Final Report

IPM program for the macadamia industry – DAF component

Project leader:

Shane Mulo

Delivery partner:

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IPM program for the macadamia industry – DAF component (MC16005)

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Level 7
141 Walker Street
North Sydney NSW 2060

Telephone: (02) 8295 2300

www.horticulture.com.au

Content

Summary

This project forms part of a larger macadamia IPM program to develop, demonstrate and facilitate adoption of efficient and profitable integrated pest management strategies for macadamia. The program is led by researchers from New South Wales Department of Primary Industries and includes five separate components (MC16004 to MC16008).

This MC16005 component is led by researchers from the Queensland Department of Agriculture and Fisheries. It encompasses three main areas of investigation including practical application and assessment of pheromone insect traps, isolation and culturing of entomopathogenic fungi for assessment as protectants against insect pests and economic assessment of emerging IPM scenarios through collaboration with industry benchmarking.

Fungal entomopathogens

Entomopathogenic fungi were isolated from soils and mycosed insects that were sourced from macadamia growing regions. Eleven isolates were characterised for optimal growth temperatures and identified through molecular analysis. Preliminary investigations were carried out to determine the endophytic potential of entomopathogens against Macadamia Seed Weevil (MSW).

Batches of selected entomopathogenic isolates were mass produced for new South Wales Department of Primary Industries entomologists to support their laboratory and field investigations. Advice was also provided on request by entomologists regarding suitable formulations of entomopathogens for field application. Cultures of entomopathogenic isolates were also provided to a University of Southern Queensland doctoral student to support research into interactions of fungal entomopathogens with synthetic insecticides.

This project component was completed in 2018 and a separate final report was accepted by Hort Innovation in 2019. For further information about this component please refer to the final report listed in Appendix A.

Benchmarking and economic analysis of IPM strategies

Annual findings from the industry benchmark project (MC18002) were reported to program entomologists, including seasonal limitations to yield and quality and factory rejects due to insect damage. These results provided baseline industry thresholds against which to compare seasonal results from IPM trial sites.

Economic analyses of integrated pest management trials were completed in 2018 and again in 2020. These trials were conducted by IPM program entomologists from New South Wales Department of Primary Industries.

Analyses in 2018 were based on yield and quality data only. No trial cost data was available from these trials in 2018 so industry average costs from the macadamia benchmarking study were used to estimate net cash flows for a single season. Forecasting of future cash flows could not reliably be reported due to lack of cost data, and discounted cash flow analysis was therefore not possible. Findings were reported to IPM program entomologists in accordance with the research agreement.

Annual and long-term cash flows were modelled using data provided from 2020 IPM trials. These included three IPM treatments and one standard broad-spectrum treatment. Cash flows were also modelled for the top 25% of Northern Rivers NSW farms in the macadamia benchmark sample to compare costs and returns with high productivity commercial farms in the same region and season. Findings were reported to IPM program entomologists in accordance with the research agreement.

Pheromone trap evaluation

This project component aimed to optimise the use of the recently commercialised Banana spotting bug BSB (*Amblypelta lutescens)* pheromone trap and investigate the potential for a similar lure to monitor Fruit spotting bug (*Amblypelta nitida*).

Problems were identified with the efficacy and longevity of the BSB lures, which affected their performance in field trials. There were also issues with the trap design, which was observed to work best in the darker regions of the canopy but rapidly lost adhesive performance when exposed to direct sunlight. This was also observed in avocado and custard apple trials.

While these issues limited the progress of trap development, the work by DAF has helped overcome some of the problems, particularity around lure efficacy, restoring some confidence in the commercial product. The work has also improved the understanding of the BSB pheromone trap performance and limitations under field conditions.

Keywords
macadamia; IPM; IPDM, sustainability; integrated pest management; entomology; fungal entomopathogens; Beauveria; myco-insecticides; pheromone traps; lures; economic analysis; cash flow; benchmarking.

Introduction
This project is part of a larger macadamia IPM program led by researchers from NSW DPI. Researchers from the Queensland Department of Agriculture and Fisheries contributed expertise in three main areas including (i) practical application and assessment of pheromone insect traps; (ii) isolation and culturing of entomopathogenic fungi for assessment as protectants against insect pests; and (iii) economic assessment of emerging IPM scenarios through collaboration with industry benchmarking.

Fungal entomopathogens

Entomopathogenic fungi are natural disease organisms of insects that can be used for controlling insect pests. A number of fungal biocontrol products based on entomopathogenic fungi are now registered worldwide. These products primarily consist of formulated fungal spores applied using application strategies similar to those used with chemical insecticides. Hence these products are termed myco-insecticides or more broadly biopesticides, with the active ingredient being live fungal spores. The most widely used fungi in myco-insecticide formulations are *Beauveria bassiana* and *Metarhizium anisopliae* (Faria and Wraight 2007). These fungi are commonly used because they have good commercial characteristics; they are relatively easy to mass produce and the spores can be easily formulated and stored for later application. Myco-insecticide formulations based on entomopathogenic fungi can provide an alternative to conventional chemical insecticides for controlling target pest populations. They offer target specificity while not leaving harmful residues on food crops. Moreover, these fungi are considered safe to use with minimal environmental or human health risks (Zimmermann 2007a; Zimmermann 2007b).

Some entomopathogenic fungi, in particular *Beauveria* spp., appear to be capable of an endophytic lifestyle, where the fungus has been found to colonise plant tissues. This can potentially benefit the host by providing some protection against insect attack. The presence and role of fungal endophytes in plant tissues is a rapidly growing area of research. It has been found that *Beauveria* can be induced to enter plant tissues and live as an endophyte after treatment, although it may only last there for weeks rather than months due to competition from the endophytes already living in the plant tissues (Posada and Vega 2005). However, this could be an advantage for an entomopathogenic fungus that is only required to be present for a short period to protect target plant tissues during the period when they are susceptible to insect attack.

A biological control agent such as a myco-insecticide, especially one with endophytic potential, could offer an important tool for use as part of an integrated pest management system. The aim of this study was to investigate, in collaboration with other research groups, entomopathogens endemic to macadamia growing areas, for their potential in myco-insecticides for the control of Macadamia seed weevil (*Kuschelorhynchus macadamiae*).

Benchmarking and economic analysis of IPM strategies

The team from the "*Benchmarking the Macadamia Industry 2015-2018*" project (MC15005) collaborated in the previous project "*A multi-targeted approach to Fruitspotting bug management*" (MT10049) to evaluate the economic viability of specific IPM strategies and provide linkages to growers and consultants via its network of Benchmark Groups. This collaboration and ongoing linkage with industry is important for uptake, feedback and ultimately industry adoption and is therefore also an important part of the stakeholder engagement plan for the IPM program. The benchmarking team contributed to the IPM program through periodic provision of factory insect damage trend data from ongoing industry benchmarking work (MC18002). These data were provided to the New South Wales Department of Primary Industries entomology team annually to inform them of seasonal pest and disease trends. Inclusion of the NSW DPI team in Benchmark Group meetings also enabled them to network with growers, seek feedback and deliver the latest pest information and recommendations to industry participants.

Economic analyses of integrated pest management trials conducted by NSW DPI in the Northern Rivers of NSW were completed twice during the project to provide program entomologists with an objective assessment of their relative economic viability. In the latter study cash flows were also modelled for the top 25% of Northern Rivers NSW farms in the macadamia benchmark sample to provide a comparison of costs and returns for high-productivity commercial farms.

Pheromone trap evaluation

Prior to the previous project (MT10049) a pheromone trap was developed for Banana spotting bug (*Amblypelta lutescens*). This trap was designed as a monitoring tool which, along with damage thresholds allowed growers to make accurate insecticide spray decisions. It also offered some promise as a lure and kill approach, but this aspect requires further research that has not taken place. The aim of the work in this project was to advise researchers and consultants on the optimisation and use patterns of the recently commercialised BSB pheromone trap in macadamias. This component also targeted the other Fruitspotting bug species (*Amblypelta nitida*). DAF staff also advised Dr Andrew Hayes (University of the Sunshine Coast) on the research into semiochemical insect behaviour, which may lead to potential pheromones for *A. nitida*.

Methodology

Fungal entomopathogens

The project component investigating fungal entomopathogens for Macadamia seed weevil was completed in late 2018 and reported separately to Hort Innovation in 2019. A brief summary of the project methodology is shown below. For a more detailed description of the methodology please see the final report for this project component in Appendix A.

Isolates of *Metarhizium* and *Beauveria* fungi were obtained from both soil samples and dead insects, including Macadamia seed weevils collected in New South Wales. Field collected mycosed Macadamia seed weevils were supplied by New South Wales DPI entomologists for isolation of the fungal entomopathogens. In addition, specimens of *Paropsisterna tigrina* and vegetation samples from the Melaleuca host of these insects were supplied for fungal isolations. Ten soil samples were also collected from under trees in five different macadamia cultivar plots in the Alstonville macadamia reference orchard.

Spores were produced via a biphasic process using liquid cultures. Thermal growth characteristics of isolates were determined by measuring radial growth on SDA plates incubated at a range of constant temperatures between 15°C and 33°C.

Species level identification of all fungal isolates used for experimental work were confirmed via molecular techniques.

Three separate trials were conducted to assess the feasibility of treating macadamia nuts with formulations of *Beauveria bassiana* to induce endophytic colonisation.

The mass production of all isolates was possible, however due to the limited field space, only the B48 and B60 isolates were mass produced for NSW DPI to conduct their field trials.

Benchmarking and economic analysis of IPM strategies

Benchmark data was analysed and reported annually to IPM program entomologists over five seasons. These analyses identified factory insect damage trends by season, region, tree age and farm size. The seasonal value of losses due to factory reject was estimated for all farms in the benchmark sample. The weight of rejects was derived from individual farm reject kernel recovery percentages and then converted to equivalent nut-in-shell (NIS) weights. The economic value of those losses was derived using the average seasonal NIS price at 10% moisture content. These data were analysed in conjunction with reported farm observations to identify trends and seasonal factors affecting factory rejects, particularly those relating to insect damage.

In 2018 the project team analysed and compared cash flows for four preliminary IPM scenarios being trialled by New South Wales Department of Primary Industries entomologists at the Centre for Tropical Horticulture in Alstonville NSW. A summary of these scenarios is shown in Table 1.

Economic assessments of these trials were based on yield and kernel recovery impacts only as cost data was unavailable. Cash flows were compared to determine the relative profitability of each pest control strategy, ranging from non-IPM approaches based on broad-spectrum chemicals and no biological control agents, through to IPM approaches based on the use of both selective chemicals and biological control agents. Cultural practices were used in all cases to maximise orchard hygiene.

Table 1: IPM scenarios analysed in 2018

2018 scenarios	Category	Description
Standard broad-spectrum chemical sprays and orchard hygiene	Chemical	Diazinon, Methidathion, Carbendazim, Beta-cyfluthrin, Acephate
	Cultural	Removal of MSW infested nuts
	Biological	None
Standard Plus broad-spectrum chemical sprays, orchard hygiene and biological control agents	Chemical	Diazinon, Acephate, Trichlorfon, Sulfoxaflor, Acetamiprid + Pyriproxyfen
	Cultural	Removal of MSW infested nuts
	Biological	Lacewing, Montdorensis, Centrodora, Mactrix
IPM-1 selective chemical sprays, orchard hygiene and biological control agents	Chemical	Butterflypea extract, Indoxacarb, Cyantraniliprole, Flonicamid
	Cultural	Removal of MSW infested nuts
	Biological	Beauveria, Lacewing, Montdorensis, Centrodora, Mactrix
IPM-2 selective chemical sprays, orchard hygiene and biological control agents	Chemical	Butterflypea extract, Pyrethrin, Cyantraniliprole, Flonicamid
	Cultural	Removal of MSW infested nuts
	Biological	Lacewing, Montdorensis, Centrodora, Mactrix

In 2020 a second economic assessment was conducted of four scenarios trialled by New South Wales Department of Primary Industries entomologists at the Centre for Tropical Horticulture in Alstonville NSW. A summary of the 2020 trial scenarios is shown in Table 2. These trials incorporated applications of both selective and broad-spectrum insecticides to small plots of trees comprising four industry standard varieties (246, 741, 849 and A4). Three of the treatments compared the use of various selective chemicals with minimal or no use of broad-spectrum chemicals, while a fourth scenario was based on heavier reliance on currently available broad-spectrum chemicals. Cultural practices were again used in all cases to maximise orchard hygiene. Yield and crop protection cost data were collected by IPM program entomologists and provided to the benchmarking team for inclusion in the economic analyses.

Table 2: IPM scenarios analysed in 2020

2020 scenarios	Category	Description
IPM-1 selective and broad-spectrum chemicals	Chemical	Flupyradifurone, Indoxacarb, Sulfoxaflor, Trichlorfon
	Cultural	Removal of MSW infested nuts, mulching, smother grass planting and hedging
	Biological	Mactrix
IPM-2 selective and broad-spectrum chemicals	Chemical	Trichlorfon, Indoxacarb, Sulfoxaflor
	Cultural	Removal of MSW infested nuts, mulching, smother grass planting and hedging
	Biological	Mactrix
IPM-3 selective chemicals	Chemical	Sulfoxaflor, Indoxacarb, Trichlorfon
	Cultural	Removal of MSW infested nuts, mulching, smother grass planting and hedging
	Biological	Mactrix
Standard broad-spectrum chemicals	Chemical	Diazinon, Acephate, Beta-cyfluthrin
	Cultural	Removal of MSW infested nuts, mulching, smother grass planting and hedging
	Biological	Mactrix
Benchmark top 25%	Various	Sample average yield, kernel recovery costs for top 25% of sample in Northern Rivers NSW.

It was not possible to reliably compare performance of IPM trials in the 2020 season with the 2018 trials as treatments were progressively refined each season. Crop protection costs were also unavailable for the 2018 trials, so costs were not comparable between the trials from these two seasons.

Results for each of the four macadamia varieties in the 2020 trials were combined to derive average kilograms of nut-in-shell per tree for each treatment. These values were then scaled up to derive an indicative yield per hectare. Hand harvesting of trials typically results in higher yields compared with commercial, mechanically harvested farms. In the absence of definitive data on commercial harvest efficiency a best estimate of 75% was used for this study. This efficiency factor is consistent with previous studies, such as evaluation of elite breeding selections planted in regional variety trials (2018).

Crop protection costs for each scenario were based on applied rates and recommended retail prices provided by local chemical resellers. The one exception was Sivanto® (Flupyradifurone), which was trialled in IPM scenario 1 but was not commercially available when the analyses were conducted. In the absence of a commercial price an indicative price was estimated, based on the assumption that on its release, Sivanto® is likely to be similarly priced to Transform® (Sulfoxaflor). Crop protection costs for IPM scenarios 1 and 3 were equivalent as a result. The remainder of annual costs were sourced from four-year averages (weighted by nut-in-shell production) from the industry benchmark sample. Costs were sourced from the last four seasons (2017-2020) and included unpaid labour, which was imputed at a standard wage rate of $30 per hour. This is consistent with the industry benchmark project (MC18002).

An additional scenario was modelled using data from the 2020 industry benchmark sample to provide an assessment of current industry practice for high-productivity farms in a similar location to the IPM trials. Average yield, kernel recovery and costs were analysed for the top 25% of farms in the benchmark sample from the Northern Rivers region of NSW in 2020.

Annual cash-flows were modelled over a 20-year period using the *Financial Planner for Macadamia* software, which has been previously used to model a range of economic scenarios within the macadamia industry. Economic indicators produced via this tool include annual net cash flow (NCF), annual cumulative cash flow (CCF), net present value (NPV) and internal rate of return (IRR). A comprehensive set of parameters and assumptions was developed to underpin each of the analyses. These assumptions were documented in the economic analysis report provided separately to Hort Innovation and IPM program entomologists. Factors such as inflation, price growth, depreciation, taxation, finance and periodic expenditure were excluded to simplify cash flows and to allow ease of comparison.

Pheromone trap evaluation

Commercial pheromone traps for Banana spotting bug (*A. lutescens*) were sourced from Organic Crop Protectants (OCP) and field tested on commercial farms by both researchers and consultants. Although prototype traps had been previously developed and tested by DAF researchers, the commercial traps were largely untested. Traps were established in Gympie, Bundaberg and Walkamin. These were generally placed at the recommended spacing (from previous research work) of at least 10 traps spaced over at least 1 hectare. Some growers and consultants adapted these use patterns according to their own needs.

NSW DPI researchers established a small number of the commercial BSB pheromone traps on macadamia farms in Bundaberg and Gympie in late August 2017 to monitor BSB activity. These traps were installed in conjunction with trap hedges for monitoring Fruit spotting bug (*A. nitida*) activity. DAF researchers established a field trial at Walkamin Research Station to test the performance of commercial traps against the original DAF-built traps and pheromones. A field trial was also conducted on a commercial lime farm, as limes tend to have a very heavy incidence of BSB.

The mid-term review of the IPM program recommended that work be undertaken to develop a lure for Fruit Spotting Bug (*A. nitida)*. Dr Newton had discussions with Dr Andrew Hayes (USC) who indicated potential capacity to undertake some of this work. Dr Newton subsequently provided advice on behavioural laboratory bio-assays and chemical work undertaken on *A. nitida* to support further investigations (see MC16007 final report).

Outputs

Fungal entomopathogens

- In accordance with the requirement to identify at least 10 isolates, a total of 11 were identified for consideration by NSW DPI entomologists for control of Macadamia seed weevil (Table 3).
- The mass production of all isolates was possible, however due to limited field trial space only *Beauveria* isolates B48 and B60 were mass produced for NSW DPI to conduct their field trials (Table 4). The *B. bassiana* B48 isolate was selected for this purpose as it originated from the target pest and had already been shown by NSW DPI entomologists to be highly pathogenic to MSW. The commercial isolate B60 was selected due to its advantage of already being registered in Australia.
- Unique sequences from molecular characterisation of the isolates were deposited in Genbank.
- A final report on the fungal entomopathogen work was accepted by Hort Innovation following its completion in 2018 (Appendix A).

Table 3: Entomopathogenic fungi isolated from different sources for consideration in macadamia seed weevil control

Entomopathogenic fungal species	DAF collection number	Source
Beauveria bassiana	B27	Infected *Bovicola ovis*
Beauveria bassiana	B48	Infected MSW, Alstonville
Beauveria bassiana	B49	Infected *Paropsisterna tigrina*, Lismore
Beauveria bassiana	B50	Infected MSW, Binna Burra
Beauveria bassiana	B51	Soil, Alstonville
Beauveria bassiana	B52	Soil, Alstonville
Beauveria bassiana	B60	Commercial strain "Velifer™"
Metarhizium anisopliae	M16	Soil, Aratula
Metarhizium anisopliae	M95	Soil, Alstonville
Metarhizium anisopliae	M97	Soil, Alstonville
Metarhizium anisopliae	M98	Soil, Alstonville

Table 4: Summary of spore production runs completed for NSW DPI

Production run	Species	Isolate	No. of production bags	Spore powder yield (g)
PR132-17	*B. bassiana*	B48	3	92
PR134-17	*B. bassiana*	B48	4	48
PR137-17	*B. bassiana*	B48	8	231
PR138-17	*B. bassiana*	B60	7	237
PR141-18	*B. bassiana*	B48	8	211

Benchmarking and economic analysis of IPM strategies

- Reports of seasonal factory reject data were provided to IPM program entomologists each year of the project. From the 2017 season onwards grower feedback on seasonal limitations to productivity and quality were also summarised and reported. An example of the most recent seasonal report is shown in Appendix A.
- Economic analyses of IPM trials were completed in both 2018 and 2020.
- Yield and kernel recovery data were collected by New South Wales Department of Primary Industries entomologists from 2018 season trials, however cost data were not available, so industry-average costs had to be uniformly applied to all scenarios modelled. In the absence of specific cost data cash flows were estimated only for the current season and scenarios were not ranked against each other. Only three of the four IPM trial scenarios modelled in 2018 (Standard, Standard Plus and IPM 1) achieved positive net cash flow when based on industry-average costs (Table 5). Some trials had little or no yield during the 2018 season and consequently achieved poor returns. The IPM 2 scenario had negative cash flow, primarily due to its low yield. Results showing annual cash flows for all trial scenarios were reported to New South Wales Department of Primary Industries entomologists.
- Yield, kernel recovery and chemical cost data were collected by New South Wales Department of Primary Industries entomologists from 2020 season trials and made available for inclusion in economic analyses. The inclusion of scenario-specific cost data allowed scenarios to be ranked according to net cash flow and for cash flows to be modelled beyond the current season. Results were reported to both IPM program entomologists and Hort Innovation. As findings were based on small scale trial results for a single site and season this report was intended only for IPM program entomologists to inform decision-making and is not considered suitable for wider industry release at this stage.
- Revenue exceeded costs in all scenarios modelled in 2020, meaning all achieved positive cash flow. Net cash flows and associated scenario ranks are shown in Table 6. Each of the IPM scenarios (IPM-1, IPM-2 and IPM-3) had both higher costs and higher yields per hectare than the standard (broad-spectrum) scenario. The IPM scenarios also achieved higher net cash flow than the standard scenario. The 20-year models show that if these seasonal gains can be consistently realised then differences in cumulative cash flow can be significant over the long-term. Given the relatively high impact of yield and nut-in-shell price on seasonal productivity, it is important to also acknowledge the potential for significant deviation from the modelled scenarios over that period. The cash flow models are intended purely to provide a comparison of the performance of each scenario relative to the others shown, as these are based on consistent assumptions and circumstances.
- Members of the team attended all major project meetings and industry consultants meetings during the project. A list of meetings attended is shown in Table 7. These meetings provided important opportunities for networking with industry consultants, promote understanding of the leading causes of rejects, alert this group to emerging pests and diseases and gain valuable insight into regional variability in relation to pest and disease issues. Reject trends from seasonal benchmark data were presented at meetings in 2017 and 2019. These presentations provided insight into seasonal factory reject trends and the relative economic significance of various categories of reject. The 2021 macadamia consultants meeting was postponed and later scaled down to a local group format in NSW due to COVID travel restrictions.
- IPM program entomologists were invited to participate in annual Benchmark Group meetings facilitated by the benchmark project team (MC18002) in all major production regions (Table 8). Entomologists presented updates on the IPM project, highlighted seasonal and emerging pest and disease issues and discussed seasonally and regionally specific approaches to pest and disease management. In many meetings entomologists presented live specimens of important pests to help growers identify and understand their behaviour. Grower interest and engagement in these sessions was typically high and involved many questions and significant follow-up discussion, indicating they were highly valued by those who attended.
- The project leader provided a detailed update on the DAF component of the IPM project at the whole team meeting in Ballina, NSW in February of 2018. Discussions with project staff at that meeting were beneficial for refining trial data collection.
- Four annual project updates were produced for inclusion in yearly updates to the Macadamia Growing Guide. These were provided to the lead NSW DPI team from 2018 to 2021.

Table 5: Single season cash flow results from economic analysis of IPM scenarios in 2018

(*+ indicates positive cash flow, - indicates negative cash flow*)

2018 scenarios	Description Scenario-specific yield/quality and uniform costs	Cash flow
Standard	broad-spectrum chemical sprays and orchard hygiene	+
Standard Plus	broad-spectrum chemical sprays, orchard hygiene and biological agents	+
IPM-1	selective chemical sprays, orchard hygiene and biological control agents	+
IPM-2	selective chemical sprays, orchard hygiene and biological control agents	-

Table 6: Rankings from 2020 economic analysis of IPM scenarios

2020 scenarios	Description Scenario-specific yield, quality and production costs	Net cash flow per hectare	Rank
IPM-1	selective and broad-spectrum chemicals, cultural and biological controls	$15,575	1
IPM-2	selective and broad-spectrum chemicals, cultural and biological controls	$13,022	3
IPM-3	selective chemicals, cultural and biological controls	$13,137	2
Standard	broad-spectrum chemicals, cultural and biological controls	$11,968	4
Benchmark top 25%	various practices including both broad-spectrum and selective chemical sprays	$11,817	5

Table 7: Participation in meetings

Meeting	Location	Date(s)
IPM program monitoring and evaluation meeting	Wollongbar	8-9 December 2016
Macadamia Consultants meeting	Brisbane	7-8 June 2017
IPM project team meeting	Ballina	6 February 2018
Macadamia Consultants meeting	Caloundra	6-7 June 2018
Macadamia IPDM Annual Research Meeting	Gold Coast	12 November 2018
Macadamia Consultants meeting	Brisbane	4-5 June 2019
IPM program workshop	Brisbane	22 October 2019
IPM project team meeting	online via Zoom	17 September 2020

Table 8: Benchmark group meetings involving NSW DPI IPM program staff (** indicate meetings cancelled due to COVID-19, # indicates external participants were excluded due to growers' preference for a confidential meeting)*

Season	Benchmark Group meeting dates and number of attending farms											
	Central Queensland		Gympie Queensland		Glasshouse Queensland		Northern Rivers NSW #1		Northern Rivers NSW #2		Mid-north coast NSW	
	date	farms	date	farms	date	farms	date	farms	date	farms	date	farms
2017	19/08	33	18/08	9	16/08	18	23/08	27	30/08	24	20/09	20
2018	23/08	26	18/08	7	15/08	13	29/08	21	30/08	7	13/09	14
2019	28/02	24	11/12	8	13/12	12	14/03	22	25/01	10	24/01	15
2020	27/02	N/A#	4/02	13	31/01	13	N/A*		N/A*		N/A*	
2021	12/03	24	4/02	10	2/02	10	12/03	13	11/03	19	17/03	15

Pheromone trap evaluation

- There was evidence of early success following the August 2017 release of BSB traps in Gympie and Bundaberg, with high numbers of BSB being caught in some of the commercial traps. At least one of the installed traps caught large numbers of BSB (10 bugs in 2 weeks), indicating that the commercial traps were effective in this first instance. Based on results from previous work (MT10049), 10 bugs in one trap is a very high number; 0.5 bugs/trap is the spray threshold in avocados and custard apples. However, crop scouts, consultants and growers reported mixed results using the BSB pheromone trap, occasionally catching high insect numbers (1 to 10 per trap) and at other times catching very few, despite BSB being concurrently observed in the field. BSB hide and are highly cryptic, therefore are generally not observed in the field unless they are in very high numbers. Often the damage is observed before the bugs are observed (thus the need for a trap). The direct observation of even a small number of bugs usually indicates very high numbers are present in the field. These results indicated that the commercial trap may not have been reliable at the time.
- Results from the Walkamin trials indicated that commercial chemical lures did not work as well, nor last as long as traps previously developed by DAF. The Australian distributor (Organic Crop Protectants - OCP) had experienced some technical difficulties with the longevity and reliability of the chemical lures and the traps were not available at times. Dr Newton worked with OCP to resolve the technical issues and the process used for sourcing the lures has subsequently been revised. Chemicals are now being imported from the USA, however lures are loaded in Australia by a contractor. This process appears to produce a more reliable lure.
- Based on small-scale field trials the new lures appeared to be effective for at least the first 3 to 4 weeks, however they may lose some efficacy after this time. Growers and consultants also expressed concern with the time and effort required when using the current commercial trap design and also the longevity of traps in field conditions. It appears that the trap loses its stick over time in sunlight. Exposing traps to sunlight causes more rapid degradation of the adhesive and generally after about two weeks most traps have lost their tack. Lures continue to attract BSB into the tree under these circumstances, however the trap will not capture them. The commercial trap comes with replacement adhesive pads, which are replaced each fortnight, but these are tedious and difficult to use. The adhesive tape is also expensive, which makes the overall trap expensive. OCP subsequently sourced a new adhesive tape that lasts longer in sunlight.
- A small-scale field trial was conducted in Walkamin to test the new adhesive tape in the field. The results showed that the new tape does retain its adhesive ability in the field over several weeks, although its efficacy does reduce over time. In the first week following installation the new tape had only caught approximately half as many BSB as the fresh original tape. Traps with the new tape (not changed fortnightly) caught a total of 47 BSB over 7 weeks, which was similar to the old tape at 45 BSB (not changed fortnightly). These catch results were however much lower than those for the current standard practice treatment (changing the tape fortnightly) which caught a total of 135 BSB. It therefore appears that the new adhesive tape catches less BSB than the current practice, which means traps still need to be replaced every 14 days. Further research may be required before an alternative trap can be developed.

Outcomes

Fungal entomopathogens

The entomopathogen work aimed to develop a preliminary novel non-chemical tool for IPM strategies for Macadamia seed weevil control. *Beauveria bassiana* was found to be a pathogen of Macadamia seed weevil occurring naturally in populations of this pest in the border regions of New South Wales and Queensland. Strains of this fungus were isolated from both the soil and infected insects from different locations in the border regions. Research into temperature characterisation of *Beauveria* isolates was conducted to identify optimal temperatures for growth.

Selected isolations B48 and B60 were mass produced in sufficient quantities to support field trials conducted by New South Wales Department of Primary Industries staff, who subsequently assessed their efficacy as a control option for Macadamia seed weevil.

In accordance with the research agreement, DAF staff collaborated with a USQ doctoral student and provided cultures of entomopathogenic isolate B27 for use in the related study 'Interactions of fungal entomopathogens with synthetic insecticides for the control of *Kuschelorhynchus macadamiae* (Coleoptera: Curculionidae)'.

Benchmarking and economic analysis of IPM strategies

Six regional benchmark group meetings were facilitated annually, totalling 27 meetings between 2017 and 2021. IPM entomologists were provided opportunity to present and discuss emerging pests and their control. These sessions provided growers with information on the latest control measures emerging from the IPM program for a range of macadamia pests and diseases. The meetings also allowed entomologists to gain a better understanding of specific regional challenges and approaches to pest and disease management. Participating growers demonstrated their interest in these sessions through good participation in discussions, obvious interest in the demonstrated samples and through the large number of follow-up questions at meetings. Participants were surveyed following each meeting to evaluate impact and establish priorities for ongoing discussions. In the 2019 benchmark group survey 77% of participating growers (representing 91 farms) indicated they had changed or planned to change practices as a result of attending these meetings.

Annual benchmark summary reports provided program entomologists with reliable data and understanding of regional pest limitations and factory reject levels caused by insect damage. These reports summarised findings across the whole benchmark sample, which represented more than 270 farms and 58% of industry annually.

Economic analyses of IPM strategies provided program entomologists with insight into the relative economic performance of a range of IPM scenarios. The accuracy and applicability of these analyses was limited by several factors including the scale of the trials, limited replication of treatments, progressive refinement of IPM trial strategies during the project and lack of scenario-specific cost data from the 2018 trials. The reliability of cash flow forecasts is also subject to the applied assumptions, which in this case included estimation and conversion of trial vs harvest efficiency. As a result, although findings from the economic analyses provided useful insight for NSW DPI entomologists, they are not considered suitable for wider industry publication at this stage.

Pheromone trap evaluation

The pheromone work aimed to provide data to support optimum use of BSB pheromone traps. Small scale trials and extension of results to program entomologists have assisted in the use of pheromone traps as a monitoring tool in macadamia. Confidence in the use of currently available pheromone traps has been impacted by issues including imperfect trap components and pheromone dosing and longevity. The work by DAF has helped commercial supplier OCP to overcome some problems, particularity around lure efficacy, restoring some confidence in the commercial product. Recommendations of use patterns in macadamia have largely been based on research in avocado, which identified the optimum number of traps required per hectare and thresholds on which to base a spray control decision. The macadamia trial work carried out in this project has however improved the understanding of BSB pheromone trap performance and its limitations under field conditions. The current commercial trap appears to work in macadamias in a similar way as it does in avocados and custard apples i.e., it works best within the darker regions of the canopy and rapidly loses performance if exposed to direct sunlight.

Monitoring and evaluation

The overarching objective of the national IPM program was to develop and extend knowledge and practices that support macadamia growers to have a sustainable, pest resilient farming system.

The role of the DAF component within this program was to:

- identify and isolate fungal entomopathogens of relevance for control of Macadamia seed weevil and mass produce spores to support NSW DPI field trials.
- provide annual summaries of factory rejects and seasonal limitations from the benchmarking project, involve IPM entomologists in Benchmark Group meetings and complete an economic assessment of New South Wales Department of Primary Industries IPM trials to inform program entomologists of their relative economic performance.
- evaluate and provide recommendations on the optimal use of BSB pheromone traps and investigate the potential for a similar lure to monitor Fruit spotting bug (*Amblypelta nitida*).

Fungal entomopathogens

A key performance measure was identification of fungal entomopathogens relevant to macadamia pests, especially Macadamia seed weevil, and to support NSW DPI entomologists to conduct small-scale field trials. Three field investigations were carried out using spores of isolate B48 generated by DAF staff. These trials provided a preliminary assessment of the feasibility of macadamia nuts at a range of maturity levels, both treated and previously colonised with formulations of *B. bassiana*, to induce endophytic colonisation.

Benchmarking and economic analysis of IPM strategies

The economic assessment of IPM trials was designed primarily to inform IPM program entomologists about the relative economic performance of their small-scale trial scenarios. There is no contracted mandate for delivery of findings from these preliminary trial assessments to industry. As such, a key performance measure of the benchmarking component of the project was the acceptance of the economic analysis of IPM scenarios by program entomologists. Meetings were regularly conducted between DAF and NSW DPI staff to facilitate a better understanding of trial data and assumptions built into the modelled scenarios. The most recent and comprehensive report '*Economic analysis of macadamia integrated pest management scenarios*' was provided to both Hort Innovation and New South Wales DPI program entomologists in June 2021. While the details of that report are not intended for industry publication, the following broad conclusions can be reported:

- The net cash flow performance of IPM scenarios compared favourably with the standard (broad-spectrum) scenario.
- All IPM scenarios had both higher costs per hectare and higher yields per hectare than the standard (broad-spectrum) scenario.
- the rank order of scenarios based on net cash flow performance matched that of saleable kernel production.

Interaction between entomologists, growers and consultants was facilitated through Benchmark Group meetings between 2017 and 2021 (see Outputs). A total of 27 meetings involving program entomologists and consultants facilitated two-way information exchange and improved understanding of IPM principles. An average of 75 separate farm businesses participated in these events in each year of the project.

Pheromone trap evaluation

Information and recommendations on the optimal use of BSB pheromone traps as part of an IPM strategy have been limited due to efficacy issues reported in 'Outputs'. The commercial BSB trap was used and evaluated by macadamia growers, crop scouts and consultants, but produced mixed and unreliable results. The results indicated that the trap was not originally working at optimal standard at the time of the evaluation. Collaboration between DAF project staff and the commercial trap producer (OCP) has since improved the efficacy and reliability of BSB pheromone traps, however ongoing refinements have been noted, requiring further investigation.

Collaboration between DAF staff and the University of the Sunshine Coast has resulted in encouraging preliminary research that indicates that a lure to aggregate *Amblypelta nitida* (FSB) to optimise timing of pesticide application may be possible, however further research is required.

Recommendations

Fungal entomopathogens

- Future research needs to focus on the best approach to formulating and applying the fungus to achieve optimal control.
- The results with the endophyte research suggest further investigations are warranted to understand the full potential of fungal entomopathogens as Macadamia seed weevil control agents.

Benchmarking and economic analysis of IPM strategies

- Replication of the IPM trials undertaken by program entomologists would provide more robust data on which to base economic modelling. Given the high variability in average seasonal production, repetition of unmodified trials over multiple production seasons would also add confidence to results.
- Recording of yield, kernel recovery and cost data should be undertaken for each trial to maximise accuracy and relevance of any further cash flow modelling. Cost data should include all chemical and labour costs associated with crop protection as well as any non-standard costs arising from each unique scenario.
- Research into the relative efficiency of macadamia harvesting under commercial conditions would allow more confident adjustment of yield data from research trials.
- No further economic analysis of IPM trials is recommended until sufficient data exists to support more robust cash flow modelling that can be more confidently reported to industry.

Pheromone trap evaluation

- Ongoing collaboration is required to support the research, development and field testing of pheromone-based lures to ensure efficacy and practicality in a commercial context. The BSB trap offers potential for lure & kill but trial results and grower feedback revealed some efficacy concerns, limitations to durability and issues relating to ongoing maintenance and costs. Further investigation of these issues is needed as lures and traps continue to be refined.
- There is some preliminary evidence from work by Andrew Hayes to suggest that pheromones may be effective against Fruit spotting bug, however more research is required to develop an *Amblypelta nitida* (FSB) lure.

Refereed scientific publications

N/A

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Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report.

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Appendices

Appendix A: project reports

- Final report on fungal entomopathogens for Macadamia seed weevil (2018)

The project component to isolate fungal entomopathogens for potential control of Macadamia seed weevil was completed in 2018 and subsequently reported to Hort Innovation. The link shown above can be used to access the final report on that work, which was accepted by Hort Innovation in 2019.

- Summary of seasonal limitations and factory rejects 2009-2020 (2021)

An annual report summarising factory rejects was produced and presented to IPM program entomologists at New South Wales Department of Primary Industries during each year of the project (2017 to 2021). The most recent report spanning the 2009-2020 seasons was produced in 2021. This report can be accessed via the link shown above.