Hort Innovation

Final Report

Contribution of the 2nd International Macadamia Research Symposium

Project leader:

Dr Craig Hardner

Delivery partner:

University of Queensland

Project code:

MC16700

Project:

Contribution of the 2nd International Macadamia Research Symposium – MC16700

Disclaimer:

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Level 8
1 Chifley Square
Sydney NSW 2000

Telephone: (02) 8295 2300

www.horticulture.com.au

Content

Summary

The objective of this project was to support the organisation of the 2017 International macadamia Research Symposium; including attendance of Australian students and extension of relevant information to the Australian macadamia industry.

Macadamia is a relatively new crop and the international research community is fragmented. Improved awareness of common and unique research challenges and areas of research investment throughout the globe will support improved information sharing and collaboration and thereby contribute to greater efficiency from the investment of the Australian industry in research and development. The last macadamia research gathering was held in 1992.

The symposium was held between the 12^{th} and 13^{th} of September 2017 in Hilo on the Big Island of Hawaii. One day pre-symposium and post-symposium tours were organised to visit Hawaiian macadamia farms and research activities. 99 people attended the symposium with delegates from Hawaii (45), Australia (32), Brazil (5), China (5), New Zealand (4), Haiti (2), Japan (2), Poland (2), Mexico (1) and Switzerland (1). Unfortunately there were no attendees from South Africa due to the impact of the 2016 drought on production and available funds. Most attendees were employed by research organisations, but there were also attendees from local and international industry and allied companies. This project supported the attendance of 6 students from Australian universities.

There were 28 oral and 7 poster presentations. The major themes were propagation, tree and fruit physiology, nutrition management, pollination, pest and disease management, orchard management, genetics and breeding, product development and developing production regions. The symposium demonstrated the leadership of Australian industry in global R&D of macadamia, but also identified developing activities in new and emerging production regions, particularly China.

An article written by Katie O'Connor (UQ) was published in the November edition of the AMS Bulletin, and Scott Hill presented a summary of the Symposium at the March 2018 MacGroups. Twelve papers have been submitted to HortScience for publication in a special section. A concept proposal has been submitted to Hort Innovation for the publication of a updated book on macadamia horticulture and management to summarise current status of knowledge.

The symposium was very successful in achieve the aim of bring together scientists across the globe to present and discuss research challenges and solutions. The number of attendees was comparable to a recent research conference held in Adelaide. Feedback of over 1/3 of attendees to an online survey indicated overwhelming support (>60%) for all aspects of the symposium. Respondents listed many areas of learning and provided feedback on ideas to improve future meetings, although there was a conflict among some of the ideas, and with the aims of the symposium.

There were also discussion about the need for ongoing international meetings and the formation of a macadamia working group in the International Society for Horticultural Science.

Keywords

Conference, Collaboration, Hawaii

Introduction

While macadamia is a profitable and expanding Australian horticultural tree crop industry, the crop a relatively young with a small production base compared to more established horticultural tree crops. As such the knowledge base supporting ongoing improvements in productivity and profitability is also less developed. In addition, the macadamia global industry is expanding and macadamia is being produced in a larger range of countries which may have similar, or different, research challenges of more established production regions. Given this environment, improved communication among the international research community to support greater awareness of research challenges and solutions experienced by others is an important mechanism for more efficient local research projects.

However, there is limited opportunity for the international macadamia research community to meet and discuss common and unique challenges, learn from each other, and establish interactions that can support future collaborations. The last international meeting of the macadamia community was undertaken in 1992. While international industry meetings are very important for understanding the global industry and technology transfer, these meetings do not necessarily provide the best venue for exchange of scientific ideas.

This project has supported the convening of the 2017 International macadamia Research Symposium held in Hilo on the big island of Hawaiian the 12th and 13th of September 2017. The symposium was held at Hilo in Hawaii as the island have a long history of macadamia production and research and is the region where most of the macadamia research in USA is undertaken.

Methodology

Overview

The 2017 International Macadamia Research Symposium was held between 13th and 14th September at The Wainaku Executive Center Hilo, Hawaii. Hilo was chosen as the highest concentration of research is located near the town and it is close to major production and processing activities. 1-day pre and post symposium tours were held to visit the research activities and in local industry on the big island.

Organising committee

The organizing committee for the symposium was Dr Craig Hardner (University of Queensland), Dr Alyssa Cho (university of Hawaii), Dr Marisa Wall (USDA) and Nathan Trump (Hawaiian Macadamia Nut Association).

Communication of symposium organisation

A dedicated website (www.macadamiaresearchsymposium2017.com) was established to display information about the symposium. A list of emails for researchers working in macadamia was developed from information supplied by Australian Macadamia Society, a review of recent publications, personal knowledge and word of mouth. This list was used to advertise the symposium as widely as possible and update potential attendees of developments in the organisation of the symposium.

Abstracts

Abstracts for oral and poster presentations were called for by the 31st of May. Submissions for an oral presentation were given an option of 15 or 30 minute presentations. Abstracts were reviewed by Dr Peter Bouches (USDA) and Dr Craig Hardner to ensure quality of presentations. Authors were notified of acceptance in early June and the final program was prepared and released om 30th of June.

Travel awards

Student travel awards of $1,300 each to support the attendance of Australian students to attend the symposium were advertised on the website and using the email list. Initially it was proposed to fund 4 awards from this project, with the remainder from the symposium general funds. Potential awardees were required to submit abstract for oral presentation. An independent scholarship committee (Dr Wall – USDA, Paul O'Hare – QDPAF, Dr Peter Bouches - USDA) was formed to review the submitted abstracts and select successful awardees based on quality of proposed presentation and diversity. Recommendations were provided to Hort Innovation for final approval.

Budgeting

Registration for the symposium was constrained to US$220 for full registration and $120 for student registration to reduce the cost of attendance being a barrier to attendance at the symposium. Local governments in Hawaii, and companies supporting the macadamia industry in Hawaii and Australia were contacted for sponsorship to help reduce costs of the symposium.

Communication of outputs

To update the Australian industry on the outputs from the symposium, an article was written for the AMS NewsBulletin, and a 10 minute presentation was made to the industry MacGroups.

To ensure that information presented at the symposium was rigorous and communicated to a wider audience, papers from presentations at the Symposium will be published in a special section of HortScience. The deadline for initial submission to the organising committee for coordination of publications was 28th February 2018. Dr Hardner, Wall and Cho will prepare an introduction to the special section summarising the major issues identified at the symposium and opportunities for future research.

Concept proposal

To ensure that challenges identified from the symposium are identified for further consideration, a concept proposal was prepared and submitted to HIA funnel.

Review of success of symposium

To measure the success of the symposium, an online survey was developed in collaboration with Paul O'Hare, and all participants invited to undertake the survey.

Outputs

Database of macadamia researchers

A database of 191 individuals involved in macadamia research and development and allied activities across the globe was developed. Seventy-two of the entries were Australian, 27 from South Africa, 26 from USA (19 form Hawaii), 24 from Brazil, 7 from China, and 6 from New Zealand. However, the database is not comprehensive. The database was provided to Hort Innovation to assist with planning for the 2018 International Macadamia Conference in China.

Attendance

There was a total of 88 attendees at the symposium (Figure 1), of which 11 were students. There were 41 attendees from United states, 27 from Australia, 5 from China, 4 from Brazil and New Zealand each, 2 from Haiti and Japan, and one individual from Switzerland, Mexico and Poland.

Figure 1. Attendees at the 2017 International Macadamia Research Symposium, Hilo Hawaii USA.

The project originally budgeted to support 4 students attending Australian Universities with AU$1,300 travel scholarships. However, 6 students attending Australian Universities applied for support to attend and after consultation and final approval by HortInnovation it was decided to offer support to all 6 students (Figure 2).

Figure 2. Students attending Australian Universities that received travel awards from Hortinnovation. Left-to-right: Gavin Chirgwin, Bryony Wilcox, Olumide Jeff-Ego, Katie O'Connor, Ben Toft, Scott Hill.

Program

The symposium was opened by the mayor Harry Kim of the big island who spoke of the harmony among Hawaiian cultures and the importance of agriculture in supporting the community and the local environment.

A total of 28 oral and 7 poster scientific presentations were made over the two days of the symposium. The major themes were tree and fruit physiology, nutrition management, pollination, pest and disease management, propagation, orchard management, value adding, genetics and breeding, and developing industries.

Australian researchers dominated the presentations with 18 of the oral, and 5 of the poster, presentations were made by these researchers. There were 3 oral, and 2 poster, presentations by US based researchers, 3 oral presentations from Chinese researchers, 2 oral by researchers from New Zealand, and 1 each from Mexican and Swiss researchers.

Symposium tours

The pre-symposium tour visited the MacFarms orchards at Honomolino and Olson Trust orchards at Pahala to observe the Hawaiian production environment and discuss challenges of the orchards. The environment was described as very good for macadamia production with relatively low water pressure deficit due to high humidity and relatively moderate temperatures, and rich soils due to volcanic origin. A major challenge of the MacFarms orchard was the terrain which was undecomposed a'a lava substrate. This terrain restricted mechanical access particularly for harvesting and hence all harvesting was done by hand. Lower yields from recent droughts had forced rationalization of harvesting. The stable climate also appeared to result in multiple and extend flowering throughout the year which resulted in overlapping flowering and fruit retention on individual trees. Trees were up to 50 years of age, but low vigour meant that little canopy management was required.

The Olseon Trust Pahala orchard appeared to grow on a substrate with a higher percentage of soil than the rocky substrate of the Honomolino orchards. Trees were more vigorous and hence challenges were experienced with canopy management.

The post-symposium tour travelled to Honoka'a to visit the processing factory of the Honokaa sugar company built in the 1930s, and one of the original seedling orchard planted in Hawaiian in the mid-1920s. The processing factory had not been sued for several decades.

The afternoon tour visited the Island Princess macadamia factory and adjacent orchard and the UH Waiakea research station that also hosted the USDA macadamia germplasm repository which contained 26 cultivars and 6 samples from related germplasm.

Communication

Website

The website that was developed to display information about the symposium has been updated with

- Program and abstracts
- A password restricted section containing: (i) images form the symposium, and (ii) presentations that were made available by authors

The website will be maintained until the end of 2018.

AMS article

Katie O'Connor prepared an overview of the symposium that was published in the November 2017 issue of the Australian Macadamia Society Newsletter.

MacGroup presentations

Mr Scott Hill presented an overview of the symposium to the February/March MacGroups.

Publication of papers in HortScience

A total of 11 papers were submitted to journal Hortscience for publication as a special section (Table 1). A summary the symposium for publication as an introduction to the special section by Drs Hardner, Wall and Cho has alos been submitted. Each paper will be reviewed by 3 referees. It is anticipated that the papers will be published prior to the end of 2018. At 1st October 2018, 5 papers have been accepted and a further 2 are still in review.

Table 1. List of authors and titles of papers from 2017 International Macadamia Research Symposium submitted as manuscripts to HortScience. This with an asterisk have been accepted for publication, or are in review (as of 1/10/2018). Following publication, copies of these papers may be obtained by contacting craig.hardner@uq.edu.au.

Authors	Title
*CM Hardner, M Wall, A Cho	Global macadamia science: Overview of the special section from the 2017 International Macadamia Research Symposium
*M Alam, CM Hardner, C Nock, K O'Connor, B Topp	Historical and Molecular Evidence of Genetic Identity of 'HAES741' and 'HAES660' Macadamia Cultivars
*CM Hardner, J Costa e Silva, E Williams, N Meyers, C McConchie	Breeding of new cultivars for the Australian macadamia industry
*BG Howlett, SFJ Read, M Alavi, BT Cutting, WR Nelson, RM Goodwin, S Cross, TG Thorp and DE Pattemore	Cross-pollination can enhance nut yields in Australian macadamia orchards, even in the presence of branch-level resource allocation limitations
JM Neal, E Howell, R Mayer, CM Hardner, BL Topp	Oil Accumulation Patterns in Kernel of Macadamia Species
*K O'Connor, B Hayes, CM Hardner, M Alam, B Topp	Selecting for nut characteristics in macadamia using a genome wide association study
*TJ O'Hare, HH Trieu, B Topp, D Russell, S Pun, C Torrisi, D Liu	Macadamia Nuts and Saturated Fat Content
*BD Toft, M Alam2, J Wilkie, B Topp	Phenotypic association of multi-scale architectural traits with canopy volume and yield: moving towards high-density systems for macadamia
Xin Zhao, Qianqian Dong, Shubang Ni, Xiyong He, Hai Yue, Liang Tao, Yanli Nie, Caixian Tang, Fusuo Zhang, Jianbo Shen	Rhizosphere processes and nutrient management for improving nutrient-use efficiency in macadamia production

Concept proposal

This symposium identified the breadth and high standard of research projects that are being undertaken in macadamia across the globe. However, there does not exist a single publication that summarises current knowledge on the crop to date that can be used as reference by researchers, students, and the industry.

At the American Society of Horticultural Science 2017 conference that was held the week following this symposium, informal discussion were held with CABI about the possibility of publishing a book to summarise the current state of knowledge of the crop. CABI suggested a book in the Crop Production Science in Horticulture series (e.g.

http://www.cabi.org/bookshop/book/9781780640914). These are the lower-priced, paperback books that are intended for growers, industry, students and teachers. The second series is Botany, Production and Uses (e.g. http://www.cabi.org/bookshop/book/9781780643540). These are higher priced, hardback monographs that are aimed at research-level specialists. CABI indicated that contribution to funding for the book would make the publication more viable as the audience may be more limited for macadamia compared to other crops.

Thus, a concept proposal suggesting the development of a book with updated technical information supported by research was submitted to funnel on 24th April 2018.

Outcomes

The results from an online survey of which 1/3 of attendees responded indicated that a large proportion (84%) of respondents considered learnings from the symposium would contribute to changes in work practices in the future. The attendance at the Symposium of members of the Hort Innovation SIP will provide a pipeline for consideration of some of the industry relevant issues discussed at the symposium. Learnings identified by attendees included:

(i) The global growth of macadamia and potential benefit of international collaboration
(ii) Improved knowledge of general macadamia biology
(iii) Microclimate variation across different production areas in Hawaii
(iv) Differences of the Hawaiian production system including use of manual labour, limited use of fertiliser, very productive organic orchards, antiquated post-harvest handling of nut
(v) The environmental extremes and associated challenges in which macadamia is produced
(vi) Importance of early-age pruning and alternative pruning techniques
(vii) Importance of pollination
(viii) Improved leaf sampling methods for nutrition management
(ix) Significance of impact of felted coccid on production in Hawaii
(x) The value of Integrated Orchard Management guide for translation of research results to support adoption
(xi) Very old trees can still be productive
(xii) The ancestry of macadamia
(xiii) Availability of new varieties, and opportunities for further development of improved germplasm
(xiv) Genetic variation for vegetative propagation
(xv) Range of tree architecture in germplasm collections
(xvi) Importance of research undertaken in Australia

New challenges identified during the symposium included:

(i) Large scale genotyping of wild macadamia to improve knowledge of the structure germplasm for future breeding and conservation,
(ii) Use of biochar for soil improvement,
(iii) Global movement of pest and disease,
(iv) Land suitability mapping particularly to support planning for adaption to new production environments and climate change, and a
(v) Alternative strategies to improve efficiency of breeding.

Locating the symposium in Hawaii provided the opportunity for attendees to better understand the context of the Hawaiian environment in which a large amount of macadamia research was undertaken in the 20th century so that opportunities and constraints to extension of these results to different production environments can be better evaluated

The range of countries attending the symposium demonstrated the global growth of macadamia into new production environments. The symposium provided opportunities for development of relationships for future interaction and collaboration. These have already lead to strengthening of international collaboration opportunities. For example, Dr Craig Hardner and Dr Brad Howlett were invited as keynote speakers to the 3rd Yunnan Conference for International Expert Professionals held in Kunming in early June 2018. In addition, as highlighted by Dr Olufemi Akinsanmi, international collaboration is important for a coordinated approach to disease prevention and control. However the symposium also generated discussion on the negative perception international collaboration could create with the Australian industry.

The symposium confirmed the global leadership of the Australian research community and the industry providing increased confidence in investment in research by the Australian industry.

The symposium has also had a wider impact. Russell Galanti was contacted by organisers of the 8th Australian Biochar conference to discuss opportunities for presenting at the conference to be held on the Gold Coast in August 2018.

It was recognised that international gatherings of researchers in macadamia was important for the development of the crop. There were informal discussions that the next symposium could be held in Australia, in either 2020 or 2021. In addition, it was suggested that a macadamia working group could be formed as part of the International Society for Horticultural Science to organise future symposium under the umbrella of the ISHS.

Monitoring and evaluation

Given the relative size of the world macadamia industry approximately 100 attendees at a research symposium with less than 12 months notices was considered a success. In comparison, the VII International Symposium on Almonds and Pistachios held in Adelaide 5th-11th November 2017, attracted approximately 140 participants. It was unfortunate that no-one form South Africa could attend, but this was explained by the lack of funds due to drought experienced in 2017. In addition, the International Macadamia Symposium to be held in Lincang in October 2018 may have also reduced the opportunity for some research to attend the 29017 symposium, although the focus was somewhat different.

One third of attendees responded to the online survey undertaken to evaluate the success of the symposium. 54%of respondents identified as students or researchers, with the remainder identifying as extension, growers, processing, marketers or others. There was overwhelming support for the location of the symposium (97% positive), suitability of the venue (87% positive), quality of the content (97%), suitable length (59%), opportunity to ask questions (97%), usefulness of pre- and post-symposium tours for providing information on macadamia production and research in Hawaii (91%), likelihood of contributing to changing practice or direction of future work (84%), likelihood of attending another gathering of international macadamia research community in 2021 (92%).

Other positive comments included:

(i) provided a good update on current research
(ii) provided good opportunity for individuals to mix and share information

Feedback for improvements for future symposia could include:

(i) More diverse content including research results for disease, post-harvest nut storage, processing and kernel storage, food science, consumer preference, microbial safety,
(ii) Improvement in venue setup to allow more room,
(iii) Increased number of student attendees,
(iv) Increased time for discussion,
(v) Family friendly,
(vi) Increased attendance from other countries

(vii) Improved networking opportunities, e.g. increased time for questions and discussion, additional networking events, accommodation at the same location
(viii) Smaller workshops
(ix) Improved communication to industry
(x) Longer program
(xi) Posters displayed in separate more accessible area
(xii) Translation
(xiii) Longer study tour
(xiv) Longer presentation times, 15->20 minutes
(xv) Video recording for future availability of presentations
(xvi) Improved information on symposium organisation

However, it should be noted that some of the suggested improvements are not consistent with the aim of the symposium – to provide researchers a platform to discuss science, and to make the symposium affordable. The content of the symposium was driven by the response of presenters – invitation of speakers for specific topics can increase the cost of symposia. In addition, the length of the symposium was considered appropriate by many attendees.

Recommendations

1. To provide improved access to current state of knowledge in macadamia research for researchers and industry, prepare and publish a multi-author book summarising the macadamia production and processing
2. To facilitate increased awareness of global activities in macadamia research and development, build a searchable website of current researchers and research projects in macadamia
3. To promote continued communication among the international macadamia research community, initiate a working group on macadamia in the International Society of Horticultural Science that can be used to support the convening of international macadamia research symposia in the future.
4. Convene an International Macadamia Research Symposium in Australia in 2019/2020.
5. To improve efficiency of research undertaken to support the development of macadamia, explore opportunities for international collaboration among research groups in different countries.
6. HortInnovation develop a mechanism to consider opportunities for joint projects between Australian and international research groups. These projects are often developed through building of relationships

Refereed scientific publications

To date, there has not been any scientific paper publications that have been fully no papers have been No papers have been published to date

It is anticipated that 12 scientific papers derived from presentations delivered at the symposium will be published in HortScience by the end of 2018.

Intellectual property, commercialisation and confidentiality

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

Acknowledgements

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Protection services, MacFarms, Edmund C Olson Trust II, Mauna Loa and Hamakua Macadamia Nut Company is acknowledged.

Appendix 1 Conference program

Program

Wednesday, September 13

7:30 AM	**UPLOAD PRESENTATIONS**	Presenters– please bring presentations on USB drive
8:00 AM	**REGISTRATION**	
8:30 AM	*Mayor Harry Kim*	Opening remarks
8:45 AM	*John Wilkie*	Some factors affecting canopy development and early cropping of macadamia
9:00 AM	*Grant Thorp*	Use of trunk girdling to advance timing of first commercial harvest in macadamia
9:15 AM	*Benjamin Toft*	Trait mining for high-density macadamia planting systems: How important are more de- tailed architectural characteristics?
9:30 AM	*Jianbo Shen*	Rhizosphere processes and nutrient management for improving nutrient use efficiency in macadamia in China
10:00 AM	**BREAK**	
10:45 AM	*Scott Hill*	Effect of leaf whorl position on nutrient content of macadamia leaves
11:00 AM	*Brad Howlett*	Cross pollination mostly increased final raceme nut counts in Macadamia compared with self or open pollination.
11:15 AM	*Lisa Evans*	Quantifying the effect of deploying honey and stingless bee hives on macadamia pollination
11:30 AM	*Bryony Willcox*	Merging crop pollination with remote sensing to better understand the spatial variability in Australian tree orchards
11:45 AM	*Gavin Chirgwin*	Limitations to fruit set in macadamia
12:00 PM	**LUNCH**	
1:30 AM	*Alyssa Cho*	Effect of macadamia felted coccid on macadamia nut yields in Hawaii
1:45 AM	*Rosemary Gutierrez*	Canopy management of macadamia trees and understory plant diversification to reduce macadamia felted coccid (Eriococcus ironsidei) populations
2:00 PM	*Bin Xu*	A brief overview of macadamia research in China
2:15 PM	*Ruth Huwer*	Towards a fully integrated pest management strategy for Australian macadamias
2:30 PM	*Olufemi Akinsanmi*	Taking back control: A valid case against pathogens in macadamia
2:45 PM	**BREAK**	
3:30 PM	*Olumide Jeff-Ego*	Rapid bioassay for macadamia germplasm screening for tolerance to *Phytopthora* species
3:45 PM	*Jeremy Bright*	Development of an Integrated Orchard Management guide for the Australian macadamia industry.
4:15 PM	*Christopher Searle*	Commercialisation of Micro-grafting in macadamia
4:30 PM	*Geoff Slaughter*	Benchmarking productivity and production costs for the Australian macadamia industry: Modelling integrated pest management outcomes using purpose-built financial analysis software (Financial Planner for Macadamia).
4:45 PM	*Rui Shu*	Potential ways to increase the value of the macadamia industry

Wednesday, September 13 continued….

Poster Session

Bruce Topp	Four new macadamia varieties for the Australian industry
Craig Hardner	Domestication of macadamia in Hawai'i
Mobashwar Alam	Historical and molecular evidence of genetic identify of HAES 741 and HAES 660 macadamia cultivars
Mobashwar alam	Genetic diversity and variability in graft success in Australian macadamia
Jodi Neal	Oil accumulation patterns in kernel of macadamia species

Thursday, September 14

8:30 AM	*Cameron Peace*	Genetic origins of macadamia cultivars: what we know so far
9:00 AM	*Craig M. Hardner*	Breeding of the new Australian cultivars
9:15 AM	*Bruce Topp*	Opportunities and Challenges in Macadamia Breeding
9:30 AM	*Catherine Nock*	The Macadamia Genome Project
10:00 AM	**BREAK**	
10:30 AM	*Katie O'Connor*	Indirect selection of macadamia yield through a genome wide association study of component traits
10:45 AM	*Gabina Sol Quintas*	*Macadamia* spp. as an opportunity to deploy a highly marginalized community in Veracuz, Mexico
11:00 AM	*Andrea Barrueto*	A review of the suitability of macadamia for growth in Nepal: spatial probability models using climatic scenarios, socio-economic context and land-use
11:15 AM	*Cameron McConchie*	Comparison of the roasting behaviour of *Macadamia tetraphylla* L. Johnson kernel with that of commercial Macadamia varieties
11:30 AM	*Tim O'Hare*	Low-saturated fat macadamia nuts - is it possible?
11:45 AM		CLOSING
12:00 PM		**Depart for Island Princess macadamia factory**
12:30 PM		**Arrive Island Princess, box lunch**
1:00 PM		**Tour of Island Princess factory**
2:00 PM		**Depart to Island Princess high elevation farm**
2:30 PM		**Arrive Island Princess high elevation farm**
3:00 PM		**Depart to UH Waiakea research station**
3:30 PM		**Arrive UH Waiakea research station**
4:30 PM		**Depart for Hilo**
4:45 PM		**Drop off at hotels**
5:00 PM		**Drop of at Wainaku Center**
6:30 PM		**Symposium Dinner**

Appendix 2. Presentation abstracts

Some factors affecting canopy development and early cropping of macadamia

J. Wilkie[1], H. Hofman[2], J. Griffin[2], S. Parfitt[2], and H. Toegel[3]

[1]Department of Agriculture and Fisheries, Wollongbar Primary Industries Institute, 1243 Bruxner Highway, Wollongbar, NSW 2477, Australia.

[2]Department of Agriculture and Fisheries, Bundaberg Research Facility, 49 Ashfield Rd Kalkie, Qld 4670, Australia

[3]The University of Queensland, Queensland Alliance for Agriculture and Food Innovation, Centre for Horticulture Science, Bundaberg Research Facility, 49 Ashfield Rd Kalkie, Qld 4670, Australia

john.wilkie@daf.qld.gov.au

Macadamia (*Macadamia integrifolia*, *Macadamia integrifolia* x *tetraphylla*) is an evergreen subtropical tree crop, currently grown in large tree, low density systems. Canopy management regimes vary widely, but in Australia are generally centred around programs of mechanical hedging, although selective limb removal is also undertaken commercially. We are currently undertaking a field systems trial investigating the effects of three planting densities (industry standard 313 trees/ha; medium-density 556 trees/ha; and high-density 1000 trees/ha) and two tree training systems (industry standard mechanical hedging; and central leader structured selective pruning) on the productivity of two cultivars. To understand the basis for differences in productivity, a range of experimentation within the trial is being undertaken to determine treatment effects on the light environment, architectural development at several scales, and the development of crop load. Tree training affected first flowering in ‘A203’, which occurred in the second year after planting, but there was no effect of tree training on raceme production in ‘A203’ in the third year after planting. There was no effect of tree training on first flowering of ‘741’, which occurred in the third year after planting. Increasing plant density led to increases in canopy volume per hectare, raceme production per hectare, total light interception and yield per hectare. There were significant differences between cultivars in early yield per hectare, largely due to differences in early flowering. The relationships between canopy volume per hectare, raceme production, total light interception and their effects on early yield are discussed.

Use of trunk girdling to advance timing of first commercial harvest in macadamia

G. Thorp and A. Smith

Plant & Food Research Australia Pty Ltd, 7 Bevan Street, Albert Park, Vic 3206, Australia

AUSTRALIAgrant.thorp@plantandfood.com.au

Trunk girdling has been used in many crops to reduce vegetative growth, increase flowering, fruit set, quality and yields. Results are generally dependent on the timing and/or severity of girdling treatments. In this project we applied two trunk girdling treatments in late-summer to promote earlier flowering and cropping on young macadamia trees. Girdling treatments were applied in a systematic design with 10 trees per treatment to 3- and 4-year-old trees planted in June 2013 and February 2012, respectively. The cultivar used was '344' grafted onto H2 seedling rootstocks. The 3-year-old trees had not produced any crop at the time of treatment; they were expected to produce some flowers in spring 2016, but their first significant crop was not expected until summer 2018. The 4-year-old trees had a small crop (<10 nuts/tree) at the time of girdling and were expected to produce their first significant crop in summer 2017. Treatments included application of a 2 mm or 5 mm wide trunk girdle, applied on 29 March 2016 (late summer), and a non-girdled control treatment. The number of floral racemes per tree was recorded in spring (October) 2016 and total yield was recorded in March 2017. A subsample of nuts was taken to determine the moisture content of the nut, and yield values adjusted to give the total weight of "nut in shell" (NIS) at 10% moisture content.

The trunk girdles did not affect either tree height or canopy dimensions, but they had a significant effect on flowering and fruit yields. The number of floral racemes was more than three-fold higher on girdled trees than on control trees, for both tree ages. Yields on 3-year-old trees of 0.83 and 0.82 kg/tree for the 2 mm and 5 mm girdled (respectively) were significantly higher than yields of 0.37 kg/tree on control trees. Four-year-old trees with a 5 mm wide girdle yielded 3.2 kg/tree while control trees yielded 1.6 kg/tree. There was a lesser, non-significant effect (P = 0.096) for the 2 mm girdle treatment on 4-year-old trees. The significance of this result for 4-year-old trees with a 5 mm wide trunk girdle is that by doubling the crop to over 2 kg/tree we have advanced the first commercial harvest for these trees by 1 year, with potential for machine harvesting.

Trait mining for high-density macadamia planting systems: How important are more detailed architectural characteristics?

B. Toft[1], B. Topp[1], John Wilkie[2], and M. Alam[1]

[1]Queensland Alliance for Agriculture & Food Innovation, The University of Queensland, Maroochy Research Station, PO Box 5083 SCMC, Nambour, Qld 4570, Australia.

[2]Department of Agriculture and Fisheries, Wollongbar Primary Industries Institute, 1243 Bruxner Highway, Wollongbar, NSW 2477, Australia.

b.toft@uq.edu.au

The successful translation of concepts from temperate high-density systems to subtropical macadamia (*Macadamia integrifolia*, *M. tetraphylla* and hybrids) orchards may depend on an understanding of the crop's specific plant architecture. A number of architectural characteristics converge and interact to create final canopy structure and resource allocation to yield. This study illustrates the abundant natural diversity in macadamia architecture, and determines useful traits for potential high-density planting systems. Fifteen clonally propagated macadamia genotypes were selected from a high-density spatially designed precocity trial planted in 2011 at the Department of Agriculture and Fisheries (DAF) research facility at Nambour, South East Queensland, Australia. Three independent clones of each genotype were phenotyped in the 2015-2016 and 2016-2017 growing seasons for architectural and reproductive traits, around the age of transition from juvenility to maturity. Trees were distinguishable as groups based on tree size, yield efficiency and branching characteristics, and particular genotypes stood-out as potential candidates for high-density systems. This research attempts to establish which architectural traits are the main drivers of yield and canopy size in macadamia, and emphasises the importance of canopy development at multiple scales. The detailed selection of macadamia plant types may maximise economic return in increasingly complex future planting systems.

For full text, please access Toft et al. 2018. Phenotype association of multi-scale architectural traits with canopy volume and yield: moving towards high-density systems for macadamia. *HortSci Accepted*.

Rhizosphere processes and nutrient management for improving nutrient use efficiency in macadamia in China

J. Shen[1], X. Zhao[1], Q. Dong[1], S. Ni[2], X. He[2], H. Yue[2]

[1]Department of Plant Nutrition, China Agricultural University, Key Laboratory of Plant-Soil Interactions, Ministry of Education, Beijing 100193, P. R. China

[2] Yunnan Institute of Topical Crops, Jinghong 666100, Yunnan, P. R. China

jbshen@cau.edu.cn

Macadamia species were introduced to China in the 1970s. At present, the planting area of Macadamia in China is over 150,000 hectares. It is estimated that China becomes one of the largest countries in Macadamia planting scale in the world. According to the government's plan, in 2020, Macadamia planting area in just sole Yunnan province is projected to reach 260,000 hectares. The market potential of China's Macadamia industry is enormous based on the estimate.

For a long time, the agronomic management of Macadamia in China is very extensive, especially nutrient management with lack of effective guidance. The time of farmers' fertilization does not match the nutritional needs of macadamia. Farmers directly apply the fertilizers to field as a broadcasting way, which greatly reduces the use efficiency of applied fertilizers. The application type of fertilizer is relatively single, mostly with the 15:15:15 (N:P2O5:K2O) compound fertilizer. Compared with the nutrient requirement of Macadamia, the input of nitrogen and potassium is relatively low but the over-application of phosphate fertilizer is very popular. The amount of P2O5 application by farmers is 2 times as much as the recommended rate. Improper fertilization has led to a series of nutritional problems of Macadamia trees: (1) excessive phosphorus application inhibited the biological potential of efficient phosphorus use by Macadamia roots with strong rhizosphere acidification and even caused phosphorus toxicity; (2) high application rates of phosphorus fertilizers also caused the lack of middle and trace elements, resulting in sub-health problems for most Macadamia trees. It is necessary to establish an optimized fertilization management strategy to match the plant, soil and local ecological conditions in China.

Macadamia is a typical crop with cluster root as a powerful "weapon" to mobilize soil phosphorus through carboxylate exudation and proton release by the special root clusters, which is induced by phosphorus deficiency. Cluster root and mycorrhizae are two adaptive mechanisms for enhancing phosphorus acquisition. Although most of the Proteaceae plants with cluster root cannot be infected by mycorrhizal fungi, Macadamia is a typical mycorrhizal plant. According to the natural infection rate in Macadamia orchard, it was found that Macadamia’s cluster roots were more susceptible to infection of mycorrhizal fungi than non-cluster roots. It is proved that investigating the rhizosphere processes and relationship between mycorrhizal infection and cluster root growth in Macadamia is critical to develop rhizosphere management strategy to increase nutrient use efficiency and nut yield with less input in China.

For full text, please access Zhao et al. 2018. Rhizosphere processes and nutrient management for improving nutrient use efficiency in macadamia production. *HortSci In review*

Effect of leaf whorl position on nutrient content of macadamia leaves

S. Hill[1] and R. Cave[2]

[1]404 Fernleigh Rd, Fernleigh, NSW 2479, Australia.

[2]The University of Queensland, School of Agriculture and Food Sciences, Gatton, Qld 4343, Australia.

scott.hill@uq.net.au

Plant tissue analysis provides an insight into plant nutrient status at time of sampling. It can identify nutrient deficiencies well before plant symptoms are observed. Macadamia leaf sampling for diagnostic nutrition purposes has been developed over the past six decades to ensure an accurate indication of nutrient content. Specific plant material is required to provide a precise comparison to published nutrient standards and provide a sound basis for nutrient recomendations. Locating sufficient satisfactory plant material can sometimes be difficult due to a spring flush occuring in sync with the recommended sampling period and plant tissue damage of the remaining recommended leaves. One of the criterions for macadamia leaf sampling is to collect leaves of the second whorl of hardened mature terminals. The current study was undertaken to provide flexibility when collecting a macadamia leaf sample by identifying differences in nutrient content of alternate leaf whorls. Consistent with published literature, phloem mobile nutrients, N, P and K were found to decline with leaf age and phloem immobile nutrients Ca, Mn, Fe and B were found to increase with leaf age. Variably mobile nutrients differed in concentration trends with leaf age. Mg, Na and Cu increased with leaf age and S and Zn decreased. Significant differences for some nutrients between whorl two and whorls one, four and five were identified with variation in the level of significance. However, whorl two and whorl three showed no significant difference for all nutrients analysed. Therefore, leaves from the third whorl could be utilised as an alternative when leaves of the second whorl are not suitable.

Cross pollination mostly increased final raceme nut counts in macadamia compared with self or open pollination

B. G. Howlett[1], S. F. J. Read[1], B. T. Cutting[2], R.M. Goodwin[2], S. Cross[2], T. G. Thorp[3] and D. E Pattemore[2]

[1]The New Zealand Institute for Plant & Food Research Limited, Private Bag 4704, Christchurch Mail Centre, Christchurch 8140, New Zealand.

[2]The New Zealand Institute of Plant & Food Research Ltd, Private Bag 3230 Waikato Mail Centre, Hamilton 3240, New Zealand

[3] Plant & Food Research Australia Pty Ltd, 7 Bevan Street, Albert Park, Vic 3206, Austrlia

brad.howlett@plantandfood.co.nz

Commercial macadamia cultivars are derived from two species, *Macadamia integrifolia* and *M. tetraphylla*. They are considered partially self-incompatible, and previous research indicates that for at least some cultivars, cross-pollination can result in increased yields. Hand cross-pollinating of flowers on single racemes and comparing nut counts with single non-crossed racemes has previously shown that this can increase nut set in at least some cultivars. However, published information on the possible benefits of cross-pollination across many cultivars has remained limited. Moreover, little is known about which cultivars in particular are most compatible for cross pollination. In this study, trials were conducted in orchards near Bundaberg (Australia) to assess whether hand cross-pollinating racemes altered final nut counts compared with non-hand pollinated racemes. All raceme treatments were left uncaged to allow potential pollen vectors to pollinate florets. Twelve separate trials were conducted using the cultivar '741', where pollen from a single alternative cultivar was used (one polliniser for each trial) to pollinate a single raceme per tree (up to twenty trees included per trial). Similarly, twelve trials were conducted on 'Daddow', twelve on 'A203', eleven on 'A268' and four on '842'. Assessments were also conducted to evaluate whether cross-pollinating multiple racemes within trees of '741' and '842' influenced nut counts within treated and untreated uncaged racemes and whether nut set occurred through self-pollination within three cultivars ('741', '816' and 'A203') using caged treatments. In most cases, hand cross-pollinating single racemes produced significantly more nuts than single racemes that were not hand cross pollinated. However, in trees where 100 racemes were hand cross pollinated, nut set within these racemes was lower compared to similarly treated racemes in trees where fewer racemes were crossed (15, 3 or 1 crosses/tree). Despite of this, overall nut counts were higher within the 100 crossed raceme trees compared to untreated control trees. Self-pollinated racemes also produced nuts, although numbers varied across the cultivars tested and were lower than from hand-crossed racemes in all cases. To improve nut yield through cross pollination, growers should evaluate potential yield gain in their own orchards through cross-pollination trials, incorporate multiple cultivars within new orchard blocks, and replace poor yielding trees within single cultivar blocks with trees of another cultivar. They should also ensure pollinators are present within their orchards.

For full text, please access Howlett et al. 2018. Cross pollination can enhance nut yields in Australian orchards, even in the presence of branch-level resource allocation limitations. *HortSci In review*

Quantifying the effect of deploying honey and stingless bee hives on macadamia pollination

L. Evans[1], S. Read[2], D. Pattemore[3] and B. Howlett[2]

[1]Plant and Food Research Australia, Pollination and Apiculture, c/o Queensland University of Technology, Gardens Point Campus, Brisbane, Qld 4001, Australia

[2]The New Zealand Institute for Plant & Food Research Limited, Private Bag 4704, Christchurch Mail Centre, Christchurch 8140, New Zealand

[3]The New Zealand Institute for Plant & Food Research Ltd, Private Bag 3230, Waikato Mail Centre, Hamilton 3240, New Zealand

lisa.evans@plantandfood.co.nz

In most cases, cross-pollination between macadamia varieties increases nut set. Honey bees (*Apis mellifera*) and stingless bees (*Tetragonula carbonaria*) are considered effective pollinators of macadamia, moving pollen directly between flowers as they forage. The introduction of honey bees or stingless bee hives into orchards is likely to significantly boost the number of these insects visiting flowers. For both insects, there is a lack of published information on how many hives are needed for optimal pollination to be achieved. To better understand the number of honey and stingless bee colonies required for macadamia pollination and how distance to hives affects pollination, we carried out a single block trial, consisting of cultivars '842' and '814' grown in alternating rows in an orchard located in Bundaberg, Australia. The aim was to assess the relationship between hive placement, bee abundance and pollination. Fifty-two honey bee and 20 stingless bee hives were placed at opposite ends of the block and bee abundance and nut set was recorded on marked racemes across 120 trees (12 trees over 10 rows) located between 0 and 325 metres away from the hives. Bee abundance was affected by both distance from the hive and flower availability on trees. Higher numbers of honey and stingless bees were observed on trees in close proximity (i.e. 0 to 75 m away) to the hives. Bee numbers were also higher on trees with more open flowers, which decreased over time as flowering progressed, and also with distance from the hives because exposed trees on the edge (where colonies were positioned) had a greater number of flowers than trees in the middle of the block. The average nut set per raceme did not appear to be affected by number of bees observed or distance from hives, but rather the date racemes opened, with earlier flowering racemes producing more nuts. We showed that bees were not distributed evenly over the study block, which is likely to affect nut set. However, we were not able to directly link hive position and nut set, due to the confounding effect of flower density on bee visits. Our data suggest that honey and stingless bee hives should be deployed throughout each block to increase the probability of even visitation. Alternatively, management of flower number through pruning could be effective at increasing tree attractiveness to pollinators across the block and thus promoting crosspollination.

For full text, please access Evans et al 2018. Abundance and distribution of honey bees and stingless bees and their effect on pollination in an Australian macadamia orchard. *HortSci In review*

Merging crop pollination with remote sensing to better understand the spatial variability in Australian tree orchards

B. Willcox[1], A. Robson[1], R. Rader[1], and B. Howlett[2]

[1] School of Environmental and Rural Science, University of New England, Armidale, NSW, Australia

[2]The New Zealand Institute for Plant & Food Research Limited, Private Bag 4704, Christchurch Mail Centre, Christchurch 8140, New Zealand

bwillcox@myune.edu.au

In Australia, a national project "Multi-scale monitoring tools for managing Australian tree crops: Industry meets innovation" is well underway with a number of outcomes produced that are relevant to global macadamia production. The project has two objectives: 1) map the location and area of every commercial avocado, mango and macadamia orchard (over 2 ha), and 2) evaluate technologies as a farm-level decision support tool using satellite imagery and on-ground sensor systems for mapping fruit yield and quality, tree health and pollination efficiency. Outcomes of the first objective will provide crucial information on grower demographics, yield forecasting, biosecurity and post disaster management. Initial findings for the second objective have demonstrated the potential of remote sensing for mapping yield parameters and tree health across macadamia, mango and avocado orchards.

Pollination services, delivered by insect pollinators, are a key driver in yield and quality variability within macadamia crops. Satellite sensor systems offer significant opportunities to support the identification of spatial variations of pollinator distribution and pollination at the regional, farm and within block level. This PhD project (i) uses innovative high resolution spatial mapping technology with on ground pollinator surveys and measures of pre- and post- pollination success to develop our understanding of the interactions between macadamia tree health, pollinator community composition and pollination success, (ii) investigates the importance of surrounding local and landscape factors to pollinators within macadamia orchards, and (iii) investigates how spatial variations found may be associated with fruit quantity and quality.

To date, pollinator surveys have been conducted in seven macadamia orchards in 2015 and six macadamia orchards in 2016 across the Bundaberg region during peak flowering. In 2015, abundance of flower visitors ranged from 0-21 flower visits per survey and species diversity ranged from 0-3 species per survey. In 2016, abundance ranged from 4-52 flower visits per survey and diversity ranged from 1-8 species per survey. While honey bees (*Apis mellifera*) were the most common flower visitor in both flowering seasons across the region, pollinator community composition differed between individual blocks within the region.

Preliminary data does not show any obvious trends, however, further collection and analysis of data is required to determine whether there are consistent or variable patterns regarding tree health of orchard species, location or temporal scale. The findings may allow growers to quickly evaluate their orchards to make predictions of pollinator distribution and yields in their specific orchards.

Limitations to fruit set in macadamia

G.A. Chirgwin and P.H. Brown

School of Medical and Applied Science, CQ University, University Drive, Bundaberg, Qld 4670, Australia

g.chirgwin@cqu.edu.au

Only a very small percentage of macadamia flowers are converted to harvested nuts, and the factors that contribute to low and irregular nut set in commercial crops are not well understood. Macadamia branches and racemes were modified to better understand the factors influencing fruit set in macadamia. Individual macadamia branches were modified by cincturing, raceme location, and defoliation, while raceme modification involved covering and altering the number of racemes. Results demonstrated leaf stomatal conductance and leaf water potential decrease during the first few weeks of fruit development in macadamia. Covering racemes significantly increased leaf stomatal, leaf water potential, and initial fruit set. Leaf stomatal conductance and leaf water potential correlations suggest initial fruit set is related to the rate of leaf stomatal conductance and leaf water potential. There was a strong correlation between leaf and fruit number in both cinctured (r2=0.76) and uncinctured (cv. 741) branches (r2=0.91). The leaf to fruit number correlation suggests a number of smaller branches attached together via a larger branch act as a single unit in the production of fruit. An important result from this experiment was that leaf stomatal conductance (indicative of the photosynthetic and transpiration rate in macadamia) and water potential decrease in response to the presence of fruit. Modification of the raceme (limit water loss) can partially alter this response and improve initial fruit set. The leaf stomatal response to reproductive presence and load, and branch and leaf dynamics could be critical factors in determining fruit set and yield in macadamia.

Effect of macadamia felted coccid on macadamia nut yields in Hawaii

A. Cho, R. Gutierrez, M. Wright and J. Mollinedo

University of Hawaii- Manoa, College of Tropical Agriculture and Human Resources, 875 Komohana Street, Hilo, HI 96720.

acho@hawaii.edu

Macadamia felted coccid (MFC) (*Eriococcus ironsidei* (Williams) was first detected in macadamia (*Macadamia integrifolia*) in Hawaii in 2005. This pest, introduced from Australia, can cause an array of symptoms including distorted leaves, new shoots, possible abortion of immature nuts, yellow spots on leaves, bleeding of branches, and eventual dieback of branches and reduced yields. Controlling this pest using insecticides can be difficult and expensive. There is a need to determine the effects of MFC on yields to develop an economic injury level and economic/treatment thresholds. Therefore, the objective of this study was to evaluate the effects of a range of densities of MFC on macadamia nut yield. This study was conducted from March 2016- March 2017 at three farms in the Kau district of Hawaii island. Treatments were the level of MFC crawler infestation on the tree. These were categorized as low (<50 crawler/in2), medium (50-100 crawlers/in2), high (>100 crawlers/in2) and compared to control trees that were being sprayed (<2 crawlers/in2). Five trees were assigned to each treatment based on MFC counts at the beginning of the study. At Farm 1 two varieties of macadamia were evaluated, '344' and '508'. At Farm 2 '344' was evaluated and at Farm 3 '508' was evaluated. MFC crawler density was monitored monthly. Two branches/tree were selected and double-sided sticky tape was placed for 1 week and the number of MFC crawlers in 1 in2 of tape was recorded. Yields were harvested according to the grower's schedule, ranging from 3-4 harvests. Yields were recorded as total fresh wet in shell weight per tree for the season. Data were analyzed using SAS software to perform regression analyses and ANOVAS followed by Tukey tests for mean separation. MFC and yield resulted in a negative relationship for all locations and varieties of macadamia, with decreasing yields as MFC density increased. In '344' trees, all three MFC levels led to a lower yield than produced by the control trees. In '508' trees, yields in the high infestation were lower than the control and low level of infestation. These results suggest that in the '344' variety, a threshold of 50 crawlers/in2 should be used to limit yield loss, whereas in the '508' variety, a threshold of 100 crawlers/in2, control measures should be implemented. Costs of treatments and market value will influence the actual economic injury level, which can be calculated as needed using current economic data.

Canopy management of macadamia trees and understory plant diversification to reduce macadamia felted coccid (*Eriococcus ironsidei*) populations

R. Gutierrez, J. Mollinedo, M. Wright, and A. Cho

University of Hawaii-Manoa, College of Tropical Agriculture and Human Resources, 875 Komohana Street, Hilo, HI 96720.

gr6@hawaii.edu

Preliminary observations suggest that macadamia tree canopy density plays an important role in *E. ironsidei* colonization and subsequent build-up of high population density. Combining canopy thinning and increasing nectar and pollen plant sources for beneficial insects in the understory may result in improved *E. ironsidei* suppression. We investigated the role of canopy modification and understory habitat in enhancing natural enemy effectiveness to reduce *E. ironsidei* populations. Plots with pruned trees plus wildflower beds resulted in 40% less *E. ironsidei* than the control plots, and the pruned-only plots had 15% less *E. ironsidei* numbers compared to the control plots. Greater abundance of natural enemies were observed in the modified plots than in the control plots. Predatory beetles were 60 % more abundant in the pruned trees plus wildflower beds than in the control plots, and in the pruned-only plots there were 50% more predatory beetles than in the control plots. *Encarsia lounsburyi*, a parasitic wasp that parasitizes *E. ironsidei*, was 20% more abundant in the pruned-only plots than in the other plots. Yield results showed an increase of up to 28 lbs wet-in-shell/tree in the modified plots compared with the control plots. Our results provide evidence that pruned macadamia trees and understory plant species diversification enhanced natural enemy populations, and may result in increased biological control of *E. ironsidei* in macadamia nut orchards.

A brief overview of macadamia research in China

B. Xu[1], R. Shi[2], L. Tao[3], J. Wang[4], M. Lu[1], and R. Wang[5]

[1]Jiangcheng Sino-Aus Agriculture Technology Development Co., Ltd, F JinPinGuo Business Building No. 19 BaiLong Road, Kunming, Yunnan, 650000 China

[2]Southwest Forestry University, Southwest China Eco-Development Academy, Key Laboratory for Forest Resources Conservation and Utilization in the Southwest Mountains of China, Ministry of Education, Yunnan, 650000 China

[3]The Yunnan Institute of Tropical Crops, 99 Xuanwei Road, Jinghong 666100, Yunnan, P. R. China

[5]Yunnan Discovery Biological Resources Development Co., Ltd

447123295@qq.com

Macadamia is an evergreen tree species belonging to the Proteaceae family. They are native to Australia and are grown in several countries including USA, AUS and South Africa. The trees main commercial value is in their fruit which provide a high level of oil rich in unsaturated fatty acid. The Yunnan Institute of Tropical Crops began a macadamia breeding program in 1993 and several varieties were selected for nut production. Yunnan has the largest plantations of macadamia in China. In 2015, there were over 6 million macadamia trees planted in the province which accounts for 70% of the macadamia trees in China. Macadamia research has been focused on breeding, plantation management, diseases and pest control. The production of macadamia has rapidly increased in recent years, reaching 10,000 tons in 2015. China has now established processing facilities for nut production and for adding value to the industrial by-products from the production process. The future is a very good for macadamia industry of China, with a wide range of new varieties selected from the breeding program and the expanding areas under cultivation, China is set to play a leading role in this industry.

Towards a fully integrated pest management strategy for Australian macadamias

R. Huwer, C.D.A. Maddox, M. Hickey, and J. Bright

NSW Department of Primary Industries, Agriculture NSW, 1243 Bruxner Highway Wollongbar, NSW 2477, Australia

ruth.huwer@dpi.nsw.gov.au

There are a number of pests impacting on the productivity of the macadamia industry in Australia, including flower and foliage pests (i.e. macadamia lace bug (*Ulonemia* spp.) and mites and thrips species), kernel and post-harvest pests (such as fruitspotting bugs (*Amblypelta spp*.) and Sigastus weevil (*Sigastus sp*.)) and pests attacking the branches and trunk (i.e. bark beetles and trunk borers). Pest management strategies in the past have been developed for single pest species. These strategies particularly for fruitspotting bugs covered a number of approaches, including monitoring tools, chemical and biological control, cultural control and a pilot study of an area wide management approach. However, no truly integrated strategy has been developed to date that has taken more than 1 or 2 of the key-pests into account.

HortInnovation tendered a large IPM programme for the Australian macadamia industry. The overall aim of the program is to develop a pest resilient farming system for the macadamia industry. Specifically, it aims to:

− Identify and address gaps in research and extension for pest management for macadamias in Australia

− Continue research as required on current key pests

− Develop a truly integrated and sustainable management approach

− Maintain and improve industry resources in pest diagnostics and IPM tools

− Maintain and build capability to respond and deal with new and emerging pests

− Build strong links to other macadamia industry programs

The larger IPM program brings together a team of highly experienced researchers with considerable experience, specifically in pest management in macadamias and in IPM extension and adoption. As part of the larger program the NSW DPI Team will take on leadership of major components of the research. The research is taking a regional approach, customising strategies for the 4 major growing regions in Australia and their differences in pest complexes.

The research will include following aspects:

- Laboratory and field ecology and biology studies of pests, including life-cycle studies and field monitoring of selected pests and beneficials

- Diagnostic and response to new emerging pests

- Development and testing of cultural control methods for selected pests

- Laboratory screening of IPM compatible chemicals

- Testing of IPM strategies in the field and monitoring of selected pests and beneficials, in four different regions and in collaboration with professional pest consultants

- Co-lead industry adoption

This 5 year research project started in January 2017. Initial monitoring and laboratory and field trials have commenced. Initial finding will be reported on.

Taking back control: A valid case against pathogens in macadamia

O. Akinsanmi[1], O. Jeff-Ego[1], B. Topp[2], and A. Drenth[1]

[1]Queensland Alliance for Agriculture & Food Innovation, The University of Queensland, Ecosciences Precinct, 41 Boggo Road, Dutton Park, Qld 4102, Australia

[2]Queensland Alliance for Agriculture & Food Innovation, The University of Queensland, Maroochy Research Station, PO Box 5083 SCMC, Nambour, Qld 4570, Australia.

o.akinsanmi@uq.edu.au

A range of pathogens cause disease in macadamias. For most of the pathogens, their impact on macadamia productivity and effective management strategies are still largely unknown. As well as the threat from endemic pathogens, an increase in global travel and trade, has resulted in more rapid spread of pathogens worldwide. This poses additional challenges to managing plant health. This problem is already apparent in many other plant industries and macadamia is not immune to this threat. Recent global increase in macadamia production area worldwide has put pressure on the crop, and increased the risks of resurgence or new encounters to major pathogens in the macadamia production system. Efforts to keep disease pressure low and reduce potential global impact on macadamia production, requires a proactive and coordinated response. While some pathogens may initially be found in limited production areas, these could potentially escalate to cause significant problem for the whole industry. Preparedness through well-coordinated response to information exchange, for surveillance and rapid diagnostic assays, is a key element of plant biosecurity. In recent past, several new pathogens have been reported to cause significant economic losses in macadamia. A case is made for research against major pathogens/diseases such as bacterium, *Xylella fastidiosa*; several species of *Phytophthora*; and flower blight complex in macadamia. Host resistance is an essential component of integrated disease management strategy. Varietal susceptibility to most of the endemic and new pathogens in macadamia across the world have not been well established. This report presents an overview of recent advances in host-pathogen interaction research on diseases in macadamia and concludes with gaps in knowledge. It highlights the rationale and content for an international collaborative research in macadamia.

Rapid bioassay for macadamia germplasm screening for tolerance to *Phytopthora* species

O. Jeff-Ego[1], O.A. Akinsanmi[1], B. Topp[2], J. Henderson[3], and A. Drenth[1]

[1]Queensland Alliance for Agriculture & Food Innovation, The University of Queensland, Ecosciences Precinct, 41 Boggo Road, Dutton Park, Qld 4102, Australia

[2]Queensland Alliance for Agriculture & Food Innovation, The University of Queensland, Maroochy Research Station, PO Box 5083 SCMC, Nambour, 4570, Qld, Australia.

[3]Department of Agriculture and Fisheries, Ecosciences Precinct,41 Boggo Road, Dutton Park, Qld 4102, Australia

o.jeffego@uq.net.au

In Australia, it's been established that *P. cinnamomi* causes trunk canker, gummosis, die back, necrotic roots rot and sometimes the eventual death of macadamia trees, however the range of susceptibility/tolerance of *Macadamia* species and cultivars has not been well established. The potential of other soil borne and aerial *Phytopthora* species as significant pathogens in macadamias has not been determined. Macadamia production area is expanding to new areas previously cultivated to other crops with known history of *Phytopthora*. Thus, macadamia trees may be subject to infections by new *Phytopthora* spp. and orchard replant problems. Reports of poor tree establishment and increasing reductions in yield are common in mature trees. In the absence of cultivars and rootstocks with acceptable levels of resistance to *Phytopthora* pathogens management practices have focused on mitigation through chemical control, but the effectiveness of control has been variable.

A key limitation of the study of *Phytopthora* infection in mature tree crops is the length of time it takes to develop in the field. Hence, the development of a rapid, reliable and robust bioassay will aid the screening of a large number of macadamia genotypes for their susceptibility to *Phytophora* spp. Using the bioassay developed in this study, multiple *Phytophora* species that are associated with macadamia ecosystems were examined for their aggressiveness on a range of macadamia genotypes including accessions of *Macadamia integrifolia* and *M. tetraphylla* cultivars 'HEAS 816', 'HEAS 344', 'HEAS 246', and 'H2'. The inoculation methods developed in this study were rapid and effective for testing varietal susceptibility to *Phytopthora* in macadamia. The results appeared promising for the bioassay as a useful tool for early and rapid screening of macadamia genotypes. Further studies will provide insights into the mechanism for resistance to *Phytopthora* species.

Development of an Integrated Orchard Management guide for the Australian macadamia industry

J. Bright[1], S. Alt[2] and R. Commens[3]

[1]NSW Department of Primary Industries, Agriculture NSW, 1243 Bruxner Highway Wollongbar, NSW 2477, Australia

[2]Givesoilachance, 204 Gordon Road, Koonorigan, NSW 2490, Australia

[3]Australian Macadamia Society, 113 Dawson Street, Lismore, NSW 2480, Australia

jeremy.bright@dpi.nsw.gov.au

Prior to the development of the Integrated Orchard Management (IOM) guide, there was confusion regarding a number of issues. Growers would describe their orchards in terms of age and tree height, production yields and ground cover. These descriptors would vary dramatically. Orchard management practices also varied in description. There was no common language throughout the industry.

The IOM guide introduced the three pillars of production to the industry, comprising of canopy, orchard floor and drainage. It put forward the idea that modifying one of the pillars would have a positive/negative affect on the other two pillars. The guide also introduced the concept of orchard stages and within this the stages of each of the three pillars. The 5 stages provided industry with easy descriptors of how an orchard is perceived. The IOM guide also introduced the idea of "Red Flags" which are the obvious signs of a problem within the orchard. Through identifying the red flags growers could then address the issues using the guide toolkit to implement appropriate practices.

The IOM guide has brought together over 30 years of canopy, orchard floor and drainage research into one publication. Previously this information was scattered through factsheets and research publications, but now it is accessible in the guide.

The industry has embraced the guide which has developed a common language. It has brought about a maturity for the Australian macadamia industry and has allowed growers to be able to select pathways to rectify the red flag issues they had, or at least develop a plan to remedy the situation. The presentation will cover the key concepts introduced in the Integrated Orchard Management guide, including red flag issues, the toolkits and practical outcomes through IOM case studies.

Commercialisation of micro-grafting in macadamia

C. Searle[1] and K. Wilson[2]

[1]MacAvo Consulting, 84 Pashley's Road, Bundaberg, Qld 4670, Australia

[2]Eureka Macadamia Management Pty Ltd, P.O. Box 12306, Clunes, NSW 2480, Australia

c.w.searle@bigpond.com

Macadamia trees have traditionally been propagated by grafting mature scion wood onto selected seedling rootstocks. This process can take anywhere from fifteen months to two and a half years from planting the seed to the grafted tree being dispatched from the nursery, which adds considerably to the cost of production. In contrast, micro-grafting, grafting young trees at 10-12 weeks of age has the potential to deliver trees faster and cheaper than conventional grafting. The objective of this study was to commercialise the micro-grafting technique developed by CSIRO, Division of Horticulture.

The original CSIRO method used soft juvenile scion material that needed to be maintained at a high humidity post-grafting in order to prevent rapid desiccation. This was achieved by enclosing each grafted plant in its own polythene bag. As enclosing each plant in its own bag is extremely labour intensive, humidity post grafting in this study was maintained by using a sophisticated temperature and humidity controlled mist house. In a series of initial experiments it was found the relative humidity had to be maintained above 95% in order to prevent desiccation of the juvenile scion material and graft failure. However, the high humidity led to major outbreaks of fungal diseases which rapidly killed the newly grafted trees despite the use of an extensive fungicide program.

In order to overcome the disease problems changes were made to the original CSIRO technique. These involved moving to more mature shoot material, which was considerably less susceptible to fungal infection, and modifying the graft technique and type in order to accommodate the older thicker scion wood. These changes increased average graft success rates from <10% to around 50%.

The project found no differences in graft success when either H2, the main rootstock used in Australia or Beaumont, the main rootstock used in South Africa, were used as rootstocks for a range of scion cultivars. There were also no differences in graft success, generally around 50%, among cultivars used as scion material when grafted onto H2 rootstock. However, this is a lower average graft success rate than the average 75% success rate encountered in a conventional nursery. While average micro-graft success rates were lower across a range of cultivars the micro-graft success rate, for the conventionally 'hard-to-graft' cultivar A4, were similar at around 50%. Micro-grafting may therefore present a method of improving the graft success rate in these conventionally 'hard-to-graft' cultivars.

Benchmarking productivity and production costs for the Australian macadamia industry: Modelling integrated pest management outcomes using purpose-built financial analysis software (Financial Planner for Macadamia)

G. Slaughter[1], S. Mulo[2], P. O'Hare[2], G. Bignell[2] and I. Jenkins[2]

[1]Faculty of Business, Education, Law and Arts, University of Southern Queensland, Darling Heights, Qld 4350, Australia

[2]Department of Agriculture and Fisheries, Maroochy Research Facility PO Box 5083 SCMC, Nambour, Qld 4570, Australia

geoff.slaughter@usq.edu.au

Yield, quality, and planting data have been collected annually from macadamia farms throughout Australia since 2009. The data are provided either directly by growers or by processors on their behalf. The data represents a cross section of farms in the Australian macadamia industry for location, farm size, tree age, irrigation status and management structure for each season. Participation rates have steadily increased in each year of the study, rising from 144 farms in 2009 up to 269 farms in 2016. These farms covered approximately 10,025 planted hectares and represented 56.7% of total Australian macadamia industry production in 2016, based on the industry nut-in-shell (NIS) estimate of 52,000 tonnes at 10% moisture content.

Since the 2013 season a smaller subset of participating farms has also submitted data relating to the costs of production. An average of 48 farms per season have submitted cost data over the last four years. These farms covered over 2,300 planted hectares and represented approximately 14% of total Australian macadamia industry production in 2016.

While there is inherent production variability at a farm and industry level due to factors such as climate, analysis and comparison of seasonal agronomic and financial data provides objective insight into management practices that support greater efficiency and improve long term farm productivity and profitability. Using benchmarking data, this paper provides an overview of key relationships between the costs of production and productivity outcomes for comparable Australian macadamia farms, focussing on production costs and returns. Integrated Pest Management scenarios are explored using benchmark agronomic and cost data. While there is a significant body of literature on the economic impacts of IPM for other tree crops such as almonds, walnuts and pecans there is limited research on the costs and returns for macadamia production in Australia.

This analysis demonstrates how modelling of benchmarking data using purpose-built financial analysis software (Financial Planner for Macadamia) can provide objective insight into the expected costs and returns from employing integrated pest management strategies in macadamia.

Potential ways to increase the value of macadamia industry

R. Shi[1,2], Z. Xiong[3], B. Li[4] and B. Xu[5]

[1] Southwest Forestry University, Southwest China Eco-Development Academy, Key Laboratory for Forest Resources Conservation and Utilization in the Southwest Mountains of China, Ministry of Education, Yunnan, 650000 China

[2]New Zealand Institute for Plant and Food Research Ltd, Private Bag 11600, Palmerston North, 4442 New Zealand

[3]Light Industry and Food Engineering College of Southwest Forestry University, Kunming Yunnan, 650224,China

[4]Yunnan Agricultural University Heilongtan, Panlong District, Kunming, Yunnan Province, China

[5]Jiangcheng Sino-Aus Agriculture Technology Development Co., Ltd, F JinPinGuo Business Building No. 19 BaiLong Road, Kunming, Yunnan, 650000 China

Rui.Shi@plantandfood.co.nz

Macadamia is an evergreen tree from the Proteaceae family. As a natural whole food, macadamia nuts contain highly unsaturated fatty acid, vitamins, minerals and antioxidants. However, there is a very high ratio (approximately 70%) of waste from the Macadamia industry and this waste is unavoidable. In fact, the volume of waste produced, which consists of organic materials could be utilized further to enhance the value of the macadamia industry. In this study, three types of agro-waste, the husks, shells and dropping flowers have been investigated. Biological activity tests were done in order to determine the uses of these wastes. It was found that some of the extracts from the husks showed whitening activity which has potential in the natural cosmetics field. The cellulose (34.65%) and acid-insoluble lignin (39.75%) were the main components in macadamia shell, its lignin is primarily composed of Syringyl (S) lignin which was a complex matrix suitable as a natural filter material. The dropping flowers have high essential oil content (0.76%) which could have a use in the natural perfume industry. The results of the studies indicated that there were other ways to increase the value of the macadamia industry.

Genetic origins of macadamia cultivars: What we know so far

C. Peace[1], C. Hardner[2] and C. Nock[3]

[1] Department of Horticulture, Washington State University, Pullman, WA 99164.

[2]Queensland Alliance for Agriculture and Food Innovation, University of Queensland, St Lucia, Qld 4072, Australia

[3]Southern Cross Plant Science, Southern Cross University, Lismore, NSW 2480, Australia

cpeace@wsu.edu

Macadamia as a crop is almost wild. Modern cultivars are very few generations removed from undomesticated forebears: typically their great-grandparents were (and perhaps still are) wild trees in natural populations. Native stands exist in a narrow strip of eastern Australia's subtropical rainforest, fragmented and highly threatened by habitat clearing and degradation. Perhaps a few thousand mature specimens remain for each of the two main crop species, *M. integrifolia* and *M. tetraphylla*.

Most of macadamia's available genetic diversity is horticulturally untapped. Around the turn of the millennium, nuclear DNA marker research compared genetic diversity in a germplasm collection from wild populations with that among a large set of cultivars from Australia, Hawaii, and South Africa. The DNA markers were also used to confirm parentages and deduce wild origins of each cultivar. Key findings were strong intraspecific provenance structure across the several sampled geographic regions, varying degrees of genetic diversity within each region, most commercial cultivars being derived from the lowest-diversity region of *M. integrifolia*, and few to no cultivars appearing to have arisen from the region of highest intraspecific diversity of *M. integrifolia* – right where the large city of Brisbane now sits. Recent chloroplast sequence analyses have corroborated those conclusions. Both sources of evidence suggest there is a large reservoir of *M. integrifolia* diversity that is yet to be explored. The earlier research also calculated species compositions for wild trees and cultivars. While natural hybrid zones were characterized at regions of multiple species sympatry, hybrid cultivars, common especially in the Australian industry, appear to have derived from more recent crosses in cultivation. Contributions to the commercial nut production industry is almost non-existent from the other species within the genus, *M. ternifolia* and *M. jansenii*.

An exciting opportunity beckons to establish a baseline for all subsequent understanding and exploiting of macadamia's genetics. Whole-genome DNA profiling, by SNP arrays or resequencing, of all mature wild trees and cultivars would reveal the critical information: patterns of diversity and recombination as represented by each individual's parental haplotypes. Haplotype patterns among trees would reveal precisely how and where cultivar genomes arose, loci favored by historical selection, and geographical regions harboring unique alleles. Systematic investigations of the genetic contribution of each allele could then ensue. The sooner that this whole-crop genetic diversity is databased the better, before further valuable alleles are lost.

Breeding of the new Australian cultivars

C. Hardner[1,2], J. Costa e Silva[1,3], E. Williams[4], N. Meyers[1,5], and C. McConchie[1,6]

[1]CSIRO Division of Plant Industry, St Lucia, Qld 4072, Australia

[2]Current address: Queensland Alliance for Agriculture and Food Innovation, University of Queensland, St Lucia, Qld 4072, Australia

[3]Current address: Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal.

[4]Statistical Consulting Unit, The Australian National University, Canberra, ACT 2600, Australia

[5]Current address: School of Education, College of Arts, Social Sciences, and Commerce, La Trobe University, Bendigo, Vic 3552, Australia

[6]Current address: Department of Primary Industry and Resources, Northern Territory Government, Berrimah Agricultural Laboratories, Berrimah Farm, Darwin, NT 0801, Australia

craig.hardner@uq.edu.au

Recently, elite new cultivars specifically selected for Australian conditions have been released. These were developed from an improvement program initiated in 1993 by CSIRO. Progeny seeds were produced by reciprocal crossing industry standard cultivars (A4, A16, HAES 246, HAES 344, HAES 660) with the cultivars that had the greatest kernel production per unit projected canopy area (Daddow, HAES 781, HAES 814, HAES 816, HAES 842, HAES 849, Own Venture). Seedlings grown from these progeny were planted in trials in NSW in 1997, and Bundaberg in 1997 and 1998 with replicated grafted plants of parents on H2 seedling rootstocks throughout at two densities (2m and 4m along row). Trials were assessed for commencement of flowering, growth, yield, kernel recovery, and components of kernel quality over 8 years, and best lineal unbiased predictions of clonal values of progeny were made using a pedigree based additive and dominance individual mixed model. A bio-economic model was developed to estimate economic weights for a selection index of clonal values to identify elite progeny. Final approval of the 20 candidates for 2nd stage assessment were made by Australian Macadamia Industry Varietal Improvement Committee using rankings guided by the selection index, and field observations of tree structure and kernel quality.

For full text, please access Hardner et al 2018. Breeding of new cultivars for the Australian macadamia industry. *HortSci In review*

Opportunities and challenges in macadamia breeding

B. Topp[1], C. Hardner[2], M. Alam[1], O. Akinsanmi[1], K. O'Connor[1], M.T. Phuong Thuy[1] and D. Russell[3]

[1]Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, Maroochy Research Station, PO Box 5083 SCMC, Nambour, Qld 4570, Australia.

[2]Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, St Lucia, Qld 4072, Australia

[3]Department of Agriculture and Fisheries (DAF), Maroochy Research Facility PO Box 5083 SCMC, Nambour, Qld 4570, Australia

b.topp@uq.edu.au

There are obvious challenges in breeding new macadamia cultivars. These relate to large tree size, extended juvenile period, cultivar longevity, securing stable funding and long-term field trials for measurement of productivity. Macadamia has been commercially cultivated for less than 160 years and current cultivars are only two to four generations removed from the wild. There is significant potential for release of improved cultivars with continued selective breeding. We are studying methods to improve breeding efficiency through the use of quantitative genetics, genome-wide selection, cooperative field trials with commercial producers and alternative breeding population structures through use of polycrosses. Previous breeding has selected primarily for nut-in-shell yield, kernel recovery and tree size. We are exploring opportunities to select for other traits including alternative tree architecture, altered reproductive biology, kernel quality characteristics and disease resistance. Part of this process involves exploitation of the wild germplasm that is native to Australia in the search for novel traits and increased diversity.

The Macadamia Genome Project

C. Nock[1], A. Baten[1], K. Langon[1], B. Barkla[1], A. Furtado[2], B. Topp[2], C. Hardner[3], R. Henry[3], and G. King[1]

[1] Southern Cross Plant Science, Southern Cross University, Lismore, NSW 2480, Australia

[2] Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, Maroochy Research Station, PO Box 5083 SCMC, Nambour, Qld 4570, Australia.

[2]Queensland Alliance for Agriculture and Food Innovation, University of Queensland, St Lucia, Qld 4072, Australia

cathy.nock@scu.edu.au

The Macadamia genome project aims to sequence the first reference genome for macadamia and the early-diverging eudicot plant family Proteaceae. A draft assembly for *Macadamia integrifolia* cultivar HAES 741 'Mauka', constructed using genome and transcriptome sequence data was released in 2016. Although fragmented, its excellent coverage of the functional gene space enabled prediction of over 30,000 protein-coding genes with 90% of the models expressed in leaf, shoot or flower tissue.

Since this time, a second draft V2 has been developed using additional Illumina short-read and PacBio long-read sequence data, and a bioinformatics pipeline that incorporates transcriptome data in the de novo assembly process. These measures have dramatically improved the assembly, reducing fragmentation and extending scaffold lengths (4,416 scaffolds, 414 kb N50). A dense genetic linkage map for 741 is under construction utilising pseudo-testcross and half-sib populations in order to anchor and orient assembled genome scaffolds.

This collaborative project is providing genetic markers for cultivar identification, paternity testing, and studies to trace domestication origins and gene flow among threatened wild populations in Australian subtropical rainforests. While assembling the genome of a highly heterozygous tree species with a long generation time is problematic, this can be mitigated by concurrent advances in sequencing technologies and bioinformatic approaches. It is anticipated that the macadamia genome will enable QTL and association (GWAS) mapping and marker assisted selection for breeding, and will be a fundamental resource for understanding the genetic basis of important crop traits.

Indirect selection of macadamia yield through a genome wide association study of component traits

K. O'Connor[1], B. Hayes[2], C. Hardner[2], M. Alam[1], and B. Topp[1]

[1]Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, Maroochy Research Station, PO Box 5083 SCMC, Nambour, Qld 4570, Australia.

[2]Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, St Lucia, Qld 4072, Australia

k.oconnor@uq.edu.au

Current macadamia breeding programs involve a lengthy and laborious two stage selection process: evaluation of a large number of unreplicated seedling progeny, followed by replicated trials of clonally propagated elite seedlings. Yield is an important selection trait, however it is difficult to select due to its polygenic nature and low heritability. Component traits such as kernel recovery and nut weight are more easily measured and have a higher heritability, and as such may be used to indirectly select for yield. A genome-wide association study (GWAS) combined with marker-assisted selection offers an opportunity to reduce the time of candidate evaluation. In this study, a total of 295 progeny from 32 families, and their parents, have been genotyped for 2322 SNP markers. A GWAS will be performed to determine if there are any significant associations between genetic markers and kernel recovery and nut weight. Significant markers and their genome scaffold position will be identified, and this will also determine if the markers are proximally located. Future macadamia breeding could involve pre-screening of individuals for desired traits using these markers, with only predicted elite individuals continuing to the second stage of selection, thus potentially reducing the selection process by 8 years.

For full text, please access O'Connor et al 2018. Selecting for nut characteristics in macadamia using a genome wide association study. *HortSci In review*

Macadamia spp. as an opportunity to deploy a highly marginalized community in Veracruz, Mexico

G.S. Quintas[1] and O.A. Valdés Rodríguez[2]

[1]Dirección General de Desarrollo Forestal, Secretaría de Medio Ambiente de Veracruz, Querétaro 1, Progreso Macuiltepetl, CP 91130 Xalapa, Veracruz, México.

[2]Colegio de Veracruz, Carrillo Puerto 26, Zona Centro, Centro, CP 91000 Xalapa, Veracruz, México.

macadamiamexico@yahoo.com.mx

The municipality of Tlalnelhuayocan in the estate of Veracruz, Mexico is a highly marginalized area characterized by a cloud mountain forest ecosystem. Currently the 70% of this forest has been transformed into pasture that is not efficiently handled. The proposal of this work is to promote agroecological alternatives that integrate the cultivation of *Macadamia spp*. However, information about this crop in the area is scarce and unpublished, for this reason the knowledge about the performance of plantations in the place is required by future investors. The objective of the present work was to make a diagnosis of the macadamia plantations in the region and evaluate one agrosilvopastoril system (macadamiacattle pasture). The investigation was carried out from April 2012 to April 2014. The methodology used was participatory action research followed by interviews, participant observation, and discussion groups among owners of the orchards older than 25 years. The results indicated that in Tlalnelhuayocan the orchards have 90% of the varieties developed under Mexican selections. These orchards have few pruning and non-systematized fertilizations. Nevertheless these varieties have great production rates in relation to kernel recovery with up to 33% and 70% of oil. Some of these orchards produce 4.5 tons/ha per year. However, these orchards begin to present fitosanitary problems, mainly with *Phytopthora cinnamomi*. The proposed agrosilvopastoril system initiated production in average until the sixth year, obtaining a full cost recovery until the eleventh year. The implementation of this system offers a possibility for the communal land holders to be incorporated as Macadamia spp. producers without abandoning their livestock activities. This productive system could also be an option with environmental, economic and social benefits.

A review of the suitability of macadamia for growth in Nepal: spatial probability models using climatic scenarios, socio-economic context and land-use

A. Barrueto[1], J. Merz[2] and T. Hammer[3]

[1]CDE University of Bern, 3012 Bern, Switzerland.

[2]HELVETAS Swiss Intercooperation Nepal, Jhamshikhel, Dhobi Ghat, Lalitpur, GPO Box 688, Kathmandu, Nepal

[3]Centre for Development and Environment, University of Bern, Hallerstrasse 10, 3012 Bern, Switzerland

andrea.barrueto@helvetas.org

Macadamia were first cultivated in Nepal in the 1970s and, apart from a few individual growers', the trees have been neglected since. Only in recent years, has the interest in the trees reawakened and young trees have been readily planted in many different districts of Nepal.

Global climate models predict changes in temperature and precipitation that will shift regional climate zones. Understanding the influence of these changes on local climates and the suitability of specific sites to produce individual crop types, at present and in future, is essential to increasing local crop resilience and to ensuring the long-term viability of plantations. This is true especially for high-value, perennial tree crops such as macadamia that require significant investment. In the context of climate change, we strive to understand how existing land-use and forest zones are influenced and what it takes for farmers to adjust their livelihood practices and adopt cash crops such as macadamia.

Based on a literature review of the macro- and microclimatic requirements, the current and future suitability of Nepal for Macadamia production was investigated by means of a spatial model based on extensive in-situ measurements, meteorological data, and climatic layers from the WorldClim dataset. In addition, we have investigated the impact of climate change on existing land-use and forest zones in one chosen district of Nepal using macadamia as an example. Moreover, through in-depth household surveys that divided farmers into those who cultivate macadamia and those who do not, we analysed the socio-economic and cultural characteristics of each category using statistical tests and a multiple logistic regression.

This review shows, that the climatic suitability for macadamia cultivation in Nepal exists under present and future climatic scenarios, but that change to the geography of the zones is to be expected as they shift in elevation. In addition, micro-climatic factors have yet to be studied. Results adjusted to show the land-use and forestry zones indicate that the growing zone of optimal suitability is expected to expand to cover over multiple land-use zones including agricultural, forest and shrub areas. As the increase is most pronounced in the forest zones, we therefore recommend that this be accounted for in policy planning. Finally, macadamias are an accepted cash crop primarily grown by wealthier farmers. To enable women and poorer farmer to benefit from this crop, alternative business models and new policies need to be explored and developed.

For full text, please access Burrueto 2018. Review of potential macadamia cultivation in Nepal in the context of climate change. *HortSci In review*

Comparison of the roasting behaviour of *Macadamia tetraphylla* L. Johnson kernel with that of commercial macadamia varieties

C.A. McConchie[1], T. Kowitz, P.L. Albertson, R.I. Forrester and C.M. Hardner[2]

CSIRO Agriculture and Food, 306 Carmody Rd, St Lucia, Qld 4072, Australia

[1]Current address: Northern Territory Department of Primary Industries and Resources, Berrimah Farm, Darwin 0801 NT, Australia

2Current address: Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, St Lucia, Qld 4072, Australia

Cameron.McConchie@nt.gov.au

The roasting responses and kernel composition of five M. tetraphylla L. Johnson genotypes from wild populations and three commercial cultivars of M.integrifolia Maiden & Betche

(HAES 246, HAES 344, HAES 849), and a single commercial hybrid (A16) were investigated. Nut---in---husk was tree harvested from all genotypes, mechanically dehusked and dried using a heat pump drier at 30oC. Nut---in---shell at 1.5% moisture content was hand cracked and resultant kernel was separated into 2 subsamples with one analysed for sugar composition using HPLC, and the other used in roasting trials. Six roasting treatments (6---30 minutes) using fan forced ovens were applied to random samples of 5 raw kernel with 3 fully randomised (for oven position and order of roasting) replications. Colour of raw and roasted kernel was measured on the abaxil and adaxil surface with a Minolta Chromameter using CIE *L**,*a** and *b** colour scheme. Results are compared with previous published the roasting responses of macadamia species. There were significant differences in the colour between species prior to roasting and significant difference were observed between species in colour changes after roasting. Contrary to previous reports the *M.tetraphylla* was paler and darkened the least after roasting. There was no significant difference in the sucrose content between the two species, although it tended to be lower for *M.tetraphylla* kernel than commercial cultivars. Sugar content was a significant covariate in colour development commercial cultivars tended to be darker after the longest roast durations. These results indicate to obtain a uniform product cultivars should be segregated but the suggestion

M.tetraphylla produce dark kernel in response roasting especially when roasted under conditions that produce kernel of colour similar to current commercially processed nuts is not supported. The belief that macadamia species and hybrids had different roast responses has limited the commercial exploitation of *M.tetraphylla*. Our results indicate that greater use of genetic diversity offered by *M.tetraphylla* could be made without detrimentally affecting the roasting response.

Low-saturated fat macadamia nuts - is it possible?

T. O'Hare[1], B. Topp[2], S. Pun[3], C. Torrisi[3], D. Williams[3], and D. Russell[4]

[1]Queensland Alliance for Agricultural and Food Innovation, University of Queensland, Health and Food Sciences Precinct, Block 10, Level 1, 39 Kessels Rd, Coopers Plains, Qld 4108, Australia

[2]Department of Agriculture and Fisheries, Maroochy Research Facility PO Box 5083 SCMC, Nambour, Qld 4570, Australia

[3]Department of Agriculture and Fisheries, Health and Food Sciences Precinct, Block 10, Level 1, 39 Kessels Rd, Coopers Plains, Qld 4108, Australia

[4]Department of Agriculture and Fisheries, Maroochy Research Facility PO Box 5083 SCMC, Nambour, Qld 4570, Australia

t.ohare@uq.edu.au

Macadamia kernels consist of approximately 76% oil. Of that, 77-80% is monounsaturated, 1-7% is polyunsaturated, and the remaining 14-21% is saturated fat. Whereas unsaturated fats are considered 'good' for health, there is a general belief that saturated fats are of less benefit. In fact, it is possible to make a low-saturated fat health benefit claim if saturated fat is less than 1.5% of total product weight (~ 2% of oil content), or a reduced-saturated fat claim if saturated fat is 25% less than a reference foodstuff. It is therefore of interest to see if it is possible to reduce the percentage of saturated fat in macadamia, based on an understanding of the fatty acid pathway. While the vast majority of oil is monounsaturated oleic acid (C18:1) and to a lesser degree, palmitoleic acid (C16:1), a significant amount of saturated fat exists as palmitic acid (C16:0) and stearic acid (C18:0). During kernel development, saturated fats are extended in length by an enzyme called 'elongase', which adds 2 carbon atoms at a time (consequently, palmitic acid is elongated to stearic acid). Each of these saturated fats then has a double bond added by an enzyme called 'desaturase', and they become monounsaturated. Therefore, to have a low saturated fat variety, it would be an advantage to have efficient desaturase enzymes, to convert the saturated to monounsaturated fats. In an analysis of 34 macadamia lines (14 cultivars and 20 breeding accessions), it was found the ability to convert stearic (C18:0) to oleic acid (C18:1) was reasonably efficient, with the stearic:oleic ratio varying from 1:17 to 1:29. By contrast, the ability to convert palmitic (C16:0) to palmitoleic acid (C16:1) was much less efficient, with a low palmitic:palmitoleic ratio ranging from 1:2 to 1:4. Although one might expect varieties with the most efficient desaturase enzymes to have the lowest saturated fat, this was not always the case. In some varieties, elongating more C16:0 to C18:0 could compensate for poorer desaturation of C16:0, as C18:0 is much more efficiently desaturated than C16:0. Ideally, lowest saturated fats in macadamia would be maximised by combining efficient elongase enzymes with strong desaturase enzymes. Although, it is likely that this would still be insufficient to qualify for a <1.5% saturated fat health claim, a reduced-saturated fat claim is potentially well within reach. Further exploration within macadamia germplasm may yield more efficient enzymes to make this eventually feasible.

For full text, please access O’Hare et al. 2018. Macadamia nuts and saturated fat content. *HortSci In review*

Genetic diversity and variability in graft success in Australian Macadamia rootstocks

M. Alam[1], J. Wilkie[2], A. Kelly[3], C. Hardner[4], and B. Topp[1]

[1]Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, Maroochy Research Station, PO Box 5083 SCMC, Nambour, Qld 4570, Australia.

[2]Department of Agriculture and Fisheries, Wollongbar Primary Industries Institute, 1243 Bruxner Highway, Wollongbar, 2477, NSW, Australia.

[3]Department of Agriculture and Fisheries, 203 Tor Street, Toowoomba QLD 4350, Australia

[4]Queensland Alliance for Agriculture and Food Innovation, University of Queensland, St Lucia, Qld 4072, Australia

m.alam@uq.edu.au

Rootstocks in tree crops play a vital role in the crop performance by regulating resource supply through translocating water and nutrients; and signaling for developmental processes to the scion. We developed macadamia (*Macadamia* sp.) seedling and cutting rootstocks of a wide range of genotypes and investigated the genetic diversity and the variability of graft success in different groups of macadamia rootstocks. We propagated 30 genotypes of rootstocks comprising 6 high performing rootstock cultivars; 3 elite cultivars with high breeding values for harvest index; 6 cultivars with high yield efficiency; 5 potential dwarf genotypes from the Australian breeding program; 1 Abnormal Vertical growth (AVG) resistant cultivar; 8 wild germplasm including 3 *Macadamia jansenii*, 3 *M. ternifolia* and 2 *M. tetraphylla*; and were grown in a water controlled mist house and shade house for one and a half years. Diversity array technology platforms were used to investigate the genetic diversity of 27 rootstock genotypes. A commercial cultivar "HAES741" was grafted onto the rootstocks and observed until planting. Graft success varied depending on the genetic background and the size of the stem diameter. We identified seedling and cutting rootstock genotypes showing extraordinary graft success with "HAES741" scion. Inclusion of wild germplasm and dwarf genotypes increased the genetic variability in the macadamia rootstocks and this wide genetic diversity can be utilized in future rootstock breeding. The extent to which this genetic diversity in rootstocks will lead to variations in scion architecture is unknown.

Historical and molecular evidence of genetic identity of HAES741 and HAES660 macadamia cultivars

M. Alam[1], C. Hardner[2], C. Nock[3], K. O'Connor[1], and B. Topp[1]

[1]Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, Maroochy Research Station, PO Box 5083 SCMC, Nambour, Qld 4570, Australia.

[2]Queensland Alliance for Agriculture and Food Innovation, University of Queensland, St Lucia, Qld 4072, Australia

[3]Southern Cross Plant Science, Southern Cross University, Lismore, NSW 2480, Australia

m.alam@uq.edu.au

The Hawaiian cultivars Keaau (HAES 660) and Mauka (HAES 741) were selected by the University of Hawaii, released in 1966 and 1977 respectively, and have been used extensively in macadamia orchards throughout the world. Recent molecular evidence suggests that these two cultivars are almost genetically identical. However, anecdotal evidence suggests they are phenotypically different. This study reviews available molecular, historical and phenotypic evidence to examine the hypothesis that these two cultivars are the same genotype.

For full text, please access Alam et al 2018. Historical and molecular evidence of genetic identity of 'HAES741' and 'HAES660' macadamia cultivars. *HortSci In review*

Domestication of macadamia in Hawai'i

C.M. Hardner[1], C.J. Nock[2], J. Batley[1,3], and A.A. Termizi[1]

[1]Queensland Alliance for Agriculture and Food Innovation, University of Queensland, St Lucia, Qld 4072, Australia

[2]Southern Cross Plant Science, Southern Cross University, Lismore, NSW 2480, Australia

[3]University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia

craig.hardner@uq.edu.au

While Australia is the natural origin of macadamia, Hawaii led much of the development of the plant into an international premium commercial crop. An understanding of the domestication of macadamia in Hawaii is important as it will add to the overall history of the crop and improve conservation and use of genetic resources. There are two well-known introductions of *Macadamia integrifolia* (the preferred species for commercial production) into Hawaii, and one introduction of *M. tetraphylla* (originally used for the establishment of the first seedling orchards in the 1910's, but superseded by the late 1920's). However, there is also evidence of a third introduction of *M. integrifolia* in the early 20th century, an early introduction of the bitter kernel *M. ternifolia*, and selections from Australia were introduced in the mid-1950's. Following the development of vegetative propagation technology in the 1930's, selections from initial seedling orchards established in the 1920's and 30's were developed into the first generation cultivars. Recently, remnants of the early introductions and the original seedling orchard have been identified and sampled for chloroplast sequencing that have identified the wild origin of the maternal line of the Hawaiian cultivars. These results are in conflict with previously accepted records for the origin of germplasm considered to contribute to these cultivars. Further research is required to evaluate the importance of the third *M. integrifolia* introduction, and the source of the *M. ternifolia* introduction.

Oil accumulation patterns in kernel of *Macadamia* species

J. Neal[1], E. Howell[2], R. Mayer[1], C.M. Hardner[3] and B. Topp[2]

[1]Department of Agriculture and Fisheries (DAF), Maroochy Research Facility PO Box 5083 SCMC, Nambour, Qld 4570, Australia

[2]Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, Maroochy Research Station, PO Box 5083 SCMC, Nambour, Qld 4570, Australia.

[3]Queensland Alliance for Agriculture and Food Innovation, The University of Queensland, St Lucia, Qld 4072, Australia

jodi.neal@daf.qld.gov.au

Oil accumulation in macadamia kernel is related to eating quality. Previous studies exploring oil content and accumulation patterns in macadamia have focused on commercial cultivars of *Macadamia integrifolia* and *M. tetraphylla* hybrids. This study examined oil accumulation and maximum oil content of wild genotypes of three macadamia species, *M. integrifolia*, *M. tetraphylla* and *M. ternifolia*, across their geographic range. Also assessed were *M. integrifolia* × *M. ternifolia* and *M. integrifolia* × *M. jansenii* hybrids, and three industry cultivars. Rapid oil accumulation was observed to occur between December and February for *M. integrifolia* and *M. tetraphylla*, with 90% of maximum oil content reached in February. *M. ternifolia* matured significantly faster, reaching 90% of maximum oil content in late December. The species hybrids and cultivars were intermediate. No significant differences were observed between species for maximum oil content.

For full text, please access Neal et al 2018. Oil accumulation patterns in kernel of *Macadamia* species. *HortSci In review*

Four new macadamia varieties for the Australian industry

B. Topp[1], D. Russell[2], J. De Faveri[3], C. Hardner[4], D. Bell[5], S. Mulo[2] and G. Bignell[2]

[1]Queensland Alliance for Agriculture & Food Innovation, The University of Queensland, Maroochy Research Station, PO Box 5083 SCMC, Nambour, Qld 4570, Australia.

[2]Department of Agriculture and Fisheries (DAF), Maroochy Research Facility PO Box 5083 SCMC, Nambour, Qld 4570, Australia

[3]Department of Agriculture and Fisheries (DAF), Mareeba Research Facility, 28 Peters Street, Mareeba, Qld 4880, Australia

[4]Queensland Alliance for Agriculture and Food Innovation, University of Queensland, St Lucia, Qld 4072, Australia

[5]Hidden Valley Plantations, Alf's Pinch Rd, Beerwah, Qld 4519, Australia

bruce.topp@daf.qld.gov.au

Four Macadamia varieties have been released by Queensland Department of Agriculture and Fisheries (QDAF) after eight years of Regional Variety Trial (RVT) evaluation at eight Queensland (QLD) and New South Wales (NSW) sites. The field trials were planted in 2008 and consisted of 20 superior clones derived from populations bred by the Commonwealth Scientific and Industrial Research Organisation, five standard industry varieties, 'HAES 741', 'HAES 344', 'HAES 816' and 'A16', and five Hidden Valley Plantation selections. The trials were planted over a range of 1400 Kms from the northern most site at Mackay (21.288299 S, 149.061305 E) in central Qld to the southernmost site at Macksville (30.847997 S, 152.871968 E) on the mid-north coast of NSW. Multi Environment Trial analysis using Best Linear Unbiased Predictions for nut in shell (NIS) yield, kernel yield, kernel recovery (KR) and tree volume, and economic traits modelling to year 20, aided in selecting new varieties for industry release.

Variety G is precocious and ranked one for cumulative kernel yield (CKY) at Booyan RVT from 2011 – 2016 with 12.1kg compared with 'HAES 816' with 10.4kg and 'HAES 741', 10.2kg. Variety G out-yielded standard industry varieties in three out of eight RVT sites for NIS and KY in 2016. It ranked seven for CKY (2013 – 2016) and four for NIS (2016) in Alstonville making G suitable for both QLD and NSW growing regions. Variety P is precocious with similar CKY to 'HAES 741' to year eight, however P is 36% smaller in tree volume at the Booyan site. P is best suited to the Bundaberg region as canopy density is considered too dense by local growers in northern NSW. Variety J has a high KR of 44%, ranks better for NIS than industry varieties in the Bundaberg region and second only in CKY to variety G at the Booyan site with 11.4kg. At Alstonville in NSW variety J ranked 19 in CKY proving it is best suited to the Bundaberg region. Variety R ranked four for CKY at Alstonville compared with 'HAES 344' that ranked 19. Discounted Cash Flow (DCF) estimates have been calculated for a 30 ha farm using economic modelling of NIS over 20 years. The average DCF of the four new industry varieties compared with the average of the five standard varieties shows an increased profitability of 11%.

Appendix 3. Macgroup presentation

Note slide

Symposium overview

Opportunity for international research industries to meet, share and discuss latest developments

- Last international meeting in 1992
- 2 day tour of farms, factories
- 2 day symposium
- Over 90 attendees
- 6 early career researchers supported by HIA
- Delegates from 10+ countries
- No South African researchers

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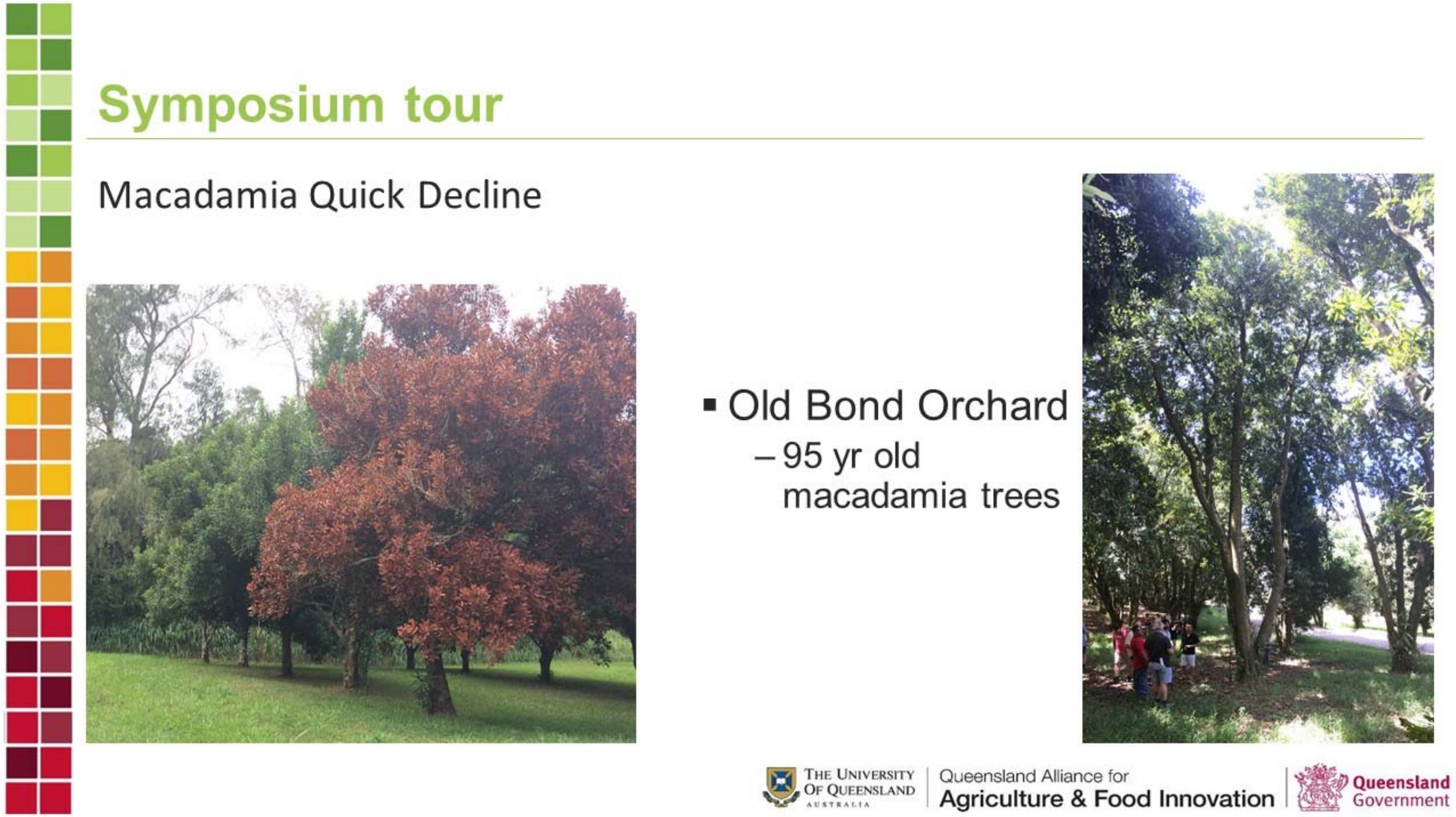
Symposium tour
MAC FARMS
OF HAWAII


Symposium tour
Macadamia Quick Decline
Old Bond Orchard
– 95 yr old macadamia trees
The University Of Queensland Australia
Queensland Alliance for Agriculture & Food Innovation
Queensland Government

Overview of symposium topics

- Propagation
- Pollination and pollinators
- Canopy architecture for high density and pest management
- Improving early age yield
- Management of fruit retention
- Soil management and nutrient monitoring
- Pathology
- Pest management
- IOM extension methods
- Product management, kernel quality and health benefits
- Genetics, breeding, domestication, genomic technologies
- Developing industries

5

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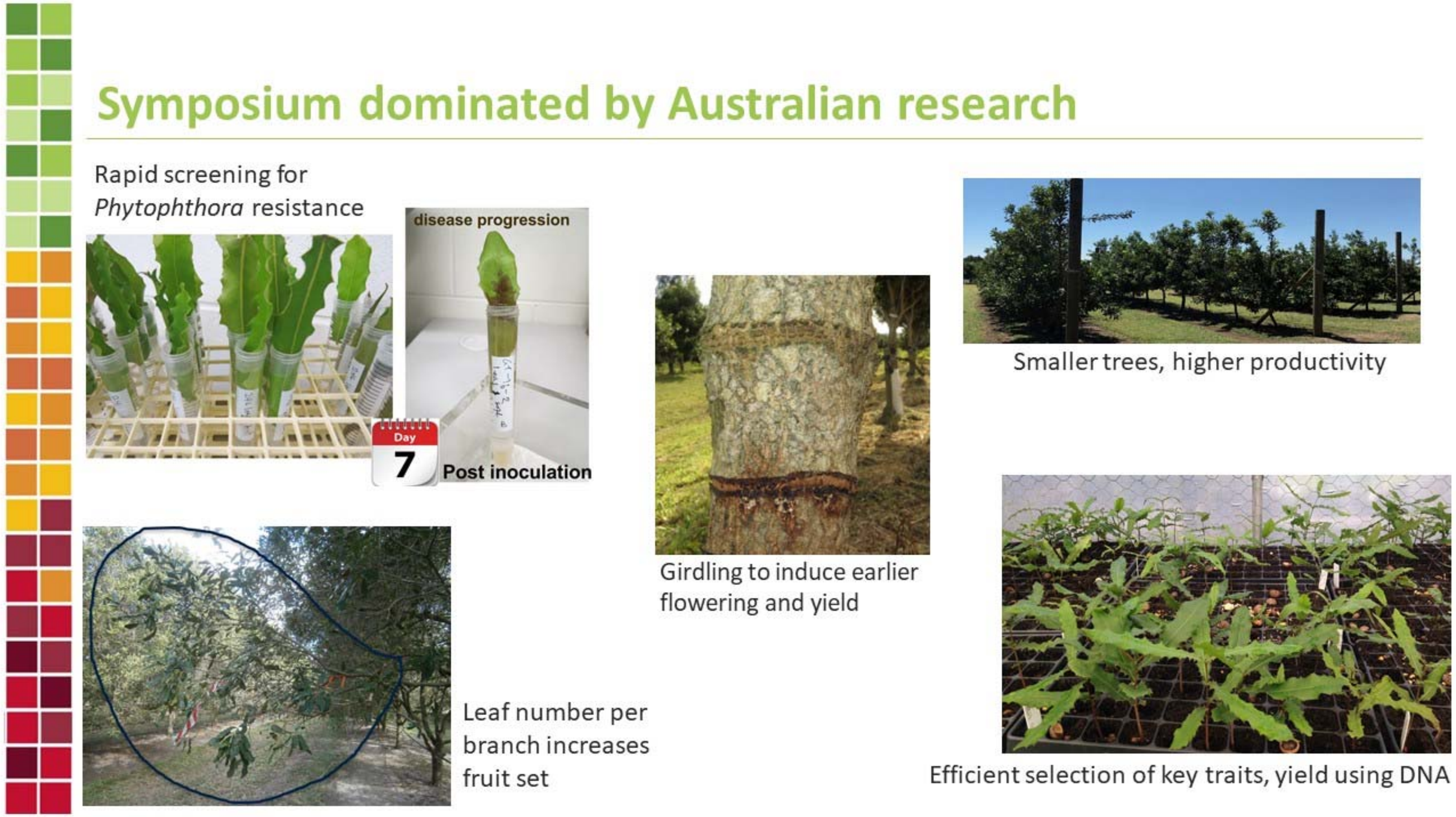
Symposium dominated by Australian research
Rapid screening for *Phytophthora* resistance
disease progression
Day
7
Post inoculation
Girdling to induce earlier flowering and yield
Smaller trees, higher productivity
Leaf number per branch increases fruit set
Efficient selection of key traits, yield using DNA

Effect of leaf whorl position on nutrient content of macadamia leaves

Scott Hill, Dr Robyn Cave University of Queensland

Aim

To identify alternative whorls, if any, for sampling.

Results

Pooled data (cultivars 741, 246, A203) for each whorl and nutrient showed no significant difference ($P<0.05$) between whorls 2 and 3.

Conclusion

Where leaves from whorl 2 are **not** available or suitable for sampling, leaves from whorl 3 could be used for leaf nutrient analysis.

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China

- Present: 130,000 ha → 2020: 270,000 ha
- Cultivars: O.C, 344, 695, 788, A16, A4, Nanya-1 and Guire-1
- Soil issues
- Breeding & propagation development
- New product development; Skin care, edible oil, whitening, abrasives, filters

Credit: Jianbo Shen and Gabina Sol Quintas

Mexico

- Incorporating macadamia trees into mixed farming enterprise
- Increased financial opportunity for highly marginalised community

8

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Land suitability mapping

9

Credit: Andrea Barrueto

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Hawaii: Macadamia Felted Coccid (MFC)

Action thresholds determined

- 344: >20 crawlers/in^2
- 508: 50-100 crawlers/in^2

- Increased light penetration:
  - improved yield in 2nd year
  - Increased parasitoid population

- Increased light penetration combined with increased plant diversity:
  - MFC down 40%
  - Predators up 60%
  - Increased biomass accumulation

Credit: Alyssa Cho and Rosemary Gutierrez

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Soil amendments to improve yield & quality

- Treatments include composted husk, biochar, EMs, woodchip and soil profiling
- Monitoring:
  - Soil N, C, pH & EC
  - plant tissue N
  - Proteoid & total root mass
  - Yield & quality
- Conducting a partial cost-benefit analysis

11

Credit: Russell Galanti

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Please email Craig Hardner or myself if you have any questions

c.hardner@uq.edu.au

scott.hill@uq.net.au

Appendix 2. Article published in November 2017 AMS Bulletion edition

2017 International Macadamia Research Symposium: Genetic improvement – an important part of the future of the macadamia industry

Katie O'Connor[1], Paul O'Hare[2] and Craig Hardner[1]

[1]Queensland Alliance for Agriculture and Food Innovation, University of Queensland, [2]Queensland Department of Agriculture and Fisheries

The 2017 International Macadamia Research Symposium held in Hilo, on the Big Island of Hawai`i on the 13$^{th}$ and 14$^{th}$ of September was a great success. This was the first international macadamia research meeting held since 1992. Over 90 attendees including researchers and industry representatives from Australia, Hawai`i, China, New Zealand, Brazil, Mexico, Japan, Switzerland and others participated in the symposium. Combined with pre- and post-tours of leading macadamia farms and processing plants, the symposium provided researchers and industry delegates from across the globe the opportunity to share their knowledge and ideas on current and future research issues.

The symposium was opened by Mayor of Hawai`i Harry Kim with what some delegates referred to as the greatest opening remarks they had ever heard. Mayor Kim's words were heartfelt and passionate, and emphasized the importance of Hawaiian culture and agriculture research today and into the future.

Highlights of the conference presentations included:

- Trellising trees and trunk girdling for increased flowering and yield
- Intercropping in China with tea and coffee to reduce soil temperature for better growing conditions
- Identifying stages of canopy and ground floor health for integrated orchard management
- More insight into the foraging behaviours of native and European bees
- Spatial mapping to identify healthy plants
- Macadamia felted coccid infestation in Hawai`i and biological management
- Aims to breed a low-saturated fat macadamia to achieve 'healthy' or 'reduced/light' ratings
- Developing the industry and the education of farmers in non-traditional macadamia growing countries, such as Mexico and Nepal.

With the Hawaiians having pioneered macadamia cultivar selection, it was fitting that a major part of the conference was devoted to genetic improvement.

Dr Cameron Peace presented results from his seminal PhD thesis undertaken in the early 2000s at CSIRO and University of Queensland on the genetic structure of the four wild species of macadamia, natural hybrid zones and the genetic ancestry of cultivars. The area of South Brisbane has the highest genetic diversity for *M. integrifolia*, and yet it appears that no cultivars originated from plants in that area. This work demonstrates that there is so much more prospective genetic improvement available for macadamia using natural germplasm that should be explored.

Dr Peace also explained that most cultivars are probably only between three and six generations removed from their wild relatives, and argued a rare opportunity exists through genotyping the entire remnant gene pool to better understand the genetic resources available to breeding. Dr Peace's PhD was the first to suggest that the Hawaiian germplasm was derived from populations north of Amamoor, and this has been subsequently confirmed by chloroplast analyses at the University of Queensland and Southern Cross University.

Dr Hardner and Associate Professor Bruce Topp followed and presented information on the Australian macadamia breeding programs. Dr Hardner described the methods used to breed the new macadamia varieties released this year including parent selection, crossing, trial design, assessment methods, development of economic model for multi-trait selection, and final approval through MIVIC. Professor Topp outlined challenges and opportunities in current macadamia breeding.

Updating the progress made in sequencing the macadamia genome was the theme of the following presentation by Dr Cathy Nock. The Hawaiian cultivar 'Mauka', also known as 'HAES 741', was used to develop the first reference genome for macadamia. Construction of the macadamia genome will inform the position of genes across chromosomes, as well as their structure and function. This will open up many opportunities for macadamia breeding, such as early selection of elite individuals using DNA information.

Katie O'Connor's presentation described approaches using genomic information to identify genes that have a major impact on yield, and component traits of yield that may be more strongly inherited, and hence easier to use for selection (see also '*Improving macadamia yield using component traits and genomics*' in the Spring 2017 edition of the News Bulletin).

Dymocks farm manager Chris Cook found the conference to be a great opportunity to learn about and understand new research. Mr Cook said, "I have developed ideas to implement when planning new orchards, such as high-density planting and trunk girdling." Making new contacts such as those at Island Harvest, and visiting old Hawaiian orchards were also highlights for Mr Cook.

Orchard owner Santiago Maldonado of Ecuador found that the research and development presentations were very informative and participation was very worthwhile for him. Mr Maldonado commented, "I found the information from the conference and the opportunity to question and discuss ideas with researchers to be very beneficial, giving me many ideas to use on my own farm". Particularly important to Mr Maldonado was Dr Femi Akinsanmi's detailed presentation of macadamia diseases.

The symposium tours provided real experiences of the Hawaiian research issues and projects being undertaken to address these issues.

The pre-symposium tour visited the MacFarms orchard at Homomalino, which was an eye-opener for many of the international visitors. The orchard grows on a recent lava flow where the only soil is that which has accumulated from litter fall in the last 50 years since the orchard was planted. Annual rainfall is 1000-1500mm. The terrain also means that it is impossible to use mechanical harvesting, hence requiring large numbers of hand pickers to harvest the crop that is near continuous throughout the year.

The main visit on the post-symposium tour was a large organic farm at Kapa`a managed by Island Harvest. This farm contains what appears to be the oldest producing macadamia orchard, planted in 1926. Felted coccid, which has been widely found on macadamia farms in parts of the Big Island, has not yet been detected on this farm. Strict quarantine protocols are maintained at Island Harvest to maintain this absence of felted coccid on their farm. The symposium tours also left plenty of time for informal interaction and discussion as ideas arose.

The 2017 International Macadamia Research Symposium was supported by Hort Innovation. As part of their support six Australian students were awarded Hort Innovation travel scholarships to support their attendance and present their work:

Gavin Chirgwin (USQ) – Limitations to fruit set in macadamia

Olumide Jeff-Ego (UQ) – Rapid bioassay for macadamia germplasm screening for tolerance to *Phythopthora* species

Scott Hill (UQ) – Effect of leaf whorl on nutrient content of macadamia leaves

Katie O'Connor (UQ) – Indirect selection of macadamia yield through genomic wide association study of component traits

Ben Toft (UQ) – Trait mining for high-density macadamia planting systems: How important are more detailed architectural characteristics

Bryony Wilcox (UNE) – Merging crop pollination with remote sensing to better understand the spatial variability in Australian tree orchards

The symposium was a great opportunity for new and experienced researcher and industry to come together and discuss the breadth of activity in macadamia across the globe. There was enthusiasm to continue international and domestic research meetings in China in 2018, in Australia in 2019, and into the future. We thank the organisers for their wonderful work putting together a well-run and valuable meeting.

Acknowledgements

KO thanks Hort Innovation for a travel award to attend and present at the symposium.

UNE – University of New England. USQ – University of Southern Queensland. UQ – University of Queensland.

Pre-conference tour at MacFarms on the Big Island of Hawai`i showing the hilly and rocky terrain. Planting at this site began in the 1950s.

Katie O'Connor and others on a tour through MacFarms.

Farm worker at MacFarms harvesting by hand due to the difficult terrain making it impossible to use mechanical harvesters

Chris Cook of Dymocks Group Farming, Dr John Wilkie of Queensland Department of Agriculture and Fisheries, and Dr Craig Hardner at the University of Hawai`i Waiakea research station.

Organic Kapa`a orchard in the north of the island of Hawai`i

Australian students who received Hort Innovation travel awards. Left-to-right: Gavin Chirgwin, Bryony Wilcox, Olumide Jeff-Ego, Katie O’Connor, Ben Toft, Scott Hill.

Appendix 5. Concept proposal submitted to HortInnovation Funnel

Concept 2462 - Macadamia Crop Production Book

Concept Aim:

The aim of this concept is to fill a gap in the availability of a summary of current knowledge on crop production as a reference for the industry, students and researchers. Currently, books on macadamia production are over a decade old and require updating, and inclusion of post-harvest and processing will allow producers and field scientists to put on-farm operations into downstream context. CABI has confirmed the proposed concept fits within their Crop Production Science series, and support from the industry would assist publishing of a book that may not have a wide audience. All current researchers and experts will be invited to participate and the content of the book will be developed through engagement with the Australian industry.

Concept Output:

This concept will create a reference of the current state of knowledge underpinning the macadamia supply chain. Possible sections could include (i) History: Uses and current production regions, (ii) botany, (iii) tree and fruit physiology, (iv) climatic requirements, (v) orchard establishment, (vi) seasonal management, (vi) nutrition and soil management, (vii) pest, disease and disorders, (viii) harvesting and processing, (ix) cultivars, (x) determinates of kernel quality.

Concept Adoption:

It is anticipated this book will be adopted by the world macadamia industry including new and existing producers, processors, marketers, students and researchers.

Concept Outcome:

It is anticipated that by providing a single foundation source of current state of knowledge this concept will support improved efficiency and innovation in the Australian macadamia industry. The documented foundational knowledge within the text will be used to build on new advances in the crop and evaluate new opportunities. It will equip new indsutry and research entrants with a summary on which to develop their knowledge of the crop and industry.