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Rambutan

Development of Integrated Pest Management

Insect Identification, Monitoring and Insecticide Evaluation

A report for the Rural Industries Research and Development Corporation

by David P. Astridge

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Foreword

Rambutan (*Nephelium lappaceum* L.) is a large tropical evergreen tree from the family Sapindaceae that is native to Malaysia, Borneo and Sumatra in South East Asia. Rambutan trees produce a fruit with an edible aril that is very popular throughout Asia. In South East Asia the commercial production of rambutan is approximately 8-900,000 t / year.

The Australian rambutan industry is a new developing industry confined to the growing areas of north Queensland and the Northern Territory. Three organisations, which include; The Rambutan and Tropical Exotic Local Producers Association (RTELPA) and the Far North Queensland Marketing Group in Queensland and the Rambutan subgroup of the Northern Territory Horticultural Association (NTHA) represent the rambutan industry in Australia.

This project is the first step in developing integrated pest management (IPM) for Australian rambutan growers. The main aims of this project are to identify the major pests and beneficial insects and mites and develop pest management strategies, which are based on monitoring pest and beneficial insect populations at different crop cycle stages to reduce the amount of insecticide applications over the growing season. New insecticides will also be evaluated to replace organophosphate chemicals, which are currently under review, by the National Registration Authority.

This publication investigates the pest complex associated with rambutans in Australia as well as their seasonal population pressures in north Queensland and the Northern Territory. It also evaluates insecticides that are suitable to IPM and resistance management. The results of this publication will culminate in the development of an insect and mite monitoring poster to assist the Australian industry with the identification and monitoring of the major pests and beneficial insects in Queensland and Northern Territory.

This project was funded from RIRDC core funds with industry support.

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Peter O'Brien
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- Northern Territory Horticulture Association (NT rambutan growers)
- Queensland Department of Primary Industries and Fisheries

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Contents

List of Tables and Figures

1. Executive Summary

Until recently, very little has been known about the insect fauna associated with rambutans in Australia. With the expansion of the rambutan industry it has become evident that several insect species are significant pests of the crop and require the development of integrated control strategies. Pest damage results in market rejection of the fruit; yield decline and the loss of income to the grower.

The current commercial practice for controlling pests of rambutan relies exclusively on calendar based spraying of broad-spectrum insecticides. The most common insecticide groups currently being used by industry are organophosphates and organochlorins, which are toxic to the environment and human health.

The rambutan industries of north Queensland and the Northern Territory along with the Department of Primary Industries and Fisheries (DPI&F) – Queensland, have identified the development of integrated pest management (IPM) as a number one priority in industry strategic plans. This project was given greater priority because of the recent reviews and restrictions placed on the use of endosulfan and chlorpyrifos by the Australian Pesticides Veterinary Medicines Authority (APVMA).

This project has successfully achieved all of its aims in starting the development of IPM in Australian rambutans. This was achieved by conducting insect fauna surveys to help identify the major pest and beneficial insect spectrum unique to the Australian environment and developing monitoring strategies to reduce the frequency with which costly and environmentally threatening insecticides are used.

Growers were educated to identify and monitor the major pest and beneficial insects and only apply pesticides as required. Environmentally safe insecticides suitable for sustainable pest management were screened and the most effective treatments have been selected for minor use registration to replace endosulfan and chlorpyrifos.

1.1 Achievements

The project adoption by industry should result in a reduction in the use of toxic insecticides and the overall frequency of insecticide applications. This will be achieved by the use of a monitoring strategy and pest monitoring tools.

The major achievements of this project have been to:

- *Identify major pests and beneficial insects unique to Australian rambutan orchards*
- *Identify the seasonal pest pressures over the growing season in Qld and NT*
- *Develop monitoring strategies for the major pests of economic importance*
- *Develop insect identification and monitoring tools to assist grower adoption.*
- *Screen insecticides that have a safe environmental profile and unique mode of action to cover the pest spectrum and assist with insecticide resistance management.*
- *Seek minor use registration of insecticides for industry use.*

Identification of the major pest and beneficial insect complex unique to Australian rambutan orchards (QLD and NT)

Thirty-one phytophagous insects, mites and five ant species (table 1) were collected and identified in orchards of north Queensland. Lepidoptera and Hemiptera were the most represented orders of pests in Queensland orchards (11 species each).

This was followed by Coleoptera and Hymonoptera (5 species each), Acarina (4 species), Diptera and Orthoptera (2 species each) and one species of Thysonoptera.

Twenty-two phytophagous insects, mites and three ant species were collected and identified in the Northern Territory (table 2). In the Northern Territory Hemiptera were the most represented order (10 species) followed by Lepidoptera (8 species), Coleoptera and Hymonoptera (3 species), Orthoptera (2 species) and Acarina and Thysonoptera (1 species each).

Identify the seasonal pest pressures over the growing season in Qld and NT
Seasonality data was collected on all pests of north Queensland and the Northern Territory (table 3-4); Pest populations were recorded over a three-year growing season at five locations in the coastal tropics of north Queensland. Historical data was used over a five-year period for the Northern Territory. Fortnightly pest and beneficial incidence and population records were recorded as well as the type and level of pest damage.

Develop monitoring strategies for the major pests of economic importance
The data collected on seasonal pest pressures was used in developing a monitoring strategy for the rambutan industry detailing the time of year individual pests of economic importance are most active, and when monitoring is critical during the crop cycle. Preliminary and conservative economic threshold levels were also developed for the major pests of economic importance.

Development of insect identification and monitoring tools to assist grower adoption of results
An integrated pest monitoring kit (poster, book and software) has been developed and released at a series of workshops in north Queensland and the Northern Territory. The kit was developed based on the seasonality for the major pests of economic importance for both Queensland and the Northern Territory. The poster and book details the major pests responsible for plant damage as well as their biology and control. They also show where to monitor pest insects within the crop cycle and when the insects are most active throughout the growing season. Insect population analysis software has also been developed to compliment the poster and book and provide growers with a decision tool on when to apply pest management strategies. Two workshops were held in the Northern Territory for 25 growers and three workshops were held in Queensland (Mossman, Innisfail and Tully) for 85 growers on insect identification and monitoring procedures.

Screen insecticides that have a safe environmental profile and unique modes of action to cover the pest spectrum.
Insecticide screening has been completed against the major pest complex of phytophagous insects in rambutan. A total of 16 insecticides were screened to cover the pest spectrum. Eight insecticides where selected because of their good environmental profiles and unique modes of action and suitability for managing insecticide resistance.

Spinosad, emamectin benzoate, tebufenozide, thiamethoxam and *Bacillus thuriengiensis var kurstaki* where the most effective insecticide treatments against *Conogethes punctiferalis* and were not significantly different to the standard chlorpyrifos ($P<0.05$) three to four days after treatment. Beta-cyfluthrin was an effective alternative to endosulfan for controlling *Amblypelta* spp. and achieved 100% mortality five days after treatment and was not significantly different to the endosulfan standard. Beta-cyfluthrin also controlled *Rhyparida* sp and achieved 100% mortality after four days. Imidaclorprid was effective in controlling *Planococcus citri* and achieved 100% mortality after three days. Spinosad gave effective control against red-banded thrips at all the rates tested in the NT bioassays, achieving 100% mortality 24 h after spraying at the highest concentration of 1.6 % and 97% mortality at the lowest concentration of 0.2% formulated product.

The mineral oils DC Tron Plus® and Fuchs Universal Spray Oil® achieved 80% and 84 % mortality respectively at 2% oil concentrations and were considered partially effective. No chemical was particularly effective against two-spotted mites but Fuchs Universal Spray Oil® and Neemtech® gave greater than 70% mortality at the highest concentrations tested.

Minor use registration insecticides for industry use.
QFVG was approached to seek minor use registration on behalf of the rambutan industry. Insecticides chosen for minor use registration included, Success® and Entrust® (spinosad), Proclaim® (emamectin benzoate) Mimic 700 WP® (tebufenozide), Bulldock Prime® (beta-cyfluthrin), Actara ® (thiamethoxam), Confidor® (imidaclorprid).

1.2 Future Directions

This project has started the development of IPM in rambutan in Australia by giving growers the ability to identify and monitor the major pests and beneficial insects and only apply insecticides as required. The insecticides selected for minor use registration cover the pest spectrum and are well suited to IPM because of their unique modes of action, which can be used in developing insecticide resistance management strategies. Conservative economic threshold levels (ETL's) have been developed for the major pests in rambutan. These levels were developed based on field observation of pest damage over the life of the project as well as the known information on the pest's biology, ecology and threshold levels set in other tree crops. At best the ETL's developed in this project are only conservative guides until more detailed economic impact assessments can be carried out for each pest. As this project is only the beginning of IPM development in rambutan, a whole range of research areas can be investigated in the future in the following broad areas.

Economic impact assessments of the major pests in rambutan
A better understanding of the level of economic damage caused be the major pests as well as the impact of beneficial insects on pest populations will help develop more accurate ETL's for future use by growers and can possibly result in further reducing the level of spray applications over the growing season.

Biological control – predators and parasitoides
Little information is known on many of the major pests natural enemies except for *Cryptoleamus montrouzieri,* which is an important and major predator of citrus mealybug (*Plannococcus citri*). An understanding of which beneficial insects or complex of beneficials impact on individual pests populations, as well as identifying ways to naturally increase these populations in the orchard will also help reduce the frequency of pesticide applications over the growing season.

Biological control – entomopathogens
The use of naturally occurring insect pathogens (bacteria, fungi, viruses), which cause disease in pest populations, is another area of research, which has the potential to compliment the rambutan IPM strategy. This technology may be well suited to north Queensland where there are tropical warm temperatures, high rainfall and humidity over the growing season. Natural strains of *Beauveria bassiana* have been recorded infecting 60-70% of field populations of swarming leaf beetles (*Rhyparida* sp.) in north Queensland.

Pheromones and kairomones
The potential for using mating disruption or insecticide baiting strategies using pheromones and kairomones also have potential to be used in the development of a rambutan IPM strategy. A pheromone for yellow peach moth (*Conogethes punctiferalis*), a major pest in Queensland rambutans has been developed but has not been tested here in Australia.

A kairomone is also being developed and tested as insecticide bait for attracting and killing fruit piercing moths (*Eudocima* spp.) which can be tested in rambutans.

Cultural control

Various cultural practices could be investigated to conserve and enhance natural enemies of pests. This could include border plantings of different plants to attract and encourage natural enemies into the orchard. Certain pollen and nectar producing plants encourage high populations of natural enemies, which could be used for this purpose. Inter-row plantings of some legumes, which attract beneficial insects, may also have the potential to promote good soil structure and increase nitrogen levels in the soil promoting increased tree health.

Crop hygiene

General crop hygiene promoting the removal of planting material infected with insect pests (e.g. fruit infected with caterpillar larvae) will reduce increasing pest populations over time and should be investigated as a control strategy.

2. Insect Fauna Surveys in Rambutan in Queensland and Northern Territory

2.1 Overview

Insect fauna surveys were carried out at five commercial orchards on the east coast in the wet tropics of north Queensland and in Darwin in the Northern Territory. Phytophagous and predatory insects and mites have been identified and recorded over a 3-year growing season from 2000–2003. Seasonality data has been collected for each insect to examine pest incidence and seasonal pest pressures over the growing season.

Preliminary economic threshold levels have been developed for Queensland and the Northern Territory to assist growers to apply insecticides only as required. Thirty-one phytophagous insects, mites and five ant species (table 1.) were collected and identified in orchards of north Queensland. Twenty-two phytophagous insects, mites and three ant species were collected and identified in the Northern Territory (table1-2). A total of forty-six beneficial insects were recorded in the coastal wet tropics of north Queensland during the sampling period (table 5).

2.2 Introduction

Most of the rambutan industry is located in north Queensland (Tully 18° S to Cape Tribulation 16° S). This area has between 80-100 growers. The Northern Territory (Darwin rural area 12-13° S) has between 25-30 growers.

The rambutan industries of both Queensland and Northern Territory are continually expanding. Current production of rambutan in Australia is around 1000 tonnes in Qld and 100 tonnes in the NT (Diczbalis 2003). This has a current average market value of around $6,000,000 AUD / year.

Until recently, very little has been known about the insect fauna associated with rambutans in Australia. With the expansion of the rambutan industry it has become evident that several insect species are significant pests of the crop and require the development of integrated control strategies. Pest damage results in market rejection of the fruit; yield decline and the loss of income to the grower. This research aims to begin the development of integrated pest management in rambutan in Australia by conducting insect fauna surveys to help identify the major pests and beneficial insects unique to Australia and develop monitoring strategies to reduce the frequency with which costly and environmentally threatening insecticides are used.

Conducting insect fauna surveys of the pest and beneficial insect complex of rambutan in Australia is the first stage in the development of integrated pest management and the main objectives are summarised as follows;

Insect Fauna Surveys of the Major Pests and Beneficial Insects in Rambutan
A survey of the phytophagous and beneficial insect fauna of rambutan in Australia (Qld and NT) has been conducted to identify and monitor the major pest and beneficial insects as well as their seasonal population levels. This will help to identify the nature and extent of the potential insect pest spectrum.

Development of a Pest Monitoring Strategy for the Major Pests and Beneficials
Once the major pests and beneficial insects have been identified in rambutans a monitoring strategy will be developed based on the insects known biology, ecology and seasonality.

2.3 Methods and Materials

Five commercial orchards were monitored along the east coast of north Queensland. Monitoring sites were located at Mission Beach / Tully (146º: 00'E, 17º: 55'S), South Johnstone / Innisfail (146º: 00'E, 17º: 37'S), Babinda, (145º: 55'E, 17º: 20'S), Deeral / Fishery Falls (145º: 57'E, 17º: 12'S) and north east of Mossman (145º: 56'E, 16º: 17'S).

Tree field maps were developed at each sampling location. Trees were randomly selected before monitoring at each sampling site. Monitoring started on 30th June 2000 and was carried out fortnightly until June 2003.

Insects were collected using several methods that included sweep nets, beating trays, manual collection, fogging and light traps. An average of 10% of the trees was randomly sampled in each tree row at each location. Each tree was visually assessed for obvious plant damage to the leaves, stems, flowers, fruit and trunk. Depending on the crop phenology stage, five branches with new leaf flush; flowers or fruit were randomly selected and checked for insect activity and plant damage.

All specimens were counted and recorded throughout the growing season along with the crop cycle. The incidence of insect populations were rated as **0** = (0), **1**= (1-4), **2** = (5-10), **3** = (11-15), **4** = (16-20) and **5 =** (> 20) and the percent of plants infested was calculated for each population. This approach was adopted to give an overall view of the population incidences and distribution in the sampling areas.

Major and minor pests were assessed by visual observations throughout the year in the field and packing sheds. Minor insects were considered sporadic and rarely influenced yield decline or fruit quality while major pests affected fruit quality and influenced yield decline from flowering through to harvest.

Unknown insects causing plant damage were collected for identification. Each farm location had a mixture of new tree plantings and mature fruiting trees. Insects were identified with reference collections at the Department of Primary Industries and Fisheries, Centre for Wet Tropics Agriculture at South Johnstone or sent away to specialist insect taxonomists.

Historical records of pest presence and population activity have been supplied from records collected from Northern Territory researchers from Department of Business Industry Resource Development (DBIRD).

2.4 Results and Discussion - Phytophagous Insects QLD

Thirty-one phytophagous insects and five ant species were collected and identified in orchards of north Queensland. Lepidoptera and Hemiptera were the most represented orders of pests in Queensland orchards (11 species each). This was followed by Coleoptera and Hymonoptera (5 species each), Acarina (4 species), Diptera and Orthoptera (2 species each) and one species of Thysonoptera. (table 1.) Seasonality data was collected on all pests of north Queensland (table 3) which will assist in the development of a monitoring strategy for the rambutan industry.

2.4.1 Lepidoptera

The major insects of economic importance to the rambutan industry vary between location, crop phenology, climatic conditions and time of year. In Queensland Lepidoptera are the most persistent and damaging insect species attacking fruit, flowers and leaves. The most damaging Lepidoptera attacking fruit include the fruit borers, *Conogethes punctiferalis* Guenee from the family Pyralidae, and *Tiarthaba rufivena* Walker and *Cryptoblabes odoceta* Turner from the family Tortricidae. These are major pests of economic importance to the wet tropical areas of north Queensland and were present at all sampling sites. All three pests can cause yield losses greater then 90% in infected fruit clusters.

T. rufivena and *C. odoceta* will cause fruit loss from fruit set till harvest, effecting green immature and mature fruits. *C. odoceta* larvae will also feed on flowers. Larvae from both species feed in between developing touching fruit particularly where tight fruit clusters are present. In mature fruit the larva will occasionally bore inside the fruit. Pupation occurs on the outside between touching fruit.

C. punctiferalis will cause just as much damage as the other two species but is more common on mature colouring fruit. *C. punctiferalis* larvae will bore into fruit and complete most of its lifecycle inside the fruit. Rambutan fruit in all species die and turn brown in infected clusters.

Fruit piercing moth (Eudocima spp.) can also cause a large amount of fruit damage and is present in the coastal wet tropics of north Queensland. Three species were recorded which include *E. fullonia, E. materna* and *E. salaminia.* All adult moths feed at night on maturing fruit by inserting their proboscis into the fruit, sucking out the juices. This is normally soon followed by the infection of secondary pathogens at the puncture site which will rot the discarded fruit. These moths commonly attack fruiting trees adjacent to rainforest (Fay 2000).

The remaining Lepidoptera in the Queensland fauna are mainly leaf and flower feeders, which can cause damage during flowering and fruit set. These include leaf rollers *Lobesia* sp. and *Adoxophyes* sp. from the family Tortricidae and *Xanthodes congenita* from the family Lymantridae.

The loopers *Achaea janata* (Linnaeus) and *Oxyodes tricolor* Guenee from the family Noctuidae can cause occasional damage to new shoots and leaf flush.

2.4.2. Hemiptera

The next largest order of phytophagous insects in rambutan is Hemiptera. This includes six scale species (5 from the family Coccidae and 1 from the family Margarodidae, see table 1). Other pests include the fruit spotting bugs (*Amblypelta lutescens lutescens* Distant and Amblypelta nitida Stal), citrus mealybug (*Plannococcus citri* (Risso), plant hopper (*Colgaroides acuminata* Walker) and the tessaratomid bug *Lyramorpha* sp.

The most persistent and damaging insects in this order are the citrus mealybug and. fruit spotting bugs. All stages of mealybug actively feed on new flush stems, flower and fruit panicles. Mealybug can cause high level of damage especially around flowering restricting fruit set if high levels of sooty mould result from their sugary secretions. Many ant species have a symbiotic relationship with mealybug feeding off honeydew produced by this insect and will move them around the tree and protect them from predators.

Nymphs and adults of fruit spotting bug damage immature and mature fruits by piercing and sucking fruit juices. This results in similar damage symptoms to fruit piercing moth as secondary infections result after feeding has been completed.

Feeding of spotting bugs at fruit set can result in premature fruit drop. Although fruit spotting bugs have the ability to cause high levels of damage high pest populations are sporadic over the growing season.

The six scale insects found in Queensland are of minor importance as the level of damage is low and seasonal pest incidence is sporadic. *Coccus viridus* Green and *Icerya seychellarum* Westwood are the most common forms of scale insects found in rambutan orchards in the wet coastal tropics of north Queensland. All scale species found in rambutan feed on new flush stems, flower and fruit panicles and developing fruit. These insects also produce sugary secretions and are farmed by ants. High scale numbers result in the presence of sooty mould and if present at flowering can reduce fruit set. *Lyramorpha* sp. and *Colgaroides acuminata* are also unlikely to be a major pest in rambutan in Queensland because of low levels of feeding damage and sporadic seasonal activity.

2.4.3. Coleoptera

The order Coleoptera had five beetle species recorded as being active in rambutan orchards in the wet tropics of north Queensland. Four of these beetles were the swarming beetles from the family Chrysomellidae that included three species from the genus *Rhyparida* (*R. caeruleipennis*, *R. clypeata* and *R. discopunctulata.*) and one species from the genus *Monolepta* (*M. australis*). The final beetle was from the family Bostrichidae (*Sinoxylon* sp.)

The most persistent and damaging species from this order were the swarming leaf beetles *R. clypeate* and *R. discopunctulata.* These beetles are a major problem especially to newly establishing trees and if left uncontrolled can greatly restrict the rate of development and sometimes even kill new rambutan plantings because of intensive feeding on the new leaf flush and terminal shoots.

In mature established trees swarming leaf beetles including *Monolepta australis* can cause damage by feeding on new leaf flush, flowers and occasionally developing and mature fruit. The Bostrichid *Sinoxylon* sp. bores into tree branches but did not seem to impact on fruit quality and yield loss over the sampling period.

2.4.4. Acarina

Surveys in north Queensland recorded four mite species. Two species were from the genus *Brevipalpus* (*B. phoenicus* and *B. lewisi* from the family Tenuipalpidae). The remaining two mite species were *Tetranychus urticae* (Tetranychidae) and *Sellnickia caudata* (Sellnickia).
None of the mite species were considered major pests of economic importance in the coastal wet tropics of north Queensland. This is because of the high rainfall in this environment. The most persistent mites were from the genus *Brevipalpus* but the levels of pest damage over all the sampling sites was low. During exceptionally hot and dry periods these mites feed on the fruit surface and cause fruit discoloration to the fruit surface. *T. urticae* and *Sellnickia caudata* were very sporadic and seasonal pest incidence was very low during the sampling periods in Queensland suggesting that these mites are not significant pests in north Queensland.

2.4.5. Hymonoptera

The order Hymonoptera recorded five ant species from the family Formicidae. These included the green tree ant (*Oecophylla smaragdina),* coastal brown ant (*Pheidole megacephala*), black rattle ant (*Polyrhachis* sp.), *Tetramorium bicarinatum* and *Technomyrmex albipes.* Although these ant species do not directly cause plant damage and under some conditions can be seen as being beneficial attacking other pests they were found to indirectly assist the development of large scale and mealybug populations.

Ants move these insects around the tree canopy protecting scale and mealybug from predators. This tended to result in high levels of sooty mould on the flower and fruit panicles. The wet tropical conditions of north Queensland tend to favour high ant populations especially *Oecophylla smaragdina* which may need to be to be controlled when high populations are present.

2.4.6. Diptera

Fruit fly records have been recorded in rambutan fruit from the family Tephritidae (*Bactrocera javisi:* 2 records and *Bactrocera tryoni*: 1 record) in north Queensland. These were from records collected from the papaya fruit fly eradication database (Hancock *et. al.* 2000). Our sampling records over three years did not collect any fruit fly larvae in rambutan fruit harvested from the tree or collected from packing sheds. Leech (2003) suggests that fruit fly is only a problem in rambutan fruit with broken skin, as the fruit pericarp does not allow egg development. Fruit flies are not considered a pest of rambutan with unbroken skin in north Queensland.

2.4.7 Orthoptera

This order included a number of grasshoppers and katydids. The most common of these found in rambutan orchards in north Queensland included *Valanga irregularis* (Acrididae) and *Caedicia* sp. (Tettigoniidae). Although not being major pests of mature established trees, adults and nymphs of both insects can cause considerable damage to young rambutan plants by chewing all the new leaf flush and terminal shoots. This results in poor plant growth and establishment and can sometimes kill new plantings.

2.4.8 Thysonoptera

Only one thrip species was recorded in rambutan. Red-banded thrip (*Selenothrips rubrocinctus*) from the family Thripidae can cause fruit damage especially during hot dry conditions. Thrips have been recorded as active feeders from flowering through to harvest but are not considered major pests in the wet tropics. Under excessively dry conditions red-banded thrips can occasionally cause fruit scarring.

2.5 Results and Discussion – Phytophagous Insects NT

Twenty-two phytophagous insects and three ant species were collected in the Northern Territory (table 2). In the Northern Territory Hemiptera were the most represented order (10 species) followed by Lepidoptera (8 species), Coleoptera and Hymonoptera (3 species), Orthoptera (2 species) and Acarina and Thysonoptera (1 species each). Seasonality data was collected on all pests of the Northern Territory (table 4).

2.5.1 Hemiptera

The order Hemiptera currently has the largest group of insects that cause economic damage to rambutan in the Northern Territory. This includes six scale species from the families Coccidae (4 species) and Margarodidae (2 species, see table 2), two species of mealy bug from the family Pseudococcidae (*Maconellicoccus hirsutus* and *Planococcus citri*), as well as one species of planthopper (*Colgaroides* sp.) and fruit spotting bug (*Amblypelta lutescens lutescens*).

Unlike Queensland, scale, planthoppers and mealybugs are major pests infecting new flush growth, and flower and fruit panicles and mature fruit. Under high populations and dry weather these honeydew-producing insects result in the development of sooty mould. Sooty mould present during flowering can reduce fruit set by causing premature flower and fruit drop.

Although present, fruit spotting bug (*Amblypelta lutescens lutescens*) and pink wax scale (*Ceroplastes rubens*) are less common and sporadic in this group of pests but will occasionally become a problem under the right conditions.

2.5.2 Lepidoptera

The Northern Territory recorded eight insects of economic importance from this group. This includes a number of unidentified caterpillar larvae from the families Geometridae, Lymantridae and Tortricidae, which feed on all stages of plant growth (new leaf flush, flowers and fruit). Three species of insects have also been recorded from the family Noctuidae. These include the leaf eating loopers, *Achaea janata* and *Oxyodes tricolour,* which have the ability to cause large levels of damage to new leaf flush and new shoots. The fruit-piercing moth (*Eudocima* spp.) has been recorded but the pest status of these insects is currently unknown at this stage, as no fruit damage has been recorded with this pest in the Northern Territory. The Tortricid leaf roller *Adoxophyes* sp. can cause high levels of damage to new leaf flush.

2.5.3 Coleoptera

Only three beetles have been recorded from this order. They include the swarming leaf beetles from the family Chrysomelidae (*Rhyparida sp.* and *Monolepta australis*) and the swarming weevil (*Myllocerus nr. darwini*). The swarming leaf beetles are pests of economic importance causing damage to new leaf flush as well as flower and fruit panicles. The swarming weevils are sporadic and only considered minor pests in the Northern Territory and occasionally feed on new leaf flush.

2.5.4 Hymonoptera

Two ant species have been recorded in rambutan from the family Formicidae (*Oecophylla smaragdina* and *Iridomyrmex* spp.) and one termite species from the family Mastotermitidae (*Mastotermes darwinensis*). The two Formicid ant species are only occasionally considered to be indirect pests in rambutan assisting scale and mealy bug populations in the Northern Territory. *Mastotermes darwinensis* feeds on tree roots and can cause ring barking of the main trunk during the build up to the wet season.

2.5.5 Orthoptera

Grasshoppers and katydids make up the two pests from this order. These include *Valanga irregularis* (Acrididae) and *Caedicia* sp. (Tettigoniidae). Although not being major pests of mature established trees, adults and nymphs of both insects can cause considerable damage to young establishing rambutan plants by chewing all the new leaf flush and terminal shoots. This results in poor plant growth and establishment and can sometimes kill new plantings.

2.5.6 Thysonoptera

The red banded thrip (*Selenothrips rubrocinctus*) from the family Thripidae cause high levels of fruit damage especially during hot dry periods. Thrips are present during these dry conditions and are active feeders during flowering and early fruit development resulting in discoloration of the fruit. Unlike Queensland red-banded thrips are a major pest in the Northern Territory because of the extensive hot dry climate it does so well in.

2.5.7 Acarina

Surveys in the Northern Territory have only recorded one mite species (from the family Tenuipalpidae). *Brevipalpus phoenicus* is a major pest of rambutan in the Northern Territory.

During exceptionally hot and dry periods these mites feed on the new terminal shots, flowers and fruit surface and cause fruit discoloration to the fruit surface. *Brevipalpus phoenicus* is considered a major and persistent pest in the Northern Territory.

2.6 Results and Discussion – Beneficial Insects

A total of forty-six beneficial insects were recorded in the coastal wet tropics of north Queensland during the sampling period (table 5). These included eight wasps and two bees (Hymonoptera), eight spiders (Acarina), eight predatory beetles (Coleoptera), eight damsel and dragon flies (Odanata), three predatory flies (Diptera), three bugs (Hemiptera), three lacewing species (Neuroptera), two mantids (Mantodea) and one earwig species (Dermaptera).

2.6.1 Acarina

This group of is mainly made up of spiders which are general predators from the families Araneidae, Heteropididae, Lycosidae, Oxyopidae and Salticidae. It is not really understood how important these predators are except to say that they are indiscriminate feeders of all insects both good and bad. One predatory mite (*Phtoseiulus persimilis*) was also recorded with a one off record of two-spotted mite on rambutan fruit.

2.6.2 Coleoptera

From the order Coleoptera, the mealybug predator *Cryptolaemus montrouzieri* is a very important predator, which can very quickly reduce and even eliminate mealybug and scale populations in orchards of Queensland and the Northern Territory. Both adults and larvae of the mealybug ladybirds are voracious feeders especially of the egg masses and should be part of biological control programs to control mealybug and some scale insects. Future insect monitoring and insecticide applications will need to consider protection of this important predator in the development of IPM of mealybugs and scale pests in rambutan. A number of other beetles from the family Coccinellidae may also be important predators of scale insects.

2.6.3 Diptera

Flies from the families Dolichopodidae, Syrphidae and Tachinidae may be important parasitoid feeders of some caterpillar larvae, scale and mealybug. Very little is known at this stage on the effectiveness of these insects in reducing pest populations. The Tachinid fly *Argrophylax proclinata* is a known parasitoid of the yellow peach moth and its presence may be important in controlling this pest.

2.6.4 Dermaptera

One species of earwig (*Labidura riparia trunctata*) was identified in rambutan orchards in Queensland. Earwigs are general predators but their population levels throughout the growing season was low indicating they may not be important in controlling pest populations.

2.6.5 Hemiptera

These included the predatory assassin bugs (*Pristhesancus* sp.) and shield bugs (*Cermatulas nasalis* and *Oechalia* sp.) The assassin bugs are the most common predatory bugs found in rambutan orchards and may be important feeders of caterpillar larvae as well as other pests. A number of different species where collected over the sampling period. All predatory bugs are generalist predators.

2.6.6 Hymonoptera

This order included two pollinating bees from the family Apidae that included the honey bee (*Aphis mellifera*) and the native bee (*Trigona* sp.). Other Hymonoptera from the families Encyrtidae, Pteromalidae and Scelionidae are recorded parasitoids of mealybugs, fruit piercing moth eggs and scale insects. It is not known at this stage how effective these parasitoids are in reducing these pest populations.

2.6.7 Mantodea

Two species of praying mantis (*Acromantis* sp. and *Bolbe* sp.) were recorded in rambutan orchards. These insects are general predators feeding on all insects. Praying mantis populations were low throughout the growing season and it is not expected that these predators by themselves will influence orchard pest populations to any significant levels.

2.6.8 Neuroptera

This order included lacewings from the families Chrysopidae (*Chrysopa* spp. and *Mallada signata*) and one species from the family Mantispidae (*Theristria* sp.). Larva and adults of lacewings are very effective and voracious predators of mites, scale, mealybug and moth eggs and small caterpillar larvae. These insects may be important in a biological control program in rambutan and may have a beneficial effect on controlling many insect pests.

2.6.9 Odanata

This order includes the damsel and dragonflies from the families Coenagrionidae, Isoptictidae, Protoneuridae, Lestidae and Megapodagrionidae. Little is known of the effectiveness of these general predators. High numbers have been recorded in north Queensland due to the abundance of water and creeks near the sampling locations.

Table 1. *Showing a list of phytophagous insect and mites (order to species) collected on Nephelium lappaceum from north east Queensland from five survey sites over three years (June 2000-2003) along with their damage and tree location found.*

Order	***Family***	***Genus***	***Species***	***Plant Damage***
Acarina	Tenuipalpidae	*Brevipalpus*	*phoenicus*	*Shoots, flowers, fruit*
Acarina	Tenuipalpidae	*Brevipalpus*	*lewisi*	*Shoots, flowers, fruit*
Acarina	Tetranychidae	*Tetranychus*	*urticae*	*Shoots, flowers, fruit*
Acarina	Sellnickia	*Sellnickia*	*caudata*	*Shoots, flowers, fruit*
Coleoptera	Bostrichidae	*Sinoxylon*	sp.	*Branches, Stems*
Coleoptera	Chrysomelidae	*Monolepta*	*australis*	*Leaves, flowers, fruit*
Coleoptera	Chrysomelidae	*Rhyparida*	*caeruleipennis*	*Leaves, flowers, fruit*
Coleoptera	Chrysomelidae	*Rhyparida*	*clypeata*	*Leaves, flowers, fruit*
Coleoptera	Chrysomelidae	*Rhyparida*	*discopunctulata*	*Leaves, flowers, fruit*
*Diptera	Tephritidae	*Bactrocera*	*jarvisi*	*Fruit broken skin*
*Diptera	Tephritidae	*Bactrocera*	*tryoni*	*Fruit broken skin*
Hemiptera	Coreidae	*Amblypelta*	*lutescens lutescens*	*Fruit*
Hemiptera	Coreidae	*Amblypelta*	*nitida*	*Fruit*
Hemiptera	Coccidae	*Coccus*	*hesperidum*	*Leaves, Stem, fruit*
Hemiptera	Coccidae	*Coccus*	*viridus*	*Leaves, Fruit*
Hemiptera	Coccidae	*Pulvinaria*	*psidii*	*Leaves, Fruit*
Hemiptera	Coccidae	*Saisettia*	*coffeae*	*Leaves, Stem, fruit*
Hemiptera	Coccidae	*Ceroplastes*	*rubens*	*Leaves*
Hemiptera	Flatidae	*Colgaroides*	*acuminata*	*Stems, Fruit*
Hemiptera	Margarodidae	*Icerya*	*seychellarum*	*Leaves, Fruit*
Hemiptera	Pseudococcidae	*Planococcus*	*citri*	*Flowers, fruit, Stems*
Hemiptera	Tessaratomidae	*Lyramorpha*	sp.	*Stems*
Hymenoptera	Formicidae	*Oecophylla*	*smaragdina*	*Farms scale, mealybug,*
Hymenoptera	Formicidae	*Pheidole*	*megacephala*	*Farms scale, mealybug*
Hymenoptera	Formicidae	*Polyrhachis*	sp.	*Farms scale, mealybug*
Hymenoptera	Formicidae	*Tetramorium*	*bicarinatum*	*Farms scale, mealybug*
Hymenoptera	Formicidae	*Technomyrmex*	*albipes*	*Farms scale, mealybug*
Lepidoptera	Lymantridae	*Xanthodes*	*congenita*	*Flowers, Fruit*
Lepidoptera	Noctuidae	*Achaea*	*janata*	*Leaves*
Lepidoptera	Noctuidae	*Eudocima*	*fullonia*	*Fruit*
Lepidoptera	Noctuidae	*Eudocima*	*materna*	*Fruit*
Lepidoptera	Noctuidae	*Eudocima*	*salaminia*	*Fruit*
Lepidoptera	Noctuidae	*Oxyodes*	*tricolor*	*Leaves*
Lepidoptera	Pyralidae	*Conogethes*	*punctiferalis*	*Fruit*
Lepidoptera	Tortricidae	*Adoxophyes*	sp.	*Leaf*
Lepidoptera	Tortricidae	*Cryptoblabes*	*odoceta*	*Flowers, Fruit*
Lepidoptera	Tortricidae	*Lobesia*	sp.	*Flowers, Fruit*
Lepidoptera	Tortricidae	*Tirathaba*	*rufivena*	*Fruit*
Orthoptera	Acrididae	*Valanga*	*irregularis*	*Leaves*
Orthoptera	Tettigoniidae	*Caedicia*	sp.	*Leaves*
Thysonoptera	Thripidae	*Selenothrips*	*rubrocinctus*	*Flowers, fruit, Stems*

** From host records collected from Hancock et.al 2000. Not found in the surveys of this project.*
Table 2. *Showing a list of phytophagous insects and mites (order to species) collected on Nephelium lappaceum by researchers from the Northern Territory (DBIRD) from local orchards and historical pest records along with their damage and tree location found*

Order	***Family***	***Genus***	***Species***	***Plant Damage***
Acarina	Tenuipalpidae	*Brevipalpus*	*phoenicus*	*Shoots, flowers, fruit*
Coleoptera	Chrysomelidae	*Monolepta*	*australis*	*Leaves, flowers, fruit*
Coleoptera	Chrysomelidae	*Rhyparida*	sp.	*Leaves, flowers, fruit*
Coleoptera	Curculionidae	*Myllocerus nr.*	*darwini.*	*Leaves*
Hemiptera	Coccidae	*Ceroplastes*	*rubens*	*Leaves*
Hemiptera	Coccidae	*Coccus*	*hesperidum*	*Leaves, Stem, fruit*
Hemiptera	Coccidae	*Pulvinaria*	*psidii*	*Leaves, Fruit*
Hemiptera	Coccidae	*Saisettia*	*coffeae*	*Leaves, Stem, fruit*
Hemiptera	Coreidae	*Amblypelta*	*lutescens lutescens*	*Fruit*
Hemiptera	Flatidae	*Colgaroides*	spp.	*Stems, Fruit*
Hemiptera	Margarodidae	*Icerya*	*aegyptiaca*	*Leaves, Fruit*
Hemiptera	Margarodidae	*Icerya*	*seychellarum*	*Leaves, Fruit*
Hemiptera	Pseudococcidae	*Maconellicoccus*	*hirsutus*	*Flowers, fruit, Stems*
Hemiptera	Pseudococcidae	*Planococcus*	*citri*	*Flowers, fruit, Stems*
Hymenoptera	Formicidae	*Oecophylla*	*smaragdina*	*Farms scale, mealybug,*
Hymenoptera	Formicidae	*Iridomyrmex*	spp.	*Farms scale, mealybug*
Hymenoptera	Mastotermitidae	*Mastotermes*	*darwinensis*	*Trunk, Roots*
Lepidoptera	Geometridae	*	spp.	*Flowers, Fruit*
Lepidoptera	Lymantridae	*	spp.	*Flowers, Fruit*
Lepidoptera	Noctuidae	*Achaea*	*janata*	*Leaves*
**Lepidoptera	Noctuidae	*Eudocima*	spp.	*Fruit*
Lepidoptera	Noctuidae	*Oxyodes*	*tricolor*	*Leaves*
**Lepidoptera	Pyralidae	*Conogethes*	*punctiferalis*	*Fruit*
Lepidoptera	Tortricidae	*Adoxophyes*	sp.	*Leaves*
Lepidoptera	Tortricidae	*	spp.	*Flowers, Fruit*
Orthoptera	Acrididae	*Valanga*	*irregularis*	*Leaves*
Orthoptera	Tettigoniidae	*Caedicia*	sp.	*Leaves*
Thysonoptera	Thripidae	*Selenothrips*	*rubrocinctus*	*Flowers, fruit, Stems*

* A number of unidentified caterpillar larvae to genus and species level
** Recorded in the Northern Territory but pest status in rambutan is unknown

Table 3. *Showing a list of phytophagous insects and mites (genus to species) collected on Nephelium lappaceum from northeast Queensland from five survey sites along with their seasonal activity over three years (June 2000-2003)*

Genus	***Species***	***Monthly Activity***
Achaea	*janata*	*Sept - May*
Adoxophyes	sp.	*Sept - May*
Amblypelta	*lutescens lutescens*	*Oct - May*
Brevipalpus	*phoenicus*	*Oct - May*
Brevipalpus	*lewisi*	*Aug - Dec*
Caedicia	sp.	*Sept - May*
Ceroplastes	*rubens*	*Feb*
Coccus	*hesperidum*	*Dec - May*
Coccus	*viridus*	*Dec - May*
Colgaroides	*acuminata*	*Oct - May*
Conogethes	*punctiferalis*	*Jan - May*
Cryptoblabes	*odoceta*	*Sept - May*
Eudocima	*fullonia*	*Jan - May*
Eudocima	*materna*	*Jan - May*
Eudocima	*salaminia*	*Jan - May*
Eudocima	sp.	*Jan - May*
Icerya	*purchasi*	*Jan - Apr*
Lobesia	sp.	*Sept - May*
Lyramorpha	sp.	*Oct - May*
Monolepta	*australis*	*Oct - May*
Oecophylla	*smaragdina*	*Aug - May*
Oxyodes	*tricolor*	*Sept - May*
Pheidole	*megacephala*	*Aug - March*
Planococcus	*citri*	*Sept - May*
Plautia	*affinia*	*Jan - Apr*
Polyrhachis	sp.	*Dec - May*
Pulvinaria	*psidii*	*Jan - May*
Rhyparida	*caeruleipennis*	*Sept - May*
Rhyparida	*clypeata*	Sept - May
Rhyparida	*discopunctulata*	Sept - May
Saisettia	*coffeae*	*Jan - May*
Selenothrips	*rubrocinctus*	*Sept - May*
Sellnickia	*caudata?*	*Dec - Feb*
Sinoxylon	sp.	*Sept - May*
Tetramorium	*bicarinatum*	*Oct - May*
Tetranychus	*urticae*	*Aug - Jan*
Tirathaba	*rufivena*	*Jan - May*
Valanga	*irregularis*	*Sept - May*
Xanthodes	*congenita*	*Dec - Apr*

Table 4. *Showing a list of phytophagous insects and mites (genus to species) collected on Nephelium lappaceum by researchers from the Northern Territory (DBIRD) from local orchards and historical pest records with seasonal activity*

Genus	***Species***	***Month Activity***
Achaea	*janata*	*Mar - May*
Amblypelta	*lutescens lutescens*	*Sept - Oct*
Brevipalpus	*phoenicus*	*Aug - Dec*
Caedicia	sp.	*June - Feb*
Ceroplastes	*rubens*	*All year*
Coccus	*hesperidum*	*June - Feb*
Colgaroides	spp.	*June - Feb*
Eudocima	spp.	*Sept - Jan*
Icerya	*aegyptiaca*	*June - Feb*
Icerya	*seychellarum*	*June - Feb*
Iridomyrmex	spp.	*June - Feb*
Maconellicoccus	*hirsutus*	*June - Feb*
Mastotermes	*darwinensis*	*June - Feb*
Monolepta	*australis*	*March - Dec*
Myllocerus nr.	*darwini.*	*Oct - Apr*
Oecophylla	*smaragdina*	*June - Feb*
Oxyodes	*tricolor*	*Mar - May*
Planococcus	*citri*	*June - Feb*
Pulvinaria	*psidii*	*June - Feb*
Rhyparida	sp.	*March - Dec*
Selenothrips	*rubrocinctus*	*March - Oct*
Valanga	*irregularis*	*June - Feb*

Table 5. *Showing a list of beneficial insects and mites (order to species and general hosts) collected on Nephelium lappaceum from northeast Queensland from five survey sites June 2000 – June 2003*

Order	***Family***	***Genus***	***Species***	***Host***
Acarina	Phytoseiidae	*Phytoseiulus*	*persimilis*	mites
Acarina	Araneidae	*Gasteracantha*	spp.	general predator
Acarina	Araneidae	*Nephila*	spp.	general predator
Acarina	Heteropididae	*Holconia*	spp.	general predator
Acarina	Lycosidae	*Lycosa*	spp.	general predator
Acarina	Oxyopidae	*Oxyopes*	spp.	general predator
Acarina	Salticidae	*Mopsus*	mormon.	general predator
Acarina	Salticidae	*Opisthoncus*	spp.	general predator
Coleoptera	Coccinellidae	*Amidellus*	*ementitor*	scale?
Coleoptera	Coccinellidae	*Coelophora*	*inoequalis*	scale?
Coleoptera	Coccinellidae	*Coccinnella*	*transversalis*	scale?
Coleoptera	Coccinellidae	*Illeis*	*galbula*	scale?
Coleoptera	Coccinellidae	*Micraspis*	*lineola*	scale?
Coleoptera	Coccinellidae	*Micraspis*	*frenata*	scale?
Coleoptera	Coccinellidae	*Cryptolaemus*	*montrouzieri*	mealybug, scale
Coleoptera	Coccinellidae	*Rodilia*	sp.	scale
Diptera	Dolichopodidae	*Psilopus*	sp.	general predator
Diptera	Syrphidae	*Melangyna*	sp.	scale, mealybug
Diptera	Tachinidae	*Argyrophlax*	*proclinata*	caterpillar larvae
Dermaptera	Labiduridae	*Labidura*	*riparia truncata*	general predator
Hemiptera	Pentatomidae	*Cermatulas*	*nasalis*	general predator
Hemiptera	Pentatomidae	*Oechalia*	sp.	general predator
Hemiptera	Reduviidae	*Pristhesancus*	spp.	general predator
Hymonoptera	Apidae	*Aphis*	*mellifera*	pollinator
Hymonoptera	Apidae	*Trigona*	sp.	pollinator
#Hymonoptera	Encyrtidae	*Anagyrus*	sp.	mealybug.
#Hymonoptera	Encyrtidae	*Coccidoxenoides*	sp.	mealybug
#Hymonoptera	Encyrtidae	*Leptomastidae*	*abnormis*	mealybug.
Hymonoptera	Encyrtidae	*Leptomastix*	*dactylopii*	mealybug
#Hymonoptera	Encyrtidae	*Ooencyrtus*	sp.	*Eudocima spp.*
#Hymonoptera	Pteromalidae	*Opelosia*	sp.	scale
#Hymonoptera	Scelionidae	*Telenomus*	sp.	*Eudocima spp.*
#Hymonoptera	Trichogrammatidae	*Trichogrammatiodae*	sp.	*Eudocima spp.*
Mantodea	Hymenopodidae	*Acromantis*	sp.	general predator
Mantodea	Mantidae	*Bolbe*	sp.	general predator
Neuroptera	Chrysopidae	*Chrysopa*	spp.	general predator
Neuroptera	Chrysopidae	*Mallada*	*signata*	general predator
Neuroptera	Mantispidae	*Theristria*	sp.	general predator
Odonata	Coenagrionidae	*Ischnura*	*fragilis*	general predator
Odonata	Coenagrionidae	*Agrionocnemis*	*argentea*	general predator
Odonata	Coenagrionidae	*Agrionocnemis*	*dobsoni*	general predator
Odonata	Isostictidae	*Austrosticta*	*fieldi*	general predator
Odonata	Isostictidae	*Isosticta*	*simplex*	general predator
Odonata	Protoneuridae	*Alloneura*	*coelestina*	general predator
Odonata	Lestidae	*Austrolestes*	*insularis*	general predator
Odonata	Megapodagrionidae	*Austroargiolestes*	*aureus*	general predator

? = predatory and found on trees but not observed feeding on any hosts
= records by Smith *et. al* 1997 and Fay 2000.

2.7 Conclusions and Recommendations

Different pest complexes exist due to the differences in climatic conditions between the wet tropics of north Queensland and the dry climate of the Northern Territory. The two climates also promote a difference in the rambutan phenology cycles and pest activity over the growing season. Based on the data collected over the survey period the following are classified as major pests of economic importance in Queensland and the Northern Territory.

2.7.1 Major pests of economic importance - Queensland

The major pests of Queensland are mainly from the order Lepidoptera. These include *Conogethes punctiferalis* Guenee from the family Pyralidae, and *Tiarthaba rufivena* Walker and *Cryptoblabes odoceta* Turner from the family Tortricidae. These insects are fruit borers and fruit feeders. The larvae of these insects cause extensive damage to developing and mature fruit by feeding on the fruit surface and boring into the fruit. It has been observed that these insects can destroy 90% of fruit clusters if left uncontrolled. Leaf and flower feeding larvae of *Lobesia* sp. and *Adoxophyes* sp. from the family Tortricidae and *Xanthodes congenita* from the family Lymantridae can also be major pests if left uncontrolled during flowering and fruit set. Larvae of these insects feed on flowers and can extensively reduce fruit set and development.

Citrus mealybug (*Planococcus citri*) are a major pest of economic importance to rambutans in north Queensland and can be extensively farmed and protected by a number of ant species from the family Formicidae. Although a major pest this insect can be effectively controlled biologically by the Coccinellid mealybug beetle *Cryptolaemus montrouzieri.*

Swarming leaf beetles from the family Chrysomelidae (*Rhyparida* spp. and *Monolepta australis*) are also pests of economic importance in rambutans in Queensland. These insects are a problem in small developing trees feeding on terminal shoots and leaf flush and under high populations can kill new plantings.

Fruit spotting bugs (*Amblypelta* spp.) can cause high levels of fruit damage if left uncontrolled and are also classified as pests of economic importance to rambutan in north Queensland. A number of scale species from the family Coccidae can cause problems from time to time infecting flowers and fruit and under large populations sooty mould will develop effecting fruit set. Ants from the family Formicidae will also farm and protect scale insects from predators. Predatory beetles from the family Coccinellidae and parasitic wasps from the family Encyrtidae can effectively control scale insect populations.

2.7.2 Major pests of economic importance – Northern Territory

In the drier climate of the Northern Territory the mite *Brevipalpus phoenicus* and the red-banded thrip (*Slenothrips rubrocinctus*) are major pests of economic importance causing fruit discoloration and blemishes to developing and mature fruit. Mealybugs from the family Pseudococcidae are also a problem of economic importance in the Northern Territory. These insects are farmed and protected by a number of ant species from the family Formicidae. Although major pests these insects can be effectively controlled biologically by the Coccinellid mealybug beetle *Cryptolaemus montrouzieri.* Scale insects from the family Coccidae are also major pests during flowering and fruit development. These insects are also farmed and protected by ants from the family Formicidae. Most of the scale insects can be controlled biologically by predatory beetles and parasitoids.

Swarming leaf beetles (Chrysomelidae) are also a problem in the Northern Territory to developing trees and need to be controlled when natural populations get too high. A number of flower feeding caterpillar larvae (Geometridae, Lymantridae, Pyralidae and Tortricidae) can cause extensive damage

to flowers effecting fruit set if left uncontrolled. Loopers and leafrollers (*Achaea janata, Oxyodes tricolour* and *Adoxophes* sp.) can become major pests feeding on new leaf flush and shoots and can severely restrict plant growth. Leaf rollers can also become a problem as they feed on flower panicles reducing fruit set in the Northern Territory.

2.7.3 Monitoring strategy for pests of economic importance

A monitoring strategy has been developed and promoted to the Australian rambutan industry in north Queensland and the Northern Territory. Preliminary economic threshold levels (ETL's), which are based on each pest's known biology, type of damage, and crop phenology stage has been developed to assist with pest control decision-making. It should be pointed out that the ETL's are only preliminary and based solely on estimates of yield decline and will change over time as more data is collected from economic impact assessments of individual pests. Market price will also be a factor, which will affect the threshold levels, which are currently set in rambutans and needs to be taken into consideration. Identification of pest and beneficial insect populations is critical to monitoring and determining ETL's. To assist growers in this process an AO size insect identification and monitoring poster, book and CD have been developed. The poster shows the pest stage, the pest's crop damage, the pest's size, where it is found in the tree and at what time of the year the pest is most active and needs to be monitored. The book supplies more detailed information on pest and beneficial insect biology and ecology and pest population management. A CD has also been developed to help growers know when their pest population levels are getting too high and need to be controlled. A series of workshops have been conducted in Qld and NT to assist grower understanding of the proposed monitoring strategy which includes the following:

- ***Development of detailed orchard maps*** The orchard is divided into blocks. A block comprises trees of the same variety and similar age in the same location. The orchard and block maps need to have accurate numbered trees and rows.

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- ***Randomly check 10-20 trees per hectare or 10% of the trees in smaller blocks.*** Once detailed monitoring maps have been developed a random selection of around 10% of the trees from each block/row are chosen over the whole orchard. This is the monitoring plan, which needs to be developed each time scouting begins.

- ***Tree sampling*** is carried out by carefully examining 4-5 random terminal shoots containing leaf flush, flower panicles or fruit clusters depending on the time of the crop cycle.

- ***Data recording at each tree sample*** needs to consider the date and time of sampling, block name or number, variety, crop cycle stage, person recording, pests and beneficial insects present with an estimation of numbers present per tree sample and an estimation of crop damage to leaf flush, flowers or fruit.

- ***Monitoring data analysis-using ETL's to carry out pest control.*** The data collected from the sampling sheets for each orchard block is then averaged over each tree sample and then averaged over the sampling block for the number of trees sampled and compared to the suggested ETL's (table 6) to decide if pest control needs to be carried out or not. If individual trees exceed the suggested threshold levels relative to averaged block data these can be treated individually as hot spots and treatments can be applied accordingly. To assist the process a CD has been developed to automatically calculate ETL's. Caution should be used when using the suggested threshold levels if the market price is too low the cost of control relative to the value of the product at the time of harvest may not be economical. If this occurs the ETL's can be set higher than normal at the growers' discretion.

***Table 6**. Recommended economic threshold levels (ETL's) for the major pests of rambutan*

Genus	***Species***	***Crop stage***	***ETL's***
Achaea	*janata*	leaf	≥ 15% loss of leaf and ≥ 2 loopers
Adoxophyes	spp.	leaf, flowers	≥ 15% loss of leaf and ≥ 2 larvae per tree
Amblypelta	spp.	fruit	≥ 1 bug
Brevipalpus	*phoenicus*	flowers, fruit	≥ 5% fruit discolouration and mites a present. Use X10 hand lens
Coccus	*hespiridum*	flowers, fruit	≥ 20% flower/fruit infestation and < 10% flowers/fruit have predatory beetles present
Coccus	*viridus*	flowers, fruit	≥ 20% flower/fruit infestation and < 10% flowers/fruit have predatory beetles present
Conogethes	*punctiferalis*	fruit	≥ 2% fruit damage and larvae are present.
Icerya	spp.	flowers, fruit	≥ 20% flower/fruit infestation and < 10% flowers/fruit have predatory beetles present
Lobesia	spp.	leaf, flowers, fruit-set	≥ 15% loss of leaf and ≥ 2 larvae per tree or ≥1 larvae present at flowering in flower panicle.
Maconellicoccus	*hirsutus*	flowers, fruit	≥ 20% flower/fruit infestation
Monolepta	*australis*	leaf, flowers, fruit	≥1 beetle flowering or fruiting or new plants leaf damage; ≥ 4 beetles leaf flush established trees
Oxyodes	*tricolor*	leaf	≥ 15% loss of leaf and ≥ 2 loopers per tree
Planococcus	*citri*	flowers, fruit	≥ 20% flower/fruit infestation and < 10% flowers/fruit have predatory beetles present
Pulvinaria	*psidii*	flowers, fruit	≥ 20% flower/fruit infestation and < 10% flowers/fruit have predatory beetles present
Rhyparida	spp.	leaf, flowers, fruit	≥1 beetle flowering or fruiting or new plants leaf damage; ≥ 4 beetles leaf flush established trees
Saisettia	*coffeae*	flowers, fruit	≥ 20% flower/fruit infestation and < 10% flowers/fruit have predatory beetles present
Selenothrips	*rubrocinctus*	flowers, fruit	≥ 5% fruit discolouration and mites a present. Use X10 hand lens

Tirathaba	*rufivena*	fruit	≥ 2% fruit damage and larvae are present.
Xanthodes	*congenita*	flowers, fruit	≥1 larvae present at flowering in flower panicle.

2.8 References

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3. Insecticide Screening

3.1 Overview

Insecticide screening has been completed against the major pest complex of phytophagous insects in rambutan. A total of 16 insecticides were screened to cover the pest spectrum. Eight insecticides where selected because of their good environmental profiles and unique modes of action and suitability for managing insecticide resistance.

Spinosad, emamectin benzoate, tebufenozide, thiamethoxam and *Bacillus thuriengiensis var kurstaki* where the most effective insecticide treatments against *Conogethes punctiferalis* and were not significantly different to the standard chlorpyrifos ($P<0.05$) three to four days after treatment. Beta-cyfluthrin was an effective alternative to endosulfan for controlling *Amblypelta* spp. and achieved 100% mortality five days after treatment and was not significantly different to the endosulfan standard. Beta-cyfluthrin also controlled *Rhyparida* sp and achieved 100% mortality after four days. Imidaclorprid was effective in controlling *Planococcus citri* and achieved 100% mortality after three days.

Spinosad was the most effective treatment against red-banded thrips in the NT bioassays, achieving 100% mortality 24 h after spraying at 1.6 % concentration. All rates of spinosad tested were effective even the lowest rate of 0.2% achieved 97% mortality after 24 hr. The mineral oils DC Tron Plus® and Fuchs Universal Spray Oil® achieved 80% and 84 % mortality respectively at 2% oil concentrations and were considered partially effective. No chemical was particularly effective against two-spotted mites but Fuchs Universal Spray Oil® and Neemtech® gave greater than 70% mortality at the highest concentrations tested.

3.2 Introduction

Current commercial practice for controlling pests of rambutan relies exclusively on calendar based spraying of broad-spectrum, insecticides to reduce damage caused by insects. The most common insecticides currently being used by industry are organophosphates, which are toxic to the environment and human health. Australian Pesticides Veterinary Medicines Authority (APVMA) is currently in the process of reviewing all chemicals that have the possibility of causing environmental contamination. Hattingh 1996 reports that new pesticide regulations in some countries have brought about a drastic reduction in the use of organophosphate insecticides, forcing growers to look for safer alternatives. The Australian government is adopting this approach to reviewing pesticides that are toxic to the environment and human health.

Besides the potential for environmental contamination and the possibility of high insecticide residues in the fruit, indiscriminate use and constant exposure of pesticides to insect populations often results in chemical resistance to insects (Bolin *et al*.1999). Miyo 1999, Hattingh 1996, Morse and Schweizer 1996, Immaraju et, al. 1989, and Georgala 1988 among others have reported insecticide resistance occurring in many different insect orders. Forgash 1984, and Grafius 1997 have described the economic impact and consequences of insecticide resistance, and the need to investigate new chemistry before complete insecticide failure occurs.

Past researchers have shown that developing resistance management strategies and insecticide application based on monitoring insect populations is a very important part of IPM (Roush and Daly 1990, Gelernter 1990, Tabashnik and Croft 1982, Immaraju et, al. 1990). Monitoring is an important part of any IPM system and allows growers to apply insecticides only as required.

New insecticides such as biopesticides, insect growth regulators (IGR's), and some natural botanicals are developing technologies that could be very well suited to IPM in rambutan. Many of these insecticides are highly specific to pest insects and are safe to the environment and human health and work well in tropical environments with high rainfall (Roberts and Wraight 1986).

A synergism between natural enemies and biopesticides has been reported (Montserrat et, al 1998). In the absence of acute toxicity beneficials are able to work with insect pathogens to increase the control of a pest outbreak (Lopez and Ferro 1995).

The rambutan industries of north Queensland and the Northern Territory along with QHI, have identified research into IPM as a number one priority in industry strategic plans. This project has been given greater priority because of the recent reviews and restrictions placed on the use of endosulfan and chlorpyrifos by the NRA.

This research aims to evaluate environmentally safe insecticides suitable for sustainable pest management. Insecticides will be screened for possible minor use registration to replace endosulfan and chlorpyrifos that are currently in use by the industry. The objectives will be to evaluate insecticides to cover the pest spectrum that have unique modes of action and a safe environmental profile. Pesticides will be selected to encourage insecticide resistance management based on chemical group rotation. QFVG will then be approached to seek minor use registrations of the most effective insecticides on behalf of the rambutan industry.

3.3 Methods and Materials

The insecticide screening had two phases which included the general screening bioassays in the lab which were used to initially identify products for field testing and further evaluation.

3.3.1 Lab bioassays

Topical or ingestion and contact assays were carried out against some of the major pests of rambutan in Queensland and Northern Territory. Major insect pest of rambutan were collected from the field and reared in the lab or glasshouse in preparation for insecticide screening in the lab. The application rate for each treatment was the registered rate used in other crops with the same pest or the most probable effective rate based on tests of similar insect species. All insecticide rates were the suggested rates supplied by participating chemical companies. Data was analysed for statistical difference of the treatment means using ANOVA Genstat 5 for windows. Arcsine transformations were carried out on the data as required and mortality was adjusted using Abbott's formula.

3.3.1.1 Yellow peach moth (Conogethes punctiferalis Guenee)

Larvae were collected from infested fruit in the field and artificially reared in the lab on a technique for rearing banana scab moth (*Nacoleia octasema* Meyrick) developed by Astridge 2001. Two experiments were conducted against yellow peach moth in the lab. This included a topical and an ingestion and residual assay.

Topical Bioassay

The topical assay examined the efficacy of six insecticide treatments. The treatments included Mimic 700 WP® (tebufenozide @ 12.9g/100L), Success® (spinosad @ 100ml/100L), Actara® (thiamethoxam @ 40g/100L), LorsbanWG750® standard (chlorpyrifos @ 167g/125L) and a water and wetting agent control (Agral® 100ml/100L). One droplet, size of 1µl was placed behind the head capsule on each larva (4 x 1^{st}, 3^{rd} and 5^{th} instar larvae) with a Burkard hand micro applicator and replicated 4 times with a control (water and wetting agent) and a standard (chlorpyrifos).

Larvae were then placed in takeaway containers (rectangle 750ml) (4 x 1st, 3rd and 5th instar larva per take away container) with perforated lids to allow for air movement and six rambutan fruit. All treatments were placed in a constant temperature (CT) room using a randomised complete block (RCB) trial design, blocking for ununiform temperature, light and air movement. CT room settings were 27° C, 80% RH and a 14:10 photoperiod. Mortality was assessed every 24 hours for 7 days.

Ingestion and Contact Bioassay

The ingestion and residual bioassays were then carried out. The treatments included Mimic 700 WP® (tebufenozide @ 12.9g/100L), Success® (spinosad @ 100ml/100L), Actara® (thiamethoxam @ 40g/100L), Proclaim® (emamectin 40g/100L), Dipel® (*Bacillus thuriengiensis var. kurstaki* 33g/100L*)*, LorsbanWG750® standard (chlorpyrifos @ 167g/125L) and a Water and wetting agent control (Agral® 100ml/100L). Chemical free rambutan fruits were collected from the orchard at DPI&F's Sth Johnstone research station. Six fruit per replicate were dipped in each treatment for 1 minute and allowed to air dry on newspaper for 20 minutes before being placed in Chinese takeaway containers (rectangle 750ml). Larvae were then placed in the takeaway containers (4 x 1st, 3rd and 5th instar larva per container) and replicated four times.

All treatments were placed in a constant temperature (CT) room using a RCB trial design blocking for uneven temperature, light and air movement. CT room settings were 27° C, 80% RH and a 14:10 photoperiod. Mortality was assessed every 24 hours for 7 days.

3.3.1.2 Fruitspotting bug (Amblypelta lutescens lutescens Disant)

Fruitspotting bug (FSB) was field collected and reared in the lab on beans placed in cylinder assay containers (30cm height x 20cm diameter). Ingestion and contact bioassays were then carried out against FSB in the lab. The treatments included Actara® (thiamethoxam @ 40g/100L), Talstar (bifenthrin 50ml/100L), Mavrik® (tau-fluvalinate, 50 ml/100L), Bulldock Prime® (beta-cyfluthrin, 10ml/100L + Agral), Endosulfan 350 EC standard (endosulfan, 150ml/100L), and a control (water and wetting agent Agral® 100ml/100L). Chemical free rambutan fruits were collected from the orchard at DPI&F's Sth Johnstone research station. Six fruit per replicate were dipped in each treatment for 1 minute and allowed to air dry on newspaper for 20 minutes before being placed in Chinese takeaway containers (rectangle 750ml). Three FSB were placed in each takeaway container and replicated 5 times.

All treatments were placed in a constant temperature (CT) room using a RCB trial design blocking for uneven temperature, light and air movement. CT room settings were 27° C, 80% RH and a 14:10 photoperiod. Mortality was assessed every 24 hours for 7 days or until all replicates had finished.

3.3.1.3 Black swarming leaf beetle (Rhyparida discopunctulata Blackburn)

Beetles were field collected from rambutan and cocoa plantings and reared in a glasshouse in an insect proof enclosure (2m x 2m x 2m) on *Theobroma cacao* and *Eucalyptus torreliana* plants. Ingestion and contact bioassays were then carried out against *Rhyparida* beetles in the lab.

The treatments included Actara® (thiamethoxam @ 40g/100L), Mavrik® (tau-fluvalinate, 30ml/100L), Bulldock Prime® (beta-cyfluthrin, 10ml/100L + Agral), Carbaryl standard (200ml/100L) and a control (water and wetting agent Agral® 100ml/100L).

Chemical free branches of new leaf flush were collected from mature rambutan trees at Sth Johnstone research station. Approximately 100g of new leaf flush as branches were measured out per replicate and dipped in each treatment and allowed to air dry for 20 minuets on newspaper.

Treated branches of leaf flush were then placed into 200ml glass jars with holes drilled through the lids to stop beetles falling in the water and drowning. 100ml of water was added to each jar to prolong the life of the leaf flush. Leaf flush in the water jars were then placed into the cylinder assay containers (30cm height x 20 cm diameter) and 10 adult beetles were then released into each assay container.

The five treatments were replicated four times and placed in a constant temperature (CT) room using a RCB trial design blocking for uneven temperature, light and air movement. The CT room settings were 27° C, 80% RH and a 14:10 photoperiod. Mortality was assessed every 24 hours for 7 days or until all replicates had finished.

3.3.1.4 Citrus mealybug (Planococcus citri (Risso))

Mealybugs were field collected from infested rambutan fruit and artificially reared in the lab CT room on butternut pumpkins (27° C, 80% RH and a 14:10 photoperiod). Ingestion and contact assays were carried out against citrus mealybug in the lab. The treatments included Chess® (pymetrozine @ 60g/100L), Confidor® (imidochlorprid 25ml/100L) Neem oil (1L/100L 1% ai), Chlorpyrifos 500 EC standard (chlorpyrifos, 100ml/100L) and a control (water and wetting agent Agral® 100ml/100L). One butternut pumpkin (1.5kg) per treatment replicate was dipped in each diluted treatment and allowed to dry for 20 minuets on newspaper. Once dried each pumpkin was placed inside a plastic container (22cm L x 16cm W x 14 cm H) overlayed with flyscreen gauze lids. Twenty female adult mealybugs were placed on each treated pumpkin inside the containers. The five treatments were replicated 4 times and all containers were then placed inside the CT room using a RCB trial design blocking for uneven temperature, light and air movement. The CT room settings were 27° C, 80% RH and a 14:10 photoperiod. Mortality was assessed every 24 hours for 7 days or until all replicates had finished.

3.3.1.5 Northern Territory bioasssays for redbanded thrips (Selenothrips rubrocinctus (Giard)) and two spotted mite (Tetranychus urticae Koch)

Although minor pests in the coastal wet tropics of north Queensland, redbanded thrips and two spotted mite are major pests in the drier climate of the Northern Territory. Researchers from the Northern Territory (DBIRD) conducted efficacy and rate trials to look at soft insecticide options for controlling these pests. Rambutan seeds were planted individually in 15 cm diameter pots in a shade house with the intention that when the seedlings were sufficiently robust (about 30 cm high), 30 individuals (larvae or adults) of red-banded thrips (RBT) or two-spotted mites (TSM) were to be introduced to each seedling. However, due to the difficulty of developing satisfactory TSM populations on rambutan plants at that time, numbers were increased on snake bean plants and the chemicals were tested on those hosts. Additionally, since most rambutan seedlings were naturally infested by RBT before they were moved into the shade house, the total number of RBT on each seedling was generally greater than 30 at the time of treatment. Each experiment tested 4 chemicals (two petroleum spray oils (PSO), a potassium soap/neem oil mixture and spinosad) and included a control treatment. Treatments applied against RBT were formulated product at (1) DC-Tron Plus®, applied at 0.5%, 1.0% and 2.0%; (2) Fuchs Universal Spray Oil®, applied at 0.5%, 1.0% and 2.0%; (3) Potassium soap/neem oil (Neemtech®), applied at 1.5%, 2.25% and 3.0%; (4) Spinosad, (Success®) applied at 0.2%, 0.4%, 0.8% and 1.6%. The same rates were applied against TSM except that the highest concentration of spinosad was omitted. The untreated controls were sprayed with tap water. Infested seedlings were sprayed to run-off with the test chemical and the water. In the case of the PSOs, potassium soap and neem oil treatments, counts of dead, dying and living thrips and mites were made as soon as the spray deposit had dried. For the spinosad treatments however, counts were made 24 hours after spray application. All experiments were replicated four times.

3.3.1.6 The effect of PSO residues on populations of RBT and TSM

Seedling rambutans were sprayed with 0.5% of DC-Tron Plus® 24 hours before infesting each seedling with 30 RBT or TSM. Seedlings were sprayed once per week for three weeks and counts made 24 hours after each spray application. Again the untreated control plants were sprayed with tap water. All experiments were replicated four times.

3.3.2 Field trials

Two insecticide field trials were carried out for black swarming leaf beetle (*Rhyparida discopunctulata*) and citrus mealybug (*Planococcus citri*) on field plantings of *Theobroma cacao* which is a known preferred host of these insect pests. Both insects feed on the new terminal shoots and leaf flush. Approximately 252 plants in three rows were used for these experiments at DPI research station located at Sth Johnstone. Both trials used a RCB trial design with 13-treatment replications. Buffer plants were used between each treatment to allow for spray drift.

3.3.2.1 Black swarming leaf beetle (Rhyparida discopunctulata (Blackburn)*)*

Rhyparida discopunctulata was collected from mature rambutan and cocoa trees on Sth Johnstone research station over a three-month period and reared on pot plants of *Eucalyptus torelliana* and *Theobroma cacao* in a 2m x 2m insect proof enclosure in a glasshouse. Beetles were collected at the time of the trial and counted out into lots of 10 and placed into petri dishes with new cocoa leaf flush. Trial trees were blocked and numbered and sprayed with insecticide treatments using a Swissmex backpack sprayer (hollow cone nozzle) to the point of runoff. Treatments included, Actara® (thiamethoxam @ 40g/100L), Mavrik® (tau-fluvalinate, 30ml/100L), Bulldock Prime® (beta-cyfluthrin, 10ml/100L + Agral), Carbaryl standard (200ml/100L) and a control (water and wetting agent Agral® 100ml/100L). Once all the treatments were applied 10 beetles / replication were released into caged branches with new leaf flush to restrict beetle movement. Live beetle counts were made 1, 7 and 14 days after treatments were applied.

3.3.2.2 Citrus mealybug (Planococcus citri (Risso)*)*

Planococcus citri was originally collected from rambutan trees and reared in a lab constant temperature room (27°C at 70%RH and 14: 10 photo period) on butternut pumpkins for three months to build up a high insect colony population prior to being used in field experiments. Trial trees were blocked and numbered. Adult and late instar mealybugs were harvested 5 weeks before the trial was to commence and counted out into petri dishes (25 mealybug per petri dish) and established on new shoots and leaf flush using camel hair paintbrushes (size 1). Twenty mealybugs per tree were placed on new leaf flush branches prior to the start of the trial and caged with fly screen netting to restrict movement and stop predation by other insects. After 5 weeks establishment each branch with mealybugs were sprayed with insecticide treatments using a Swissmex backpack sprayer (hollow cone nozzle) to the point of runoff. Actara® (thiamethoxam @ 40g/100L) was added to the treatment list because of the effectiveness of Confidor in lab assays. Thiamethoxam and imidochlorprid are neonicitynal compounds which have similar modes of action. Other treatments included; Confidor® (imidochlorprid 25ml/100L), Chlorpyrifos 500 EC standard (100ml/100L), Neem and K-soap 2L/100L, Parafin Oil (500ml/100L), Fuches Oil (500ml/100L) and a control (water and wetting agent Agral® 100ml/100L). Live mealybug counts were made 1, 7 and 14 days after treatments were applied.

3.4 Results and Discussion

3.4.1 Lab bioassays – yellow peach moth (*Conogethes punctiferalis*)

Two sets of bioassays were conducted for yellow peach moth. These included topical assays of 1µl placed behind the head capsule of 1st, 3rd and 5th instar larvae and ingestion and contact assays using rambutan fruit dipped in the different insecticide treatments.

Topical bioassays

In the topical bioassays the insecticides spinosad, tebufenozide and thiamethoxam performed well for the overall larval population (1st, 3rd and 5th instar) when compared to the standard chlorpyrifos and the control treatments (figures 1-4). These insecticides achieved 100% insect mortality and were not significantly different after 72 hours ($P<0.05$) when compared to the standard chlorpyrifos. All insecticide treatments achieved 100% insect mortality 4 days after treatment compared to the control insects at 6.3 percent. The treatment tebufenozide achieved 100% insect mortality within 48 hours. This was followed by spinosad and chlorpyrifos, which achieved 100% mortality within 72 hours. The final treatment thiamethoxam achieved 100% mortality at 96 hours.

All insecticide treatments were equally effective on 1st instar larvae which all died after 24 hours after application (figure 2). As the larval age and size increased from 1st to 3rd to 5th instar mortality times increased. First instar larvae achieved 100% mortality after 24 hours. Third instar larvae achieved 100% mortality after 48 hours and fifth instars over all treatments achieved 100% mortality after 96 hour. The results show that the lava age and size can impact on insecticide performance.

The insect growth regulator tebufenozide was the most effective treatment overall against all insect stages achieving 95.8% mortality after 24 hours and 100% mortality after 48 hours. This performed well when compared with chlorpyrifos, which achieved 77 % mortality after 24 hours, 95.8% after 48 hours and 100% after 72 hours. Spinosad was equally as effective as the chlorpyrifos standard achieving 79.2% mortality after 24 hours, 91.7% after 48 hours and 100% mortality after 72 hours. The final product thiamethoxam also performed well achieving 66.7% mortality after 24 hour, 85.4% after 48 hours, and 97.9% after 72 hours and 100% mortality after 96 hours. This treatment was equally as effective for controlling 1st and 3rd instar larvae when compared to the other insecticides but mortality was slower against older and larger larvae. This being said all treatments were effective and adequately controlled yellow peach moth larvae.

Ingestion bioassays

The ingestion bioassay included all the previous treatments of the topical bioassay and also included two more insecticides (emamectin benzoate and *Bacillus thuriengiensis var. kurstaki* (Btvk)). In this trial all insecticides accept for Btvk achieved 100% mortality against all larval stages 5 days after the treatments were applied. The Btvk treatment achieved 96.4% mortality after 5 days, which was not significantly different to the other treatments, and the standard, which achieved 100% mortality during this period.

The insecticides emamectin and tebufenozide achieved 100% mortality for all insect stages 3 days after treatment (figures 5-8) and were quicker acting than the standard chlorpyrifos, spinosad, thiamethoxam and the Bt treatments at the rates tested. This was followed by the standard chlorpyrifos, which achieved 100% mortality after 4 days.

Thiamethoxam and spinosad achieved 100% mortality 5 days after treatment. The final insecticide BTvk achieved 96.4% mortality after 6 days and was the least effective treatment of the products tested in response time and efficacy but was still acceptable for industry use. The final control mortality after 7 days was 8.3%.

The insecticides emamectin, tebufenozide, spinosad, thiamethoxam and Btvk performed well when compared to the standard chlorpyrifos and the control and with their unique modes of action are well suited to the development of IPM in rambutan and insecticide resistance management.

3.4.2 Lab bioassays – fruitspotting bug (*Amblypelta lutescens lutescens*)

The insecticides beta-cyfluthrin, bifenthrin and tau-fluvalinate although not as quick acting were not significantly different ($P<0.05$) to the endosulfan standard after the 7 day assay period and were significantly better then thimethoxam and the control treatments.

The endosulfan standard was generally the most effective treatment in this assay achieving 100% insect mortality 4 days after treatment but was not significantly different to beta-cyfluthrin which achieved 98.5% insect mortality. Beta-cyfluthrin, achieved 100% mortality 5 days after treatment, and was not significantly different to bifenthrin (93.6%) and tau-fluvalinate (93.6%). Beta-cyfluthrin, bifenthrin and tau-fluvalinate were just as effective and were not significantly different to the standard endosulfan after 7 days. The insecticides tau-fluvalinate and thiamethoxam achieved 86.7% and 73.3% mortality 7 days after treatment. The control mortality was 6.7% after 7 days. The assay technique use for this trial may have contributed to insect mortality delays as many of the bugs tended to stay off the fruit for a period of time after the treatments were applied. The insecticides beta-cyfluthrin and bifenthrin although effective against fruitspotting bug are broad-spectrum pyrethroids, which may be harmful to some beneficial insects. If used as an alternative to endosulfan for the control of fruitspotting bug their use should be restricted to spraying hotspot areas based on pest monitoring.

3.4.3 Lab bioassays – black swarming leaf beetle (*Rhyparida discopunctulata*)

There are about 6 species of *Rhyparida* in the wet topics region of north Queensland. Three species have been recorded in rambutans in Queensland and one in the Northern Territory. Most species are predominantly feeders of new foliage and shoots and can be a major pest in new tree plantings. When beetle populations are high they will sometimes feed on flower panicles and reduce fruit set. *R. clypeata* has occasionally been recorded feeding on the developing fruit in orchards of the wet tropics of north Queensland.

For the insecticide assays *R. discopunctulata* was selected, as it is the most persistent beetle species and is the hardest to control compared to the other beetle species. In the lab bioassays the standard carbaryl and the pyrethrin beta-cyfluthrin were the most effective insecticides and the only insecticides that achieved 100% insect mortality after 4 days but were not significantly different to thimethoxam and tau-fluvalinate treatments which achieved 96%and 95% mortality. The control insect mortality was 5 % after 7 days. All treatments were evaluated further in field trials

3.4.4 Field trials – black swarming leaf beetle (*Rhyparida discopunctulata*)

The field trials tested the same insecticides as those used in the lab bioassays and included a liquid formulation of silicone sharps as another treatment.

This formulation works similar to an abrasive dust by breaking down the insect cuticle reducing the insect's natural ability to conserve water. All treatments except for the silicone sharps performed well when compared against the carbaryl standard and were not significantly different ($P<0.01$) 14 days after treatment. The insecticides beta-cyfluthrin and thimethoxam performed significantly better then the standard carbaryl 7 days after treatment. Only 3 insecticides achieved 100% mortality after 14 days. These included the carbaryl standard, beta-cyfluthrin and thiamethoxam (unadjusted mortality). The insecticide tau-fluvalinate performed better then expected achieving 98% mortality after 14 days (figure 12). The silicone sharps treatment achieved 22% insect mortality and was significantly better then the control treatment ($P=0.05$), which had 8% insect mortality after 14 days.

3.4.5 Lab bioassays – Citrus mealybug (*Planococcus citri*)

The insecticide imidochlorprid performed well when compared to the standard chlorpyrifos. Both treatments achieved 100% insect mortality after 3 days. This was followed by pymetrozine, which achieved 100% insect mortality after 6 days. On days 1 – 4 the imidochlorprid and chlorpyrifos performed significantly better ($P<0.01$) than the other treatments and were not significantly different to each other. After 5 days pymetrozine and imidochlorprid were not significantly different from each other and the chlorpyrifos standard. The neem oil product was only considered partially effective at the rate tested but was able to achieve up to 81.5% mortality after 5 days. The control mortality after 7 days was 3.8 % (figure 11 and table 12). All products were further evaluated under field conditions.

3.4.6 Field trials – Citrus mealybug (*Planococcus citri*)

This trial included all the treatments in the lab bioassays as well as two other oil formulations (paraffin and Fuchs oil). High populations of citrus mealy bug were present and established throughout the duration of this trial. The insecticides imidochlorprid and thiamethoxam were as equally as effective when compared to the standard chlorpyrifos after 14 days and achieved 98%, 98% and 99% mortality respectively. The K+ neem soap treatment also performed well achieving 95% insect mortality after 14 days. The oil formulations of paraffin and Fuchs (84%) and the insecticide formulation pymetrozine (83%) also achieved similar results after 14 days. The adjusted control mortality was 3 %. The treatments of imidochlorprid, thiamethoxam pymetrozine and the K-soap performed well and were not significantly different ($P<0.05$) when compared to the chlorpyrifos standard after 14 days.

3.4.7 Lab bioassays Northern Territory–Redbanded thrips (*Selenothrips rubrocinctus*)

Comparisons of different rates of 4 chemicals for efficacy against Redbanded thrips (RBT)

Since the rambutan plants used were naturally infested with RBT, the number present pre-treatment were not known. However post-treatment counts were made of both live and dead RBT, and the number alive was expressed as a percentage of the total. This data, for each product, is shown in figures 12-15. Neemtech Oil® had very little effect on RBT numbers, the two PSOs gave very similar results with reasonable mortality (>60%) at the highest concentration but little effect at the lower concentrations, while Success® gave excellent mortality at all concentrations.

The effect of petroleum spray oil (PSO) residues on populations of Redbanded thrips

The results are shown in Table 14. Reduction of the population continued after every spray. Comparison of the population reduction between control and treatment indicated that some population reduction was caused by RBT escaping. Larvae of RBT were very active and moved fast when they were disturbed at the time of release.

3.4.8 Lab bioassays NT– Two spotted mite (*Tetranychus urticae*)

Comparisons of different rates of 4 chemicals for efficacy against TSM

In this case the pre-treatment counts were 30 TSM per plant and the number alive post-treatment was expressed as a percentage of this (% survival). This data, for each product, is shown graphically in figures 16-19. Both Neemtech Oil® gave progressively higher mortalities, reaching 85% at a concentration of 3.0%.

Fuchs Universal Oil® gave similar results reaching a mortality of 77.5% at a concentration of 2.0%, but the other PSO and DC-Tron Plus®, gave much poorer control. The results for Success® are difficult to interpret due to two replicates of the control treatment having only 4 and 7 live TSM after treatment, while one replicate of the 0.2% treatment had 40 TSM after treatment.

The effect of PSO residues on populations of TSM

The results are shown in Table 15. TSM were released 24 hrs after first spray, and the mite population was reduced about 37% 24 hrs later. Although the population also decreased in the control treatment during the first 48 hrs, the population increased rapidly after the mites settled down. On the contrary, 0.5% treatment showed that the mite population was unchanged after several sprays.

Table 7. *Showing significant treatment effects in a topical bioassay with a 1µl droplet placed behind the head capsule of each larva, and percent population mortality for 3rd and 5th instar larvae of Conogethes punctiferalis*

	% mortality			
Instar	**3rd**	**5th**		
Treatment	**Day 1**	**Day 1**	**Day 2**	**Day 3**
Control	0 a	0 a	0 a	0 a
thimethoxam	69.1 b	30.9 b	56.6 b	98.3 b
spinosad	93.3 bc	50.0 b	85.4 b	100 b
chlorpyrifos	93.3 bc	50.0 b	93.3 bc	100 b
tebufenozide	100 c	96.2 c	100 c	100 b

Repeated measures analysis of 5th instar % mortality across days 1-3 : time
* treatment interaction significant ($p<0.05$)
Treatments means with different letters in the same column show a significant interaction ($p<0.05$)

Figure 1. *Showing the percent mortality results of all larval stages of Conogethes punctiferalis using a topical bioassay with a 1µl droplet placed behind the head capsule of each larva, 7 days after treatment for spinosad, tebufenozide, thiamethoxam and the standard chlorpyrifos and the control treatment*

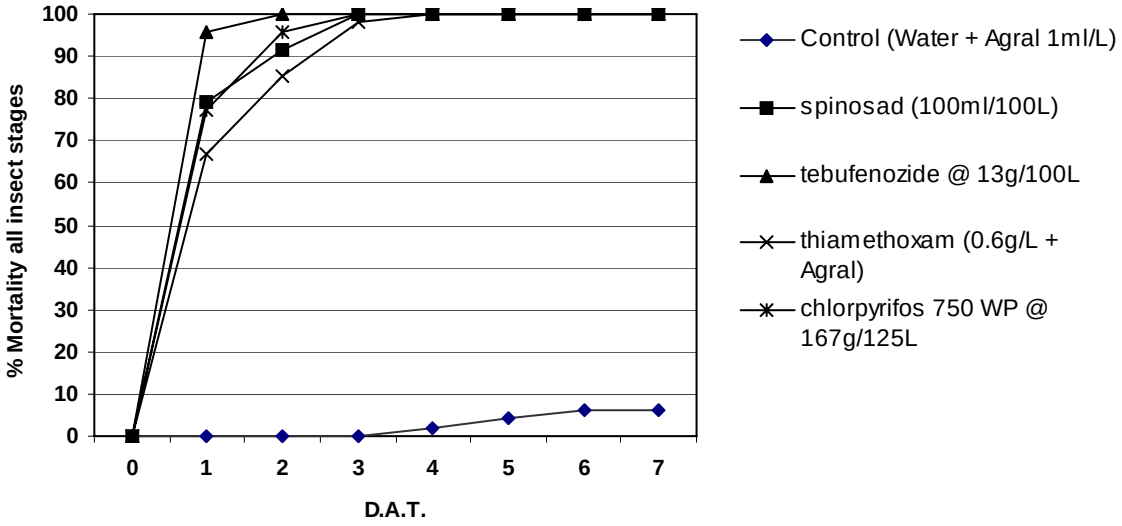


Figure 2. *Showing the percent mortality results of 1st instar larvae of Conogethes punctiferalis using a topical bioassay with a 1µl droplet placed behind the head capsule of each larva, 7 days after treatment for spinosad, tebufenozide, thiamethoxam and the standard chlorpyrifos and the control treatment*

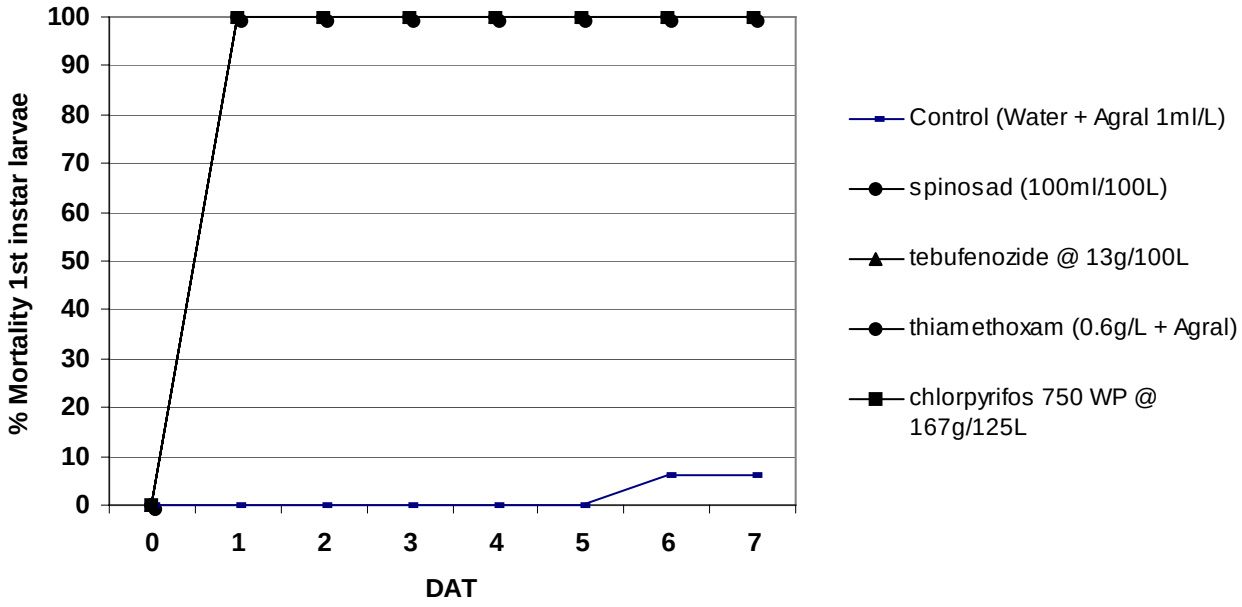


Figure 3. *Showing the percent mortality results of 3rdt instar larvae of Conogethes punctiferalis 7 days after treatment using a topical bioassay with a 1µl droplet placed behind the head capsule of each larva, for spinosad, tebufenozide, thiamethoxam and the standard chlorpyrifos and the control treatment*

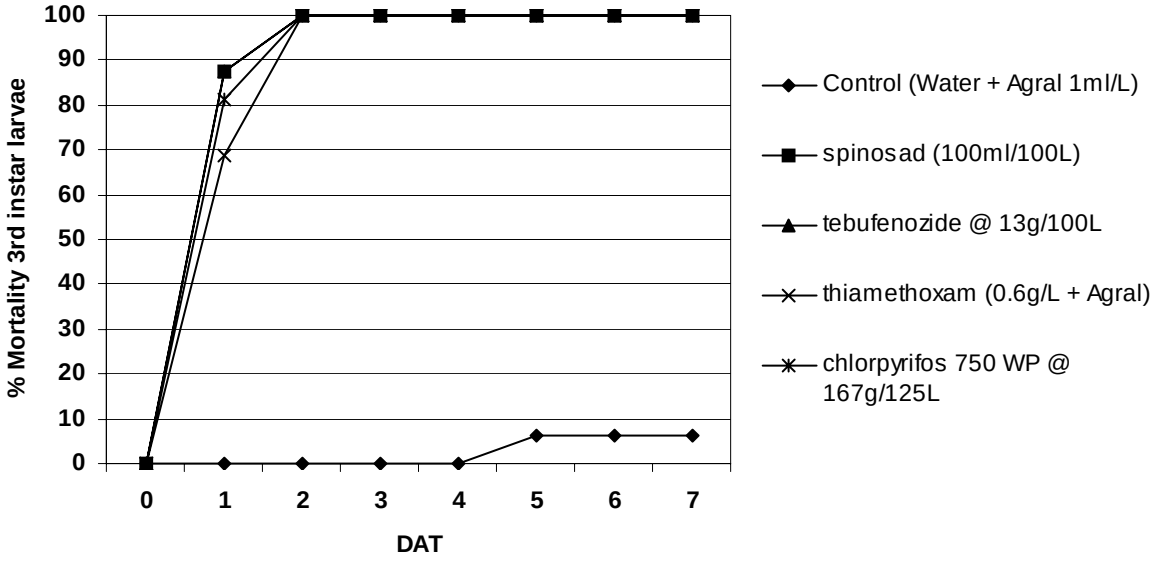


Figure 4. *Showing the percent mortality results of 5th instar larvae of Conogethes punctiferalis 7 days after treatment using a topical bioassay with a 1µl droplet placed behind the head capsule of each larva, for spinosad, tebufenozide, thiamethoxam and the standard chlorpyrifos and the control treatment*

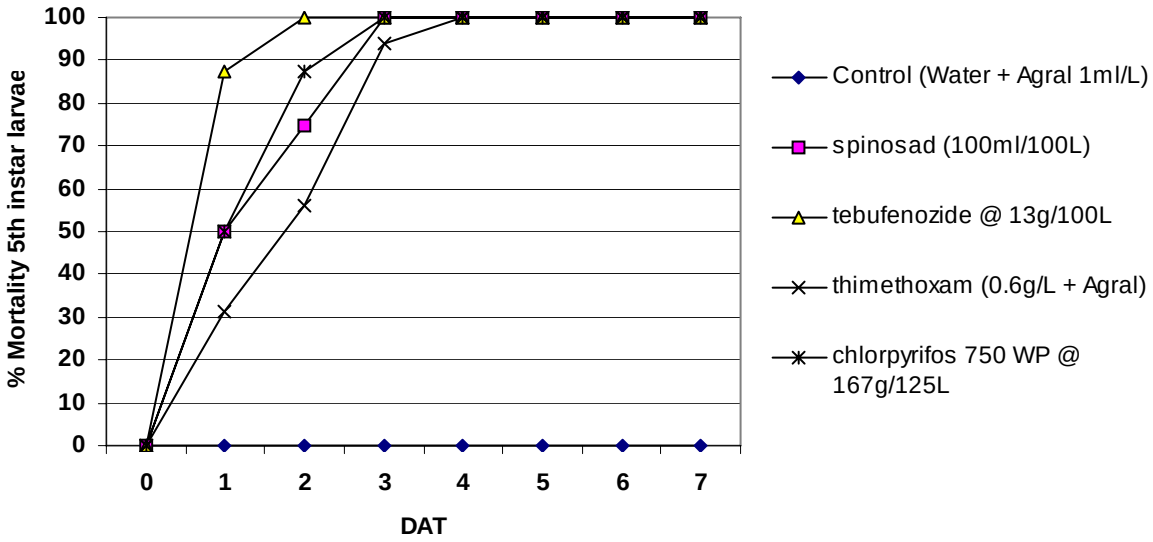


Table 8. *Showing significant treatment effects of a contact ingestion assay with percent population mortality and the change in percent mortality for 1st instar larvae of Conogethes punctiferalis*

	% mortality		
Treatment	**Day 1**	**Day 2**	**Day 3**
control	0 a	0 a	0 a
Bt var. kurstak	10.3 a	88.9 b	98.2 b
thimethoxam	75.0 b	92.9 b	100 b
spinosad	89.7 b	100 c	100 b
chlorpyrifos	96.2 b	100 c	100 b
tebufenozide	98.3 b	100 c	100 b
emamectin	98.3 b	100 c	100 b

Repeated measures anova of 1st instar % mortality across days 1-4: interaction sig. ($p<0.01$)
Treatments means with different letters in the same column show a significant interaction ($p<0.01$)

Table 9. *Showing significant treatment effects of a contact ingestion assay with percent population mortality and the change in percent mortality for 3rd instar larvae of Conogethes punctiferalis 7 days after treatment*

	% mortality				
Treatment	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**
control	0 a	0 a	0 a	0 a	0 a
Bt var. kurstak	1.7 ab	69.1 b	75.0 b	93.3 b	97.9 b
thimethoxam	62.9 c	80.1 b	82.5 bc	98.3 bc	100 b
spinosad	37.1 bc	85.4 b	100 c	100 c	100 b
chlorpyrifos	69.1 c	96.2 bc	100 c	100 c	100 b
tebufenozide	43.5 c	98.3 bc	100 c	100 c	100 b
emamectin	80.4 c	100 c	100 c	100 c	100 b

Repeated measures anova of 3rd instar
Treatments means with different letters in the same column show a significant interaction ($p<0.05$)

Table 10. *Showing significant treatment effects of a contact ingestion assay with percent population mortality and the change in percent mortality for 5th instar larvae of Conogethes punctiferalis 7 days after treatment.*

	% mortality				
Treatment	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Days 5,6,7**
control	0 a	0 a	0 a	0 a	0 a
thimethoxam	25.0 b	50.0 b	80.5 b	96.2 b	96.4 b
Bt var. kurstak	14.6 b	43.5 b	69.1 b	98.3 b	100 b
spinosad	19.5 b	56.5 b	85.4 b	98.3 b	100 b
chlorpyrifos	19.5 b	56.5 b	89.6 b	100 b	100 b
tebufenozide	56.6 b	96.2 c	100 c	100 b	100 b
emamectin	62.9 b	98.3 c	100 c	100 b	100 b

Repeated measures analysis of 5th % mortality across days 1-7:
Treatments means with different letters in the same column show a significant interaction ($p<0.05$)

Figure 5. *Showing the percent mortality results of all larvae stages of Conogethes punctiferalis 7 days after treatment for spinosad, tebufenozide, thiamethoxam, emamectin, Bt var k, and the standard chlorpyrifos and the control treatment using an ingestion and contact assay*

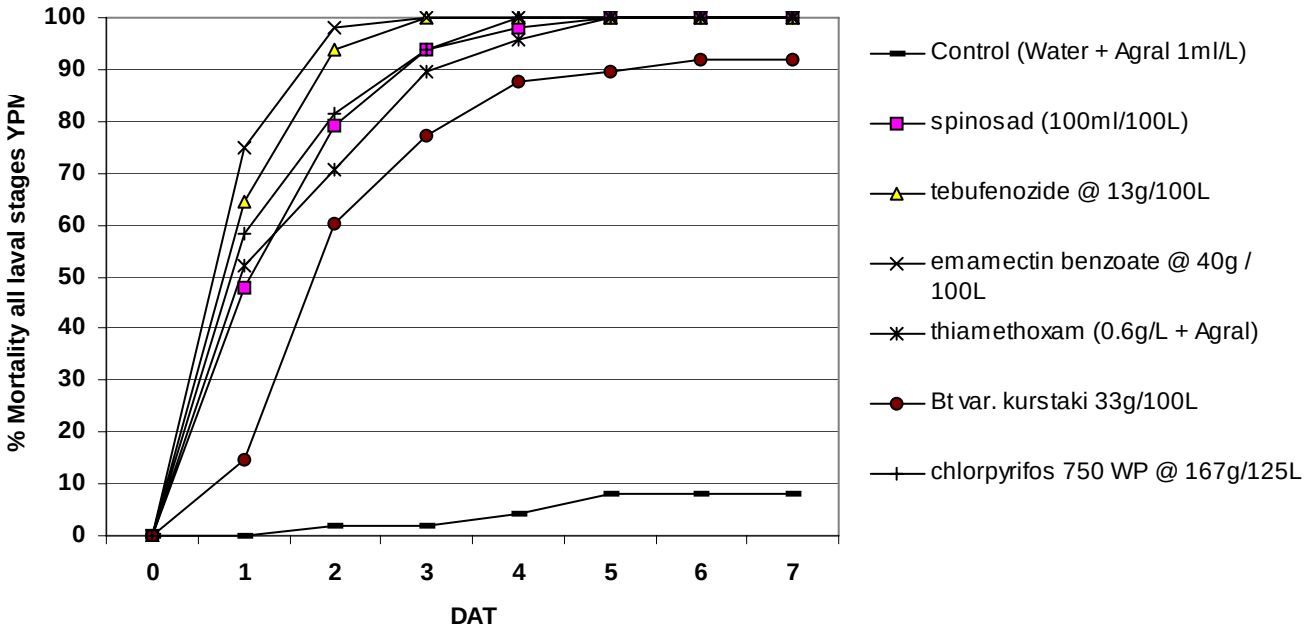


***Figure 6**. Showing the percent mortality results of 1st instar larvae of Conogethes punctiferalis 7 days after for spinosad, tebufenozide, thiamethoxam, emamectin, Bt var k, and the standard chlorpyrifos and the control treatment using an ingestion and contact assay*

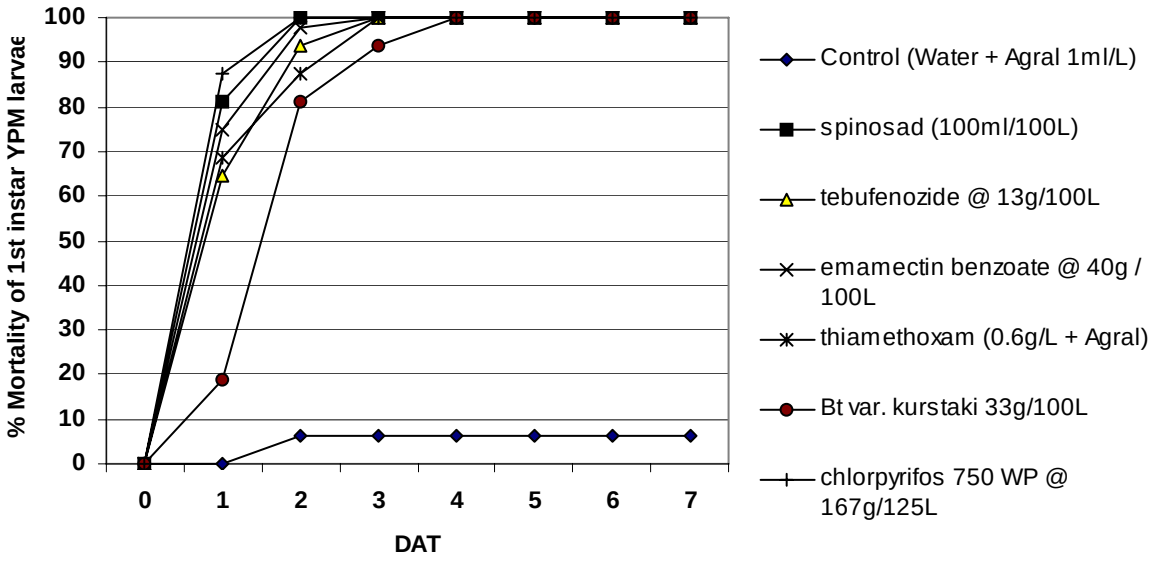


***Figure 7**. Showing the percent mortality results of 3rd instar larvae of Conogethes punctiferalis 7 days after treatment for spinosad, tebufenozide, thiamethoxam, emamectin, Bt var k, and the standard chlorpyrifos and the control treatment using an ingestion and contact assay*

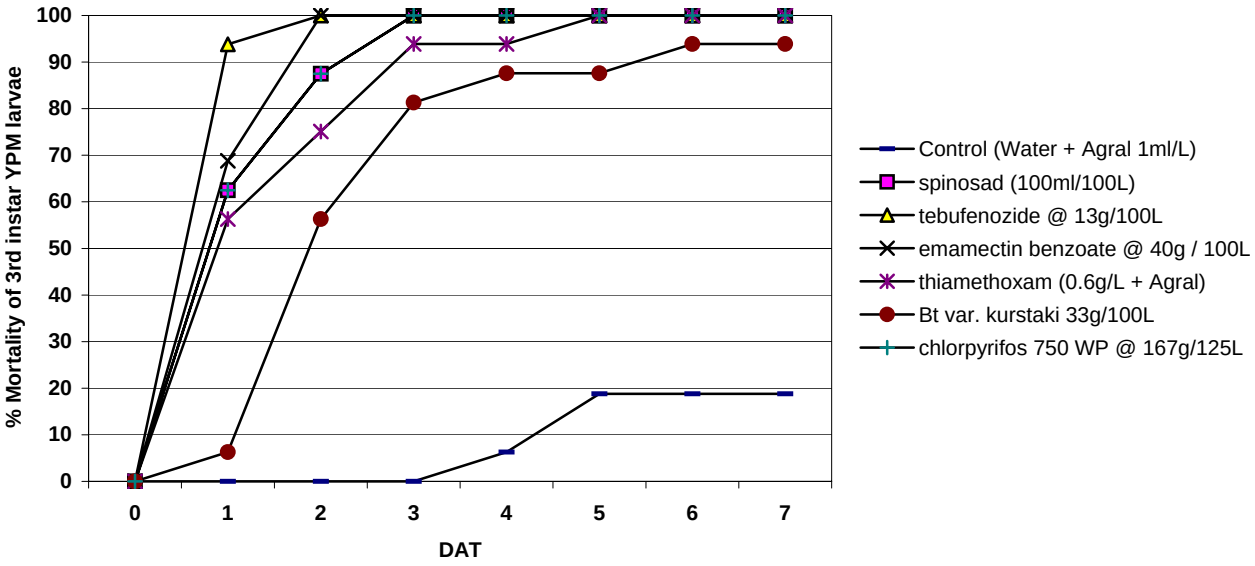


***Figure 8**. Showing the percent mortality results of 5th instar larvae of Conogethes punctiferalis 7 days after treatment for spinosad, tebufenozide, thiamethoxam, emamectin, Bt var k, and the standard chlorpyrifos and the control treatment using an ingestion and contact assay*

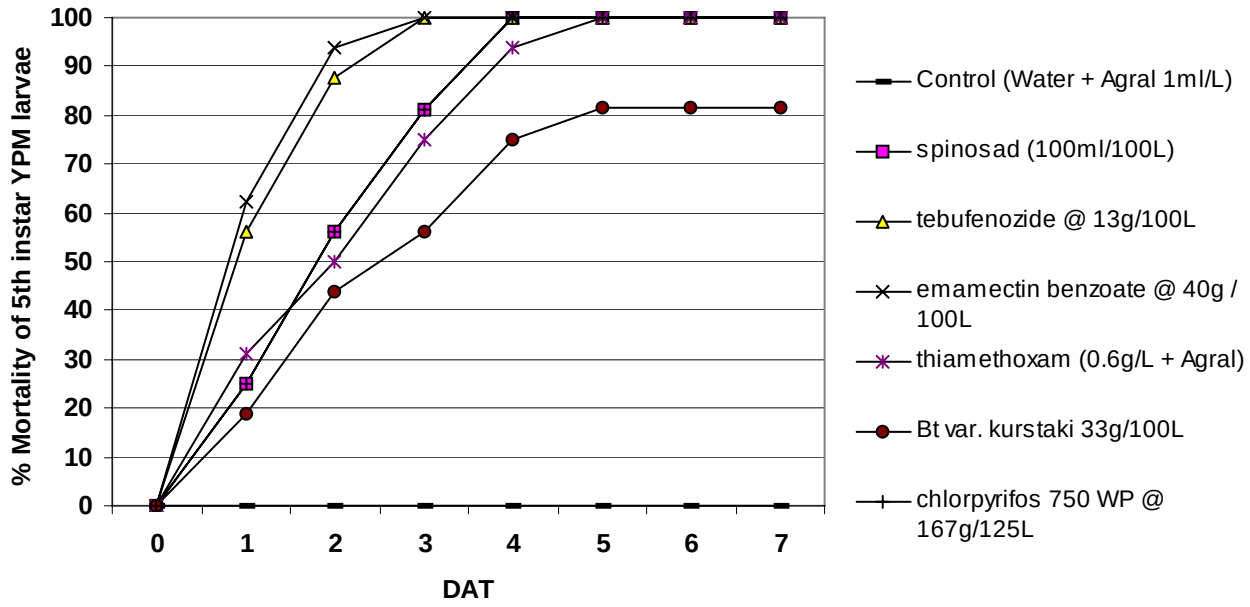


***Table 11.** Showing significant treatment effects of a contact ingestion assay with percent population mortality and the change in percent mortality for adult Amblypelta lutescens lutescens 7 days after treatment*

	% mortality						
Treatment	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
control	0 a	0 a	0 a	0 a	0 a	0 a	0 a
thimethoxam	0 a	13.0 b	41.1 b	60.1 b	76.0 b	76.0 b	76.0 b
tau-fluvalinate	9.5 ab	71.7 cd	87.0 c	94.1 cd	93.6 bc	93.6 bc	93.6 bc
bifenthrin	17.9 b	58.9 c	82.1 c	87.0 bc	93.6 bc	100 c	100 c
beta-cyfluthrin	34.5 bc	71.7 cd	94.1 c	98.5 cd	100 c	100 c	100 c
endosulfan	82.1 c	96.4 d	98.5 c	100 d	100 c	100 c	100 c

Repeated measures analysis : \
Treatments means with different letters in the same column show a significant interaction ($p<0.05$)

***Figure 9**. Showing the percent mortality results of adult Amblypelta lutescens lutescens 7 days after treatment for beta-cyfluthrin, thiamethoxam, tau-fluvalinate ,bifenthrin and the standard endosulfan and the control treatment using an ingestion and contact assay*

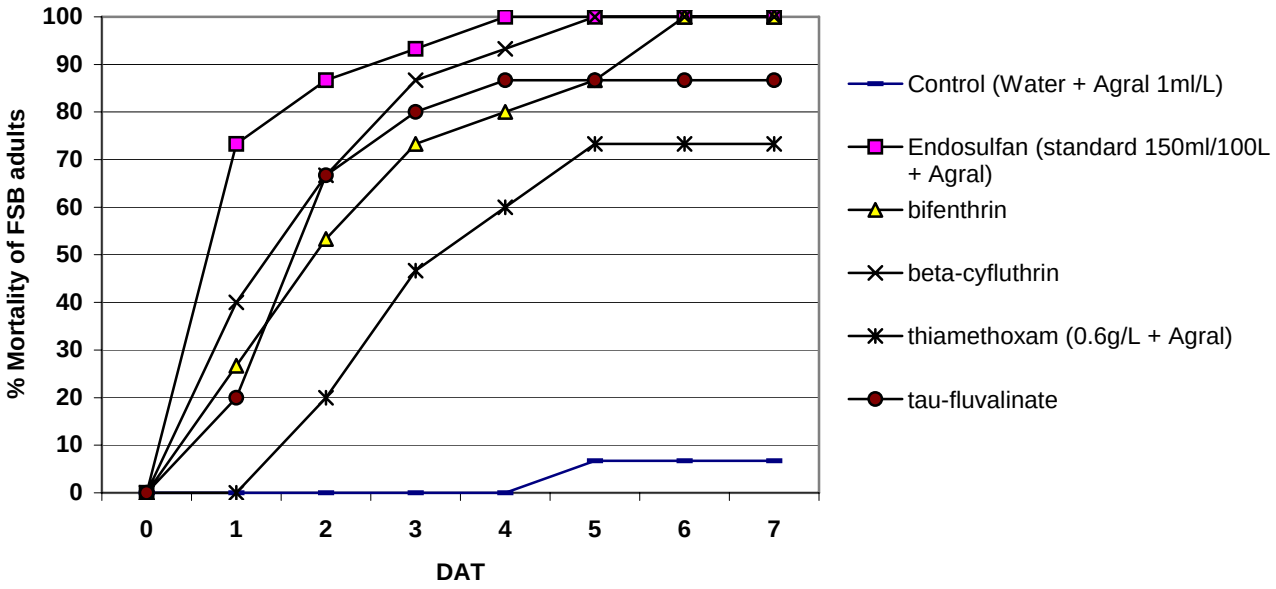


***Table 12.** Showing significant treatment effects of a contact ingestion assay with percent population mortality and the change in percent mortality for adult Rhyparida discopunctulata 7 days after treatment*

	% mortality						
Treatment	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
control	0 a	0 a	0 a	0 a	0 a	0	0
tau-fluvalinate	36.9 b	65.5 b	81.2 b	94.9 b	99.3 b	0	0
thimethoxam	42.4 b	60.6 b	78.2 b	96.1 b	99.3 b	0	0
carbaryl	52.3 b	83.2 b	99.4 c	100 b	100 b	0	0
beta-cyfluthrin	70.2 b	88.7 b	99.4 c	100 b	100 b	0	0

Repeated measures analysis :
Treatments means with different letters in the same column show a significant interaction ($p<0.05$)

Figure 10. *Showing the percent mortality results of Rhyparida discopunctulata 7 days after treatment for beta-cyfluthrin, thiamethoxam, tau-fluvalinate, and the standard carbaryl and the control treatment using an ingestion and contact assay*

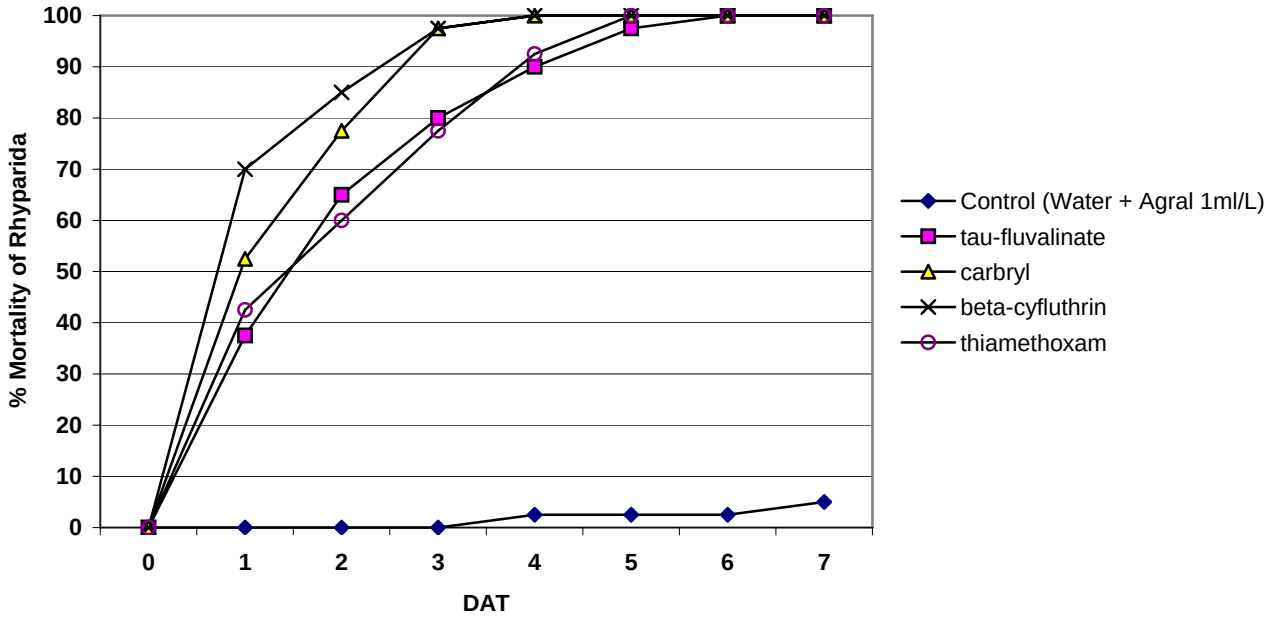


Table 13. *Showing significant treatment effects of a contact ingestion assay with percent population mortality and the change in percent mortality for Plannococcus citri 7 days after treatment*

	% mortality						
Treatment	**Day 1**	**Day 2**	**Day3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
control	0 a	0 a	0 a	0 a	0 a	0 a	0 a
neem oil	27.3 b	42.5 b	57.5 b	76.3 b	81.3 b	81.1 b	81.1 b
pymetrozine	46.2 c	75.8 c	91.5 c	98.1 c	99.7 c	100 c	100 c
chlorpyrifos	62.7 d	96.1 d	100 d	100 d	100 c	100 c	100 c
Confidor	74.1 d	99.0 d	100 d	100 d	100 c	100 c	100 c

† Mortality had already reached 100% at the start of the period
Repeated measures anova on % mortalities across the 7 days
Treatments means with different letters in the same column show a significant interaction ($p<0.01$)

Figure 11. *Showing the percent mortality results of Plannococcus citri 7 days after treatment for imidochlorprid, pymetrozine, neem oil, and the standard chlorpyrifos and the control treatment using an ingestion and contact bioassay on butternut pumpkins*

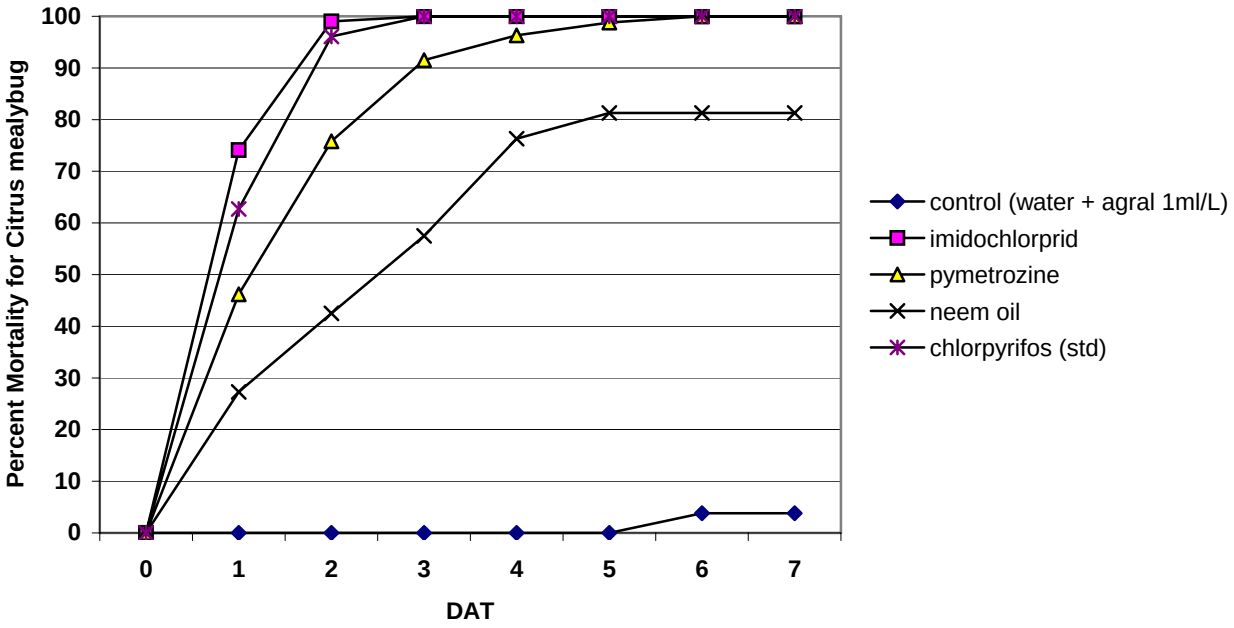


Figure 12. *% RBT alive after treatment with DC-Tron®*

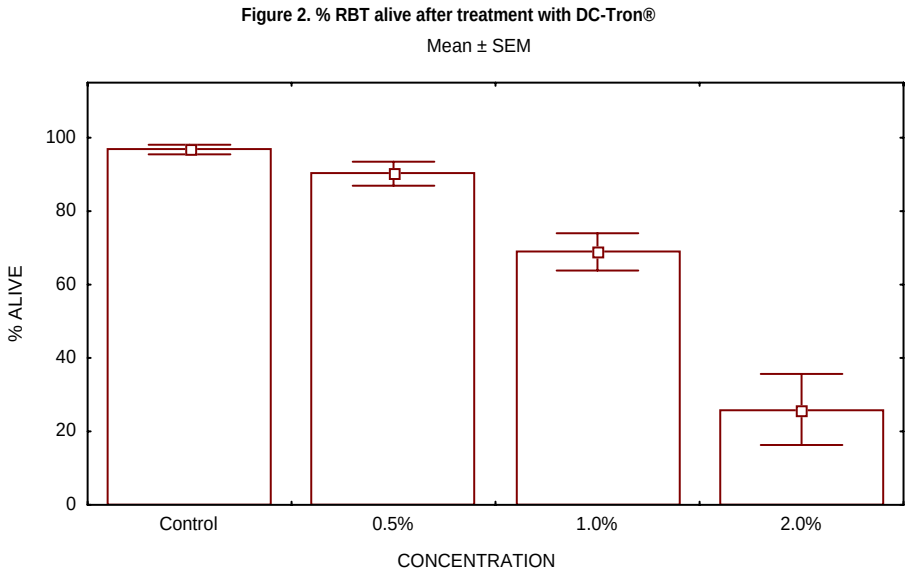


***Figure 13**. % RBT alive after treatment with Neemtech Oil®*

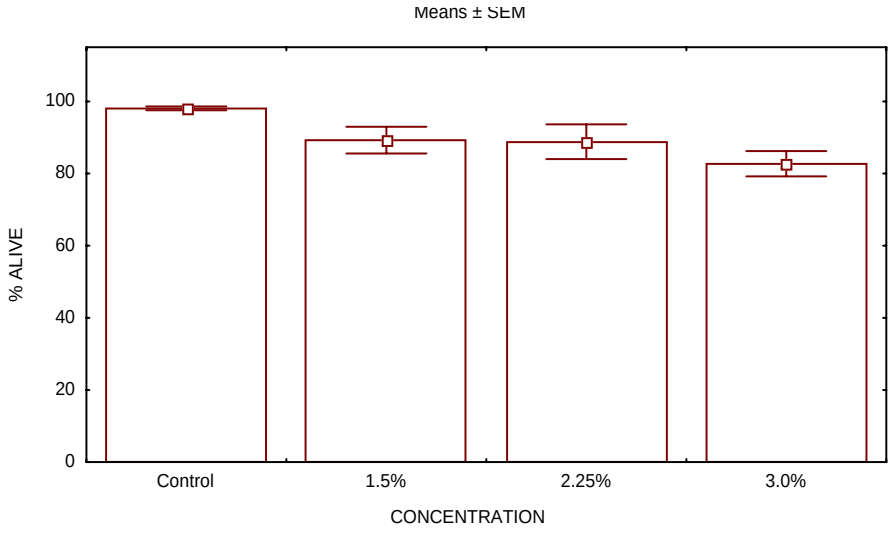


***Figure 14**. % RBT alive after treatment with Fuchs Universal Oil®*

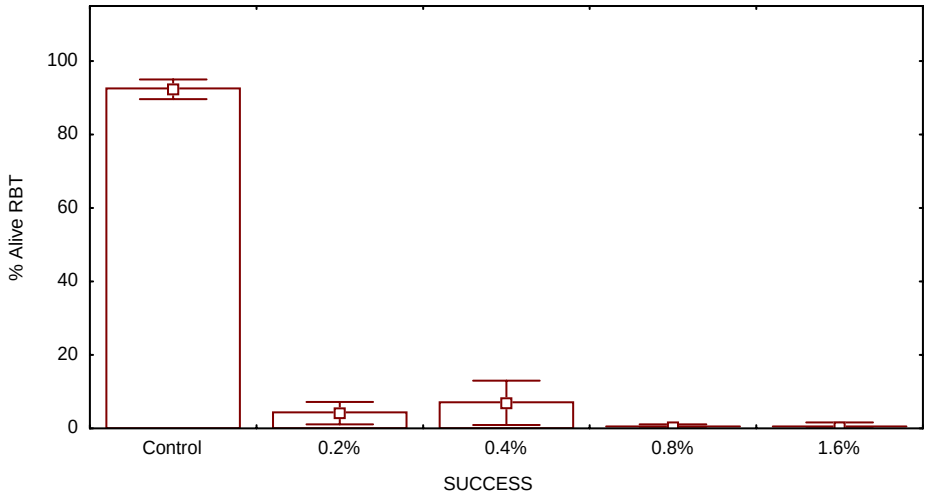


***Figure 15**. % RBT alive after treatment with Success®*

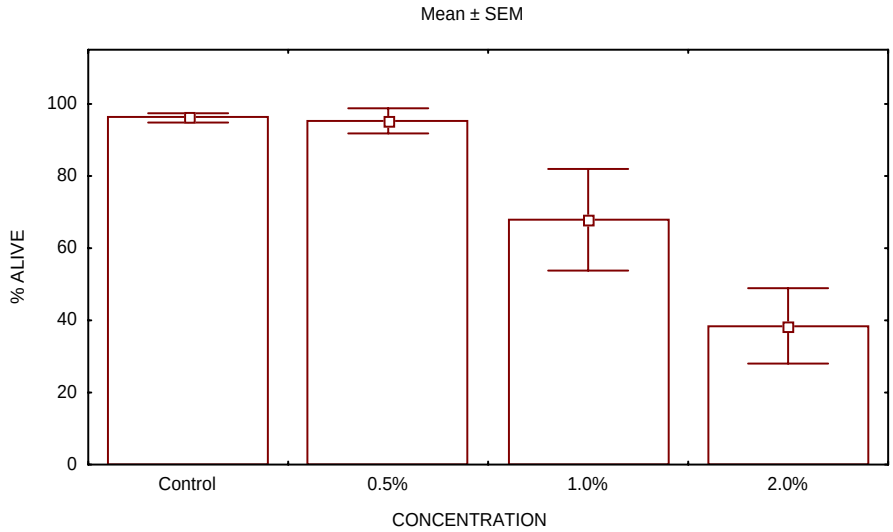


***Table 14**. Trial on the effect of DC-Tron Plus residues on RBT larvae population*

Treatment	Population reduction (%)			
	24 hrs after releasing	24 hrs after second spray	24 hrs after third spray	24 hrs after fourth spray
Control	42.5	77.5	68.3	82.5
0.5 %	17.4	77.7	94.6	95.4

Interval between sprays is one week;
Population reduction (%) was adjusted by Abbott's formula

***Figure 16**. % survival of TSM after treatment with Neemtech Oil®*

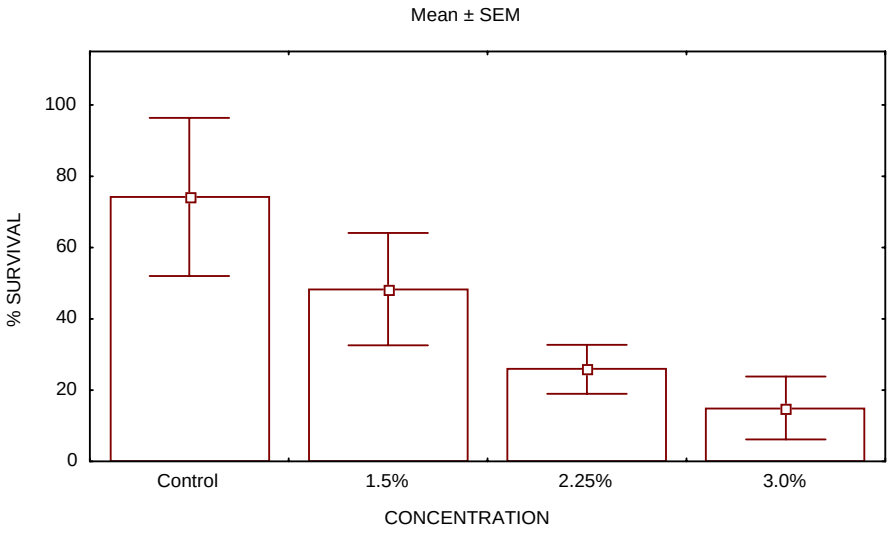


Figure 17*.% TSM alive after treatment with DC-Tron®*

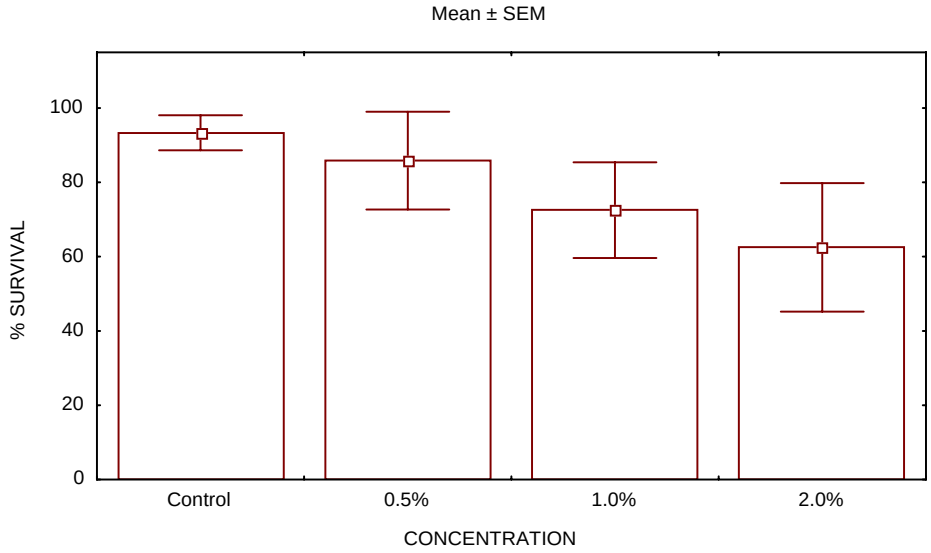


Figure 18*. % survival of TSM after treatment with Fuchs Universal Oil®*

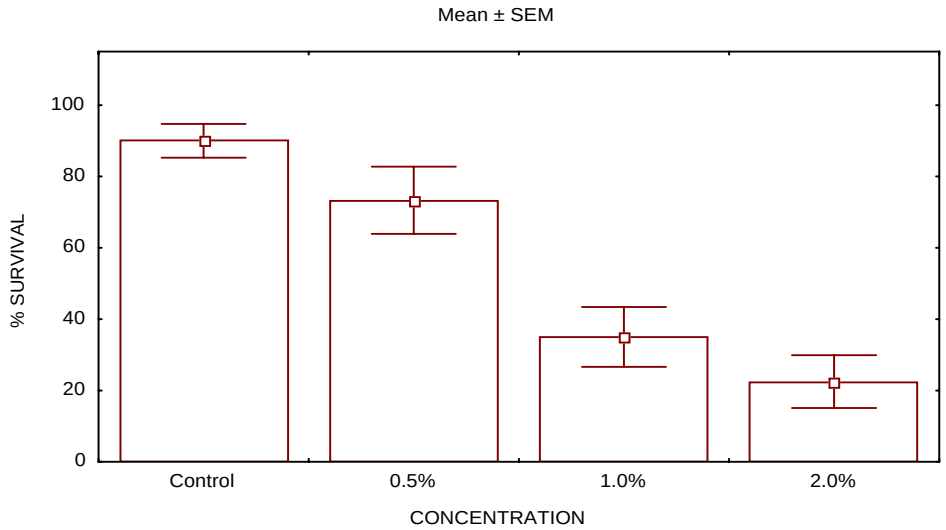


***Figure 19**. % survival of TSM after treatment with Success®*

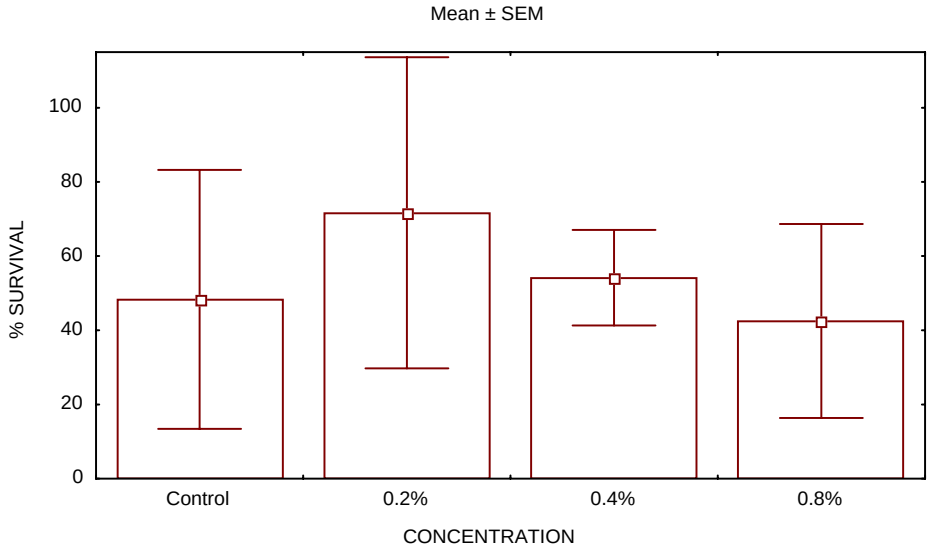


***Table 15**. Trial on the effect of DC-Tron Plus residues on TSM population*

Treatment	Changes in population size (%)			
	24 hrs after releasing	24 hrs after second spray	24 hrs after third spray	24 hrs after fourth spray
Control	-20	-13.3	+ 512.2	+ 1042.2
0.5 %	-36.7	-33.3	+ 0.83	0

Interval between sprays is one week
Population reduction (%) was adjusted by Abbott's formula

***Table 16.** Showing significant treatment effects of a contact ingestion assay with percent live population and the change in percent living Rhyparida discopunctulata 1, 7 and 14 days after treatment using silicone sharps, tau-fluvalinate, beta-cyfluthrin, thimethoxam and the standard carbaryl and the control treatment*

	% live *		
Treatment	**Day 1**	**Day 7**	**Day 14**
Control	100 e	100 d	100 c
silicone sharps	98.1 d	93.1 c	81.0 b
carbaryl	66.1 c	36.7 b	0.2 a
tau-fluvalinate	67.7 c	27.5 b	0.6 a
beta-cyfluthrin	39.7 b	7.8 a	0.2 a
thiamethoxam	25.7 a	7.1 a	0.4 a

* Corrected for control mortality (Abbott's formula), arcsine transformed for analysis – figures presented are equivalent % means
** Corrected for control mortality
Treatments means with different letters in the same column show a significant interaction ($p<0.05$)

Figure 20. *Showing the percent live population of Rhyparida discopunctulata 1, 7 and 14 days after treatment using silicone sharps, tau-fluvalinate, beta-cyfluthrin, thimethoxam and the standard carbaryl and the control treatment*

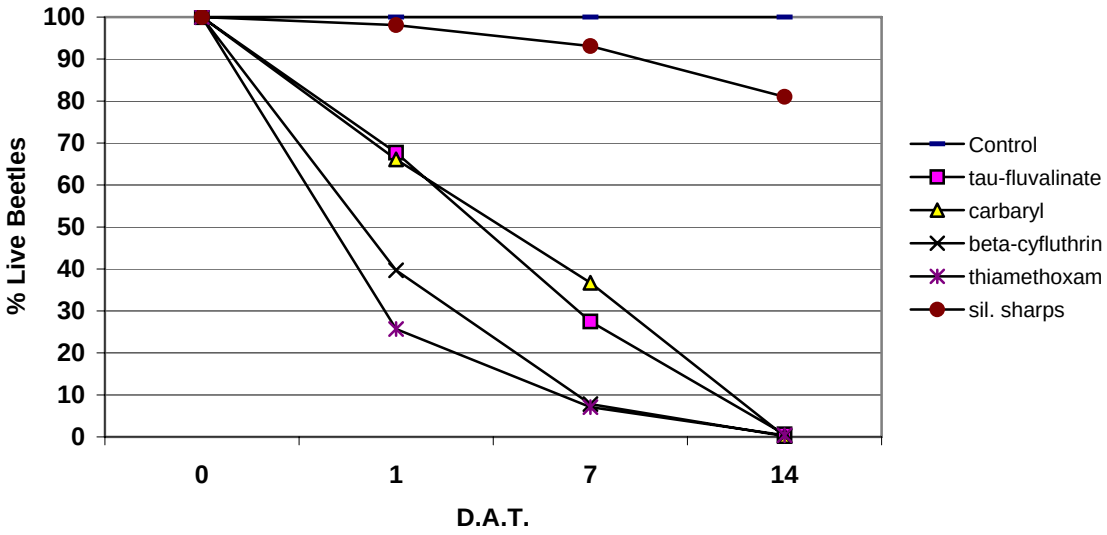
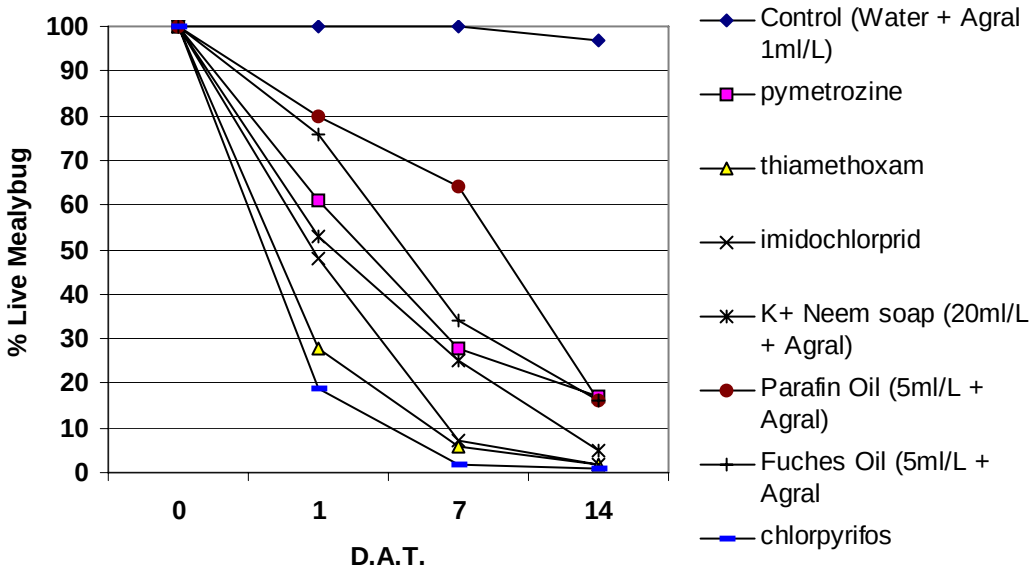


Table 17. *Showing significant treatment effects of a contact ingestion assay with percent live population of Plannococcus citri 1, 7 and 14 days after treatment using pymetrozine, thimethoxam, imidochlorprid, k-soap, paraffin oil, fuches oil and the standard chlorpyrifos and the control treatment.*

Number of Live Mealybugs*	**Days After Treatment**			
	0	**1**	**7**	**14**
Control	43.3 a[†]	48.7 c	53.7 c	42.0 d
pymetrozine	35.5 a	21.9 b	9.9 b	6.0 abc
thiamethoxam	64.6 a	17.8 ab	3.7 ab	1.1 ab
imidochlorprid	60.5 a	29.0 bc	4.2 ab	1.2 ab
K+ neem soap	46.3 a	24.5 b	11.8 b	2.5 abc
Parafin Oil	60.8 a	48.7 c	38.9 c	9.9 c
Fuches Oil	43.6 a	33.1 bc	14.7 b	7.0 bc
chlorpyrifos	45.7 a	8.7 a	0.7 a	0.5 a

* Square-root (x+0.5) applied to data for analysis. Means shown are equivalent counts.
[†] Values with the same letter are not significantly different at the P< 0.05% level.

Figure 21 *Showing treatment effects of a contact ingestion assay with percent live population of Plannococcus citri 1, 7 and 14 days after treatment using pymetrozine, thimethoxam, imidochlorprid, k-soap, paraffin oil, Fuchs oil and the standard chlorpyrifos and the control treatment*



3.5 Conclusions and Recommendations

3.5.1 Insecticides for Lepidoptera larvae

Good control was achieved against yellow peach moth larvae (*Conogethes punctiferalis*) with all of the insecticides tested. All treatments in the topical bioassays (thiamethoxam, spinosad and tebufenozide) were not significantly different ($P<0.05$) when compared to the chlorpyrifos standard and could be used as alternative treatments to this insecticide. The other treatments included in the ingestion contact assays emamectin benzoate and *B.t. var. kurstaki* also performed well when compared to the chlorpyrifos standard and are suitable alternatives to this product. The unique modes of action of these products make them suitable candidates for use in resistance management based on chemical group rotation. It will be important that the use of these insecticides be carefully managed and based on monitoring pest and beneficial population level to prolong their effectiveness.

3.5.2 Insecticides for fruitspotting bugs *(Amblypelta lutescens lutescens)*

The endosulfan standard used in the series of lab bioassays was the most effective treatment achieving 100% mortality of adult bugs 4 days after treatment but was not significantly different to the pyrethrin beta-cyfluthrin which was just as effective over the 7 day period. The other treatments bifenthrin achieved 100% mortality after 6 days and tau-flubanilate achieved 93.6% mortality after 7 days. Thiamethoxam was the least effective treatment when compared to the chlorpyrifos standard, beta-cyfluthrin and bifenthrin. As the most effective insecticides in this assay where pyrethrins from the same chemical group, only beta-cyfluthrin could be selected as a possible alternative to endosulfan for the control of fruit spotting bugs as this product was the best performing pyrethroid over the duration of the trial.

3.5.3 Insecticides for Coleoptera

All insecticide treatments used for the control of *Rhyparida discopunctulata* performed well during the lab bioassays and were not significantly different when compared to the carbaryl standard. This being said both the carbaryl standard and beta-cyfluthrin were significantly more effective ($P<0.05$) 3 days after treatment compared to thimethoxam and tau-flubanilate. The results were very similar in the field with the silicone sharps treatment being the least effective. Carbaryl and beta-cyfluthrin and thiamethoxam could all be used together in resistance management because of their unique modes of action for the control of swarming leaf beetles in rambutan.

3.5.4 Insecticides for citrus mealybug (*Planococcus citri*)

Thiamethoxam and imidochlorprid were the most effective insecticides when compared to the chlorpyrifos standard over the 14 day field trial period. This was followed closely by pymetrozine and the neem + k-soap which were not significantly different ($P<0.05$) to the chlorpyrifos standard after 14 days. The mineral oils (Fuchs and paraffin) also performed well achieving 84% mortality 14 days after application but was not as effective as the other insecticide treatments during this period. This being said the high level of mortality achieved with these oils was still acceptable. The K+ neem soap and the oil based treatments may provide a good natural alternative to the synthetic insecticides used in the field trials. These treatments kill insects primarily by anoxia (suffocation). This being said the various physical characteristics of the oil (saturation and oil fraction) can also work in other ways. For example oils with light saturated hydrocarbons (< nC19) pass through insect body cavities, and dissolve fat bodies and eventually cell structure causing cell desiccation (Taverner 1999). The efficacy of these products is normally increased with a repeat application. Other advantages of using oils in IPM is that insecticide resistance does not occur, they are safe to human health and the environment and they are economic to use. No phytotoxic effects were observed when spraying 6 mature rambutan trees with fruit up to 10 days.

3.5.5 Insecticides for redbanded thrip (*Selenothrips rubrocinctus*)

Spinosad was the most effective treatment against red-banded thrips achieving 100% mortality 24 h after spraying at 1.6 % concentration. All rates of spinosad tested gave good control including the lowest rate of 0.2% achieving 97% mortality after 24 hr. The mineral oils DC Tron Plus® and Fuchs Universal Spray Oil® achieved 80% and 84 % mortality respectively at 2% oil concentrations and were considered partially effective.

3.5.6 Insecticides for Acarina

No chemical was particularly effective against two-spotted mites but Fuchs Universal Spray Oil® and Neemtech® gave greater than 70% mortality at the highest concentrations tested and may be able to be used in a control strategy with a general miticide. Further work is required to evaluate the potential to combine PSO's and miticides for controlling mites in rambutan.

Table 18. Showing a summary of the most effective insecticide treatments that were not significantly different to the industry standard insecticides (P<0.05) with the mode of action classification for resistance management and the active pest spectrum

Active ingredient	**Mode Class for resistance management**	**Other pests controlled**	**Minor Use**
beta-cyfluthrin	3A	Beetles, spotting bug, others	Yes
Bt. var. kurkstaki	11C	*caterpillar larvae*	Yes
carbaryl	1A	Beetles, caterpillar larvae and others	Yes
emamectin	6A	Caterpillar larvae	Yes
imidochlorprid	4A	mealybug, scale and thrips	Yes
K+neem soap	No resistance	Mealybug, scale	No
Pymetrozine	9A	Mealybug	No
spinosad	5A	*caterpillar larvae, thrips*	Yes
tau-fluvalinate	3A	Beetles, spotting bug, others	No
tebufenozide	16A	*caterpillar larvae*	Yes
thiamethoxam	4B	*caterpillar larvae, mealybug, Rhyparida sp.*	Yes

The work carried out in this project has only looked at a general initial screening of all the insecticides mentioned in this project. Further work should investigate the residual activities of each compound as well as the most economical and effective rate.

3.6 References

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4. List of Publications

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