, the population in the three sites was almost of the same, with a trend of less than 5,000 flies per month at each site. From June the population increased and peaked in August in all three sites. However, from September to December the fruitfly population in Babak and Samal districts decreased, whilst in Kaputian district the population continued to increase.

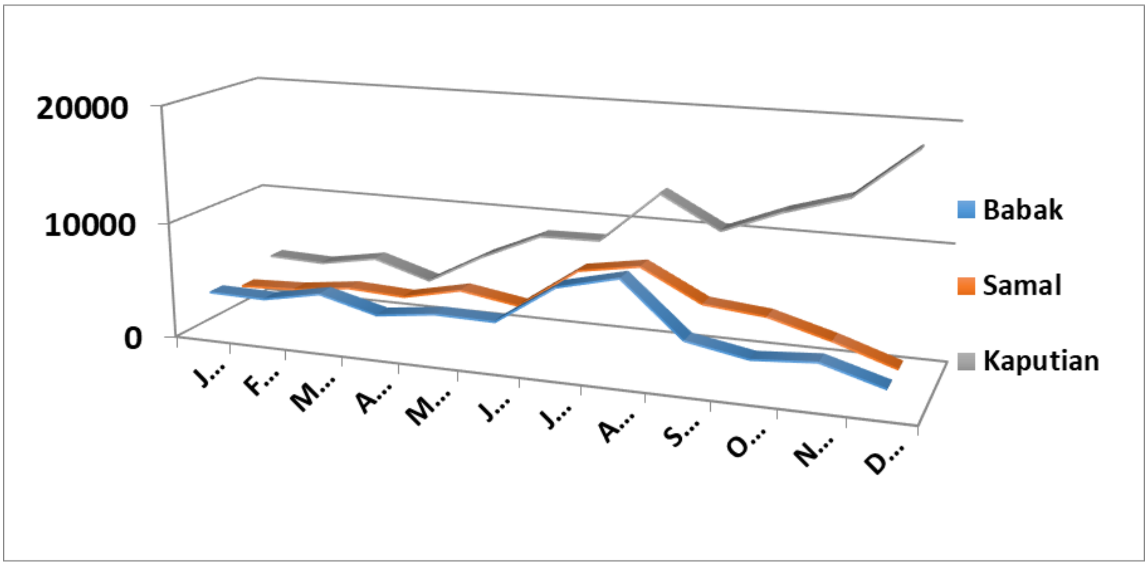


Figure 1.2.1. The mango fruit fly trapping, showing monthly populations from the three farm districts of Samal Island.

The data shows the same population trend in the three urban sites, where the population increases from July to August and then decreases from September to December (Figure 1.2.2). The data revealed that when the fruitfly population increases on there will be in increase of population in urban areas, thus urban areas can be a fruit fly source.

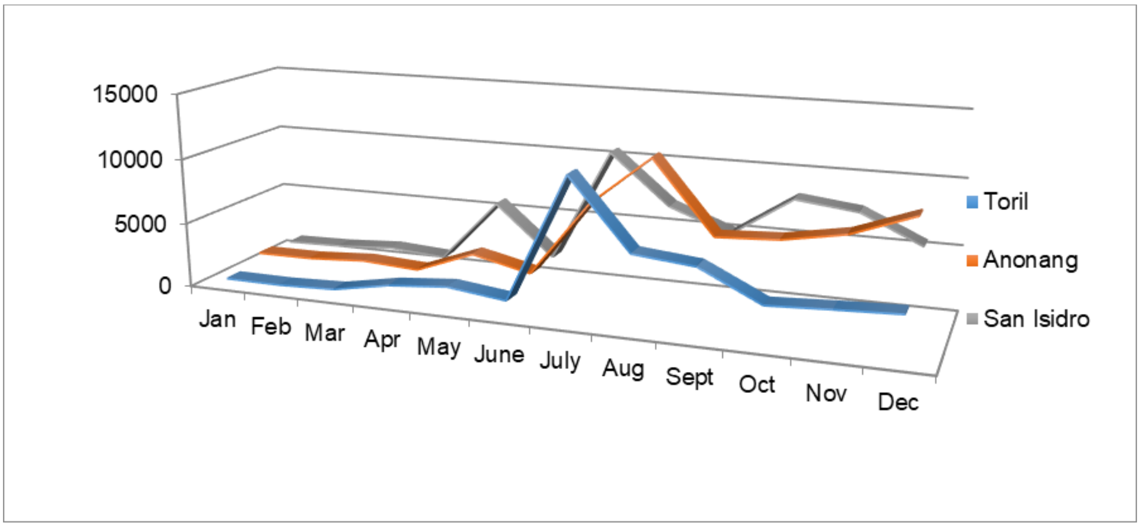


Figure 1.2.2. Fruit fly trapping, showing monthly populations from the three urban sites on Samal Island.

AWM intervention trial complete, documentation of efficacy and economics complete. A Notarte (PC).

Not complete, as outlined in methods section.

Activity 1.3. Studies will be undertaken of the biology and control options for managing sucking hemipteran pests in Australia

Taxonomy status of sucking bugs is determined. I Newton (A)

A comprehensive literature review of Australian sucking mango pests was conducted; it concentrated on planthoppers (*Colgaroides acuminata*), Tea Mosquito Bug (*Helopeltis* sp.) and Fruitspotting bugs (*Amblypelta l. lutescens*) (see appendix 1.3-A). The review focused on taxonomy, biology and control options. A suite of natural enemies associated with these pests and their taxonomy and biology was also discussed.

Documentation of the biology and control options for managing sucking hemipteran pests in Australia. I Newton (A).

Biology Studies

Approximately 100 planthopper nymphs were collected and 26 were observed as being parasitised by Dryinids. Nineteen planthopper adults were collected and no parasitism was observed. Approximately 230 Dryinid pupal cases were also collected on mango leaves, of which 171 successfully produced adult Dryinid wasps in the laboratory. The male and female wasps were identified as *Dryinus australiae* Olmi, 1984 Dryinidae (Hymenoptera). Dryinid parasitism levels differed dramatically between sites. Only 7.5% of nymphs collected from Mareeba were parasitized compared to 100% at Ayr. It is likely the lack of insecticide use at Ayr contributed to the establishment of a greater population of parasitoids. One specimen was collected from the genus *Neodryinus* (unidentified species). A hyperparasitoid emerged from several of the Dryinid pupae and was identified as *Cheiloneurus chlorodryini* Perkins (Encyrtidae).

Forty planthopper egg rafts were collected in total with 14 being parasitised. The parasitoids were identified as: *Ooencyrtus minor* (Perkins) Encyrtidae, *O.* sp. B near *minor* (Perkins) and *Aphanomerus pusillus* Perkins Platygastridae by by Andrew Polaszek. Egg parasitism rates ranged from 17% to 50%, with the highest rate being recorded at Mareeba, however these differences may have been due to sample size or timing. Planthopper eggs were not always present, and may have been reduced by high Dryinid activity. For further details see full report in appendix 1.3-B.

Pesticide Trial with sulfoxaflor (Transform™) as an IPM alternative for control of Mango Planthoppers (*Colgaroides acuminate*) and Bananaspotting bugs (BSB) (*Amblypelta lutescens lutescens*).

The sulfoxaflor appeared to work as well, or was better at controlling BSB compared to the industry practice of using Trichlorfon and Beta-cyfluthrin. It also appeared to work longer, as only one application was required to keep BSB numbers below fruit damaging levels. Sulfoxaflor may be a reasonable IPM alternative for managing BSB in mangoes; however, it does not appear to be as affective for the control of planthoppers. The results should be interpreted with caution as this was not a fully replicated trial. Larger replicated trials should be undertaken. For further detailed results, see appendix 1.3-C.

Monitoring Integrated Lure and Kill (MILK): A method of managing *A. lutescens lutescens* using an aggregation pheromone combined with limited pesticide use.

Damage levels were approximately 2-3% of fruit for both treatments we were attempting to protect (i.e. the trap-tree and the non-sprayed non-trap trees). Trap trees are normally the most heavily damaged as the pheromone lure attracts the bugs to that tree. These test treatments were not significantly different from the positive control, which had the same low level of damage (2.5%). Damage was higher (8%) in negative controls (this was the aim), but the difference was not statistically significant; however, the statistical test was not conclusive (at P=0.14) suggesting that the damage in the negative controls could be higher, but requires more data collection. For further detailed results, see appendix 1.3-C.

Overall, the MILK system is very promising for BSB control, considering the extremely high BSB pressure in this trial. Furthermore, the trial was quite small with limited replicates for a highly mobile insect. Further trials or farm/block wide demonstrations are required.

Transmission of *Beauveria bassiana* and *Metarhizium anisopliae* to male *Bactrocera tryoni* via para-pheromone lures and subsequent transmission to females

In these experiments, the fungi impregnated lures were highly successful at transmitting *B. bassiana* to male flies, with up to 100% mortality (94% confirmed infection by sporulation on cadavers) from one *B. bassiana* isolate. However, the subsequent transmission of fungi from male to female flies was not as high, with a maximum of only 20% of confirmed infected females for the same *B. bassiana* isolate. The rates of *M. anisopliae* transmission were lower than the *B. bassiana* lures.

Given the low female mortality rates, it would appear that this method alone would be unlikely to be successful in the field. However, with further improvements it could improve Area Wide Management techniques. While female bait sprays would still be required, some females would be killed from male fungal transfer; effectively complimenting the bait sprays. The system could be improved with perhaps a different formulation used on the lure. For further detailed results and discussion, see appendix 1.3-C.

Activity 1.4. IPM compatible control solutions and an insecticide resistance management program will be developed (Philippines)

Farmer survey complete, IPM & resistance management program designed and implemented with selected farmer groups. C Medina.

The majority of the respondents have received formal training on pests and pest control. However, the level of knowledge gained was low, leading to misuse and abuse of pesticides. About 84% of the respondents tank mix and of these, 92% use doses below the recommended rate. Most were calendar based spraying. The number of sprays ranged from 2 to 26 times per season, 50% of the respondents sprayed 11-16 times per season.

An IPM & resistance management program was developed implemented and used by a select group of farmers in Davao del Sur.

IPM package testing complete & documented with farmer groups. C Evangelista.

Thrips were found to be highly resistant to profenofos and cypermethrin in Mindanao. The most effective insecticide tested was Cartap hydrochloride. However, the newer chemicals clothianidin avermictin and spinosad were also effective. Deltamethrin was no better than the unsprayed controls and thrips are likely to be resistant to it (see results in activities 1.1). This information was documented and delivered to extension teams. Growers will now be advised to avoid using pyrethroids and profenofos. An IPM & resistance management program was developed, implemented and used by a select group of farmers in Davao del Sur.

Objective 2: To improve fruit quality through developing effective solutions to mango pre and postharvest fungal diseases

Activity 2.1. Investigate economical alternatives to conventional chemical disease control. J Silvestre USM.

Trial 1. *Evaluation of commercially available fungicides (biological and chemical) for the management of pre- (blossom blight of mango) and postharvest (anthracnose and stem-end rot of mango) diseases of mango.*

Application of biofungicides significantly reduced the proportion of disease incidence of blossom blight (*C. gloeosporioides*) of mango from 38 to 23%, whilst the highest fruit set and fruit retention was observed in trees treated with Serenade 250. For the postharvest treatments, fruits harvested from the ICC treated trees showed the lowest proportion of anthracnose (*C. gloeosporioides*) disease incidence nine days after harvest, but was similar to the chemical checks (Propineb and Mancozeb) and hot water treated fruits. The proportion of stem-end rot incidence was significantly lower in hot water treated fruits regardless of the biofungicides applied, demonstrating the effectiveness of hot treatments. However, hot water treated fruit resulted in fruit weight reduction. The lowest fruit weight reduction was observed in Serenade 500 treated fruits (5% loss) while the highest weight reduction was obtained in the hot water treated fruits (55% loss).

All of the biofungicide treatments were rated as 1 (Good: Slight defects) based on a visual quality rating except MPQ, which was rated 2 (Fair: Moderate defects; limit of marketability) (see appendix 2.1). The weight of marketable and non-marketable fruits was comparable regardless of the fungicide treatments. However, numerous “large” category fruits were obtained from ICC and Serenade 500 treatments (84 and 80% large, respectively).

Trial 2. *Verification trial on the efficacy of potential fungicides (biological and chemical) for the management of pre- (blossom blight of mango) and postharvest (anthracnose and stem-end rot of mango) diseases of mango.*

The lowest proportion of blossom blight infected panicles was found in MPQ treated panicles (40%), but was not significantly different than the Serenade and Propineb (Chemical check) treatments (41%). In the AZ41 treatment, 59% of panicles were infected which was similar to the “Farmers Practice” (57%). Among all trees treated with biofungicides, Timorex gold treated trees had the highest fruit set, while MPQ produced the highest fruit retention.

Among all biofungicide treated trees, the treatments that produced the heaviest marketable fruit were observed in trees treated with MPQ (4.80kg/10 panicles) followed by AZ41 (3.40kg), which similar to Timorex gold (3.27kg). The highest weight of non-marketable fruits was observed in the *T. harzianum* treated trees with a comparable result to that of Serenade, Mancozeb (Chemical check) and Farmers practice (means of 2.19 to 2.56kg.

There was a significant difference in anthracnose infection between field treated fungicides observed at nine days after harvest (means ranging from 11-33% infection); whereas there was no difference in stem-end rot symptoms between the treatments. Moreover, fruits from MPQ treated trees were not infected with either anthracnose or stem-end rot after nine days post-harvest.

The most fruit-weight reduction was observed from fruits applied with Timorex gold, but it was not significantly different to the rest of the biofungicide treatments, including the chemical checks (Propineb and Mancozeb) and untreated control (22 to 30%). The least fruit weight reduction was observed in the farmer's practice (11%). The visual quality rating (VQR) of fruits were rated at nine days post-harvest. Fruits applied with the three biofungicides (Serenade, MPQ and *T. harzianum)* had excellent appearance (VQR, 0-no defects), while those treated with ICC, Timorex gold and AZ41had good appearance (VQR, 1-slight defects).

Trial 3. *Management of pre- and postharvest fungal diseases of mango using different rates of four fungicides (biological and chemical) in Padada, Davao del Sur.*

The different rates of the four fungicides (biological and chemical), significantly reduced disease severity of blossom blight (compared to negative controls), which was comparable to the effect of Trichoderma (biological check) and Propineb (chemical check). Regardless of the rate and type fungicides applied, the number of fruits/panicle ranged from 2 to 4 at 50 days after flower induction (DAFI) with a retention rate of 1-2 fruits/panicle at 65 DAFI.

The heaviest marketable fruits (8.8kg/20 panicles) was recorded in the ICC treatment (50ml/100L water), but was no different to the farmers practice (8.9 kg/20 panicles). The most number of large fruits (88%) were obtained from trees applied with Timorex Gold (200ml/100L water), the most medium fruits (33%) came from treatments with MPQ (150ml/100L water) and farmers practice (33%), while most of the small fruits (17%) were from the untreated control.

Fruits sprayed with Serenade (250ml/100L H_2O), Timorex Gold (150 and 200ml/100L water), MPQ (200ml/100L water), and ICC (25, 50, and 75 ml/100L water) had significantly less SER (0.6-2.2%) compared to other treatments, but was no different from the Trichoderma treatment (biological check), which was not infected and fruits were healthy (at 9 days post-harvest).

The lowest incidence of anthracnose on fruit was observed in fruits sprayed with ICC (25ml/100L water), but was not significantly different to the rest of fungicide treatments, including Trichoderma (biological check), Propineb (chemical check) and farmers practice (1.8 to 4.6%). The untreated control had the highest incidence of anthracnose (9.60% at 9 days post-harvest).

The fruit-weight reduction was similar regardless of the pre-harvest fungicide or rate. Fruits applied with the different rates of four fungicides (Serenade, MPQ, ICC, and Timorex Gold*)* had excellent appearance (VQR, 0-no defects), except MPQ (250 ml/100 L water) and ICC (75 ml/100 L water) which had good appearance (VQR, 1-slight defects). The fruits from chemical control (Propineb) and biological check *(T. harzianum)* had excellent appearance (VQR, 0-no defects), while the untreated control fruits had poor appearance (VQR, 3- serious defects; limit of edibility).

Cost-Efficacy Analysis. A cost analysis was performed with six cycles of application at 8 days interval of the fungicide (chemical and biological) treatments for a 1ha mango farm, based on the treatment costs, labour expenses and other related expenditures for the management of blossom blight was performed (details in appendix 2.1).

The application of at ICC 25 ml/100L water incurred the lowest production cost of ₱18,876/ha followed by ICC 50 ml/100L, Serenade 200 ml/100 L, *T. harzianum* (biological check), Serenade 250 and ICC ml/100L, with production cost ranging from PhP20,076 to ₱21,276. These treatments were relatively cheaper compared to the Farmers Practice (Propineb applied alternately with Trichoderma) and Propineb (chemical check), ₱21,696 and ₱22,716 respectively.

A similar trend was observed in cost of pre harvest fungicides for 1,000 kg of mango fruits for the management of postharvest diseases of mango (anthracnose and stem-end rot) with a total production costs ranging from PhP53,204 to PhP63,704 (Appendix 2.1).

The results show that lower rates of chemical fungicides (e.g. ICC at 50 and 25ml ml/100L water) and biological fungicides such as Serenade (250 and 200 ml/100L water), can be used to manage pre-harvest and postharvest diseases, and are relatively cheap compared to the conventional chemicals.

Activity 2.2. Explore the potential of plant growth regulators for the control of pre and postharvest diseases (Philippines)

Ugay, V.P. and Limbaga, C. Jr. A.

The mango trees responded well to calcium nitrate applied to induce flowering. Trees flowered profusely (98-100%) but trees applied with PGRs reached full bloom at 25 days after flower induction (DAFI), three days ahead of the untreated control trees. The PGR-treated trees had longer and sturdier panicles and with extended flower life allowing longer time for pollination. These plant responses are attributed to Gibberellic Acid (GA) present in the PGR products used. GA is known to enhance bolting and flowering in long day plants.

Fruit set was higher (2.56 fruits per panicle) in trees sprayed with (SA+GA+CaB), comparable to trees applied with (Aux+Cyt+GA+CaB) at 2.12 fruits per panicle. The trees that were applied with systemic fungicides had lower fruit set (1.67 per panicle) which was comparable to positive control trees (1.13 fruits per panicle). The higher fruit set in trees applied with PGR products containing GA, SA, and CaB is attributed to their significant roles as growth regulators.

Fruit retention in trees applied with (SA+GA+CaB) was highest (1.6 fruit per panicle) but comparable to other treatments except (Aux+Cyt+GA) at 0.84 and positive control at 0.33 fruit per panicle. The comparable results on fruit set can be attributed to the application of CaB on all treatments. However, trees applied with CaB-containing PGR product received greater amount of CaB, thus enhancing higher fruit retention.

A**verage yield production per tree** of the treated trees were comparable between treatments ranging from 48-82 kg. The positive control trees produced significantly lower yields at an average of 7.2 kg of fruits per tree (Appendix 2.2).

Efficacy of PGRs applied at pre-harvest against postharvest diseases of mango, The treatment with the least anthracnose incidence (29%) was found from trees sprayed 7 times with fungicides (selected based on efficacy trials in previous experiments). This was followed by trees sprayed 4 times with fungicides and 3 times with (Aux+Cyt+GA + CaB) at 41%, then by trees sprayed 7 times with fungicides preferred by the farmer cooperator (47%) and then by trees sprayed 4 times with fungicides and twice with (SA+GA+CaB) at 51%. In these treatments, anthracnose incidences are comparable. Fruits from trees applied sequentially with different PGR products had the most number of anthracnose infected fruits (68%). The control trees failed to produce enough fruits required for the postharvest experiment, thus severity and incidence of anthracnose and SER on this treatment was no longer determined (Appendix 2.2).

Anthracnose severities were similar in all treatments (1.2 - 3.8%) except on the treatment with sequential application of all PGRs, which had 7.5%.

SER incidences were similar in all treatments (5.3 - 20%) except in fruits from trees that were sprayed 4 times with fungicides and 3 times with (Aux+Cyt+GA) which had 36%.

The above results showed that substitution of fungicides with PGR products applied at panicle elongation, pre-bloom and full bloom have a similar effect to the 7 straight sprays of fungicides on postharvest diseases. Data also showed that a single PGR product worked better than sequential use of several PGR products. The PGRs role in disease management is on the host. An *in vitro* test (not shown here) of PGR products used in this study against anthracnose and SER demonstrated that the PGRs lack direct antifungal activity.

Anthracnose and SER incidence and severity of anthracnose on fruits from trees sprayed with PGRs and fungicides, and subjected to hot water dip (59 C for 1 minute). Fruits from all treatments when subjected to hot water dips had similar incidences of anthracnose (4.7- 17%) and SER (0.7- 3.3%). Anthracnose severities were likewise similar ranging from 0.2- 0.8%. However, hot water dip reduced the incidence of anthracnose and SER and severity of anthracnose (Appendix 2.2)

Activity 2.3. Investigate the efficacy of endophytes against anthracnose and SER

In the Philippines, **Ugay, V.P. and Limbaga, C. Jr. A.**

Sixty (60) endophytic fungi were isolated from various mango tissues but grouping based on cultural appearance in PDA and microscopic structures reduced the number to 32. These were screened for pathogenicity to 'Carabao' mango fruits then the non-pathogenic isolates were tested for antagonism against the postharvest pathogens. None of the endophytes showed "halo zone" when paired with both pathogens indicating that the endophytes do not produce antifungal products. The invasive endophyte coded as FSLDf was chosen for field testing against mango pre and postharvest diseases because of its competitive ability *in vitro*. It overruns the pathogens growth rapidly, exploiting the space and nutrients therein (Appendix 2.3). Correct taxonomic identification of FSLDf is yet to occur.

Characteristics of the endophytic fungus. FSLDf endophyte was isolated from mango flowers, soft stem, leaves, and developing fruit. Its presence in the mango tree appears to be systemic. It is fast growing, covering a plate of PDA in 24h (Appendix 2.3). It is non-spore forming in PDA and Carrot Agar. It grows very well on mango leaves and is able to fully colonize 100g (fresh weight) of sterilized mango leaves in 7 days.

Field spraying of FSLDf mycelial suspension at the rate of 1.7 kg colonized mango leaf tissues/200L water starting from panicle elongation did not affect flowering, blossom blight, and fruit set but significantly increased fruit retention (2.69 fruits per panicle) as compared to positive control trees (1.39 fruits per panicle). Fungicide treated trees had 3.44 fruits per panicle which was comparable to trees applied with FSLDf.

The FSLDf application improved fruit yield (38 kg/tree), which was comparable with the fungicides applications (37.5 kg/tree) when compared to control trees (no fungicide) which only produced 5.25 kg/tree (Appendix 2.3).

Postharvest observation of anthracnose and SER on fruits taken from trees subjected to the pre-harvest application of fungicides and FSLDf endophyte

Due to insufficiency of fruits collected from positive control trees, only fruits harvested from trees applied with fungicides and FSLDf were assessed. Anthracnose severities of fruits from trees applied with FSLDf (4.9%) and those applied with fungicides (4.3%) were comparable. The proportion incidence of anthracnose in fruits from trees applied with FSLDf (53%) and fungicides (64%) are likewise similar.

Fruits from trees applied with fungicides had 1.1% incidence of SER, which was statistically similar to the FSLDf treatment, which produced 3.33% SER incidence (Appendix 2.3).

It should be noted that FSLDf was applied to mango trees starting at bud break. Considering that the colonization process involves several steps such as host recognition, germination, penetration of the epidermis, growth and colonization, the timing of application of FSLDf was relatively late. Endophytes may need a longer time to fully colonize and establish in the host prior to the build-up of pathogen inocula, which is thought to reach a peak during the flowering stage because of abundance of food in the form of succulent blossom tissues.

When applied as a postharvest treatment to fruits sourced from a commercial mango plantation, FSLDf failed to prevent or reduce anthracnose incidence and severity and incidence of SER. Disease ratings of control fruits, *Bacillus subtilis*-treated and FSLDf-treated were all similar (not included here). It is possible that the population of pathogens present in the fruits were very high making the treatments ineffective. It was also thought that the application of FSLDf as a postharvest treatment is not effective because of the same reason stated earlier (applied too late). If the mechanism of action of the endophyte is competition, it needs to establish in the harvested fruit and this requires time. Since the postharvest pathogens, have already established in the fruit in advance while the fruit is still developing, FSLDf will not be able to compete with both postharvest pathogens. More so, the pathogenic fungi have already penetrated the fruit peel and just await ripening to resume its activity in the fruit.

In Australia **Trevorrow P.**

Selection and Isolation of Endophytic fungi:

A range of fungal organisms were recovered from symptomless panicles (Table 2.3.1)

Potential pathogens for examples *Neofusicoccum* and *Colletotrichum* species were also recovered from symptomless panicles.

Bioassay for screening endophytes: It was observed that symptom development of anthracnose was reduced by both *Diaporthe* and *Pestalotiopsis* species compared to all other endophytes tested. Further development or refinement to the bioassay would need to be conducted and to evaluate other commercial products containing *Beauveria bassiana* or *Metarhizium* spp. There may be potential to modify the level of endophytic fungi present in trees to reduce post-harvest fruit losses.

Activity 2.4. Develop a best practice economically viable disease control package

Potential chemical and biological fungicides were documented and delivered to Dr Notarte to be updated and implemented with the best bet package. The biological fungicides (Serenade, Timorex Gold, and MPQ) and one chemical fungicide (ICC) were effective control for the pre and post-harvest fungal diseases and were recommended for use to the extension team.

Table 2.3.1. List of fungi recovered from mango panicles.

Organisms recovered from mango samples								
Accession no.		Cultivar		Collection date		Identification		
J3721 (BRIP 60069)		KP (Mackay)	Endophyte (panicle)	27/09/2013		*Melanconium* sp.		
J3722b (BRIP 60070b)		KP	Endophyte (panicle)	26/09/2013		*Pestalotiopsis* sp.		
J3722c (BRIP 60070c)		KP	Endophyte (panicle)	26/09/2013		*Pseudoplagiostoma* sp		
J3824 (BRIP 61002)		Keitt	Endophyte (panicle)	26/09/2013		*Fusarium pseudocircinatum*		
J3828 (BRIP 61112)		R2E2	Endophyte (panicle)	26/09/2013		*Pilidium concavum*		
J3729 (BRIP 60072)		*Mangifera laurina*	Fruit rot	26/09/2013		*Diaporthe* sp.		
J4086a		KP	Stem cankers	13/05/2015		*Neofusicoccum* sp.		
J4086b		KP	Stem cankers	13/05/2015		*Colletotrichum* sp.		
J4086c		KP	Stem cankers	13/05/2015		*Cytosphaera* sp.		

Objective 3: To improve fruit quality, size and yield by optimising nutrition and canopy management.

Activity 3.1. Field trials will be conducted which will optimise nutrition and canopy management techniques with the aim of improving fruit quality, size and yield.

Ms Graciela L. Caballero and Mr Eddie Batoctoy (Philippines).

Study 1 : Effect of Light Interception under Pruned Trees

Highest number of shoots per tree, early shoot emergence and longest shoots were observed from the canopy area which received full light interception (see appendix 3.1).

Study 2 : Canopy Management Verses No Canopy Management

Highest number of fruits/tree and heaviest fruits/tree were obtained from trees applied with the canopy management protocol (Figure 3.1.1). Full yellowing of fruits were attained 7 days after harvest. Low yield was obtained at this first stage of the canopy management trial. Evidence of stem end rot and anthracnose diseases were observed early on fruits obtained from up-pruned trees and SER infection elevated to 100% in all fruits 7 days after harvest, while 23% of fruits from pruned trees showed no infection at 7 days after harvest (Figure 3.1.2).

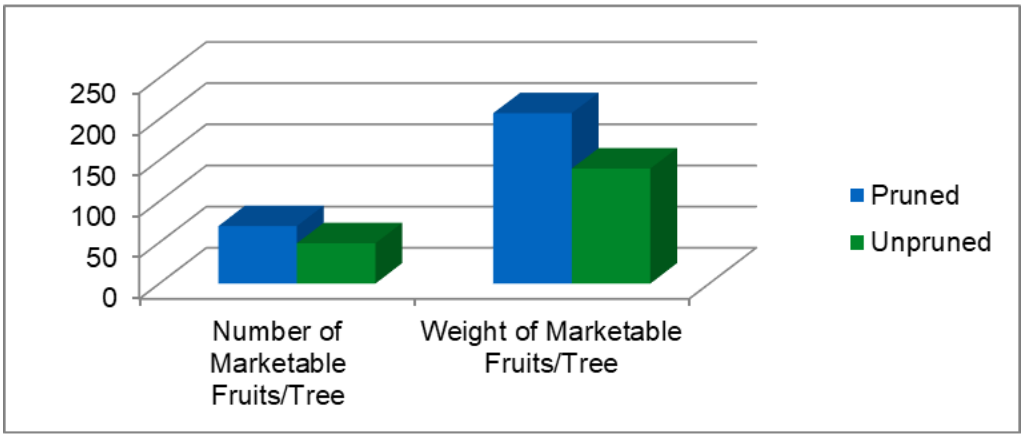


Figure 3.1.1. Number of fruit (per tree) and yield (Kg/tree) for pruned and unpruned trees.

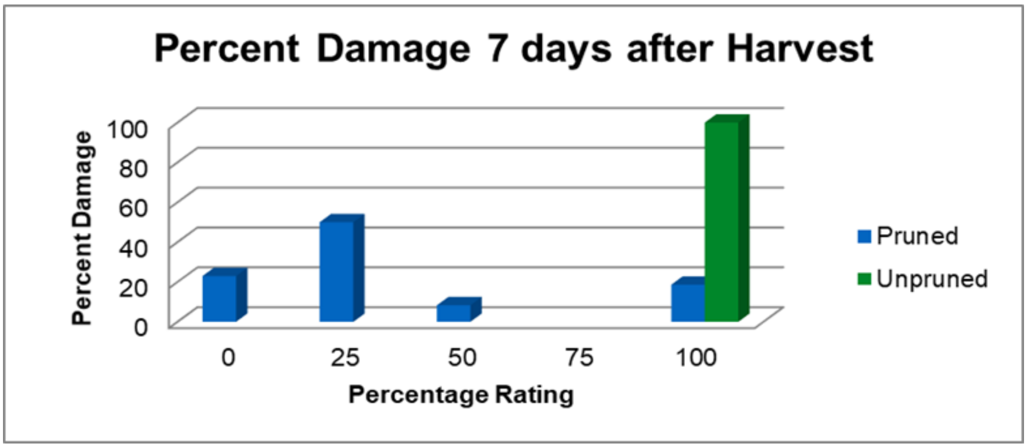


Figure 3.1.2. Proportion of fruit damaged (% damage) by disease incidence 7 days after harvest for different visual disease ratings (0, 25, 50, 75, 100%).

STUDY 3: Canopy Management and Nutrient Optimization

The highest number of shoots/tree was gathered from fertilizer applied trees based on T1 soil analysis (SA) and T3 farmer's practice (FP) under canopy area with light interception. Under canopy area that received no light interception, longest shoots were observed from SA applied trees. The Longest and most vigorous shoots were observed from T1, SA applied trees in canopy with light interception while T2, the "recommended fertilizer" from the "Package of Technology" for mango applied trees produced the longest (but fragile-looking) shoots under no light interception area in the canopy.

The earliest days to shoot emergence was dominated by SA applied trees from canopy area with or no light interception.

There was no significant difference among treatments on fruit size (in terms of fruit length and width). There was no significant differences among treatments on the number of fruits, average weight of fruits and yield per tree. However, the numerical values alone indicated the SA applied trees produced the most number of fruits and yield per tree at 347 pieces and 100 Kgs, respectively. The lowest number of fruits were observed under the farmers practice treatment. No significant difference was found in terms of the average weight per fruit per tree. There were no significant differences between treatments in terms of fruit size classification (extra large, large, medium, and small). However, the numerical values indicated that the highest percentage of fruits produced were recorded as under medium and small sizes.

Overall results in terms of fruit quality from all treatments can be summarized as good in terms of visual (Visual Quality Rating-9, no blemish) and for consumption (as result of the taste test). There was minimal malformed and damaged fruits at harvest (only 1%).

Daily recording of rain (frequency, lightness or heaviness, time), sunny days, cloudy days, etc., served as guide for the farmer and the researcher to intervene with program activities such as flower induction, spraying of pesticides and saved labour.

The income assessment demonstrated a 48% reduction in expenses per tree after providing the canopy management intervention from ₱1,452/tree expenses prior to intervention (Appendix 3.1).

Activity 3.2 Develop a nutrition and canopy management package that aims to improve fruit quality, size, yield and efficiency of harvest

15 mango growers were trained under the Farmer's Field School adopted pruning. The demonstrated technology was presented through training grower training sessions (in coordination with the ACIAR Davao Sur Extension Team) to another 96 mango orchard owners and a few spray contractors. A yearly farmer's forum was conducted by SPAMAST, a field day was conducted which focused on the actual demonstration of the canopy management during the second pruning activity in the research area.

Activity 3.3. Investigate harvesting tools and operations to maintain fruit physical appearance (solutions to control sap burn).

Dr Ana Notarte (Philippines).

The conventional tool had the highest proportion of fruit fall (3.41%) followed by tool B (with blade alone) with 1.68% The lowest proportion of fallen fruit was from tool A (with a blade and cable), with 1.20%. The conventional tool produced the highest number of fruit with sap stains (9.58%), while tool A had the lowest sap stained fruits (2.18%) (Table 3.3.1).

Tool A was also the most time efficient harvest aid. The newly developed tools must be refined as to the size of the basket or (fruit catchment) and the round bar used that causes some bruises in the fruits.

Table 3.3.1. Mango fruits harvested with the use of different harvesting tools.

Indicator	Conventional Tool	Tool A	Tool B
No. of fruits harvested	991	1,147	973
No. of fruits fallen(cracks)	35	14	17
Percent fruit fall (%)	3.41	1.20	1.68
Presence of sap in the fruits	95	25	40
Percent fruit with sap (%)	9.58	2.18	4.11
Time consumed in harvesting (min.)	251	214	204
Ave. minutes consumed in harvesting /fruit	0.25	0.19	0.21

Activity 3.4. Investigate the effects of early establishment training frameworks on tree architecture, growth and yields (Australia)

Ibell P and Bally I.

Experiment 1 – Alternative training systems for mango

Yield at 4 years old

Orchard yields for the alternate training systems were higher at 4 years when compared to the conventional training systems at the same age (Table 3.4.1). Further detailed results can be found in appendix 3.4.

Tree and orchard canopy volume (m^3)

While there was no significant difference for tree canopy volume between the different alternate training systems for 2016, 2017 or 2018, the canopy volumes per ha were also not significantly different for the alternate training systems. However, the canopy volumes per Ha for the alternate training systems were vastly greater when compared to the conventional training systems for both 2016 and 2018 (Table 3.4.2). In most cases there was nearly 6 times more canopy volume in the high density alternate training systems compared to the conventional training systems.

Orchard light interception 2017

By 2017 the interaction of training system and variety was significantly different (p=0.002) where the NMBP 4069 and Keitt varieties had significantly lower light interception than NMBP 1243 and Calypso when grown as Cordon training system (Figure 3.4.2). For the espalier TS, NMBP 4069 and Calypso had a significantly lower mean light interception than NMBP 1243 and Kiett. Calypso trained in the Palmette TS system had a significantly higher mean light interception than the other varieties with NMBP 4069 having a significantly lower mean than both NMBP 1243 and Calypso. In addition, the alternate training systems had approximately 100- 150 % more light interception than the conventional systems at the same age.

Tree size

When comparing the alternative training systems to the low density conventional systems, tree canopies were thinner (by approximately 50%) (NMBP 1243 - 105 cm; Calypso - 102.5 and Keitt – 103.8 cm compared to 238.1, 200.3 and 204.2 cm respectively) and stems were approximately 20% smaller as in the high density plantings (NMBP 1243 – 100 cm^2; Calypso – 79.0 cm^2 and Keitt – 89.6 cm^2 compared to 151.77, 97.1 and 112.56 cm^2 respectively).

Table 3.4.1. Orchard yields (t/ha) for three and half year old trees of NMBP 1243, NMBP 4069, Calypso and Keitt varieties under different training systems (palmette, espalier and cordon) compared to four year old conventional trained mango trees planted at low density. Results are compared to trees of a similar age in an adjacent experiment trained with a conventional training system, and planted in a commercial type, low density configuration.

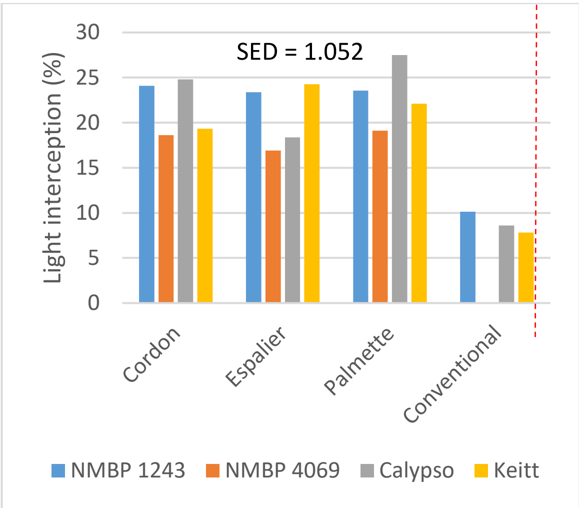
Density	Training system	NMBP 1243	NMBP 4069	Calypso	Keitt
High	Cordon	21.367 ab	21.972 ab	30.646 bc	49.547 d
	Espallier	16.554 a	26.361 ab	29.820 bc	64.041 e
	Palmette	27.034 ab	28.154 ab	41.624 cd	46.194 d
	P value	0.019			
	Sed	5.7935			
	Lsd	11.8271			
Low	Conventional	4.7	-	7.6	9.1

Table 3.4.2. Tree and orchard canopy volumes per Ha for different Mango varieties in June 2016, 2017 and 2018 compared to a four year old conventional training systems planted at Walkamin, Far North Queensland, Australia.

Year		Cordon	Espallier	Palmette	Conventional low density
2016	Pred mean	3163	2875	3072	560
	P value	0.864			
	SED	543.9			
2018	Pred mean	3781	4232	4681	801
	P value	0.073			
	SED	220.3			

Times to train and prune the different training systems

The results of pruning and training for 2016 and 2017 show that the cordon systems took less time to prune compared to the conventional low density, Espalier and Palmette systems. The mean times for bending and training branches showed that the Espalier, Palmette and conventional TS took similar times to prune, but that the espalier TS took slightly longer to bend shoots per tree, being 28 min compared to 22 min.



(a) (b)

Figure 3.4.2. Mean light interception results for (a) 2017 in the Mango planting systems experiment. Each Training System is compared to the means for the low density conventional systems. The SED represents the standard error of the alternate training systems, not including the conventional low density system; (b) An example of an unpruned mango tree prone to lodging and branch breakages.

Experiment 2 – to prune or not to prune

Pruning had significant effects on a range of mango architectural traits including the number of 2^{nd} order growth units, proportion of terminals that were vegetative (greater in pruned trees) and the average number of growth units on a branch (greater in unpruned trees). Yield was also greater in the unpruned trees (pruned Kensington Pride 21.35 kg vs unpruned 50.34 kg), and yield per ha (pruned KP 23.72 vs unpruned 55.94).

Variety was a significant influencer of tree architecture. For example, architectural traits influenced by variety included the total number of fruit per tree, fruit weight per tree and yield per ha, 0^{th} and 1^{st} order number of branches, number of terminal growth units and number of flowers, 2^{nd} order average number of growth units, average number of growth units per order and the total sum of growth units per tree.

Discussion

Yield improvement

Alternate training systems for mangoes produced considerable improvement in the yield of trees at 4.5 years of age compared to conventional training systems. However, the increase was at the orchard level. Increasing planting density of trees per ha also led to an increase in canopy per hectare. Increased canopies per ha have the potential to increase the light intercepted by trees across the orchard, leading to higher orchard productivity.

Vigour control and redirection of energy into flowering

The alternate training systems also offered a method of vigour control as measured by reduced stem cross-sectional area. This allows trees to invest energy into growing more flowers and fruit and less vegetative shoots. The training systems also led to improved percentage of flowering terminals and a thinner canopies, which have been associated with better light diffusivity throughout the canopy and increased fruit quality in other trellised tree crops.

Other potential efficiencies of high density orchards

While the alternate training systems do come with some increases in the initial time to train and prune these systems, they offer other potential benefits. These include increasing production efficiency such as the time saved for general management, including harvesting from the ground or mechanically, increased spray and fuel efficiency from reduced area across the same amount of trees and better light utilisation and distribution in the canopy leading to potentially better fruit quality. Finally there is some benefit of the trellising systems for cyclone prone regions, where trees on trellises have a better chance of recovery compared to trees not on trellises.

Pruning and varietal selection for improved tree health and yield

With respect to pruning, although yields were slightly higher without pruning, unpruned trees were highly susceptible to branch breakages. These breakages damaged the stem and left the tree with large open wounds and missing branches leaving the tree unbalanced and susceptible to lodging and further breakages. The opportunities to use variety selection that may help to increase yields early in an orchards life should also be considered when establishing new orchards.

Objective 4: To improve mango farmer livelihoods and profits through, developing and implementing an integrated management package of "best practices" with mango farmers.

Activity 4.1. Develop a communication and research adoption plan.

Dr Ana Notarte (Philippines).

The communication and research adoption plan was developed and presented at the inception meeting. The plan essentially outlined the methods and activities as detailed in activities 4.2 to 4.5.

Activity 4.2. Develop and document a best practice management package with farmers and contractors. Implement the best bet package using farmer clusters.

Dr Ana Notarte (Philippines).

The survey showed the following mango common practices:

A. Demographic Profile

Survey was completed with 259 respondents; with an average of 50-60 years old. Mostly males managed the farms and owned the land with an average land area of 3.13 hectares. All of the farms were under contract scheme, where 70% of the produce goes to the contractor whilst 30% goes to the owner.

B. Farm Location

Most of the farms of the respondents were located in rolling topography and some in undulating areas. The distance between planting ranged from 10 x 10 to 12 x 12 m, no fence and not aware of waste disposal and segregation of bio and non-biodegradables. Most owners do not have any shed/warehouse access to place their agricultural inputs.

C. Cultural Management Practices

Pre-conditioning activities

- Most of respondents used formative/centre pruning once a year and one province did this right after harvest;
- Hygiene and fertilization was generally implemented once a year after pruning;

- Paclobutrazol application was not practiced by many respondents.

Flower Induction

- Most of the respondents use the colour and brittleness of the leaves as their indicator for timing of flower induction;
- Calcium nitrate was the common flower inducer used at the rate of 5 kg/200L water.

Pest and Disease Management

- All of the surveyed respondents applied pesticides without using pest monitoring prior to spraying. Selection of insecticides was based on the calendar method.
- Most of the respondents used a “cocktail” type of mixed pesticides, with 1-2 insecticides and fungicides in each spray application.
- Mindanao respondents sprayed 10-12 times per cropping season while Visayas respondents sprayed an average of 6-8 times and Luzon respondents sprayed 5-6 times per season.
- Major insect pests surveyed were leafhopper, cecid fly, thrips and fruitfly;
- Common diseases mentioned were blossom blight, scab, anthracnose and sooty mould.

D. Yield Component

- From their management practices, they reported 80% fruit set, 19% fruit drop, 66% fruit retention and 80% fruit retention after bagging

E. Post Production

Harvesting

- Maturity indices were observed by counting the number of days from flower induction;
- Harvesting was generally between 115-120 day old fruits and harvested at 8AM.

Fruit Quality

- All respondents completed fruit sorting in the field
- They reported 85% of their produce was marketable

Packing

- All of the packaging was done in the field; of the nine provinces surveyed, only Davao del Sur used fungicide dipping for the management of post harvest diseases.
- They use cartons, bamboo baskets and plastic crates for packaging materials
- They use calcium carbide for ripening of fruits retained for retail

Marketing

- Most of produce was directly sold to local markets except Davao del Norte, Davao Oriental and Davao del Sur, which were sold to exporters
- For local markets buying is “all-in”, while for exporters it was sorted into class A and B.

Activity 4.3. Implement the best bet package with farmer clusters; evaluate and refine the package as required (PC).

Dr Ana Notarte and Julia D. Sagolili (Philippines).

After consolidating common best management practices from the survey data, and some refinement of the package, the first “Mango Season Long Training” was conducted (February – August 2016). The training was participated by both technical staff (Agricultural Extensionist) and mango growers not only in the Island Garden City of Samal but in Region XI-Davao Region namely the provinces of Davao del Sur, Davao Oriental and Region X.

For Samal Island, eleven clusters, two representatives of each cluster (22) were selected for the first batch of the mango season long training, together with five technical staff from the Samal City Agriculturist Office. Other participants were from the Provincial Agriculturist Office (1), two farmers from Davao del Sur, one from Davao Oriental with one farmer and two technical staff from Misamis Oriental; with nine mango farmers, a total of 46 participants; of which 34 completed the 10 day intensive training and hands-on/field activities or 74% satisfactorily completed all the necessary activities as part of the training course, while two attended the intensive training with partial field activities (4%).

A Second round of mango season long training was conducted in February 2017, again participated by mango growers from Samal clusters, Panabo City, New Corella, Tagum City, Sto. Tomas, Davao City and Carmen, North Cotabato. Five Agricultural Extentionists from Samal, Provincial Agriculturist and Panabo City also participated in the season long training. The mango site was located in Del Monte.

There are now 21 cluster farmer groups with 21 trained cluster leaders (10 Davao del Sur + 11 Davao del Norte) that have developed specialist leadership training/skills and have now acquired new knowledge in mango best management practices (BMP). They have the skills/structure to provide future Mango BMP training to others. A total of 185 mango growers (75 Davao del Sur + 110 Davao del Norte) have participated in farmer field school season-long training. These growers acquired the latest knowledge in mango BMP and have committed to make changes to their businesses to improve farm profitability. There are another 73 cluster groups with 73 trained leaders (51 Davao del Sur + 43 Davao del Norte) being developed, that will be up and running in the next 1-2 years.

Activity 4.4. Develop capacity and train extension and scientific staff to deliver best practice packages

From the season long training, there were 50 extension officers (15 Davao del Sur + 35 Davao del Norte) that were trained in extension methods, training techniques, best practices and new R&D innovations to improve their capacity to train farmers and to improve farming practices. Capacity and training activities for extension and scientific staff are listed in detail in section 8.3 (Capacity Impacts).

Activity 4.5. Investigate options for a repository of advisory and extension information for mango farmers and others

Dr Geoff Dickinson DAF and Dr Ana Notarte PAGRO (Philippines)

Exploration of the discontinued PCAARRD Mango Information Network website and the Davao del Sur and Davao del Norte Provincial government websites, found all three Philippines sites were unsuitable as mango information repositories. This highlights the long-term difficulties, high costs and risks of relying on a designated website as a repository of mango information in the Philippines. YouTube and other independent carriers may provide a free and longer-term solution, however these are poorly regulated and often can be difficult to locate specific resources, without accurate reference numbers or resource titles. This activity concluded with no highly suitable options identified as a repository for mango information in the Philippines.

A number of electronic education information campaign materials were initially produced (leaflets into video) as a tool to facilitate technology dissemination. An ACIAR project information video for HORT/2012//019 “Integrated crop management for mango production in the Philippines” was completed and made publically available on YouTube in 2018 with nearly 1000 views in the first 6 months. Another grower instruction video “It’s not the size of the tree that counts” was produced by the Davao del Norte Provincial Agriculturists Office (PAGRO) in 2017. This video covers recommended practices and grower case studies of mango canopy management in older orchards in the southern

Philippines. The video has been used at numerous workshops and has had some limited local distribution. It awaiting final PAGRO approvals before it is planned to be loaded to YouTube to be made publically available to a wider audience.

A new grower manual “Mango protocol for best practices for off-season production” has been produced by the Davao del Norte Provinical Agriculturists Office (PAGRO). This draft manual details a package of mango technology from pruning/canopy management, fertilization, paclobutrazol application, flower induction, pesticide use and harvesting. The manual draft is currently under internal review by PAGRO, before it can be publically released.

Activity 4.6. Develop electronic extension delivery methods for the Australian mango industry

Dr Geoff Dickinson DAF

Website Delivery of Electronic Resources

Feedback from mango industry stakeholders throughout this project was that a “One-stop Shop” website would be the most desirable vehicle to deliver electronic information resources to the Australian mango industry. The AMIA website is considered the most suitable repository for mango information resources as it is grower focused, is regularly updated and is not restrained by government protocols which may restrict the sharing of information or the listing of external information resources.

In 2014 the AMIA website was highly functional, and contained the majority of best available and current electronic mango extension resources available to the Australian mango industry at the time. The complete redesign and restructuring of the AMIA website throughout 2014, resulted in the removal of most of these electronic resources at this time. The unsuitability of the new web-site structure, combined with a lack of resources to update, reformat and load information has resulted in little of these existing available information resources being reloaded onto this site over the past 4 years (2014-2018).

The variable performance of the three Australian websites (AMIA, QDAF and NTDPIR) over the 4 year duration of this project provides a sound warning that these systems must balance continuity and growth to serve effectively as a long-term information storage and delivery tool. The AMIA website with its grower focus, independence from government restrictions and regular maintenance program sets it as the most suitable website repository for mango information resources. However, the removal of the majority of existing grower information resources during website restructuring in 2014 and the limited progress to date to reload these valuable information resources, indicates greater prioritization and long-term resourcing of website content needs to occur. The new AMIA website needs considerable redevelopment before it can be considered a true “one stop shop” for mango information and extension resources.

Videos for mango communication

‘How-to’ and ‘training’ videos have proven to be valuable resources for Australian mango growers and are particularly useful for viewing new techniques, training workers at the start of the season, or for refreshing knowledge of irregularly used techniques. Information videos of new innovations, products, industry initiatives and research activities are other common video topics. The Australian Mango Industry Association, and their partners including Queensland’s Department of Agriculture and Fisheries have produced a number of mango videos. These include: nutrition management, orchard sprayer application, picking, packing and news on R&D initiatives and communication activities.

Australia’s most successful mango extension video, “Mango picking – How to do it right” remains a key grower training resource explaining all aspects of mango picking, including picking technique, optimising fruit quality and maintaining workplace health and safety. This 11-minute video was released in 2014 and was produced by DAF and AMIA, with funding support from Horticulture Australia Ltd and the Queensland Government.

Hosted on AMIA's Ausmangoes1 YouTube channel, the video has now amassed over 55,000 views over the past 4 years. A summary of the videos YouTube parameters are summarised in the article "Videos for mango communication" in the industry publication Mango Matters (2017, V29, p19). The metrics reveal some interesting statistics:

- Main viewer locations: India (23%), U.S.A. (20%), Australia (12%), Philippines (6%), U.K. (3%), Malaysia (3%) and Pakistan (2%).
- Viewer gender: Male (78%), Female (22%).
- Average view duration: 4:10 minutes.
- Device used: Mobile phone (44%), Computer (41%), Tablet (11%), Smart TV (4%).

In Australia this video is viewed over 2,000 times each year. Australian viewing peaks have coincided with the mango harvesting period (October – February), with the highest viewing month occurring in January 2017. The promotion of this video at the commencement of each Australian harvest season, via the AMIA communications program, has also likely contributed to increased views over this period. In Australia the average view time of this video is high at 5:18 minutes, which indicates that most viewers found the content useful, watching a considerable proportion of the video at each occasion.

The "Mango picking – How to do it right" video is an example of how video can be used as a highly successful electronic extension delivery method, with the ability to rapidly provide key information on demand, for both a domestic and international viewing audience.

Facebook for mango communication

At the start of this project it was recognized that the use of social media tools by mango growers and many stakeholders in the Australian mango industry (including researchers > 40 years old) was very low and that the suggestions of an "Australian Mango Blog" or "Australian Mango Grower Facebook" site would not have wide utilization across the mango industry. In order to explore the potential of Facebook as a new tool for electronic extension communication and to build capacity in this area, QDAF prioritised the development of over 20 mango information posts from 2014-2018 on the QDAF Queensland Agriculture Facebook site. This Facebook site aims to connect with primary producers and industry members, providing information about key issues, innovations, upcoming events and research outcomes in the state.The mango posts included an 8-month promotion "Queensland Mango Moments" where a monthly post was made updating the progress of the 2016/17 Mareeba mango season. Each monthly post corresponded to a particular operational practice (eg fertiliser, irrigation, maturity assessment) with a link provided to guide growers to the relevant electronic information resource for that practice. A summary "Queensland Mango Moments – a campaign by the Queensland Department of Agriculture and Fisheries" is presented in the industry publication Mango Matters (2016, V25, p12) (Dickinson 2016).

The use of Facebook proved to have some good potential as an electronic delivery method. The Queensland Agriculture Facebook site has over 6,000 followers and these followers were exposed to many mango stories that they may not have otherwise seen. An assessment of the 20 mango posts, determined that most posts received 50 likes and 10-15 shares. While it is recognised that the majority of followers were not mango industry stakeholders, it does indicate that Facebook is another useful tool that can be used to communicate mango information to a broader audience.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Objective 1: Entomology

The entomology work that commenced by UPLB is ongoing into other new projects. There is ongoing cecid fly research (funded by the Philippine Department of Agriculture); this work involves chemical pesticide control and resistance management (Oct 2017 to Sept 2019). The project work on cecid flies has now extended to cecid fly taxonomic work outside of the ACIAR project. The entomology researchers from this project continue to collaborate with the Australian Cecidomyiida taxonomist Dr Peter Kolesik, which has included the taxonomy of the Philippine cecid flies (compared to other species around the world) in workshops and publications. The results were presented at the XI International Mango Symposium in Darwin Sept/Oct 2015. This work has included collaborative work on the taxonomic state of Mango cecid flies in the Philippines, Australia and other countries. This work is being used by researchers globally to understand the distribution, biology and control of mango cecid flies. Dr Medina's work has confirmed that one New Guinea (and now Australian) cecid fly species, *Procontarinia pustulata*, is also one of the same species that exists in the Philippines and the results were presented at the symposium (Medina *et.al*. 2015). This work was cited and used in another paper by Peter Kolesik *et. al.*, given at the same symposium titled "Mango gall midges on Australia's doorstep" (Kolesik *et.al*. 2015). There is potential further host specificity work on the cecid fly parasitoid. This would be beneficial for the Australian mango industry, for developing a future biological control program if/when the cecid fly becomes established in Australian mango production areas.

The ACIAR project demonstrated proof that mango thrips were resistant to commonly used pesticides in Mindanao; from this result, Dr Medina will be conducting ongoing research into resistance management of mango leafhoppers funded by a large international pesticide company. The mango thrips biology work has also now extended into other countries, with Dr Medina supervising a foreign student from Indonesia (Indonesian Government funded -Indonesian Tropical Fruit Research Institute), researching the population dynamics of thrips in Indonesia (Afandi and Medina 2013, Afandi *et al.* 2018). The thrips biology research has also extended into other crops. A UPLB Phd Student (Joeseph Quisado) working on mango thrips (*Thrips hawaiiensis*) has found it to be the same thrips pest as banana flower thrips. Consequently, the ecology work on thrips is now important to the banana industry, e.g. a large banana company (Tagum Agricultural Development Company Inc.) previously used a host plant (*Arachis pintoi*) as a cover crop, however this plant is known to be a thrips host (research from this ACIAR project), and is now being removed as a cover crop. Koppert Biological Systems (The Netherlands), are utilizing the research results from this ACIAR project (i.e. biology and ecology of cecid flies and thrips and pesticide resistance) and have started a research and extension project, "Holistic Biological Alternative for Sustainable Mango Production" (funded by the German Development Bank), with potential information distribution through CABI. Their project aims to find natural solutions for the mango agronomical problems and reduced use of chemicals for the control of mango insect pests.

USM entomology, have planned future work on thrips pesticide efficacy in banana (and other possibly other crops). Using university funding, three Masters Student projects are planned to complete more work on insecticide efficacy and the effects of pesticides on natural enemies. Five USM student graduates have gone on to work for pesticide companies and government agencies where they continue research pesticide efficacy.

In fruit fly research, the Area Wide Management component was not completed in this project due to budget restraints. However, the baseline data that was collected in this project is being used in another ACIAR/DAF funded fruit fly AWM project in the Philippines

(HORT/2015/042). The Monitoring Integrated Lure and Kill (MILK) method for managing banana spotting bugs in Australia is particularly promising and DAF is planning more research into this technique, which will extend beyond mangoes and into other crops, such as avocadoes, papaya, custard apples, macadamia and other crops.

Objective 2: Plant Pathology

During this project, USeP conducted research on isolating and screening endophytic fungi from mango, which was screened for its use as a protectant against pathogenic fungi. This work has wider scientific impacts, as the USeP work was then extended (with other funding sources) to also isolate more endophytes and conduct screening from banana, cocoa and papaya. This work is ongoing and continuing into the next 5 years. Two former USeP postgraduate students (MSc) are now employed in private industry for large corporate banana producers (The Marsman Estate Plantation Inc. and Tagum Agricultural Development Company Inc.), where they are continuing endophytic fungi research using the skills and knowledge developed during this project. A new USeP MSc project is planned which will continue the endophytic fungi research into mangos, which will work in another location in Mindanao and also look at protecting the flushing growth stage.

In the USM plant pathology component, the biopesticides (Temarax Gold™ and MPQ) that were trialled and found to be effective against mango diseases (anthracnose and SER), have also been tested in another crop (for coffee rust in coffee). USM masters students also tested the biopesticides on other crops, including: coconut, rice, banana and rubber. One large farmer is now undertaking private research on combinations of various biopesticides. There is potential for registration of Temarex Gold™ and ICC in multiple crops. From the skills and networks obtained during the ACIAR project, USM pathology technician Endralyn Catubay, is now a teacher/instructor at SPAMAST (a collaborating university), and is using those skills in her teaching (teaching more than 50 second year Batchelor of agriculture students per year). Ms Catubay has started an MSc and will research biopesticides as the subject for the thesis.

Objective 3: Canopy Management

The canopy management research work that was completed by SPAMAST in this project, has inspired the university to undertake further work in other tree crops; the Agroforestry Department is now researching similar canopy management techniques in breadfruit, using internal university funding. SPAMAST is also now planning a mango demonstration site (0.25 Ha) using medium density plantings and funding from the Commission on Higher Education (Philippine Government). Through the project work, the university staff identified a need for regular soil analysis; the laboratory was subsequently upgraded with necessary equipment with funding from the Commission on Higher Education (Philippine Government). SPAMAST is planning to continue mango canopy management research; they are utilising undergraduate research thesis projects, with ongoing research into mango canopy management & floral induction. There are plans for one Master of Agricultural Science student project in agronomy/canopy management and climate change. The canopy management research work that was completed by SPAMAST and the work in high-density orchards work in Australia (by DAF) has also inspired private ongoing research, into high-density plantings in Mindanao.

Objective 4: Extension

In the extension component, the highly successful “Cluster and Participatory Grower” extension strategy, that was developed and used by this project for the first time in Mindanao, has been adopted by concurrent Mindanao mango RD&E projects including new cocoa, coffee, banana and vegetable projects by PAGRO & OPAG in the region. This strategy was presented at the Asia Pacific Extension Network Conference Townsville, 2017, (200 attendees) as a model for other international extension projects (Dickinson *et al.* 2017).

A new scientific research trial facility; the Provincial Mango Research and Extension Centre (PMREC), San Isidrio, Babak, Island Garden City of Samal, was established as the premium mango research station facility in Mindanao for future RDE activities. There were 11 long-term Canopy Management Demonstration sites established on growers' properties (5 growers in Davao del Sur, 2 at SPAMAST Malita and 4 Samal growers) as valuable resource for future RDE activities. A high-density demonstration trial has been designed and the first trees were planted at Talicud Island/Samal Island in July 2017. It has 3 densities of tree planting, (8x8m, 8x4m, 4x3m trellis).

8.2 Capacity impacts – now and in 5 years

There have been over 700 growers, contractors, industry representatives, scientists, students and extension staff that have receiving some sort of training from the project. This training has occurred through workshops, lectures, farmer field schools, field days, conferences, participating in research trials, student projects and receiving extension materials. Over 580 growers and contractors and at least 92 extension staff received some sort of training. More than 90 students have had some sort of project involvement and training, with 40 of those students having significant involvement (thesis, technical assistant training, or other major involvement).

Project Staff, Science and Extension Training

Within the project and project teams, there were 24 researchers directly connected with Mindanao mango growers via the farmer field schools, other extension activities and on-farm trials; which has improved the researcher's knowledge of current industry practices, industry needs/priorities/ impediments and their ability to develop future R&D priorities and projects. A number of other scientific and extension staff that were not working directly on the project also received training.

The scientific and extension project staff and students have received training in experimental design and statistical analysis, which has improved their capacity to design trials and experiments and their capacity to analyse data to a rigorous scientific standard. The training on experimental design and statistics was conducted on August 1-3, 2016; it was conducted by two Australian DAF Biometricians (Dr Carol Wright and Mr Bob Mayor) and having 19 project scientific and extension staff participants. The workshop was co-funded by the Crawford Fund and DAF. Three of the graduate students (from UPLB) that completed the training, went on to replicate and teach the same course to seven (7) other graduate students and 12 undergraduate students from UPLB. The course was also adopted by the SPAMAST biometry teaching unit and is being taught to approximately 50 undergraduate students per year.

A training workshop on canopy management, tree architecture and tree-training systems was given by Dr Paula Ibell (DAF), in Davao August 2015, to 10 project staff from the extension and research teams. Dr Geoff Dickinson (DAF) delivered a training workshop in extension techniques at SPAMAST Campus Digos, Davao del Sur. The training was to 21 participants, including extension staff (9), and university researchers (12) on February 22nd 2016. Dr Dickinson also delivered a mango/plant nutrition workshop to 15 Filipino researchers and extension workers in Davao, May 2015.

During the project, Dr Medina has gained capacity, particularly in the area of cecid fly taxonomy. Dr Medina attended the XI International Mango Symposium in Darwin (Sept 2015) and participated in a session on ACIAR research, and workshops with collaborations on cecid fly, and fruit fly. Dr Medina has continued to work with Dr Peter Kolesik on cecid fly taxonomy.

Ms Edralyn Catubay (was employed as the USM plant pathology technician on the project) is now a teacher/instructor at SPAMAST (another project collaborator), and uses the statistics, experimental design, plant pathology and other skills that were learnt from the project in her teaching and own studies (completing an MSc on biopesticides).

Likewise, Jayson Suhayon (USM entomology technician on the project) is now employed as a teacher/instructor at the Sultan Kudarat State University and is using similar skills that were learnt from the project in his teaching.

Students

More than 90 students have had some sort of project involvement and training, with 40 of those students having significant involvement (thesis, technical assistant training, or other major involvement). Student thesis titles are listed in section 10.2.

From this ACIAR project, Dr Celia medina from UPLB trained (now graduated) two MSc entomology students and one undergrad student thesis was completed. An MSc graduate (Ms Jena Joy) working on thrips biology, is now working on the pesticide Mode Of Action (MOA) classifying/labelling for the National Crop Protection Centre (Philippine Government). One other PhD student (Joeseph Quisado) is ongoing PhD and due to complete in 2019; after which he will return to the USM faculty teaching. At the beginning of the project, Mr Quisado was working on the USM entomology component, but was selected by USM and UPLB for PhD training.

From USM, Dr Conrado Evangelista trained four (4) undergraduate entomology students and one MSc student. These students are now working in related fields (e.g. on pesticide trials), one in a large pesticide company and four others working for government departments. The research outcomes on pesticide efficacy have been included in recommendations to the extension teams.

At the USM Dr Jaime Silvestre trained 15 undergraduate students (plant pathology projects) and two MSc. (crop protection) students in mango plant pathology (bio-fungicides for managing anthracnose and SER). All graduates are now working in the field (government agencies, private companies, and one mango farming contractor).

At USeP, the ACIAR project and Dr Virgie Ugay supported two (2) graduate students (1 PhD and 1 MSc) dissertation/thesis and trained two (2) undergraduate students (BSc.Ag.) as laboratory assistants. As part of the project 11 MSc.Ag. (crop protection) students were trained and one MS& Ag (Soil science). Of the graduates; one is now an extension worker at the Agriculture Training institute, one is a technical manager for Del Monte. Other graduates are expected to move into industry.

Through Ms Graciela Caballero at SPAMAST, 50 undergraduate students received general mango agronomy training; the students participated in the mango trials, which were also used as demonstrations for teaching (e.g. learning experimental/trial design). Two masters students and one faculty member were trained (hands on) in mango canopy management research. The students are now working in private companies (pesticides company, consultant), in mangoes (& other crops) and recommending canopy management to growers. Future SPAMAST undergraduate students will gain capacity in agronomy and canopy management from the staff involvement/capacity building learnt from this ACIAR project. Ms Caballero is continuing to teach/research undergraduate student (Hort major) thesis topics in mango canopy management (5 students per year for 5 years) and general training of approximately 50 undergraduate students per year, (laboratory research techniques, orchard agronomy management etc.). Five (5) other SPAMAST faculty members received training/capacity in canopy management & agronomy.

Farmers and other Extension Officers

Over 580 growers and contractors and at least 92 extension staff received some sort of training.

There were 50 extension officers (15 Davao del Sur, 35 Davao del Norte) that were trained in extension methods, training techniques, best practices and new R&D innovations to improve their capacity to train farmers and to improve farming practices.

There are now 21 cluster farmer groups with 21 trained cluster leaders (10 Davao del Sur + 11 Davao del Norte) that have developed specialist leadership training/skills and have now acquired new knowledge in mango best management practices (BMP). They have the skills/structure to provide future Mango BMP training to others. There are another 73 cluster groups with 73 trained leaders (51 Davao del Sur + 43 Davao del Norte) being developed, that will be up and running in the next 1-2 years. A total of 185 mango growers (75 Davao del Sur + 110 Davao del Norte) have invested their time and money in farmer field school season-long training. These growers acquired the latest knowledge in mango BMP and have committed to make changes to their businesses to improve farm profitability. As part of above the training, the Australian DAF staff conducted individual workshops on: mango tree nutrition, canopy management and tree-training (pruning trees to productive form), extension training techniques, Integrated Pest and Disease Management, chemical safety and insecticide resistance management. Within the "Season Long Training program", workshops were also delivered by the collaborating mango projects in post-harvest (HORT /2012/098) and value chains (AGB/2012/109).

SPAMAST trained 17 extension technicians (from 5 different municipalities) and 268 farmers and contractors from Regions 8 (Caraga) and 11 (Davao), in canopy management skills. SPAMAST also conducted a field day at Digos (Davao del Sur) with more than 25 farmer/industry participants. As part of their farm visits to Davao del Sur, the Australian DAF staff had recommended accurate record keeping to farmers; one grower believed that this simple strategy has allowed them to adapt to climate change. This particular farmer has been included in extension/ lectures to the Davao del Sur farmer field schools. Other growers involved in ACIAR trials/demonstrations will also be involved in future extension in Davao del Sur (SPAMAST is looking into various funding sources). One SPAMAST staff member has adopted the canopy management on his own farm, which is now used as a demonstration site. Through involvement in the project, five (5) USeP faculty members, are now also growing mangoes.

Dr Medina (of ULPB) and the Department of Agriculture (Region 12) also conducted training on thrips and cecid fly management on June 15-16, 2016 in South Cotabato. This was attended by 35 farmers and local government technicians. In June 2018 in Davao del Sur, Dr Medina trained another 56 farmers and 50 teachers and agriculture students in Mango Pest Management.

Public access to the new mango best management practices is estimated to benefit at least 5000 other mango growers in Mindanao with the next 5 years.

Industry and other organisations

As listed above in the "Students" section, many of the students that have worked on the project, or worked with project staff, have used their new skills and are now employed in agricultural businesses, such as chemical companies, government departments and corporate farming.

The project cluster groups formed in this study have also been used by other non-project organisations (e.g. Bayer, Syngenta, Organic re-sellers) as a resource to communicate information and skills to mango growers. As previously mentioned (in Scientific Capacity), Koppert Biological Systems, are utilising the entomology research results from this ACIAR project and have started a research and extension project in Mindanao. This project will have a significant extension focus. The research production practices and disease work will also be used in another USeP extension project (funded by PCCAARD).

Infrastructure

This project provided the incentive for the purchase and development of the Provincial Mango Research and Extension Centre (PMREC), Island Garden City of Samal (Davao del Norte, purchased by local Government). This mango research station and training centre will provide ongoing research, teaching and demonstration facilities for the next 5 years and beyond. The project also assisted to set-up 11 long-term canopy management demonstration sites on other properties (5 growers Davao del Sur + 2 sites at SPAMAST [Malita], and 4 growers from Samal Island Davao del Norte). These sites are an on-going resource for future RDE activities and new activities.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The project aim was to increase the livelihood of smallholder mango farmers by increasing their profit margins. This was achieved in the following ways: increasing yields (per ha), increasing postharvest fruit quality (and shelf-life) through better pre-harvest disease control, decreasing losses (due to pests and diseases) and decreasing input costs (less pesticide applications).

Economic Impacts from Extension

Through the training and extension to farmers and extension staff, the farmers have increased their yields primarily through better canopy management. Prior to this project, most farmers did not actively manage their mango tree canopies (as found from the grower surveys), but only undertook minimal pruning (mostly dead/dying under-canopy limbs). Many farmers believed that any upper canopy pruning would reduce fruit yields. Consequently, trees were largely unpruned and canopies were allowed to close-over, grow to unmanageable heights and became unproductive; leading to widespread yield decline. Through the extension program farmers learned (through hands-on participatory on farm demonstrations) how trees could be maintained and pruned to produce higher fruit yields, whilst preventing canopy closure and subsequent yield declines. Having smaller more open canopy trees has also reduced the amount of pesticides and other chemicals (e.g. chemicals for flower induction) required and has improved the spray coverage and performance of the same chemicals. This improved spray coverage has resulted in higher yields due to improved chemical flower induction and using overall less chemicals (chemicals are one of the highest input costs), less off-target waste and less flower and fruit loss (yield loss) due to pests and diseases. The improved canopy/light management and pesticide spray coverage has also resulted in higher quality fruit. However, a negative impact from adopting high-density small trees could be that the fruit are easier to steal. While the pruning activities and associated costs have increased in some cases, these are not overall significant costs (e.g. compared to chemicals) due to the relatively low labour costs in the Philippines.

Through the extension program farmers have also adopted Integrated Pest and Disease Management, which has meant using less prophylactic calendar based broad-spectrum pesticide spraying and a more targeted approach; using pest monitoring, economic thresholds and more pest specific insecticides with the correct dose (rate).

The adoption of best practices and season-long training has resulted in yield improvements ranging from a 60 to 185% increase, with an average of 115% yield increase. Input costs increased or decreased with each grower, but net profits consistently increased from a 43% increase, up to an 11-fold increase.

The training and adoption of best practices has resulted in substantial improved yields & increased profit margins to the 185 farmers that participated in the season-long training, with the following examples:

- Farmer A, (Samal Island), has 178 trees and was the first grower trained. After 3 seasons their 10t harvest increased to 16t (56kg to 90kg/tree). A 60% yield increase.
- Farmer B, (Region 10) has 270 trees and after 3-4 seasons, their yield increased from 20t to 57t (74kg to 211kg/tree), a 185% yield increase. Furthermore, over 3 years they decreased their annual farm input costs by 25%, from ₱400,000 to ₱300,000 PHP (₱1,481 to ₱1,111 per tree). Net profit increased from $₱360,000 to ₱1.866M (based on prices at ₱38/kg), an increase of 418%. Reduced input costs were mainly due to

reduced spray and pesticide costs (6 sprays x 3 chemicals/spray [18], now down to 12 sprays x 1 chemical/spray). The labour is not a significant cost compared to the chemicals. The chemicals are a significant input expense and previously his treatments were not very effective. He now uses pesticides that are more specific and gets better results.

- Farmer C, (Davao del Sur) has 650 trees and after 3 years has increased yields from 35t to 95t (54kg to 146kg/tree), a 171% yield increase. Their input costs over this period actually increased from ₱900,000 to ₱2,000,000. However, gross returns increased from ₱1.3M to ₱6.5M and net profit increased by 11 times from ₱395,000 to ₱4.46M.
- Farmer D, (Davao del Sur) has 100 trees that are 15-18 yrs old. With the training, he has increased his yield from 7t to 13t total (70 to 130kg/tree) an 86% yield increase. He was earning ₱266,000 gross (at ₱38/kg), with expenses of ₱70,000 leaving ₱196,000 net. He is now earning ₱416,000 gross (at ₱32/kg), with expenses of ₱135,000, leaving ₱281,000 net; a 43% increase in net profit.

Economic Impacts from Research Outcomes

The adoption of some of the research outcomes has come quite late in the project, or will be adopted after the project has finished, but these impacts will continue for the next 5 years and beyond.

An income assessment from the canopy management work showed that undertaking selective pruning produced a 48% reduction in expenses per tree after providing the canopy management intervention from ₱1,452/tree expenses prior to intervention.

The thrips biology/ecology research results have provided the basis for developing future pest management strategies to manipulate farm habitats (e.g. removal or spraying plant hosts) to manage mango thrips, thus has potential to reduce input costs and improve fruit quality. However, more research is required to prove this concept and quantify the economic gains.

The thrips pesticide resistance work proved that thrips are resistant to certain chemical pesticides in Mindanao. Policy outcomes from this research will now include the pesticide industry having to adopt mandatory Mode of Action (MOA) classification on labels. Ongoing pesticide regulation, extension and farmer's education, should further improve farmer profit margins by reducing input costs (by farmer's no longer using ineffective pesticides) and providing higher quality fruit and less wastage.

Within the next 5 years, the replacement of ineffective pesticides and adoption of newer alternative pesticides, biopesticides, endophtyes, PGRs and other alternatives will further improve famer profits by reducing input costs, reducing waste, producing higher quality fruits and higher pack-outs. Farmers that adopt a pure organic certified system could receive a premium price for their fruit. Using PGRs with fungicides could reduce the number of spray applications (8 sprays to 4). The PGRs could to be registered and taken up by growers within 5 years. The research (see results) also showed that lower rates of some newer chemical fungicides (e.g. ICC) and biological fungicides such as Serenade (*Bacillus subtilis*), can be used to manage pre-harvest and postharvest diseases and are cheaper than using some conventional chemicals.

In Australia a trial was undertaken that looked at the efficacy of a new pesticide Sulfoxaflor (Transform™) against planthoppers and Fruitspotting Bugs in mangos. This data has now been used to obtain permits and registration for control of Fruitspotting and Banana spotting bugs in a number of crops including Mango. The availability of this product will improve the profit margins for Australian farmers for the next 5 years and beyond.

Return on ACIAR Investment

The project could deliver at least a 16 to one (16:1) return on investment for the total ACIAR investment in the next five years.

From the survey results, an average sized farm is approximately 240 trees (10x12m 3Ha), with an average yield of 63kg/tree. A 115% increase would boost yields to 135kg/tree. Input costs usually decreased for most participating farmers, however, assuming no net change in input cost (extra pruning costs were compensated by reduced chemical costs), and assuming prices remained at ₱38/kg, gross returns would rise from ₱2,394 to ₱5,130/tree, an increase of ₱2,736/tree ($68.4AUD/tree). For the average farm of 240 trees, this equates to an extra ₱656,640, or $16,416AUD/farm. Approximately 40% of the 185 farmers that received season long training are now self managing their farms and have adopted the best management practices. This would equate to 75 farms, gaining $16,146AUD average each, or $1.2M per year total, or $6M over 5 years.

However, some 50 trained extension officers and 21 farmer cluster leaders will continue to train other farmers in mango best management practices. It could be assumed that they will train at least another 150 farmers that will adopt best practices in the next five years, which would triple the return to $3.6M/yr or $18M over five years. This represents a 16 to one (16:1) return on investment for the total ACIAR investment (of $1.08M) or is a six to one (6:1) return on total project investments ($3.04M including all in-kind). This is a minimal figure as it does not include other factors such as improvements to fruit quality and associated price (difficult to calculate due to seasonal price fluctuations), improved market access, return on investments from R&D and wider extension and public access (e.g through field days, social media, public access, printed materials etc). This access will benefit at least 5000 other mango growers in Mindanao with the next 5 years.

As more growers adopt the best practices, economic gains will continue to improve for the next 5 years and beyond. Furthermore, by increasing the volumes of high quality fruit and reducing potential pesticide residues, the project has also increased export market potential.

8.3.2 Social impacts

Changes in equity

The project has resulted in changes to equity amongst the smallholder mango farmers in Mindanao. Numerous smallholder growers who have graduated from the extension training have taken control or plan to take control back of orchard management from contractors, empowering them to take control of their business and increasing their profitability. This change will result in greater small-holder farmer income, therefore lifting poverty in low income families and providing more resources for food, children’s education and health benefits.

Of the 110 growers trained in Davao del Norte (original season-long training program), prior to the training there were seven (6%) existing self-managers and 103 participants used contractors (94%). After the training, there are now 47 participants (43%) that are managing their own farms and 63 are still using contractors. However, the remaining 63 participants plan to manage their own farm within the next 5 years. In Davao del Sur, 30 (40%) smallholder growers (out of 75) are now managing their farms and are independent of contractors.

Cultural impacts

Grower co-operatives (e.g. Samal Island Growers Association SIMAGA, Samal Island Mango Marketing Cooperative SIMMCO) were supported and strengthened though the ACIAR project training and research activities. The project created the formation of grower clusters, which are essentially a new social group for continued learning and exchange of farming ideas. Previously farmers tended to work in isolation, not working cooperatively with their neighbours. The clusters produced a cultural change, so that farmers are more open to working together, e.g. communication amongst farmers is essential to manage pesticide resistance.

Health impacts

The outcomes of the project should see positive health impacts in the mango farming communities in the southern Philippines. The adoption of IPDM, better canopy management and chemical safety education (delivered through the extension training) will result in less toxic chemical exposure to farmers, farm workers, families, communities and consumers. Overall, less harmful chemicals will be used (both the type of chemical and the quantity) and chemicals will be applied in a safer manner. The project identified older chemicals that are no longer effective because the pests have developed resistance (e.g. Profenofos an organophosphate). As a result, these chemicals will be reduced or withdrawn from use, which will have a positive health impact to the farming communities. The project tested biological alternatives to using some chemicals, such as fungal endophytes and biopesticides. Future adoption of these biological alternatives will further reduce chemical exposure to the farming communities.

Gender impacts

This project had a high female participation rate in the Philippines, with females representing 62% of researchers, 60% of extension staff, 50% of students and 30% of farmers.

Of 18 Filipino project researchers, 11 (62%) were female and 7 (39%) were male. Of the Australian researchers 3 (38%) were female and 5 (62%) were male. Total project staff from both countries had 14 (54%) female and 12 (46%) male.

Of the 92 Filipino extension officers that received any training, 55 (60%) were female and 37 (40%) were male. Of the 40 undergraduate and postgraduate students from the Philippines that had significant involvement (thesis, technical assistant training, or other major involvement) in the project, 20 (50%) were female.

Of more than 580 Filipino mango farmers and farm contractors that received some sort of training from the project, 30% were female participants. This was a large female participation rate as most mango farm owners and contractors in the Philippines are male.

Political impacts

This project will have political impacts over the next five years. It is expected that the work of Dr Celia Medina and her team on pesticide resistance will have an impact in the area of pesticide regulation. Dr Medina has contributed to the “Mango Road Map” for the Department of Agriculture (a medium term 5 year plan); which includes policy, regulation, investment, research and extension plans. Together with the pesticide resistance work, results from the project surveys of pesticide use by farmers, showed the widespread misuse of pesticides in mango production. It is anticipated that these outcomes will lead to policies on regulating broad-spectrum pesticide use. It will now be mandatory for the pesticide industry to adopt Mode of Action (MOA) classification on labels for use in mangos.

8.3.3 Environmental impacts

Environmental impacts include reducing the number and types of hazardous pesticides used. The initial farmer surveys confirmed that most Filipino growers would tank-mix a “cocktail” of multiple insecticides and fungicides (often using the incorrect dose), which were repeatedly spayed over the course of the growing season.

The farmers that have received the extension training have adopted an IPM approach, which has reduced the pesticide reliance; they are using less chemical volume and a lower number of spray applications. Improvements in canopy management have also improved chemical spray efficiency and reduced non-target effects.

The types of pesticides will change, from the older broad-spectrum and sometimes highly toxic pesticides (mostly organophosphates, carbonates and synthetic pyrethroids), to the softer, targeted and generally less toxic pesticides (e.g. insect growth regulators and biopesticides). This approach will result in less non-target effects (e.g. on humans, beneficial invertebrates, livestock, fish etc.) and less toxins entering the food chain. Improving pesticide application techniques to reduce run-off and non-target drift will also reduce environmental contamination of the soil, air and water.

In Australia, project data that was developed on a newer safer IPM pesticide (Sulfoxaflor) for controlling spotting bugs was used to assist in the registration and promotion of the product in mangoes and other industries. The work on the Monitoring Integrated Lure and Kill system could potentially reduce pesticide use by 90% for spotting bug control. Reducing water contamination from pesticides is particularly important for Australia, particularly in Queensland, where efforts are being made to protect the Great Barrier Reef from pesticide runoff.

Reduced used of broad spectrum pesticides will increase invertebrate biodiversity of the mango orchards and surrounding landscapes, including natural wild/forest areas. Furthermore, profitable and well managed farms generally have better pest/weed management and have less noxious weeds including lantana, vines etc.

The identification and proof of pesticide resistance in Mindanao and the identification of potential chemical/biological alternatives, coupled with policy change and other future IPM strategies (e.g. habitat manipulation for thrips hosts), will further reduce the effects of environmentally harmful pesticides into the next five years and beyond.

8.4 Communication and dissemination activities

Information was communicated and disseminated in a number of ways that will have current and future impacts.

Through the farmer field schools and extension activities information was presented to some 600 farmers, contractors and extension staff (see 8.2, capacity impact section). The wider extension and public access (e.g through field days, social media, public access, printed materials etc). This access will benefit approximately 5000 other mango growers in Mindanao with the next 5 years.

Numerous capacity building workshops (e.g. statistics and experimental design, IPM, chemical safety, plant nutrition and canopy management – details and impacts listed in 8.2) were delivered to scientists, students, extension staff and farmers, using oral and participatory approaches. This information will continue to be disseminated into the next 5 years by the various researches, university teachers/instructors, extension staff and growers (farmer to farmer within and between clusters).

The project produced a number of scientific publications (see section 10.2), presentations at numerous national and international conferences and student thesis papers, which have and will continue to have scientific and capacity impacts for the next 5 years and beyond.

The project was also promoted by social, electronic and traditional media. A list of project publications, including industry journals and magazines is provided in section 10.2.

Two videos have also been shot (a mango production guide and farmers testimonials), although these are yet have the final editing finished. The mango production guide

Has been uploaded to YouTube at: Mango Production Guide (ACIAR). https://www.youtube.com/watch?v=F810_xUAyyw&feature=youtu.be

The video: “Integrated crop management for mango production in the Philippines: marvellous mangoes”. Is available on the ACIAR website: https://aciar.exposure.co/philippines-marvellous-mangoes

A Facebook Blog “Mango Moments” was set up as part of QLD Agricultures Facebook page giving farmers growing advice throughout the season. A journal article in the industry journal “Mango Matters” was produced about electronic extension and communications.

As well as the industry and electronic publications listed in 10.2, the project was also promoted by other external sources including the Australian Embassy in the Philippines and the ABC in Australia.

The project was promoted by the Australian Embassy, where it was showcased on the Philippines-Australia Friendship Day with a visit by Deputy Head of Mission, Mr Mat Kimberley, and a media release.

Philippines-Australia Friendship Day: Davao City Australian Embassy Celebrate Philippines-Australia Friendship Day. Philippine Daily Enquirer. 28 May 2018.

https://twitter.com/ausambph/status/999793182090113024

A radio interview was given by the project leader by the ABC at:

Fitzgerald D. (interviewing **Newton I**.) (2015). Research helping poor mango farmers in south east Asia also preparing Australian industry against cecid fly incursion. NT Country Hour, ABC Radio. http://www.abc.net.au/news/rural/2015-09-04/cecid-fly/6749202 (*Radio Interview*)

9 Conclusions and recommendations

9.1 Conclusions

Insecticide resistance studies (both laboratory and field studies) proved that Mindanao thrips populations were resistance to both profenofos and cypermethrin, both of which are regularly used to control thrips and other mango pests throughout Mindanao. Field trials with deltamethrin found it also had no effect on thrips. It is likely that thrips are resistant to the other synthetic pyrethroids and organophosphates commonly used in mangos. Surveys showed that these chemicals are commonly (i.e. nearly always) misused by farmers and contractors by: under/over dosing, repeated use with no rotation and multiple-dose multiple-chemical tank mixes, “cocktail mixes”. The continued misuse of such pesticides is likely exacerbating the thrips problems. Insecticide trials showed that the application of Clothianidin, Spinosad and Cartap Hydrochloride gave effective control of thrips, whereas deltamethrin performed no better than the unsprayed controls. The population dynamics of the two most dominant species of mango thrips, *Thrips hawaiiensis* and *Scirtothrips dorsalis,* showed that *Lantana camara* and other weeds were important alternative host sources for thrips. In the Philippines, a parasitoid wasp (*Synopeas mangiferae*) has been found attacking mango cecid flies. This is of significant importance for future biological control programs in both the Philippines and Australia, as the same species of cecid fly has invaded Torres Straight and threatens Australian mango production. In Australia, a number of parasitoid species were identified attacking mango planthoppers eggs and nymphs, which were thought to have a significant effect on planthopper populations, particularly in the absence of insecticides. The new pesticide Sulfoxaflor appeared to work at managing Banana Spotting Bugs; however, it is not as affective for the control of planthoppers. A lure and kill system was also developed for managing Spotting Bugs.

In plant pathology trials, the biological fungicides Serenade™ (*Bacillus subtilis*), Timorex Gold™ (a tea-tree extract) and a chemical fungicide (ionic copper concentrate) were effective at reducing blossom blight, anthracnose and stem-end rot of mangos. Substitution of fungicides with plant growth regulators had comparable results with using fungicide applications alone. Seven applications of fungicides per production cycle can be reduced to four with the supplementation of PGRs. Furthermore, PGRs enhanced panicle length, fruit set, fruit retention and volume of fruit produced. A hot water dip (59°C for 1 minute conducted within 24h from harvest) is highly effective as a postharvest treatment against anthracnose and SER. An endophytic fungi used as pre-harvest treatment against fruit drop and postharvest diseases has potential as an alternate to synthetic fungicides.

In the Australian canopy management research, high density trellised training systems produced early yield improvements for newly established orchards compared to conventional training systems. Increasing the planting density of trees led to an increase in canopy per hectare. Increased canopies per ha have the potential to increase the light intercepted by trees across the orchard, leading to higher orchard productivity. Typically, most farmers throughout the Philippines do not actively manage their tree canopies, but only carry out minimal pruning (mostly dead/dying under-canopy limbs). Consequently, trees are largely unpruned and canopies are allowed to close-over, grow to unmanageable heights and became unproductive; leading to widespread yield and quality decline. Through the extension program, farmers learned how trees can be maintained and pruned to produce higher fruit yields, whilst preventing canopy closure and subsequent yield declines. An income assessment from the canopy management work showed that undertaking selective pruning produced increased income with a 48% reduction in expenses per tree.

Over 670 growers, contractors and extension staff have receiving some sort of training from the project. 50 extension officers were trained in extension methods, training techniques, best practices and new R&D innovations. 185 mango growers have completed farmer field school season-long training and adopted best management practices, which has resulted in at least 115% increase in yield improvements and net profit increases of 43% to 11-fold increase.

9.2 Recommendations

In the Philippines declining mango production yields and poor quality fruit could largely be addressed by rolling out simple extension and demonstration programs promoting basic canopy management and pesticide resistance management practices developed from this project.

The insecticide resistance studies, field trials and farmer surveys have demonstrated that the continued misuse of pesticides such as profenofos, cypermethrin, deltamethrin (and other synthetic pyrethroids and organophosphates) is largely causing, or at least exacerbating the thrips problems in Mindanao. These findings have important policy implications, which should influence pesticide regulation and labelling. Growers need to be made aware that these chemicals are no longer affective at managing thrips in Mindanao and are potentially making the problem worse. Policies may need to consider restricting the use of these pesticides. Labelling of pesticides should also introduce Mode of Action and chemical resistance grouping (based on the Insecticide Resistance Action Committee IRAC) with additional recommendations/information on resistance management, maximum number of sprays and rotation of pesticide groups. Future extension programs will need to advise growers of the existing resistance problem with explicit advice on avoiding profenofos and the synthetic pyrethroids; they should also adopt and roll-out the resistance management plan that has been developed in this project. As this specific information is recent, very few farmers are aware of the pesticide resistance issue, and this information needs urgent and wide reaching extension and promotion in Mindanao. Some alternatives to using profenofos and the synthetic pyrethroids have been identified in this project (Clothianidin, Spinosad and Cartap Hydrochloride), but there is an urgent need to continue to find other more efficacious and softer insecticides. The thrips ecology studies showed the close association of thrips in mangos and in weeds. With further research, strategically timed removal or spraying of weeds coud be a way to manage thrips. Further research on the biology and host range of the parasitoid *Synopeas mangiferae* (and other parasitoids attacking the mango cecid fly) should be investigated, as it could lead to more affective biological control and would benefit both the Philippines and Australia. A lure and kill system was developed for managing Banana Spotting Bugs in Australia. However, this research needs to be proven with larger farm-wide/block-wide trials.

Using a combination of plant growth regulators combined with reduced fungicides also showed some positive results. Plant growth regulators have the capacity to reduced blossom blight and increase fruit set. However, these chemicals are currently not registered in mangos. Additional trials may be required for chemical registration. The use of the endophytic fungus (FSLDf) is also promising. Trials should examine optimization of inoculum, formulation, and timing of application. Correct taxonomic identification of FSLDf is also recommended. Future research should include trials integrating PGRs with endophytes and/or biopesticides.

Dealing with a changing climate has been a challenge for researchers during this project, but is perhaps more of a challenge for the livelihood of Philippine mango farmers, dealing with extended draughts or excessive rain and frequent severe typhoons. Future research will need to focus on developing climate resilient technologies for mango production.

Most farmers throughout the Philippines do not actively manage their tree canopies. In this project, farmers learned how trees can be maintained and pruned to produce higher fruit yields, whilst preventing canopy closure and subsequent yield declines. By simple pruning techniques, farmers reduced expenses and increased their income. Basic canopy management is the most effective and efficient extension activity to improve mango productivity and profitability. Rolling out this simple extension activity with demonstration sites across the Philippines could prevent the continued yield and quality decline.

10 References

10.1 References cited in report

Affandi A. and Medina C.dR. (2013). Age Structure and Sex Ratio of Thrips Scirtothrips dorsalis Hood (Thysanoptera: Thripidae) Associated with Mango Agroecosystem in East Java, Indonesia. Agrivita Vol 35(3): 227-236.

Affandi A. Medina, C.dR. and LRI Velasco L.R.I. (2018). Development and survivorship of Scirtothrips dorsalis in different growth stages of mango and selected weeds. Agrivita Journal of Agricultural Science 40(1):101-106.

Buguis M. L. (2014). Value Chain Analysis and Competitiveness Strategy: Fresh Mango in Mindanao: Philippines Rural Development Program.

DOST-PCAARRD (2012) Industry Strategic S&T Plan for Mango. http://www.pcaarrd.dost.gov.ph/home/isp/index.php/mango

Dunmall T. (2013). Australian Mango Industry Association. Mango Export Forum. Novotel Brisbane Airport Hotel. 8th May 2013.

FAOSTAT (2016). Mango Production, Production Area, and Yield by All Reporters, 2007-2016 (based on Mangoes, Mangosteens, Guavas). Retrieved October 21, 2018, from Food and Agriculture Organization of the United Nations.

Fernandez-Stark K., Couto V. and Gereffi G. (2017). The Philippines in the Mango Global Value Chain. Center on Globalization, Governance & Competitiveness, Duke University, for USAID/Philippines.

Horticulture Innovation Australia (2018). Australian Horticulture Statistics Handbook – Fruit 2016/17. 116pp. www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/australian-horticulture-statistics-handbook-2016-17/

Kolesik P., Rice A., Thistleton B, Tenakanai D., Quintao V., Medina C.D.R., Thein M.M., Heng C. H., Halling L.A., Tsatsia F., Bellis G.A. (2015). Mango gall midges on Australia's doorstep. XI International Mango Symposium, Darwin NT Australia. 28 Sept – 2nd Oct 2015. Acta Hortic. 1183, 279-286.

Oakeshott, J., Baxter, L., and Faylon, M. (2013). Notes from ACIAR / PCAARRD mango R & D planning meeting, 25 Feb 2013 Davao.

Newton, I., Eusebio J. and Siano A. (2013). Final report ‘Improved and sustainable value chains for mango production in the Philippines and Australia. ACIAR final report, project No. HORT/2007/067/4.

PCARRD-DOST (2011). Reaping the Sweet Promises of the Philippine Mango Industry: PCARRD-DOST.

10.2 List of publications produced by project

Journals, conference papers and poster presentations

Apolinario J.J.G., Medina C.D.R, Velasco L.R.I and Mendioro M.S.(2018). Molecular and Life History Homogeneity among Local populations of *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) in the Philippines. Philipp Agri Scientist 101(3): 271-278. *(Journal).*

Apolinario J.J.G., and **Medina C.D.R.** and Velasco L.R.I. (2014). Spot the difference: The search for population variations of *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) in mango using morphological and molecular data. Paper presented in the 45th Annual Conference. Pest Management Council of the Philippines. Cebu City, May 2-6, 2014. *(Oral).*

Batoctoy E.D., Caballero G.L. and **Patagoc R.D.** (2017) Canopy management to Improve Fruit Quality, size and yield by optimizing nutrition, canopy and harvest management. 30th Research Development Highlights, Southern Mindanao Agriculture, Aquatic and Natural Resources Research and Development Consortium, Davao City, 23-35 August 2017 (Appendix 3.1). *(Poster).*

Caballero G.L., Batoctoy E.D. and **Patagoc R.D.** (2017) Canopy Management and Optimizing Nutrition for Mango (Carabao Variety) in Davao del Sur and Davao del Norte. 30th Research Development Highlights, Southern Mindanao Agriculture, Aquatic and Natural Resources Research and Development Consortium, Davao City, 23-35 August 2017. *(Oral).*

Dickinson G., Notarte A., Sagolili J., Oakshott J. and Newton I (2017). Facilitating practice change to improve mango farmer livelihoods in the southern Philippines. Asia Pacific Extension Network Conference, Townsville, Australia, 12-15th September 2017.

Ibell, P. Wright, C., **Bally, I**, Kare, M. (in Prep). The effects of different tree training systems on canopy development and productivity in mango (*Mangifera indica*). Under development, draft attached (Appendix 3.4).

Kolesik P., Rice A., Thistleton B, Tenakanai D., Quintao V., **Medina C.D.R.**, Thein M.M., Heng C. H., Halling L.A., Tsatsia F., Bellis G.A. (2015). Mango gall midges on Australia's doorstep. XI International Mango Symposium, Darwin NT Australia. 28 Sept – 2nd Oct 2015. Acta Hortic. 1183, 279-286. (*Oral and Published Proceedings*).

Medina C.D.R., Ronquillo S.J.Q., Mendioro M.S., Kolesik P. and **Newton I.** (2015). Morphological and molecular characterisation of the various species of *Procontarinia* (Diptera: Cecidomyiidae) attacking mango in the Philippines. XI International Mango Symposium, Darwin NT Australia. 28 Sept – 2nd Oct 2015. Acta Hortic. 1183, 287-290. (*Oral and Published Proceedings*).

Medina C.D.R. and **Apolinario J.J.G.** (2015). Localisation of populations of *Scirtothrips dorsalis* collected from various mango growing areas of the Philippines. XI International Mango Symposium, Darwin NT Australia. 28 Sept – 2nd Oct 2015. Acta Hortic. 1183, 305-310. (*Oral and Published Proceedings*).

Medina C.D.R., Apolinario J.J.G, Doronio, I.S. and Magboo., J.P.S. (2017). Understanding the mango thrips problem in Southern Mindanao. ACIAR Philippines Annual Conference. Quest Hotel, Hoote, Cebu City Philippines, *(Poster).*

Newton I. and **Cheesman J.** (2017). Monitoring Integrated Lure and Kill (MILK): A new approach to control the banana spotting bug, *Amblypelta lutescens lutescens* (Distant) (Coreidae). Australian Entomological Society 48th AGM and Scientific Conference. Terrigal NSW Australia. 17-20 Sep 2017. (*Oral*).

Newton I. and **De Faveri S.** (2018). Transmission of *Beauveria bassiana* and *Metarhizium anisopliae* to male *Bactrocera tryoni* via para-pheromone lures and subsequent transmission to females. The 2018 International Congress of Invertebrate Pathology and Microbial Control. Gold Coast QLD Australia. 12-16 August 2018. *(Oral).*

Silvestre J.C., Evangelista R.B. and Masanit J.A. (2015). Management of blossom blight of mango with plant and manure teas in Libungan, Cotabato. Higher Education Research Forum 2015. Century Park Hotel, Malate, Manila. Aug 19-20 2015. (*Oral*).

Silvestre J.C., Evangelista R.B. and **Catubay E**. (2016). Management of postharvest diseases of mango using biofungicides. The 2nd National Organic Agriculture Scientific

Conference. Visayas State University, Baybay City, Leyte. February 16-19, 2016. *(Poster).*

Silvestre J.C., Evangelista R.B. and **Catubay E**. (2016). Management of blossom blight of mango using biofungicides. The 2nd National Organic Agriculture Scientific Conference. Visayas State University, Baybay City, Leyte. February 16-19, 2016. *(Poster).*

Silvestre J.C., Evangelista R.B. and **Catubay E**. (2016). Management of postharvest diseases of carabao mango (*Mangifera indica*) applied with five biofungicides. The USM Student RD&E in- House Review, April 13, 2016 and the College Undergraduate Research In House Review. University of Southern Mindanao, Kabacan, Cotabato. March 31, 2016. *(Poster).*

Silvestre J.C., Evangelista R.B. and **Catubay E**. (2016). Management of postharvest diseases of mango using biofungicides in Padada, Davao Del Sur. University of Southern Mindanao, Kabacan, Cotabato.The 36th USM Research, Development, and Extension Review. November 10-11, 2016 (Appendix 2.1). *(Poster).*

Silvestre J.C., Evangelista R.B. and **Catubay E**. (2016). Management of blossom blight of mango using biofungicides. The 36th USM Research, Development, and Extension Review. University of Southern Mindanao, Kabacan, Cotabato. November 10-11, 2016. *(Poster).*

Silvestre J.C., Evangelista R.B. and **Catubay E**. (2016). Management of blossom blight of mango using biofungicides. The Philippine Agriculturist' Summit. Grand Men Seng Hotel, Davao City. November 13-16, 2016 (Appendix 2.1). *(Poster).*

Silvestre J.C., Evangelista R.B. and **Catubay E**. (2017) Management of pre and postharvest diseases using different rates of four biofungicides. UMDC Regional Interdisciplinary Research Congress. UM Digos Campus, Roxas Extension, Digos, Davao del Sur. March 10-11, 2017. (*Oral*).

Silvestre J.C., Evangelista R.B. and **Catubay E**. (2017). Evaluation of seven rates of crop vaccine against anthracnose of mango fruits. College of Agriculture Student In-House Review. University of Southern Mindanao, Kabacan, Cotabato. May 25, 2017. *(Poster).*

Silvestre J.C., Evangelista R.B. and **Catubay E**. (2017). Management of fruit diseases of mango using biofungicides. Final Annual Review Meeting of ACIAR-PCAARRD, Philippines Horticulture Program. Quest Hotel and Convention Center. Cebu. July 17-20, 2017. *(Poster).*

UP Los Baños Student Thesis supervised by Celia DR. Medina

Age structure, sex ratio and abundance of thrips , Scirtothrips dorsalis Hood and Thrips hawaiiensis Morgan, in non-cultivated plants in a mango agroecosystem. - **Ian S. Doronio (Male)** MSc Entomology Special Problem (June, 2016).

Studies on Insecticide Resistance of Scirtothrips dorsalis Hood in Mango. - **Ian S. Doronio (Male)** MSc Entomology Thesis (June, 2018).

Population dynamics of Scirtothrips dorsalis Hood and Thrips hawaiiensis Morgan (Thysanoptera: Thripidae) in mango and selected weeds in Davao del Sur. **John Paul D. Magboo (Male)** BS Agriculture Major in Entomology Thesis (June, 2017).

Morphological variations among local population of Thrips hawaiiensis (Thysanoptera: Thripidae) species-group from Carabao mango and three cultivars of banana within Davao Region. - **Joeseph M. Quisado (Male)** PhD Entomology Special Problem (June, 2017).

USM Entomology Student Thesis supervised by Conrado Evangelista.

Efficacy evaluation of five different insecticides against mango thrips – **Dale Ian R. Cedeño (Male)**. Bachelor of Science in Agriculture Major in Entomology, April 2016.

Evaluation of new insecticides againts mango flower thrips (*Scirtothrips dorsalis hood.)* – **Joven U.Bulol (MALE).** Bachelor of Science in Agriculture Major in Entomology, April 2016.

Field evaluation of clothianidin and spinosad at different rates for the control of mango thrips. **Karen May B. Abejar (Female).** Bachelor of Science in Agriculture Major in Entomology, April 2017.

Field evaluation of clothianidin and spinosad at different rates for the control of Cecid fly and mango leafhopper. **Raymee Ranches (Female).** Bachelor of Science in Agriculture Major in Entomology, April 2017.

USM Pathology Student Thesis supervised by Silvestre J.

Management of blossom blight of mango with plant and manure teas in Libungan, Cotabato. **JAYRON A. MASANIT (Male).** BSA Plant Pathology. April 2015.

Management of Blossom Blight of Mango caused by *Colletotrichum gloeosporioides* Penz using Various Organic Based Formulations. **JANE O. OQUERIZA (Female).** BSA Plant Pathology. April 2015.

Disease Assessment of Mango Scab in Five Municipalities of North Cotabato and In vitro Assay of Organic Fungicides Against the Causal Pathogen – **GIO S. CRISPOLON (Male).** BSA Plant Pathology. April 2015.

Efficacy evaluation of hot water treatment plus biofungicides against postharvest diseases of carabao mango (*Mangifera indica*). **ANTHONY JAMES B. VALDEZ (Male).** BSA Plant Pathology. April 2016.

Management of stem end rot and anthracnose of mango applied with five pre-harvest biofungicides. **CHARLENE C. MALACAD (Female).** BSA Plant Pathology. April 2016.

Management of Blossom Blight of Mango in Island Garden City of Samal. **JAPHET B. CORSINO (Male).** BSA Plant Pathology. April 2016.

Evaluation of two formulations of Marvelous Premium Quality (MPQ) at various rates for the control of post - harvest diseases of mango *(Mangifera indica).* **LAWRENCE KENT T. MODESTO (Male).** BSA Plant Pathology. April 2016.

Management of postharvest diseases of carabao mango (*Mangifera indica*) applied with five biofungicides. **RAVIN M. HERMIDA (Male) *Cum Laude.*** BSA Plant Pathology. April 2016.

Comparative evaluation of four biofungicides for the control of *Colletotrichum gloeosporioides* Penz. Causing anthracnose of mango. **MA. CORAZON G. PASCUA (Female).** BSA Plant Pathology. June 2017.

Evaluation of seven rates of crop vaccine against anthracnose of mango fruits. **AR-B B. SARCAJOGA (Male).** BSA Plant Pathology. June 2017.

Endophytic fungi associated with mango and their potential as biocon against *Colletotrichum gloeosporioides* causing anthracnose of mango. **QUEENCY JEAN T. ANDOY (Female).** BSA Plant Pathology. June 2017.

Fungal endophytes associated with mango and their potential as biocontrol against *Diplodia natalensis* causing stem-end rot of mango. **DANDY A. TEVES (Male).** BSA Plant Pathology. June 2017.

Awards Received

1st best poster entitled "Management of postharvest diseases of mango using biofungicides in Padada, Davao Del Sur" during the 36th USM Research, Development, and Extension Review, November 10-11, 2016.

2nd place Best Poster entitled "Management of postharvest diseases of carabao mango (*Mangifera indica*) applied with five biofungicides" during the USM Student RD&E In-House Review, April 13, 2016.

2nd place Best Poster entitled "Management of postharvest diseases of carabao mango (*Mangifera indica*) applied with five biofungicides" during the College Undergraduate Research In House Review, March 31, 2016.

Top 10 finalists for Best Research Paper entitled "Management of blossom blight of mango with plant and manure teas in Libungan, Cotabato" during the 2015 Higher Education Research Forum, August 19 – 20, 2015, Century Park Hotel, Malate, Manila.

USeP Student thesis supervised by Virgie P. Ugay and Cesar A. Limbaga Jr.

Irog-irog, Edna C. (female). Exploring the potential of plant growth regulators for the control of major insect pests of mango (*Mangifera indica* L.). MSc Crop Protection Thesis, 2016. University of Southeastern Philippines, Tagum-Mabini Campus, Apokon, Tagum City.

Esconde, Rowena T. (female). Plant Growth Regulators: Its potential for the control of field and postharvest diseases of 'Carabao' mango (*Mangifera indica* L.). Ph. D. in Horticulture, 2017. University of Southeastern Philippines, Tagum-Mabini Campus, Apokon, Tagum City.

SPAMAST Student Thesis supervised by Caballero G.L. & Batoctoy E.D.

Characterization of Mango Orchard In Five Municipalities In Davao Del Sur (Hagonoy, Padada, Kiblawan, Sulop, Malalag). **Dellito B. Alivo. (Male).** Bachelor in Agricultural Technology. June 2015.

Characterization Of Mango Orchard In Five Municipalities In Davao Del Sur (Sta. Cruz, Digos, Bansalan, Matanao, Magsaysay). **Jackson B Paran (Male).** Bachelor in Agricultural Technology. June 2015.

Practices and Profitability of Contracted Mango Orchard in Davao del Sur. **Julia Codeno, (Female).** Master in Agri-Business Management (2015).

Industry Journals/Publications/Extension

ACIAR (2017). Integrated crop management for mango production in the southern Philippines and Australia. Fact Sheet (FS2017). (https://www.aciar.gov.au/node/13261)

ACIAR (2018). Integrated crop management for mango production in the Philippines. Video. (https://www.youtube.com/watch?v=KPYuUQQcbJs)

ACIAR (2016). Integrated Crop Management for mango production in the Southern Philippines and Australia. ACIAR Project Factsheet.

Dickinson G. (2016). Queensland Mango Moments – A social media campaign by Queensland Department of Agriculture and Fisheries. Mango Matters. Vol 25. September 2016.

Dickinson G. (2017). Videos for mango communication. Mango Matters, Vol 29. October 2017.

Dickinson G. (2018). ACIAR mango crop management in the Philippines and Australia impacts smallholder farmers. Mango Matters. Vol 32. July 2018.

Ibell, P. and **Bally I.** (2017). Training systems for trellised mangoes. Mango Matters. Vol 26. January 2017.

Ibell, P. (2017). Trellises deliver high density mango trees, republished from “Training systems for trellised Mangoes, by Paula Ibell” in the Queensland Country Life 2017.

Markham R. (2017). Smaller Trees, Bigger Rewards. Partners Magazine. Issue 3. 2017.

Medina C.dR. and **Apolinario J.J.G.** (*In Prep*) Biology and Management of thrips in Mango. Brochure.

Newton I. (2016). Researchers looking to Asia to prepare for possible Cecid fly incursion. Mango Matters. Vol 24. July 2016.

Newton I. (2018). Philippines’ Marvellous Mangoes: Mango production at risk from pest and disease is benefiting from integrated management actions in the Philippines. Partners Magazine. Issue 1. 2018. (https://reachout.aciar.gov.au/philippines-marvellous-mangoes).

Notarte A. (2017). It’s not the size of the tree that counts. Grower training video.

Notarte A. (*In Prep*) Mango protocol for best practices for off-season production. Provincial Agriculturists Office, Davao del Norte.

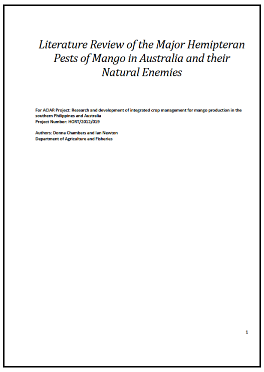
Queensland Government (2013-2018) – Queensland Agriculture Facebook site. (https://www.facebook.com/pg/QldAgriculture/posts). 20 Posts on various Mango R, D & E stories.

Queensland Government (2018) – Department of Agriculture and Fisheries website (www.daf.qld.gov.au). Pages on current/recent R&D projects and links to available DAF mango information resources. Site currently under revision again (as at 07/01/2019).

11 Appendixes

11.1 Appendix 1:

Appendix 1.3-A. Literature Review of the Major Hemipteran Pests of Mango in Australia and their Natural Enemies.



Literature Review of the Major Hemipteran Pests of Mango in Australia and their Natural Enemies

For ACIAR Project: Research and development of integrated crop management for mango production in the southern Philippines and Australia
Project Number: HORT/2012/019

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Department of Agriculture and Fisheries

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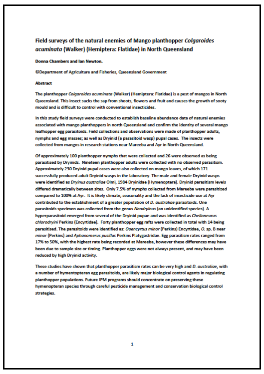
Appendix 1.3-B. Field surveys of the natural enemies of Mango planthopper *Colgaroides acuminata* (Walker) (Hemiptera: Flatidae) in North Queensland.



Field surveys of the natural enemies of Mango planthopper *Colgaroides acuminata* (Walker) (Hemiptera: Flatidae) in North Queensland

Donna Chambers and Ian Newton.

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Abstract

The planthopper *Colgaroides acuminata* (Walker) (Hemiptera: Flatidae) is a pest of mangos in North Queensland. This insect sucks the sap from shoots, flowers and fruit and causes the growth of sooty mould and is difficult to control with conventional insecticides.

In this study field surveys were conducted to establish baseline abundance data of natural enemies associated with mango planthoppers in north Queensland and confirm the identity of several mango leafhopper egg parasitoids. Field collections and observations were made of planthopper adults, nymphs and egg masses; as well as Dryinid (a pasasitoid wasp) pupal cases. The insects were collected from mangos in research stations near Mareeba and Ayr in North Queensland.

Of approximately 100 planthopper nymphs that were collected and 26 were observed as being parasitised by Dryinids. Nineteen planthopper adults were collected with no observed parasitism. Approximately 230 Dryinid pupal cases were also collected on mango leaves, of which 171 successfully produced adult Dryinid wasps in the laboratory. The male and female Dryinid wasps were identified as *Dryinus australiae* Olmi, 1984 Dryinidae (Hymenoptera). Dryinid parasitism levels differed dramatically between sites. Only 7.5% of nymphs collected from Mareeba were parasitized compared to 100% at Ayr. It is likely climate, seasonality and the lack of insecticide use at Ayr contributed to the establishment of a greater population of *D. australiae* parasitoids. One parasitoids specimen was collected from the genus *Neodryinus* (an unidentified species). A hyperparasitoid emerged from several of the Dryinid pupae and was identified as *Cheiloneurus chlorodryini* Perkins (Encyrtidae). Forty planthopper egg rafts were collected in total with 14 being parasitised. The parasitoids were identified as: *Ooencyrtus minor* (Perkins) Encyrtidae, *O.* sp. B near *minor* (Perkins) and *Aphanomerus pusillus* Perkins Platygastridae. Egg parasitism rates ranged from 17% to 50%, with the highest rate being recorded at Mareeba, however these differences may have been due to sample size or timing. Planthopper eggs were not always present, and may have been reduced by high Dryinid activity.

These studies have shown that planthopper parasitism rates can be very high and *D. australiae*, with a number of hymentopteran egg parasitoids, are likely major biological control agents in regulating planthopper populations. Future IPM programs should concentrate on preserving these hymenopteran species through careful pesticide management and conservation biological control strategies.

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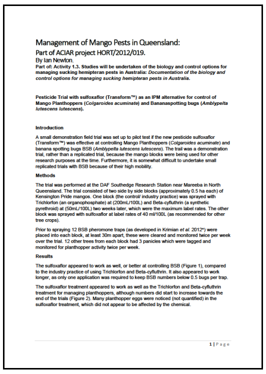
Appendix 1.3-C. Management of Mango Insect Pests in Queensland.



Management of Mango Pests in Queensland:
Part of ACIAR project HORT/2012/019.
By Ian Newton.
Part of: Activity 1.3. Studies will be undertaken of the biology and control options for managing sucking hemipteran pests in Australia: *Documentation of the biology and control options for managing sucking hemipteran pests in Australia.*

Pesticide Trial with sulfoxaflor (Transform™) as an IPM alternative for control of Mango Planthoppers (*Colgaroides acuminate*) and Bananaspotting bugs (*Amblypelta lutescens lutescens*).

Introduction

A small demonstration field trial was set up to pilot test if the new pesticide sulfoxaflor (Transform™) was effective at controlling Mango Planthoppers (*Colgaroides acuminate*) and banana spotting bugs BSB (*Amblypelta lutescens lutescens*). The trail was a demonstration trial, rather than a replicated trial, because the mango blocks were being used for other research purposes at the time. Furthermore, it is somewhat difficult to undertake small replicated trials with BSB because of their high mobility.

Methods

The trial was performed at the DAF Southedge Research Station near Mareeba in North Queensland. The trial consisted of two side by side blocks (approximately 0.5 ha each) of Kensington Pride mangos. One block (the control/ industry practice) was sprayed with Trichlorfon (an organophosphate) at (200mL/100L) and Beta-cyfluthrin (a synthetic pyrethroid) at (50mL/100L) two weeks later, which were the maximum label rates. The other block was sprayed with sulfoxaflor at label rates of 40 ml/100L (as recommended for other tree crops).

Prior to spraying 12 BSB pheromone traps (as developed in Krimian *et al.* 2012*) were placed into each block, at least 30m apart, these were cleared and monitored twice per week over the trial. 12 other trees from each block had 3 panicles which were tagged and monitored for planthopper activity twice per week.

Results

The sulfoxaflor appeared to work as well, or better at controlling BSB (Figure 1), compared to the industry practice of using Trichlorfon and Beta-cyfluthrin. It also appeared to work longer, as only one application was required to keep BSB numbers below 0.5 bugs per trap.

The sulfoxaflor treatment appeared to work as well as the Trichlorfon and Beta-cyfluthrin treatment for managing planthoppers, although numbers did start to increase towards the end of the trials (Figure 2). Many planthopper eggs were noticed (not quantified) in the sulfoxaflor treatment, which did not appear to be affected by the chemical.

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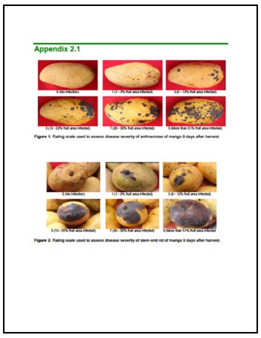
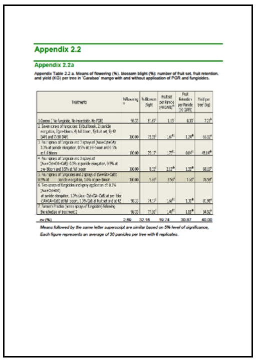
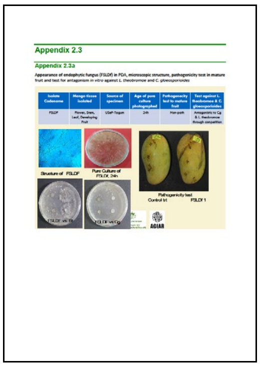
Appendix 2.1. Alternatives to conventional chemical disease control.


Appendix 2.1

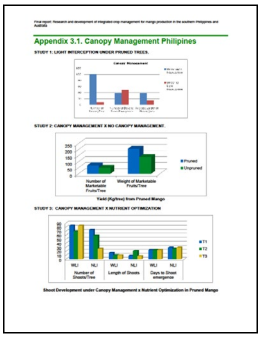
Appendix 2.2. The potential of plant growth regulators for the control of pre and postharvest diseases.


Appendix 2.2

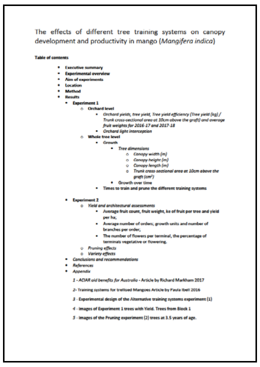
Appendix 2.3. The efficacy of endophytes against anthracnose and SER.


Appendix 2.3

Appendix 3.1. Canopy Management in the Philippines


Appendix 3.1. Canopy Management Philipines

Appendix 3.4. The effects of different tree training systems on canopy development and productivity in mango (Australia).



The effects of different tree training systems on canopy development and productivity in mango (*Mangifera indica*)

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