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Australian Centre for International Agricultural Research

# Final report

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# Contents

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# List of abbreviations

| | |
|---|---|
| ai | Active ingredient |
| CePaCT | Centre for Pacific Crops and Trees, Pacific Community |
| CI | Chilling injury |
| FAO | Food and Agriculture Organisation of the United Nations |
| FNU | Fiji National University |
| HWT | Hot water treatment |
| IFAD | International Fund for Agricultural Development |
| FIRST | Food security and nutrition impact, resilience, sustainability and transformation programme |
| MoA | Ministry of Agriculture, Fiji |
| MAF | Ministry of Agriculture and Fisheries, Samoa |
| MAFFF | Ministry of Agriculture and Food, Forests and Fisheries, Tonga |
| MORDI | Mainstreaming of Rural Development Innovation |
| NCDs | Non-communicative diseases |
| NGO | Non-Government organisation |
| NWC | Nature’s Way Cooperative Ltd |
| PHAMA+ | Pacific Horticultural and Agricultural Market Access Program |
| PICs | Pacific Island Countries |
| QDAF | Queensland Government's Department of Agriculture and Fisheries |
| SROS | Scientific Research Organisation of Samoa |
| UQ | The University of Queensland |
| USC | University of the Sunshine Coast |
| USP | University of the South Pacific |

# Disclaimer

This report presents research results and findings undertaken in support of ACIAR Hort 2014.077. This information does not constitute a recommendation or endorsement of any treatment, product, chemical, brand or company.

Sept 2021.

# Further Information

Further information can be obtained by contacting the University of the Sunshine Coast, Australia (Commissioned organisation - Prof Steven JR Underhill sunderhi@usc.edu.au or ACIAR aciar@aciar.gov.au

# 2 Executive summary

HORT/2014/077 achieved significant economic impact in Tonga (new citrus orchards established), social impact in Fiji (pineapple community practice change), important scientific impacts (dwarfing breadfruit, new postharvest diseases identified, strategies to aid breadfruit cyclone recovery), supported regional institutional capacity building, and increased awareness of the Pacific fruit industries in the region.

1. Four commercial-scale citrus orchards involving +600 grafted trees[1] with an anticipated yield of 150 tonnes/year (in 2025) have now been established on Eua and Tongatapu Islands, Tonga. In 2020, the Tongan Government funded the importation of an additional 1500 grafted citrus trees to distribute to farmers. One of the citrus orchards we established on Tongatapu had its first commercial harvest in 2021, resulting in significant interest amongst Tongan farmers to further expand local citrus production. Collectively, these achievements will enable long-term pro-health impacts in Tonga, due to increased local access to affordable locally grown fruit.
2. As a result of extensive pineapple industry capacity building support in Fiji, the Vulagi pineapple farmers have adopted contour planting (reducing soil erosion), have increased production by 30%, and secured significant Fiji Government support assistance to improve farm infrastructure and enabled diversification into pineapple value-adding.
3. Postharvest research, development and training capacity has been significantly improved in Fiji and Samoa. FNU, MoA and SROS now have PhD-level staff with expertise in postharvest horticulture.
4. A study of postharvest diseases of mango in Fiji identified six new stem-end rot pathogens on mango and *C. brevisporum* on papaya, diseases not previously reported on these crops in Fiji. This new knowledge will enable more effective postharvest control strategies to be developed.
5. A mango hot water treatment protocol was shown to reduce the incidence of postharvest rots by 95% for *cv. Maqo Dina*, 52% in *cv. Tommy Atkins* and 44% in *cv. Tahitian*. Further work is now required to evaluate commercial-scale treatments.
6. Paclobutrazol application significantly improved breadfruit flowering and fruit set following tree pruning. While application rates need to be optimised and local chemical registration sought, Paclobutrazol is likely to aid breadfruit tree recovery after a cyclone, by promoting early flowering and fruiting.
7. This project has increased the awareness of fruit industries in Fiji and Tonga. In April 2019, the Fiji Government launched its Fiji fruit industry development initiative. In Tonga, MORDI has built a new plant nursery and processing facility, and the Tonga Government has imported fruit trees to enhance farmer access.
8. Research undertaken by the project resulted in 18 research academic papers, 1 book, 7 conference papers and numerous technical reports.

This project also worked in close partnership with other donor initiatives. HORT/2014/077 and PHAMA+ co-funded the importation of +200 grafted Tahitian limes into Tonga creating two lime orchards on Tongatapu Island in support of a future export pathway, we collaborated with FAO FIRST programme and the youth in agriculture initiative through joint postharvest farmer capacity building in Tonga and Samoa, and we provided

[1] Collectively 2142 grafted citrus trees have been imported into Tonga since 2016. To put this into context, in 2015 (prior to project commencement) the Tonga Agricultural Census reported there were only 1045 citrus trees in Tonga.

significant technical support and advice to the MORDI-led IFAD-TRIP 2 initiative in Tonga.

# 3 Background

Fruit production in the Pacific represents less than 10% of the overall horticultural output, despite favourable climates and increasing market opportunities. In part, this situation can be attributed to a prevalence of low-intensity and semi-commercial fruit production systems, poor postharvest handling practices and limited value chain development. Far from being intractable, the rapid expansion of the 'Fiji Red' papaya industry provides clear evidence that the Pacific can establish internationally competitive niche fruit export industries (Prasad, 2018; Anon 2020a). A plethora of fruit value chain and export-opportunity reports undertaken prior to project commencement supports this view (Young and Vinning, 2006; McGregor *et al*., 2009; McGregor and Stice, 2009; Stice *et al*., 2009; Tamasese, 2009; Mael, 2011; McGregor, 2012; Young, 2012; Campbell *et al*., 2014; Martyn *et al*., 2014).

The need to expand fruit production has been widely acknowledged by Pacific Governments and is reflected in national sectorial development policies. The emerging focus on fruit crops is based on seeking to enhance and diversify existing horticultural production to better capture domestic and export markets opportunities, supporting efforts to improve national food security, and as part of a wider dietary-based NCD remediation strategy.

This project sought to assist the development of resilient tropical fruit value chains in Fiji, Samoa, and Tonga, based on five fruit crops: papaya, pineapple, mango, breadfruit, and citrus. The selection of these target crops and the proposed research interventions was based on consultation with PIC Government agencies and ACIAR, a desk top review of prior fruit-industry initiatives and incorporated a direct request for mango industry development assistance from the Fiji Government[2].

This project had four core objectives:

1. To increase the efficiency of fruit value chains through improved productivity and postharvest handling practices.
2. To improve climatic resilience of breadfruit through improved canopy management and investigating the diversity of breadfruit tree form.
3. To provide targeted capacity building to private sector and government extension services in support of identified fruit value chains.
4. To enhance the engagement of smallholder farmers and communities in functional supply chains.

Research activities undertaken involved a range of pre-harvest and postharvest research interventions that sought to remove key impediments along the value chain that limited their profitability. This project sought to improve pineapple production and postharvest handling efficiency in Fiji and Samoa; improve breadfruit production practice in Fiji through better canopy management; explore postharvest strategies to enable sea-freight export of fresh breadfruit; enable papaya production in Tonga and Samoa through the facilitated transfer of elite 'Fiji Red' papaya seed; improve the quality and supply of mango on the Fiji domestic market; improve access to locally grown out-of-season fruits in

[2] The Fiji Government requested that the Australian Government provide technical assistance to support local mango industry development. ACIAR commissioned a rapid review of the Fiji mango industry ACIAR C2014/154 (undertaken by Mr Ian Baker), with recommendations of that review incorporated into HORT/2014/077 work plan.

Tonga focussing on citrus.

This project had a strong Pacific Institutional (Government, university and NGO) and private-sector capacity building focus. This was achieved through targeted Higher Research Degree (HRD) training, technical mentoring, on-farm and participatory workshops, and hosted attendance at international technical and industry events.

To undertake this project technical expertise was sourced from: The University of the Sunshine Coast (USC); The University of Queensland (UQ); Pacific Community (SPC); Scientific Research Organisation of Samoa (SROS), Ministry of Agriculture, Food, Forests and Fisheries of Tonga (MAFFF); Fiji National University (FNU); Ministry of Agriculture Fiji (MoA), Natures Way Cooperative Ltd (Fiji) and commodity-specialist consultants; A/Prof John Chapman [citrus], Mr Ian Baker [mango], Dr Aad van Santen [pineapple], Dr Andrew McGregor [breadfruit]).

In 2018, the project team was informally expanded to included Nishi Trading (private-sector partner in Tonga) and MORDI (NGO in Tonga). This project further collaborated with UN-FAO based on joint postharvest capacity building in Samoa, and PHAMA+ involving co-funded importation of Tahitian limes in Tonga.

# 4 Objectives

Within the broader development goal of contributing to economic development, food and nutrition security and enterprise development, this project sought to increase the economic and disaster resilience of selected tropical fruit value chains based on four core objectives:

1. Increase the efficiency of fruit value chains through improved productivity and postharvest handling practices.
2. Improve climatic resilience of breadfruit through improved canopy management and investigating the diversity of breadfruit tree form.
3. Provide targeted capacity building to private sector and government extension services in support of identified fruit value chains.
4. Enhance the engagement of smallholder farmers and communities in functional supply chains to maximise pro-poor and livelihood outcomes.

**Objective 1:** Increase the efficiency of fruit value chains through improved productivity and postharvest handling practices.

**Objective 1.1** Papaya value chain support.

- Improve access to elite seed material for small-holder farmers in Samoa.

**Objective 1.2** Breadfruit value chain support.

- Improve the commercial viability of sea-freight exports in Samoa by developing postharvest protocols for small consignment shipments.
- Assess existing breadfruit postharvest value chains in Samoa to identify key risk factors.
- Reduce losses and improve product quality of domestic breadfruit supply chains in Samoa.

**Objective 1.3** Pineapple value chain support.

- Assess the level of agribusiness capacity of pineapple farmers in Tonga, Samoa and Fiji.
- Introduce agronomic practices that support year-round production and provide agribusiness support.
- Evaluate the existing postharvest handling constraints along pineapple value chains in Fiji, Samoa and Tonga, and provide appropriate remediation.
- Undertake capacity building of local pineapple farmers in Samoa, Tonga and Fiji.
- Undertake postharvest optimisation of sea freight storage protocols for Samoan pineapple.

**Objective 1.4** Fiji mango industry development.

- Evaluate the use of paclobutrazol and azoxystrobin to better regulate flowering.
- Evaluate the use of fruit bagging to improve fruit quality for better varieties.
- Identify key pre-harvest pests and postharvest disease risk for mango production in Fiji.
- Initiate cultivar evaluation trials for cv. Tommy Atkins and Mango Salusalu.
- Undertake a training workshop with smallholder mango farmers in Fiji.

**Objective 1.5** Citrus industry development support in Fiji, Tonga, and Samoa.

- Assess the viability of the Vanua Levu, Fiji citrus value chains.
- Identify and source existing citrus material imported into Tonga and relocate to sites in Tonga. Where appropriate we purchased and imported additional citrus cultivars into Tonga.
- Identify and prioritise training and capacity support to growers.
- Establish a community-based citrus nursery on `Eua Island.
- Undertake capacity building on `Eua to improve orchard and tree management.

**Objective 1.6** Economic impact.

- Baseline economic data will be gathered at the commencement and conclusion of the project associated with the target crops to determine impact.

**Objective 2:** Improve climatic resilience of breadfruit through improved canopy management and investigating the diversity of breadfruit tree form.

**Objective 2.1** Identify best practice canopy and tree management options consistent with smallholder farmer production systems.

- Assess a range of pruning practices and schedules to control tree vigor, in terms of net yield and fruit quality.
- Assess alternative non-mechanical strategies to reduce tree vigor (including variable tree spacing and potential for soil nutrition management).
- Undertake smallholder farmer training in Fiji to communicate trial results.

**Objective 2.2** Investigate the genetic diversity of breadfruit to identify potential low tree form traits.

- Investigate diversity of breadfruit tree forms across the Pacific islands.
- Evaluate morphological traits of potentially natural dwarf/semi-dwarf varieties under standard growth conditions.
- Investigate grafting effects on breadfruit tree form.
- Analyse genetic diversity of tree form through characterising GA-related genes and comparative genomic analysis.

**Objective 3:** Provide targeted capacity building to private sector and government extension services in support of identified fruit value chains.

- Identify extension staff to receive training in pineapple, mango and citrus pre-harvest and postharvest handling practices. Provide pre-harvest and postharvest capacity building through participatory engagement in objective 1.
- A semi-commercial and demonstration tree fruit block established at Nishi Trading.

**Objective 4:** Enhance the engagement of smallholder farmers and communities in functional supply chains to maximise pro-poor and livelihood outcomes.

- Identify farmers, villages and communities based on a set of selection criteria that seeks to maximise poverty alleviation outcomes and gender-based engagement.
- Undertake ongoing engagement with collaborating communities to identify, minimise and mitigate risks to smallholder farmers participating in the project, and work with women within the value chains to ensure gender equity objectivities.
- Develop a monitoring, learning and evaluation framework using participatory methods, to evaluate and quantify project impact in terms of project outcomes and livelihood impacts for participating smallholder farmers.

# 5 Methodology

This project involved five fruits (papaya, breadfruit, pineapple, mango and citrus), selected on the basis of Pacific Government consultation, a desktop review of prior ACIAR Pacific horticultural projects, and input from the ACIAR Horticulture RPM. Project activities occurred between January 2016 and April 2021 in Fiji (Viti Levu and Vanua Levu Islands) Samoa (Upolu and Savai′i Islands) and Tonga (Tongatapu, Vava'u and `Eua Islands), with supplementary glasshouse and laboratory trials also undertaken in Queensland, Australia.

**Papaya**

Papaya value chain development focussed on supporting a future 'Fiji Red' papaya production capacity in Tonga and Samoa, based on better access to improved planting material. While a previous ACIAR-funded project [PC/2008/03] had enabled the expansion papaya industry in Fiji there had been little regional scale-out, with smallholder farmers in Samoa and Tonga having limited access to elite 'Fiji Red' papaya certified seed. In 2019, we commercially sourced 'Fiji Red' papaya seed from NWC in Fiji and assisted with its importation into Tonga and to Samoa. Seed was successfully germinated, and a small 'Fiji Red' papaya orchard established at the MORDI nursery at Nuku'alofa and at the SROS field station. Training in papaya agronomy and seed harvesting and storage was provided by staff from NWC, at the MORDI nursery. Concurrent training was not provided to SROS staff, given existing propagation expertise at MAF-Samoa.

**Breadfruit**

The breadfruit program included laboratory, glasshouse and field-based trials in Fiji, Samoa and Australia, involving NWC, MoA, SROS, CePaCT, UQ and USC. Noting prior ACIAR-funded research had improved breadfruit propagation, we focussed on research to improve agronomic and postharvest handling practice to address the following research questions: (1) Can postharvest shelf-life be extended to enable future sea-freight export? (2) Can fertiliser, pruning and cincturing protocols improve productivity? (3) Are there naturally occurring low form breadfruit trees? (4) Can tree height be manipulated (as a strategy to reduce cyclone vulnerability)?

1. **Extending postharvest storage life.** To enable sea-freight export of fresh breadfruit from the Pacific into New Zealand, postharvest shelf-life needs to be increased from 5 days[3] to 28 days. Postharvest research was led by SROS with trials undertaken in Samoa (Fig. 1). Consumer surveys (that included Pacific Islanders residing in New Zealand and Australia) were initially completed to create a fruit quality index[4] (Suppl. 1, pp. 17-18). Postharvest experiments assessed the effect of temperature x cultivar (*Puou* and *Maafala*) x location (north, north-west, south and north-east Upolu Island) interactions. Further trials to optimise shelf-life involving packaging and pre-conditioning were commenced, but subsequently discontinued due to limited success. In response to the end-of-project review recommendations, an alternative work program to explore breadfruit response to hot water disinfestation treatment (a low-cost alternative disinfestation in support of existing export pathways) was commenced with assistance from researchers at Plant and Food Research New Zealand. Postharvest trials examined the potential application of hot water treatment (HWT) verses existing high temperature forced air (HTFA) protocols, involving different temperature ramp rates,

[3] Under ambient storage conditions.

[4] Breadfruit fruit quality index [developed by SROS ] was a simple qualitative tool used to aid consumer surveys, and subsequent evaluation of skin damage during postharvest storage.

and cultivar (*Puou* and *Maafala)* response variability. There was a strong capacity building effort underpinning SROS's breadfruit postharvest research, with ongoing mentoring by Emeritus Professor Ron Wills, two SROS staff were funded to attend the UC David Postharvest short course in USA, and short-term research visits by SROS staff to postharvest laboratories in Australia and New Zealand.

Figure 1. Postharvest work to compare fruit quality from breadfruit heat treated with commercial high temperature forced air and hot water treatment.

2. **Breadfruit agronomy.** To increase net yield per hectare (especially in the early years of breadfruit orchard production) current tree spacing of 9 m x 9 m needs to be reduced (Jackson, 1989; Roberts-Nkrumah, 2015). In higher density-plantings, breadfruit trees will eventually require pruning to prevent loss of production as trees shade adjacent trees. Pruning is also required even for border planting trees.

   Given little published information on breadfruit agronomy and breadfruit production systems in the Pacific, a series of field trials were established by NWC and MoA in Fiji, with technical support provided by Ian Baker (Fig. 2). These trials assessed flowering and fruit development after pruning[5], tree response to varied fertiliser application regimes, and the effect of cincturing[6] and paclobutrazol[7] application on breadfruit flowering, with studies incorporating two commercial breadfruit cultivars, *Balekana ne Samoa* and *Uto Dina.*

   A preliminary pruning trial established at the Sigatoka Research Station confirmed that pruned shoots (5-10 cm back from the tip or cutting back a branch 50 cm-100cm from the tip) experienced delayed flowering (by up to 12 month). A trial to explore the effectiveness of paclobutrazol as either a soil (30 mL/tree) and foliar (4 mL/L, 3-4 Litres/tree, 2 doses) application, and Pro Cal (Regis) as a foliar spray following branch pruning was undertaken. This trial used four-year old *Balekana ne Samoa* and *Uto Dina* trees located at Votua Levu Methodist farm and involved five treatments and three replicates. A further trial to refine application treatment, involving increasing Pro-Cal (Regis) application rates from 0.25 g/L to 1 g/L was undertaken in 2019.

[5] In breadfruit trees, flowering is commonly delayed after pruning with farmers often reticent to prune resulting in large trees that are difficult to harvest and more vulnerable to high-wind events.
[6] Cincturing is used in some horticulture tree crops (such as litchi, mango and avocado) to moderate tree height and enhance flowering.
[7] Paclobutrazol is a plant growth retardant used to maintain tree form and cause early fruit set.


Figure 2. Breadfruit pruning trials in Fiji. (A) Breadfruit tree before pruning. (B) Breadfruit tree after pruning.

Three fertiliser trials were established by NWC, with trials located at Tui orchard in Nadi, the Sigatoka Research Station and Prakash orchard in Lautoka, to compare variable fertiliser protocols (i.e. monthly application compared to the current recommendation of every 3 months) on flowering. Trials included cultivar (*Balekana ne Samoa* and *Uto Dina*) x location x treatment effects relative to monthly fruit yield. There was lack of mature breadfruit trees co-located in the same place had a major impact on our capacity to undertake statistically sound agronomic trials[8]. A sugarcane burn on an adjacent farm also impacted on trial results (Fig. 3). These issues with trial design highlighted a need for local capacity building in experimental design and statistical analysis for collaborating NGOs. While plot design and analysis training was successfully provided to NWC staff in late 2019[9], this was undermined by the subsequent loss of project-funded staff when the project ceased.

Figure 3. Fire damage to trial

A small observational trial was undertaken at the Legalega Research Station, Nadi to determine the potential use of cincturing (involving ring barking of selected branches) on *Balekana ne Samoa* and *Uto Dina*, as a strategy to improve flowering and moderate tree height. While flowering of *Balekana ne Samoa* was increased

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[8] The lack of sufficient breadfruit trees [of a commercial-fruit bearing age] in a randomised experimental plot design, available for research trials in Fiji (or in Tonga and Samoa) not only had a major impact on our capacity to undertake statistically sound agronomic trials, but remains an ongoing issue. While a breadfruit cultivar evaluation plot exists at the Legalega Research Station, Fiji this was not suitable for potentially high intervention-type trials (i.e. pruning studies), highlighting the need for a second breadfruit agronomy plot to be established in Fiji.

[9] In response to the end-of project review recommendations.

following cincturing, a similar response was not observed in cinctured branches of *Uto Dina*. While cincturing may have a role in conjunction with pruning large trees *Balekana ne Samoa*, further trials were not undertaken (due to concerns about anticipated limited commercial adoption).

3. **Investigate the genetic diversity of breadfruit to identify potential low tree form traits.** UQ and CePaCT undertook field-based surveys of breadfruit genetic diversity in Fiji, Samoa, and Vanuatu in collaboration with MAF Samoa and VARTC Vanuatu. Morphology characters, including tree height, branch number, canopy shape, flower and fruit periods were documented. Dried leaves of the cultivars were also collected for molecular assay.



Figure 4. (A) Ms Arshni Shandil from the Centre for Pacific Crops and Trees (CePaCT- Pacific Community) surveyed the breadfruit diversity in Fiji. (B) A joint team from Fiji, Australia and Vanuatu conducted a breadfruit diversity survey on Malo Island, Vanuatu. (C) A joint team of the Secretariat of the Pacific Community (SPC), the University of Sunshine Coast (USC) and Ministry of Agriculture and Fisheries (MAF) of Samoa conducted breadfruit survey in Samoa.

4. **Can tree height be manipulated?** Glasshouse experiments undertaken by UQ and USC demonstrated that the stem elongation of breadfruit could be controlled by the exogenous application of gibberellin inhibitor, paclobutrazol. The genetic variation in GA biosynthetic genes was further investigated in breadfruit samples collected during the tree surveys.

   Intra species grafting, using both seeded and seedless varieties as rootstocks was carried out at CePaCT, Fiji. These included two seeded (*Uto Samoa* and *Uto Buco ni Samoa*) and two seedless (*Balekana* and *Uto Dina*) varieties. A total of 35 grafted plants had survived in the CePaCT screen house. However, only 25 breadfruit plants (9 controls, 16 grafted plants) were successfully growing in the field plot. CePaCT collected data on plant height and agronomic characteristics.

Figure 5. SPC CePaCT breadfruit field collection.

CePaCT has carried out the documentation of fruiting patterns for the breadfruit varieties currently in the field collection (Fig. 5). These included a total of 37 breadfruit plants with 31 unique varieties.

**Pineapple**.

A pineapple agribusiness desk-top study was undertaken by Koko Siga (Fiji) Ltd at the commencement of the project to identify and prioritise potential project research interventions (Suppl. 2). Based on this study, we focussed on improving pre-harvest and postharvest practice of smallholder pineapple farmers in Fiji, and to a lesser extent pineapple farmers in Samoa. Community selection and consultation was faciliated by MoA and FNU. Our pineapple research and capacity building effort centred on a large pineapple farming community located in the hills of Lawaki in Tailevu[10], North-east Viti Levu Island, Fiji (Fig. 6). A series of on-farm agronomic and postharvest pineapple farmer workshops were held in 2017 and 2018, with training provided Dr Aad van Santen, and staff from Koko Siga, USC, MoA and FNU. Additional pineapple farmer capacity building workshops were undertaken in the Ba and Ra Province with a supplementary pineapple masterclass for MoA extension staff held at the Seaqaqa Research Station, Vanua Levu, Fiji in June 2017. Through these week-long workshops, Fijian farmers and MoA extension staff received training in land preparation, erosion control, crop rotation, identifying nutritional deficiencies, fertiliser application, various floral induction methods, and postharvest handling practice.

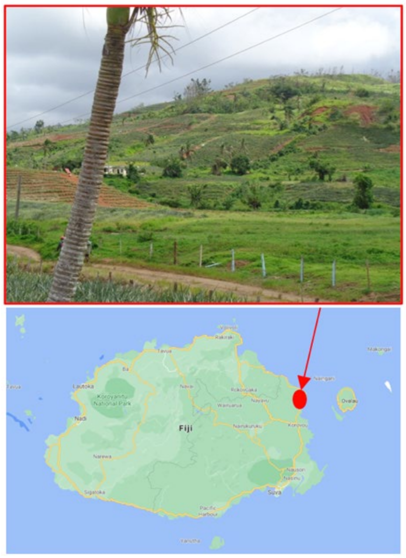

Figure 6. The location of the Vulagi settlement in Fiji.

To improve smallholder pineapple farmer postharvest practice in Fiji, baseline studies were undertaken in 2016 and again in 2017 by USC and FNU researchers. These studies centred on Vulagi Pineapple Farmers Association supplying into the Suva and Nausori municipal markets, and sought to identify current postharvest practice, key risk factors and quantify current commercial loss. Using participatory methodology, research results were shared with the association members through community dialogues, during which postharvest interventions were discussed and prioritised. Design options for improved harvesting equipment were developed and fruit colour grading charts produced (Suppl. 3), which were collectively provided to local stakeholders (MoA and Vulagi Pineapple Farmers Association).

In Samoa, postharvest pineapple supply chain studies were undertaken in 2016, involving farms in Alesia supplying product into the Fugalei municipal market, Upolu Island. Alesia farmers were selected based on prior engagement through a previous FAO-funded project. A rapid chain assessments were undertaken by USC and SROS. Based on research findings from a concurrent FAO-studies (Suppl. 4, 5), and a rapid postharvest chain analysis (Suppl. 6), 100 postharvest packing crates was sourced, imported and supplied to farmers throughout Upolu Island. A postharvest handling manual[11] (Suppl. 20) was further prepared and distributed to farmers and to USP, SROS and MAF.

In Tonga, a rapid assessment of pineapple production and postharvest handling practice was undertaken in Vava'u Island in late 2018 and early 2019[12]. Poor temperature

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[10] Most of whom were members of the Vulagi Pineapple Farmers Association. This farmer-led co-operative was very supportive of the project and actively engaged in capacity and research interventions. For further information on Vulagi settle please refer to: https://www.youtube.com/watch?v=3uSTDWUOcyA

[11]https://research.usc.edu.au/discovery/fulldisplay?docid=alma99450698802621&context=L&vid=61USC_INST:ResearchRepository&lang=en&search_scope=Research&adaptor=Local%20Search%20Engine&tab=Research&query=any,contains,steven%20underhill&offset=0

[12] But further information on postharvest handling practice in Tonga is available from https://research.usc.edu.au/discovery/fulldisplay?docid=alma99451108202621&context=L&vid=61USC_INST:ResearchRepository&lang=en

management associated with the use of small steel sea-freight containers to ship produce between Vava'u and Tongatapu was identified as a key risk factor. Further on-farm participatory postharvest trials could not be undertaken due to COVID-19 international travel restrictions.

**Mango**

The mango program was specific to Fiji[13] and involved trials to improve production practices through better management of flowering, fruit quality, cultivar selection and site location (collectively undertaken by Ian Baker and MoA staff), research to gain a better understanding of postharvest diseases of mango in Fiji (undertaken by Dr Mereia Fong Lomavatu), and a survey of pre-harvest pests of mango in Fiji (undertaken by FNU).

Figure 7. Trial application of Paclobutrazol to mango tree in Fiji.

Nine trials at four locations (Legalega Research Station, Nadi, Momi farm, Tom's farm Korovutu and Jack's farm) using six different varieties of mango (*Tommy Atkins, Nang Klang, Dina, Tahitian, Nam Dok Mai*, and *Kensington Pride*) and variable treatments of Paclobutrazol were established in 2016. Paclobutrazol was evaluated as a possible method to improve mango crop uniform in Fiji (based on enhanced flowering in poor seasons and stimulating early flowering to extend seasonality. In December 2017, MoA established further mango Paclobutrazol experiments at Saioko village, Ra province. The trial design involves three treatments (control, 20 ml and 40 ml[14] /tree) with seven replicates per treatment, using the cv. *Baramasia (Maqo Salusalu).* MoA extension staff received hands-on training in paclobutrazol dosage and application. Trials were maintained and monitored through to 2020. However, the limited number of replication due to not enough cultivars per location, and fruit theft throughout the project, compromised data interpretation.

Figure 8. Ms Mereia Fong Lomavatu, at the Ecoscience laboratories, Brisbane, working on mango disease identification.

Research on postharvest diseases of mango was undertaken in Fiji and in Australia. Initial field-based disease surveys occurred during the 2016 and 2017 mango season. Five local mango cultivars (*Maqo Dina, Maqo uto, Maqo loa, Salusalu* and *Peach* mango) were surveyed across five mango growing areas (Nadi, Ba, Lautoka, Rakiraki & Tavua) for postharvest mango diseases. Apart from local cultivars, five exotic cultivars (*Tommy Atkins, Kensington pride, Nam Doc Mai, Nang Klan Wan* and *Tahitian* mango) were also surveyed. Pathogen identification was undertaken by MoA staff (with support from QDAF pathologist Dr Lindy Coates). Field experiments to explore the possible suitability of hot water treatments, and optimise temperature

[13] The mango work plan was based on research interventions identified by a separate ACIAR-commissioned rapid assessment of the Fiji Mango industry ACIAR C2014/154, undertaken by Ian Baker in 2015.
[14] Dosage rate based on active ingredient.

was undertaken in 2018 in Fiji.

Concurrent mango pest surveys to be undertaken by FNU were only partially completed due to a series of staff changes and resignations. Various strategies including supplementary technical capacity building and re-aligning the program to other FNU staff were not successful, highlighting an urgent need for entomology capacity building assistance into FNU.

A variety trial of 10 selected mango-types in 5 replications was established by MoA at Legalega Research Station, Nadi between 2019 and April 2021. This trial included:

- *Mango Dina* – local Fiji variety, used for pickles. Susceptible to thrips and rainfall.
- *Tahitian* – early maturing variety.
- *Kensington Pride* – some rain tolerance, early maturing variety.
- *Baramasia* – rain tolerant, good quality, cropping. Long season. Not planted in Nadi.
- *Tommy Atkins* - rain tolerant in Fiji, good quality and good cropping.
- *Carabao* – some rain tolerance, good quality.
- Nang Klang – Thai variety.
- *Nam Dok Mai* – Thai variety with good postharvest disease tolerance.
- *Keitt* – late maturing to extend season, rain tolerant, good quality and cropping.
- *Brooks* - late maturing to extend season, rain tolerant, good quality and cropping.

In response to an end-of-project review recommendation to undertake a supplementary activity to support the development of a mango research strategy, a mango workshop was held in Fiji in Dec 2019. While the project team provided further technical support and promoted the merit of a research strategy, a shift in MoA research priorities in response to COVID-19 coupled with international travel restrictions, negated further progress.

## Citrus

The citrus program focussed on increasing commercial citrus production in Tonga[15], specifically the main population centre of Tongatapu Island and the adjacent `Eua Island. There was preliminary community and farmer consultation in Fiji and preliminary postharvest capacity building in Samoa.

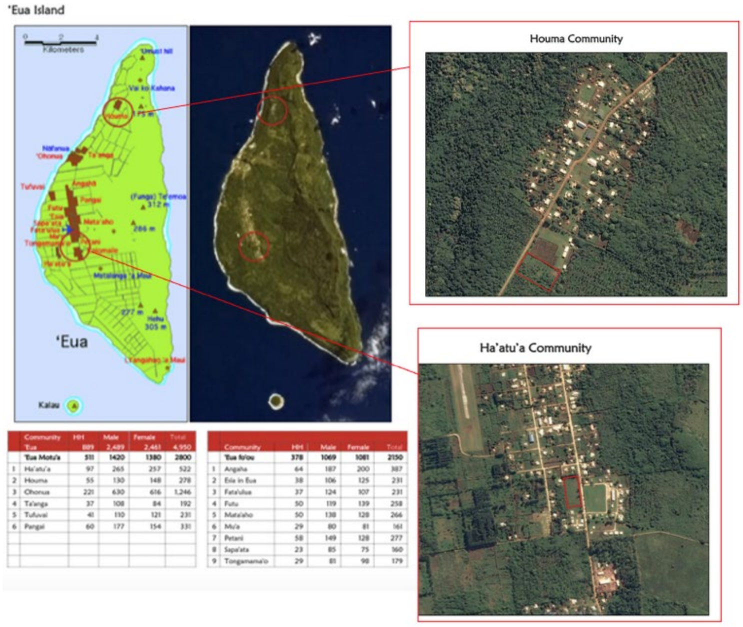
Most of Tonga's citrus historically comes from `Eua Island, however, production is primarily sourced from aging bush plantings that are predominantly seedling sourced, impeded by a lack of agronomic management, with associated declining product quality and production volumes. To increase local citrus production, new orchards needed to be established. We undertook multiple community-engagement fora[16] supported by MAFFF and MORDI to prioritise community and site selection (Suppl. 7, 8). Three potential orchard locations on Eua island were identified with sufficient area, good soil, availability of water for irrigation, and closeness to a community, with the Houma and Ha'tua communities on Eua Island finally selected in 2016. Negotiations with the Tonga Government was then undertaken to gain all approvals necessary, as the Ha'tua site was on Education Department Land and the Houma site was on King's land.

[15]Activities in Samoa and Fiji were limited to farming community consultation and value chain assessments, and postharvest capacity building workshop. Future support for the citrus industry in Samoa has been integrated into HORT/ 2019/165.

[16] Building on extensive community consultation undertaken by ACIAR SRA/HORT/2016/108.

Local citrus trees in Tonga are bush-grown and often difficult to harvest due to their height and large thorns. Being seeded-type, the fruit quality of these local trees is declining with time. Eating qualities of the fruit (texture, sweetness, shape, size, colour) are inconsistent and difficult to market relative to the imported citrus. Given this, we needed to source and import new citrus grafting material into Tonga. Multiple consignments of grafted citrus trees were imported into Tonga between 2016 and 2019, with material sourced from commercial citrus nurseries located in NSW. Given little information on potential cultivar compatibility to local soils and consumer cultivar-preferences, we sourced a wide range of citrus cultivars.[17] Varietal selection was restricted to those commercially available in Australia[18]. We were keen to plant a range of easy peel mandarins to give us the widest possible maturity window of up to six months. The earliest was *Imperial* followed by *Emperor* and then *Afourer.* They were selected based on proven performance in the sub-tropics/tropics with origins in sub-tropical China (Guandong Province). *Ellendale* (Tangor) is the latest selection planted. Further research has pointed to *Daisy* and *Fremont* due to their performance in the Northern Territory, which we plan to further import into Tonga via ACIAR HORT.2019.165. Similarly we are looking for a wide season for oranges using a *Navel* and a late Va*lencia* selection. These varieties are more challenging to grow because of their temperate Mediterranean origins. The *Tahitian Lime* and *Meyer lemon* were obvious selections because of their origins and well known good performance in warm climates.

Citrus trees were planted at the Houma community and at the Ha’atu’a community on `Eua Island (Fig. 9), and at Nishi Trading, Utulau, on Tongatapu Island. Land preparation and planting was conducted in November 2016 (Nishi Trading orchard) and in April 2017 (`Eua Island orchards) (Fig. 10). The citrus orchards on Tongatapu have benefited from extensive in-kind[19] contributions from Nishi Trading. Planting at the two `Eua Island sites involving participation from the Houma and Ha’atu’a community, and support from MORDI, MAFFF and the local District officers. In early 2017, a workshop was undertaken at each orchard community to raise awareness and provide preliminary training in orchard and tree management. Given the need to carefully monitor the trees in the first 12 months after planting, and to overcome a few unforeseen soil nutrition challenges, we initially employed a part-time community member to provide regular maintenance and technical updates. In early 2018, we moved into an important partnership with MORDI (a local NGO specialising in community engagement and development), with MORDI now coordinating ongoing orchard management and leading the




| | Community | HH | Male | Female | Total |
|---|---|---|---|---|---|
| | 'Eua | 889 | 2,489 | 2,461 | 4,950 |
| | 'Eua Motu'a | 511 | 1420 | 1380 | 2800 |
| 1 | Ha'atu'a | 97 | 265 | 257 | 522 |
| 2 | Houma | 55 | 130 | 148 | 278 |
| 3 | Ohonua | 221 | 630 | 616 | 1,246 |
| 4 | Ta'anga | 37 | 108 | 84 | 192 |
| 5 | Tufuvai | 41 | 110 | 121 | 231 |
| 6 | Pangai | 60 | 177 | 154 | 331 |

| | Community | HH | Male | Female | Total |
|---|---|---|---|---|---|
| | 'Eua fo'ou | 378 | 1069 | 1081 | 2150 |
| 1 | Angaha | 64 | 187 | 200 | 387 |
| 2 | Esia in Eua | 38 | 106 | 125 | 231 |
| 3 | Fata'ulua | 37 | 124 | 107 | 231 |
| 4 | Futu | 50 | 119 | 139 | 258 |
| 5 | Mata'aho | 50 | 138 | 128 | 266 |
| 6 | Mu'a | 29 | 80 | 81 | 161 |
| 7 | Petani | 58 | 149 | 128 | 277 |
| 8 | Sapa'ata | 23 | 85 | 75 | 160 |
| 9 | Tongamama'o | 29 | 81 | 98 | 179 |

Figure 9. The location of the Houma and Ha’atu’a community orchards established on `Eua Island, Tonga.

[17] Citrus cultivars selected and imported into Tonga included *Imperial mandarin, Meyer lemon, Emperor mandarin, Afourer mandarin, Valencia orange, Washington navel, Tahitian limes, Meyer lemon* and *Cox Hybrid* rootstock.
[18] New lines coming on stream over the last decade tend to be protected by PBR with consequent royalties.
[19] In kind support included extensive access to labour, equipment, land, chemical sourcing and application, tree monitoring, irrigation and pest and disease monitoring

project local community engagement activities. Importantly, MORDI has provided extensive co-investment into the two Eua Island orchards, purchasing farm equipment, chemicals, and water irrigation systems.

In April 2019, more citrus trees were imported into Tonga, including: 220 *Tahitian limes*, 15 *Imperial mandarin*, 11 *Meyer lemon*, 5 *Emperor mandarin*, 5 *Afourer mandarin*, 3 *Valencia orange*, 3 *Washington navel* and 7 *Cox Hybrid* rootstock. The importation of *Tahitian limes* sought to capitalise on a pending export pathway for *limes* into New Zealand (B. Wiseman *pers com.* 2018) and was co-funded by PHAMA+. Imported citrus trees were hardened at the newly established MORDI plant nursery, with 100 *Tahitian limes* deployed to expand Nishi Trading citrus orchard, and 100 to establish a new citrus orchard at MORDI's Nuku'alofa complex (Fig. 11). Other citrus species were planted at the two Eua orchards and the Nishi Trading orchard to replace a few plants that failed to survive the initial orchard establishment phase, and to expand plantings based on available


Figure 10. Project-established citrus orchards on Eua' and Tongatapu (Nishi trading site) Islands, Tonga during planting phasing in 2017 and in April 2021 concurrent with project completion)

To support a future local scaling-out of plantings, we sourced and imported commercial citrus rootstock seed (i.e. *Cox mandarin* hybrid and *Troyer citrange*). Earlier attempts to import root stock seed into Tonga in December 2018 and February 2019, needed to be postponed due to limited seed availability and then potential poor seed viability. In late 2019, root stock seeds were successfully germinated, and a root-stock seedling plot established at the MORDI plant nursery, with a preliminary citrus plant propagation workshop on fruit tree grafting undertaken in July 2020. Tree maintenance and monitoring continued through to April 2021 coordinated by Prof John Chapman, MORDI, and Nishi Trading[20] based on a project WhatsApp group.


Figure 11. The project has also provided technical support to a private-citrus orchard on `Eua Island (A), and in 2019 established a second citrus orchard at the MORDI nursery complex (B), on Tongatapu Island, Tonga.

**Fiji Citrus**. In 2017, USC and MoA undertook two missions to Vanua Levu Island to scope possible Fijian citrus community collaborators, with the Naweni community on the Southern side of Vanua Levu identified as a possible future collaborator. Multiple community fora were undertaken to scope community engagement capacity and support priorities (Suppl 9). An opportunity to assist this community, based on collaboration with a concurrent ACIAR agroforestry project FST/2014/067, was further identified during the mid-term review undertaken in late 2017. Researchers from both FST/2014/067 and HORT/2014/077 visited the community again in February 2018. While there was local stakeholder interest in expanding citrus production in Vanua Levu, to translate this interest [illegible] ding critical training support and overcome challenging inter-island postharvest transport logistic. Given limited available project resources and the project end date, we decided to alternatively focus on supporting and consolidating our newly established citrus orchards in Tonga.

**Samoa Citrus.** A series of preliminary community dialogues focussing on smallholder citrus farmers in the villages of Asau and Sataua[21], on Savaiʹi Island, Samoa were undertaken by USC, SROS and MAF in 2017. A rapid postharvest review and local stakeholder surveys of Savaiʹi to Apia citrus market value chain were completed, highlighting a need to improve the transport coordination and limited citrus cultivars diversity. While postharvest capacity building workshops were subsequently held in February 2017 and May 2018 in partnership with FAO, research interventions have been integrated into the work plan of the pending new ACIAR project HORT/2019/165.

**Research Ethics**

[20] From July 2021 through to Dec 2025, ACIAR-project (HORT/2019/165) will provide further technical support and additional capacity building to enable orchards to transition into sustainable enterprises.
[21] These villages (both located on north-western Savaiʹi Island) represent Samoa's main citrus production region.

This project had human research ethics approval from the University of the Sunshine Coast A16814, A16836, A16808, A201397 and S181253. MAFFF Tonga research permit was issued on 3/5/2016.

# 6 Achievements against activities and outputs/milestones

### *Objective 1: To increase the efficiency* of *fruit value chains through improved productivity and postharvest handling practices*

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| 1.1 | Papaya –value chain support | Regional papaya seed distribution chains improved–evidenced by new plantings or increased seed supply in Samoa and Tonga. | Yr2, m1 | **(Completed)** Seed was sourced and provided to MORDI (Tonga) and SROS (Samoa) in May 2019. Training in seed propagation was provided to staff at MORDI by NWC in Sept 2019. Papaya trees were planted at the MORDI and the SROS sites. MORDI is planning to distribute seed to rural communities via its TRIP-2 community development initiative once fruiting occurs. A trialled plot at SROS, planted by SROS staff failed. The trees did not grow well (poor tree structure) with low yield, and small fruit size. However, this seed has now been made available and may result in farmer uptake if persistent. While there appears to be a seed germination issue – it is unclear whether this was due to storage condition prior to sourcing or after importation into Samoa. It is also unclear whether poor tree growth reported in Samoa was due to poor agronomy or poor tree genetics. Given no issue was reported by MORDI (based on the same seed supply batch) we suspect poor agronomy. |
| 1.2 | Breadfruit –value chain support | Breadfruit postharvest sea-freight storage protocols (Samoa) trial completed, documented, and communicated to industry stakeholders. One report. | Yr4, m6 | **(Completed)** Postharvest experiments have shown that the maximum storage life for cv. *Puou* was 11 days and 16 days for *Maafala* fruit based on 17°C cool storage. 1 report was completed: Molimau-Samasoni S., et al., (2020) Effect of low temperatures on the storage life of two Samoan breadfruit (Artocarpus altilis) cultivars. J. Hort. Post. Res. 3:91-96. However, that maximum storage period was less than the required 21 days to allow the reliable shipment of fruit by sea. While further trials were proposed to explore supplementary strategies the end of project reviewers requested an alternative review of the agribusiness investment case for Breadfruit. To action, SROS travelled to Fiji, and Tonga in late 2019 and have completed this assessment. A report has been prepared by SROS (Suppl. 10). |
| | | Domestic breadfruit postharvest handling practices in Samoa assessed and remediation options communicated to the industry. One report. | Yr1, m12 | (**Completed**) Breadfruit postharvest handling practices for Alesia to Apia supply chains were assessed in October 2017. A short report has been prepared and was distributed to the participating enterprise (Suppl. 6) - *Natural Foods Samoa*. |

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| | | One postharvest workshop in Samoa | Yr1, m6 | **(Completed)** Rather than hold a parallel and possible competing breadfruit workshop, we alternatively gave a series of presentations at the Samoan Breadfruit Summit in October 2017 – this ensured a wider audience.<br>We also incorporated postharvest breadfruit harvesting recommendations in two FAO postharvest workshops held in Samoa (February 2017 and March 2018). |

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| 1.3 | Pineapple – value chain support | Agribusiness assessment of pineapple industry chains in Tonga, Samoa and Fiji completed. One report. | Yr1, m12 | **(Completed)** An agribusiness assessment of the pineapple industry in Tonga, Samoa and Fiji was completed by Koko Siga Fiji in April 2017 and a 65-page report produced. Report available (Suppl. 2). |
| | | Hormonal flowering induction methodology training workshop undertaken in Fiji, and Samoa. | Yr2, m6 | **(Completed)** Three pineapple workshops that included hands-on training in flowering induction methodology have been held in Fiji (one in Natovi in February 2017, one in Ba in March 2017, and one in Seaqaqa Research Station in June 2017). These workshops were undertaken jointly with MoA staff with the Seaqaqa Research Station workshop being specifically targeted at MoA extension officers. Workshop reports are available (Suppl. 8). Given PIFON undertook a similar pineapple floral induction training in Samoa in the last 12 months, there was little merit in repeating this training in Samoa. Instead, two additional training workshops (Ba and Seaqaqa) were undertaken in Fiji.<br>Suppl. 14 highlighted very good attendee feedback. MoA Fiji has now taken the lead on promoting flowering induction practice to farmers in Fiji<br>https://www.youtube.com/watch?v=bCj-UQ5nOVE |

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| | | Analysis of pineapple postharvest supply chain risk factors in Fiji, and Samoa completed. | Yr1, m12 | **(Completed)** An assessment of pineapple supply chains in Samoa was undertaken in October 2016. Two postharvest supply chain reviews were undertaken in Fiji (peak and out-season supply chains from Natovi, Fiji) in October 2017, and February 2018, with results communicated to farmers in July 2018. FNU has revisited farmers in late 2019 to provide further extension support. Two additional pineapple supply reviews were commenced in late 2018 by JAF PhD scholar Mr Shalendra Prasad and ACIAR Twinning Master student Mr Kelemeni Navucu. Both studies aimed to quantify postharvest best practice and key loss determinants in Fiji in support of possible future postharvest farmer handling practice remediation. Mr Kelemeni Navucu completed his master's thesis in Feb 2020. Mr Prasad completed analysing survey data in June 2020[22] |
| | | Analysis of pineapple postharvest supply chain risk factors in Tonga completed; and collective results for Fiji, Samoa and Tonga communicated to industry. | Yr3, m12 | **(Tonga –completed).** FNU, USC and MORDI staff visited Vava'u Island (Tonga) in November 2018 and undertook a rapid assessment of pineapple handling practice. Postharvest handling temperature management during ferry-based transport between Vava'u and Tongatapu was examined in February 2019. Postharvest loss for pineapples in the Tongatapu market were assessed and not found to be significant. **(Fiji-Completed)** Research results were communicated back to Fiji pineapples through a workshop undertaken in July 2018 at Vulagi, Viti Levu (report available). While this activity is completed, we are still working with pineapple farmers at the Vulagi settlement based on new participatory trials to assess new sledge designs aimed at improving harvest practice from steep slope plantations. Two representatives from Vulagi were also funded to travel to Seaqaqa Research Station in early 2019, to see the ongoing MoA pineapple cultivar trial studies. **(Samoa- completed)** Two postharvest handling workshops were held (jointly with FAO) in Alesia, Upolu Island and in Asau Savai'i Island, to communication postharvest results and farmer recommendations. |

[22] Data is part of a PhD thesis ongoing [as of August 2021]. When completed in July 2022 – a copy of the thesis will be available from USC Research Bank https://research.usc.edu.au/discovery/search?vid=61USC_INST:ResearchRepository

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| | | Developed and optimised sea freight storage protocols for Samoan pineapples. | Yr3, m12 | **(Not-Completed.)** While niche export opportunities for Samoan pineapples to New Zealand were identified (McGregor, 2017), the current domestic pineapple production in Samoa has remained small and limited to a few medium-scale farmers. Efforts to establish the Samoan pineapple export pathway into New Zealand (first flagged in 2013) has not been finalised, and remains under-consideration, (B. Wiseman *pers com.* 2019). It is therefore premature to undertake trials to optimise sea freight storage protocols for Samoa pineapples. In discussion with the end-of project review team and RPM, it was agreed that this milestone should not be progressed, but rather further work on hot water treatments for breadfruit as possible lower cost alternative to HTFA be undertaken. This activity was successfully undertaken and results published: *Molimau-Samasoni, S., et al. (2019). A comparison of postharvest quality of breadfruit (Artocarpus altilis) after disinfestation with hot air or hot water treatments. New Zealand Plant Protection, 72, pp.67-74* |
| 1.4 | Fiji mango industry development | Field trials to test the Paclobutrazol and azoxystrobinin regulating flowering established in Fiji. | Yr1, m12 | **(Completed)** Field trials have been established based on six different varieties of mango (*Tommy Atkins, Nang Klang, Dina, Tahitian, Nam Dok Mai, and Kensington Pride*) and variable treatments of Paclobutrazol. Based on preliminary data, paclobutrazol appeared to improve flowering in some mango cultivars and in some production conditions in Fiji. Because treatment is relatively low cost (FJD $4-5/1.5 kg) and easily applied as a soil drench, we believe it has potential as a commercial treatment in Fiji.<br><br>Ian Baker travelled to Fiji in Dec 2019, to assist NWC, and MOA to analyse mango flowering data for 2019. Data supported a similar response observed in previous years (i.e. more flowering due to paclobutrazol treatments). |
| | | Small fruit bagging trial established in Fiji. | Yr1, m12 | **(Completed)** Field trials have been established at Legalega research station. |

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| | | Small fruit bagging trial assessment completed. | Yr4, m12 | **(Completed)** Results collected in 2018/2019 have shown that bagging improved fruit quality; based on the incidence of skin blemish being reduced from 38% in the control, to between 13% and 19% when fruit were bagged (depending on the number of fruit per bag). However, based on the time and cost incurred to effectively bag fruit during the trials, MoA does not consider this technique commercially viable in Fiji at the present time. |
| | | A technical report on mango pre-harvest pests in Fiji. | Yr2, m12 | **(Not Completed)** There were a series of delays in initiating this study due to several FNU staff resignations. An attempt to link this work to an ACIAR-USP twinning scholar was also not successful. An initial preliminary baseline study commenced [in Feb 2019] (prelim. report available). As requested in the end-of-term review, Dr Mike Furlong was approached to provide some mentoring to FNU staff undertaking this survey. There has been a further resignation from FNU (in early 2020), negating this training opportunity. We have now collaborated with three FNU staff, each of which have either failed to start or to complete research tasks. Research mentoring and training to overcome this problem has also not proven successful due to staff changes and resignations. |
| | | A publication on pre-harvest pathogens in mango in Fiji. | Yr2, m12 | **(Completed)** An extensive review of mango pathogens was undertaken by Ms Mereia Fong Lomavatu published as part of her PhD thesis. This study also identified a series of farmer strategies to reduce the incidence of postharvest disease in Fijian-grown mango. Ms Lomavatu was awarded her PhD in December 2018 and has now returned to MoA, creating additional Institution capacity outcomes (i.e. MoA now has research expertise in postharvest plant pathology, expertise not previously present) |
| | | Cultivar evaluation trial established to compare cv. *Tommy Atkins* and cv. *Mango salusalu* (Baramasia). | Yr2, m12 | **(Completed)**. A variety trial of 10 selected mango varieties has been established at Legalega Research Station, Nadi this trial includes cvs. *Tommy Atkins, Kensington Pride, Nang Klang, Brook, Baramasia*; *Dina, Carabao, Tahitian, Nam Dok Mai,* and *Keitt*. |
| | | Mango training workshop. | Yr4, m12 | **(Completed)** A Fiji mango farmer workshop was undertaken by Ian Baker and MoA in December 2019. |
| 1.5 | Citrus industry development support in Fiji, Tonga and Samoa. | Review citrus value chain in *Vanua Levu* in terms of agribusiness potential. One joint report | Yr2, m12 | **(Completed)** Prof Chapman travelled to Vanua Levu in Nov 2017 to assess citrus plantings. Further community discussions were undertaken by Dr Singh-Peterson in Feb 2018.<br>One detailed report "*Appraisal of a potential community-based citrus project in Fiji*" has been prepared by USC and MoA researchers (Suppl. 9). |

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| | | Citrus commodity specialist has assessed horticultural skill needs in Tonga and identified appropriate cultivars for planting | Yr1, m12 | **(Completed)** Two trips were undertaken in early/mid 2016 to assess current horticultural skills, identify key risk factors in advance of deployment of new citrus planting material. In Nov 2016, a workshop featuring both the Houma and Ha'atu'a communities was undertaken with planning for the future management of the trees plus a technical workshop conducted. |
| | | New citrus genetic material imported in and commercial planted. | Yr2, m12 | **(Completed**) A total of 657 citrus trees have now been imported into Tonga (based on two imported shipments) to help re-build domestic fruit production. Citrus trees have been deployed to three sites; Houma and Ha'atu'a communities on `Eua Island; and Nishi trading on Tongatapu Island. To date, we have had extremely good establishment rates, with a current mortality rate of 5% associated with initial importation in 2016.<br>**(Additional output)** To support local propagation, importing commercial root stock seed (based on Cox Mandarin Hybrid and Troyer Citrange material into Tonga in June 2019. Two prior attempts in late 2018 and early 2019 were unsuccessful due to limited seed availability and more recently seed viability issues.<br>MORDITT has also sourced and planted local citrus seed, with the aim of including them in a future rootstock evaluation trial in Tonga. |
| | | `Eua community fruit nursery established and appropriate training provided. | Yr3, m12 | **(Not undertaken)** Given Tongan citrus orchards (established by the project) are still less than 3 years-old, our primary focus was to ensure that current orchards were well maintained and progressed to a first commercial harvest. Establishing a community-nursery at this stage [and in the absence of suitable root stock material being available] was considered premature – this objective has been alternatively incorporated into phase-2 project HORT/2019/165. This action was discussed and supported by the end-of-project review.<br>**(Alternatively undertaken).**<br>Commercially sourced citrus root stock seed was imported into Tonga in August 2019 and successfully germinated. Similarly, locally-sourced citrus material for root stock evaluation has also been planted. Given COVID-19 travel restriction a virtual citrus propagation/grafting workshop was undertaken in August 2020. Initial success was unfortunately poor. Follow-up and more intense training is planned for late 2021 (by HORT/2019/165). |

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| | | Postharvest handling training provided to community. | Yr3, m6 | **(Completed)** Postharvest training has been provided to Samoa farmers in NE Savai'i in 2018. Given the nascent nature of citrus production in Tonga, generic postharvest awareness training was provided to Tongan farmers (and vendors) in Dec 2019. |

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| 1.7 | Economic impact | Baseline economic data will be gathered at the commencement and conclusion of the project (USC, supported by MAF, MoA and MAFFF) | Yr1 m6 & Yr3 m12 | **(Completed).** The Fiji, Tonga and Samoa government departments and local stakeholders were interviewed in March to April 2021 to document potential project impacts. (see appendix and Section 8 – IMPACT in this report).<br><br>**Product, community engagement and agribusiness data.**<br>• Information on the Tonga fruit industry has been collected and reported in *Journal of Agriculture and Rural Development in the Tropics and Subtropics 118 (1): 91-103.*<br>• Information on the pineapple industry in Samoa, Fiji, Tonga has been collected and reported in *McGregor, A (2017) Pineapple Agribusiness Opportunities for Fiji, Samoa and Tonga: Report Prepared for the ACIAR Tropical Fruit Project (ACIAR HORT/2014/077) 67pp.* (Suppl. 2)<br>• Information on citrus in Fiji has been collected and reported in: Rapid appraisal of a potential community-based citrus project in Fiji” prepared by Dr Singh-Peterson (USC), Mr Iranacolaivalu (MOA Fiji) and Ms Colaitiniyara (MOA Fiji) (report available).<br>• Baseline data on the Fiji mango industry has been collected (Baker 2016 report).<br>• Baseline data on Breadfruit input costs have also been collected (Baker 2018 April report).<br>**Postharvest data.**<br>• Quantification of postharvest economic loss associated with existing fruit value chains has been reported in a series of academic papers, and book chapters, specifically:<br>o Underhill, S.J.R, Sherzad, S., Zhou, Y., Molimau-Samasoni, S., Tagoai, S.M. (2019) Postharvest loss in fruit and vegetables markets in Samoa. In Food Security in Small Island Developing State. Edits. Connell, J., and Lowitt, K. Chapter 7. pp 27. Springer publishing, United Kingdom.<br>o Underhill, S.J.R, Sherzad, S., Zhou, Y., Singh-Peterson, L, Tagoai, S.M. (2017) Horticultural postharvest loss in municipal fruit and vegetable markets in Samoa. Food Security. 9(6): 1373-1383 (DOI: 10.1007/s12571-017-0734-7) |

***Objective 2: To improve climatic resilience of breadfruit through improved canopy management and investigating the diversity of breadfruit tree form***

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| 2.1.1 | Assess a range of pruning practices and schedules to control tree vigor, in terms of net yield and fruit quality. | In consultation with Ian Baker, NWC a range of pruning techniques identified and trials to evaluate their effectiveness in reducing tree size and relative to yield established. | Yr1 m12 | **(Completed)** A series of field trials were established in August 2017, at various sites to evaluate different pruning application on breadfruit.<br>An initial small pruning trial at Sigatoka, highlighted that pruned shoots can take a long-time to flower, reducing subsequent fruiting. These trials were finally assessed in Dec 2019. |
| | | A minimum of three pruning methods assessed over at least 2 years in terms of yield and fruit quality, and a cost benefit margin calculated. | Yr4 m12 | A subsequent trial to assess the potential of Paclobutrazol as a possible treatment to counteract the negative effect of pruning on flowering intensity, demonstrated good results. We found that Paclobutrazol applied as either a soil drench or a foliar spray had an immediate and positive effect on the incidence of flower production in pruned breadfruit trees. This effect was sustained in the next flowering in November and there were no obvious negative effects on the tree or leaf production. Ian Baker travelled to Fiji in Dec 2019, to assist NWC, and MOA to initiate three new breadfruit trials on farmer properties on paclobutrazol rate and timing. |
| | | 1 report/workshop or conference paper documenting research findings | Yr4 m12 | While a presentation at the International Conference on Agriculture (IC-AGRI-21) in Suva, Fiji was planned, this has not occurred due to the event being rescheduled due to COVID-19 local travel restrictions. A technical report has been prepared (Suppl. 11). |
| 2.1.2 | Assess alternative non-mechanical strategies to reduce tree vigor (differential tree spacing, soil nutrition status). | A trial plot of 3 different tree-planting densities (of the same cultivar) will be established; one of which being the existing plot associated with the PARDI Breadfruit project.<br><br>Data on tree height, yield obtained from first fruiting<br><br>The potential relationship between soil nutrition and tree vigor has been assessed | Yr1 m12<br><br>Yr4 m12<br><br>Yr4 m12 | (**Completed)** Three trials were established by NWC to assess the effect of variable fertiliser applications (Sigatoka and Lautoka – two trials), and a combined fertiliser + pruning regime (Legalega – one trial), on tree productivity.<br>Preliminary observation showed cv. *Uto Dina* variety, treatment with a N.P.K fertilising regime of (13:13:21) at 2 kg per year with 500g/quarter, without pruning, appeared to the largest yield. Unfortunately, this trend in the first two trial could not be replicated.<br><br>In mid-November 2019, Dr Yuchan Zhou provided training on statistical analysis and experiment design @ NWC, Fiji to technical staff (including Kaitu) aimed at improving experimental design and data interpretation capacity. |

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| | Undertake smallholder farmer training in Fiji to communicate trial results. | One training workshop for local smallholder farmers undertaken in Fiji to communicate key research findings | Yr4, m12 | **(Completed)** A smallholder farmer workshop to communicate the research findings from the project was held in Nadi, Fiji in December 2019 (coordinated by Ian Baker, and attended by local farmers, NWC, and MoA staff). |
| 2.2.1 | Investigate diversity of breadfruit tree forms across the Pacific islands. | USC research visit to Fiji to refine experiment plan undertaken | Yr1, m6 | **(Completed.)** Meetings were held between the USC/UQ project team (Professor Underhill and Dr Zhou) and CePaCT Team (Valerie S. Tuia, Logotonu Waqainabete, Reapi Masau, *et al*) in April 2016. Discussion involved the project overview, budget and activities involved. |
| | | Survey of varieties in Pacific Islands to investigate and collect reported low-habit trees completed. | Yr2, m12 | **(Completed)**<br>1) A survey by CePaCT was carried out in Fiji along Viti Levu, Tailevu and Nadi villages where the most genetic diversity of breadfruit exists. Fourteen varieties were characterised. A further 41 breadfruit accessions held at CePaCT were also characterised.<br>2) A breadfruit survey joined by CePaCT, USC and Samoa Ministry of Agriculture and Fisheries was carried out in Samoa from 27th Nov. to 2nd Dec 2018. The survey covered most of the coastal areas at Upolu and Savai'i islands. Nineteen varieties were characterised.<br>3) A breadfruit survey in Vanuatu was conducted in June 2017 through collaboration of CePaCT, USC and Vanuatu Agricultural Research and Technical Centre (VARTC). Eighty-two breadfruit varieties were surveyed, and leaf samples were collected (Suppl. 12). |
| 2.2.2 | Growth of potential natural dwarf varieties | Nursery-based cuttings of potential natural dwarfing material established at SPC CePaCT glasshouse and evaluation commenced | Yr2, m12 | **(Completed)** No dwarf phenotypes were found during all the survey trips,[23] however:<br>1) Nine varieties following the Fiji survey were collected and raised at CePaCT. A further 18 breadfruit varieties were marcotted at Natewa Bay, Vanua Levu through collaborative work between the Ministry of Agriculture and CePaCT.<br>2) Due to changed policy in Biosecurity Authority of Fiji (BAF), varieties from Samoa and Vanuatu have not been transported back to CePaCT. |
| | | Nursery-based cuttings of potential natural dwarfing material completed. | Yr3, m12 | **(Completed)**<br>No dwarf phenotype was found during the surveys. |

[23] We did not anticipate identifying any natural dwarfing types, but based on some reports in the literature, we needed to first exclude this possibility.

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| 2.2.3 | Evaluation of intra-species grafting of fertile (seedy) breadfruit to reduce tree stature. | Grafting experiments to assess the potential of seedy breadfruit as stock completed.<br><br>1 report and results presented through breadfruit workshop identified in milestone 2.1.2. | Yr4 m12 | **(Completed)** CePaCT has continued intra species grafting, using seeded *vs* seedless varietal combinations of scions and roots stocks. For seeded, 2 varieties were used – Uto Samoa and Uto Buco ni Samoa. For seedless, Balekana and Uto Dina varieties were used. Unfortunately, only 35 plants survived the 'adjustment' period in screen house and were planted in the field.<br><br>Preliminary results generally indicate that self-grafting regardless of variety type (seedless or seeded) reduces plant height. In addition, balekana as a normal low growing variety appears to have an effective impact on reducing plant height when using as a scion regardless of root stock type. Unfortunately, the effect of balekana as a rootstock could not be determined from this small research.<br><br>Documenting breadfruit fruiting pattern has been ongoing for a total of 31 varieties currently in the CePaCT field collection.<br><br>**(Completed)** Inter-specific grafting was carried out at USC. Breadfruit was successfully grafted onto Marang, Pedailai and Lakoocha rootstocks. Growth analysis revealed a dwarf phenotype of breadfruit trees growing on marang rootstocks. The height of breadfruit trees on marang rootstocks was reduced by 59% within 18 months after grafting. Recent results suggest GA plays a role in the dwarf phenotype of breadfruits growing on marang rootstocks. The findings can be applied to breadfruit breeding program for vigour control and developing dwarf phenotype.<br><br>Sourcing Marang seeds for inter-species grafting trials in Fiji could not be resolved. Despite several efforts, we were not successful in getting seeds into Fiji. A key factor is the short fruiting season of Marang and the short storage life of the seeds. |
| 2.2.4 | Genetic diversity through charactering GA-related genes and comparative genomic analysis | Sampling, isolation and sequencing of GA genes completed<br>Genome structure of GA gene characterised<br>Gene expression analysis completed<br>DNA extraction and PCR completed. | Yr3, m12 | **(Completed)** A total of six GA20-oxidase genes, *AaGA20ox1- AaGA20ox6*, and four GA2-oxidase genes, *AaGA2ox1-AaGA2ox4* were isolated from breadfruit. Two DELLA genes, *AaDELLA1* and *AaDELLA2* were also cloned from breadfruit. Sequencing of these full-length genes were completed, and genomic structure characterised.<br>The expression profiles have been investigated in both vegetative and reproductive organs of breadfruit plants, and under different growth conditions, including treatment of exogenous application of gibberellin and paclobutrazol, and treatment of drought and high salinity. |

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| | | Genetic diversity through comparative genomic analysis Completed. | Yr4, m12 | **(Completed)** Genetic variation in two GA biosynthetic genes, *AaGA20ox2* and *AaGA20ox3* was investigated in breadfruit samples collected during the tree surveys. These include 16 varieties from Fiji, 19 varieties from Samoa, 48 varieties from Vanuatu, and 28 varieties from CePaCT collection (Kiribati, 5; Marshall Islands, 2; Solomon Island 1, Samoa, 3 and Fiji, 10). Sequence comparison across all samples revealed that the *AaGA20ox3* genes share 99% similarity across all samples at protein level. The Samoa *AaGA20ox2* genes have 96% identity to the *AaGA20ox2* of all other pacific regions while the rest of the *AaGA20ox2* genes share 99% similarity at protein level. |

***Objective 3: To enhance private sector and Government research and extension capacities in support of fruit industry development.***

| No. | Activity | Outputs/ Milestones | Completion date | Comments |
|---|---|---|---|---|
| 3.1 | Extension officer training | A steering committee established. | Yr1, m6 | **(Completed)** Steering committee[24] meetings involving Government representation from Samoa, Fiji and Tonga were held in June 2016 (Samoa) and July 2018 (Brisbane). The 2017 steering meeting was not held due to delays in the MAFFF Tonga nomination, the mid-term review preparations, and a change in the Samoa representation. The 2019 meeting was held in Samoa concurrent with the breadfruit summit. A series of six-monthly country specific project reports were provided to Tonga, Fiji and Samoan Government. |

[24] The project steering committee included Government representatives from each of the collaborating countries/agencies [including: Tilafono David Hunter (Samoa), Villiami Manu (Tonga), Shalendra Prasad (Fiji), Dr Siosiua Haiavatau (SPC)] and the ACIAR project leader (Australia).

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| | | Based on participatory involvement in objective 1 activities, MAF, MoA and MAFFF extension provided with training in pineapple, mango and citrus pre-harvest and postharvest handling practices (USC to coordinate) | Yr2, m12 | **(Completed)**<br>**(Fiji).** A pineapple master class was held in Seaqaqa, June 2017. This workshop was aimed at capacity building MoA extension, research and field staff (25 attendees) to help them better assist Fiji Pineapple farmers. Participatory training of MoA has also been provided in mango Paclobutrazol application provided in December 2016.<br>**(Tonga)** Capacity building of MAFFF and MORDI staff in citrus tree management has been ongoing since Nov 2016, based on staff co-involvement in nutrient disorder identification, pruning and tree management, and fertilise scheduling, associated with the `Eua community citrus blocks. Additional training support has also been provided to a commercial citrus orchard owner on `Eua Island.<br>**(Samoa)** Staff from SROS have travelled to Fiji in Dec 2018 to meet with NWC breadfruit researchers and visit breadfruit production and export facilities. SROS staff have also travelled to NSW (University of Newcastle, NSW and to New Zealand to receive further training in postharvest methods in support of breadfruit trials.<br>Fijian MoA extension staff have benefited from the mango workshop held in December 2019.Two SROS staff attended the UC Davis Postharvest short course in June 2019. |
| 3.2 | Establish ongoing fruit demo and training plot in Tonga | A semi-commercial and demonstration tree fruit block site preparation and appropriate fencing completed, and initial sourcing of planting material commenced. | Yr1, m12 | **(Completed)** Site preparation for the demonstration block at Nishi trading completed in 2016. |
| | | A semi-commercial and demonstration tree fruit block established at Nishi Trading (Nishi trading, supported by USC consultants, and MAFFF) | Yr4, m 12 | (**Completed)** A collection of mixed citrus cultivars were imported into Tonga in Nov 2016 and planted in early 2017 at Nishi Trading. A further shipment of 68 mixed fruit trees was purchased and relocated to Tongatapu in Oct 2017, but experienced high mortality due to poor in-transit preparation by the Australian nursery. A further shipment of planting material from a different nursery was imported in November 2018 and similarly planted at Nishi Trading in early 2019. MAFFF has self-funded the importation of further citrus material (+1500 trees into Tonga in Feb 2020.) In partnership with PHAMA+ an additional 200 T/limes were imported into Tonga in April/May 2019 with 100 plants to be added to the Nishi trading fruit orchard and a second fruit demonstration plot established at the MORDI complex in Dec 2019. |

***Objective 4: To enhance the engagement of smallholder farmers and communities in functional supply chains to maximise pro-poor and livelihood outcomes***

| No. | Activity | Outputs/ milestones | Completion date | Comments |
|---|---|---|---|---|
| 4.1 | Identify farmers, villages and communities in Tonga that the project team will work with, based on a set of selection criteria | Selection criteria developed and communities consulted to assess interest to participate | Yr1, m6 | **(Completed)**<br>Undertaken as a two-part selection exercise.<br>• `Eua was chosen based upon socio-economic, and agribusiness criteria established in previous ACIAR Small Research Project.<br>• Site selection criteria were developed from consultation with project partners MAFFF, MORDI and private industry partner Nishi Trading. Further consultation was undertaken with the Government Representative of `Eua, the People's Representative of `Eua (current Minister Finance), CEO Ministry of Education and Trade, the King's Advisors, District Officers, School Principals, and Town Officers in `Eua.<br>• Discussion forums were held with the Houma School PTA and the Ha'atu'a School PTA in April 2016 to introduce the project, outline the work program of a potential citrus project and to determine if the community was interested in participating in the project. |
| | Identify farmers, villages and communities in Samoa and in Fiji that could potentially participate in a proposed citrus project - based upon a set of selection criteria | Selection criteria developed and communities consulted to assess interest to participate | Yr1, m6 | **(Completed)**<br>• Selection criteria was established for Samoa and Fiji community-based projects – amended from that determined for Tonga.<br>• Interviews undertaken with MoA, SROS, and market vendors in June 2016. A discussion forum in Savai'i with the Sataua community undertaken in February 2017.<br>• Interviews undertaken with pineapple farmers in Ba, the pineapple co-ops in Natovi Jetty region, Viti Levu, and MoA in September 2016. These interviews revealed that there was little community impact of activities with individual farmers, and women were not involved in activities with the pineapple co-ops.<br>• Further 8 interviews undertaken with the MOA research and extension staff, Batiri citrus orchard manager, horticulture consultant.<br>• Community discussion forum with the Naweni community identified a citrus community facing disadvantage who were enthusiastic about being involved in a horticulture-based project. 1 report was prepared (Suppl. 9). |

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| 4.2 | Undertake ongoing engagement with collaborating communities in Tonga to identify, minimise and mitigate risks to smallholder farmers | Stakeholder analysis and community workshops undertaken.<br><br>Project tasks are aligned with community's governance structure. | Yr1, m12 | (**Completed)**<br>Stakeholder analysis and community governance structure have been identified. Work program prepared for citrus tree planting and a maintenance program developed. MORDI took over leadership of the community consultation and engagement activities in late 2018, which has involved ongoing consultation with local communities and local small holder farmers interested in expanding into citrus production. |
| | | Discussion forums and targeted interviews undertaken to identify risks, challenges and barriers to the `Eua citrus project in Tonga. Strategies to remediate or minimalise obstacles have been identified. | Yr1, m12 | **(Completed)** Community workshop held for both participating communities in April 2017, sessions facilitated by project partners MAFFF, MORDI and USC.<br><br>Community maintenance programs and Risk strategies developed. |
| | | Interviews to determine how a side project can be attached to the community citrus projects in `Eua that will specifically benefit women and girls. | Yr1, m12 | **(Completed)** While extensive community engagement has occurred in Tonga (see above), this objective was impacted due to the resignation Dr Lila Singh-Peterson in August 2018. Two projects were subsequently identified (women-based fruit value-added enterprises and women-based household plant nurseries). Both of these initiatives were included in the design of the HORT/2019/165, which commences in July 2021. |
| | Community engagement with a community of subsistence farmers in Savai'i, and another in Vanua Levu will be undertaken to determine the logistics and needs / requirements to expand the local citrus industry. | A stakeholder analysis and select stakeholder interviews undertaken to evaluate (i). requirements for a citrus project (skills / training/ knowledge needed) (ii). Risks associated with a prospective project and (iii). Willingness of the community to contribute to a citrus project. | Yr2, m12 | **(Completed)** Community consultation has been successfully undertaken at four citrus communities:<br>• Sataua community in Savai'i, Samoa<br>• Naweni community, Vanua Levu, Fiji<br>• Houma and Ha'atu'a communities on `Eua Island, Tonga<br>HORT/2019/165 will continue the process of community engagement, specific seeking to better understand the incentives and barrier to community participation in citrus value chains (particularly focussing on women). |
| 4.3 | Develop a monitoring, evaluation and learning framework using participatory methods to evaluate and quantify project impact in terms of project outcomes and livelihood impacts for participating small holder farmers. | Community workshops undertaken in Tonga and Fiji to identify livelihood goals and livelihood transition pathways.<br><br>A baseline assessment will be compiled for the `Eua citrus project. | Yr3, m12 | **(Completed)** A baseline survey has been completed for the `Èua community citrus project in May 2017.<br><br>Stakeholder interviews were undertaken in May and April and a MEL report has been prepared. Key MEL findings are included in section 8 of this report. |
| | | MEL assessments undertaken for the `Eua citrus project via a community discussion forum and data compilation | Yr3, m12<br>Yr4, m12 | (**Could not be completed)** Given the `Eua citrus orchards are yet to bear a crop, and the Tongatapu citrus orchard had its first commercial harvest in March/April 2021, it was impractical to quantify livelihood impacts for participating small holder farmers. This activity has alternatively been integrated acted into the second phase on this project (i.e. HORT/2019/165). |

# 7 Key results and discussion

Given a relatively complex project design; five fruits, three Pacific Island countries and diverse research questions, we have presented the research results on the basis of the targeted fruit crops.

**Papaya** (Objective 1.1)
'Fiji Red' papaya seed was imported[25] and successfully germinated at the MORDI nursery in Nuku'alofa (Tonga), and at the SROS field station in Nafanua (Samoa) in late 2019. As a result of training provided by NWC, MORDI now has a small 'Fiji Red' papaya seed orchard, and the capacity to harvest and distribute seeds to smallholder farmers throughout Tonga. The papaya seed orchard has been integrated into an ongoing MORDI-led rural communities initiative funded by IFAD. In Samoa, a small 'Fiji Red' papaya orchard was also established as part of a horticultural field planting, though there were issues with germination and tree growth. Harvested seeds were made available to farmers through MAF's ongoing planting material distribution scheme. Poor seed viability experienced in Samoa would suggest the current commercial Fiji papaya seed storage and testing capacities have not yet been optimised.

**Breadfruit**
**Extending postharvest storage life** (Objective 1.2)
Based on postharvest storage temperature trials (Fig. 12 and 13), we found that breadfruit fruit (which has an ambient [25°C] shelf life of 5 days) could be stored for up to 16 days at 17°C. Shelf-life varied with cultivar-type, with cv. *Puou* able to be stored for 11 days and cv. *Maafala* for up to 16 days at 17°C, with chilling injury (CI) as the limiting factor. At 15°C fruit shelf-life was 8 and 9 days respectively for cvs. *Puou* and *Maafala*. Production location (north-east Upolu verse north Upolu Island, Tonga) had a significant effect on the incidence of CI during storage. Cultivar *Puou* sourced from North-eastern Upolu Island (higher rainfall site) developed CI earlier than fruit sourced from north Upolu Island. While cv. *Maafala* sourced North-eastern Upolu Island had higher incidence of CI, this result was not significant. The rate of weight loss during storage was significantly higher in cv. *Puou* compared to cv. *Maafala*. Our results showed that breadfruit grown in Samoa[26] was more susceptible to CI than fruit grown in the Caribbean, where CI is not observed in fruit stored at 12°C (Worrell et al., 2002). We found that postharvest rots during low temperature storage were not a limiting factor, contrary to other published studies. While a 16-day shelf-life would support airfreight export of breadfruit from Samoa to New Zealand, it is insufficient for sea-freight export pathways into New Zealand (which would need 28 days). While there are options to further extend breadfruit-shelf (i.e. pre-conditioning and/or modified atmosphere packaging), at the request of the end-of-project review these were not explored. If future postharvest storage trials were undertaken, we recommend focussing on *Maafala* given its longer shelf-life, and further work to better understand pre-harvest effects on fruit shelf-life.

Figure 12. Postharvest breadfruit trials and assessments undertaken by SROS.

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[25] Seed [approx. 200 g x2] was commercially sourced from NWC and supplied to MORDIT (Tonga) and SROS (Samoa).
[26] Possibly due to cultivar type, production practice and local production conditions.

Supplementary breadfruit postharvest research (in lieu of Objective 1.3.5 [27]) was undertaken by SROS to investigate hot water treatment (HWT) as an alternative to existing high temperature forced air (HTFA). While HTFA disinfestation protocols currently enable Fiji to export fresh breadfruit into New Zealand, similar commercial-scale HTFA equipment does not exist in Samoa. A HWT protocol for breadfruit could provide a lower-cost export pathway for Samoa breadfruit (and other Pacific countries similarly lacking HTFA equipment). Postharvest trials were undertaken with the assistance of Plant and Food Research, New Zealand[28]**.** A preliminary trial using minimal HTFA (47.2°C for 20 mins), HTFA (49°C for 120 mins)[29]**,** HWT (47.2°C for 20 mins) and controls was undertaken at SROS. Fruits were assessed pre-treatment and 2, 9 and 12 days after treatment. We found that the extreme treatment that fruit would be exposed to at the bottom of treatment bins in commercial scale HTFA become unacceptable at a much earlier time point than fruit at the top of the bin exposed to the minimal required treatment (for further results see Molimau-Samasoni et al., 2019).

Further supplementary breadfruit postharvest research (*in lieu* of Objective 1.3.5) included an initial assessment of the current approved HTFA treatment against potential alternative treatment in light of new data on fruit flies thermotolerance. These alternative treatments included 47.2°C for 0 mins[30] (currently used in the USA), 46°C for 15 mins (tolerance of *Bactocera kirki*), and 43°C for 0 mins[30] tolerance of *Bactocera xanthodes*[31]). We found that changes to the treatment temperature and treatment time did not significantly change the quality of breadfruit compared to breadfruit treated at the currently approved treatment of 47.2°C for 20 mins.

Figure 13. Postharvest breadfruit trials and assessments undertaken by SROS and Plant and Food Research, NZ.

**Breadfruit canopy management**

(Objective 2.1)

Statistics analysis on preliminary data showed the fruit number of the Paclobutrazol treatments (either in soil application or foliar spray) was significantly higher than those of the pruned-only control (Fig. 14). The results suggest that Paclobutrazol treatment may significantly improve breadfruit flowering and/or fruit set following tree pruning. Both the Paclobutrazol treatments were found to perform significantly better than the Regis

[27] While we planned to undertake trials to optimise sea freight storage protocol for Samoa pineapples, in discussion with ACIAR (and supported by the end-of project review team) there was a consensus view that pineapple production in Samoa was still too small to sustain niche export pathway, and that this milestone should not be progressed. In lieu, additional postharvest trials were undertaken to explore the potential application of hot water treatments for breadfruit as possible lower cost alternative to HTFA.

[28] SROS has developed a close partnership with Plant and Food Research New Zealand as a result of this research. This now provides important long-term technical support to SROS, building on technical capacity established through this project.

[29] Temperature selected based on extreme HTFA as experienced by fruits at the bottom of the bin.

[30] The treatment related to increasing fruit core temperature to 47.2°C, but once achieved treated was ceased (i.e. 0 mins).

[31] There are three reports fruit fly on Breadfruit in the Pacific (including Samoa)**:** *Bactocera xanthodes, Bactocera facialis,* and *Bactocera passifora*. This trial, co-designed by Prof Allan Wolf [team leader of the Plant and Food Research NZ], sought to explore fruit tolerance at various temperature profiles.

treatment (0.25g /L water, at 3 - 4Litres / tree, 2 applications). In fact, there was no significant difference between the Regis treatment and the pruned-only control. Interestingly, in the period of 6 months after application, the fruit number of the Paclobutrazol soil-treatment was also significantly higher than those of the unpruned control. However, the interaction of treatment x time could not be determined. There was a big variation in the unpruned control g

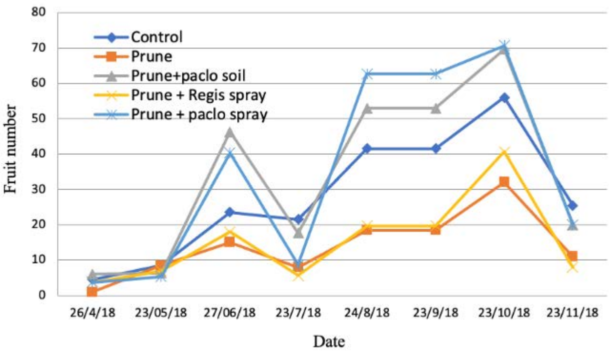


Figure 14. Effect of Paclobutrazol on breadfruit flowering (in Fiji)

In addition to increasing number of replicates, it is necessary that future trials to be conducted in a homogeneous population (such as tissue-cultural propagated trees) in a standardized orchard. More experiments are also required to evaluate the possible interaction of treatment x time x cultivar.[32] Taken together, the current findings provide opportunity for the potential of Paclobutrazol to assist tree recovery (in terms of promotion flowering) after a cyclone event.

Figure 15. Breadfruit pruning experiment at the Sigatoka Research Station in June 2017.

[32] There was only one Regis rate with a complete set of data. After statistic anlaysis, there was an intent to establish more trials in a well-maintained orchard. While we did initiate three fruit trials, unfortunatley these were not continued due to lost of critical staff in Fiji in late 2019, and local and international travel restrictions due to Covid-19.

**Breadfruit fertiliser trials** (Objective 2.1.2)
Trials to assess the potential benefit of frequent low concentration fertiliser applications (monthly verses the current industry standard of every three months) did not yield consistent results. In cv. *Balekana* flowering and fruit number seemed to increase four months after the commencement of low concentration frequent fertiliser applications. In a subsequent fertiliser application x pruning x cultivar trial, fruit yield was increased in cv. *Uto Dina* based on a N.P.K fertiliser regime of (13:13:21) at the rate of 2 kg per year split into four applications (500 g/quarter). The cv. *Balekana* also seemed to have a trend of reduced yield if a fertiliser application was applied in the absence of pruning. Unfortunately, due to the small pot size and limited number of trials, these data did not warrant statistical significance. However, it is worth noting that we observed the influence of soil type on breadfruit growth. The river flood soils at Sigatoka Research Station and the Methodist farm at Nadi (Votua Levi) produced excellent tree growth and high fruit yield. Similarly, red soils at the Lautoka trial (Prakash) resulted in high yields. Interestingly, while the block on Tui's farm at Legalega, Nadi was considered to have relatively poor soil, trees did not seem to respond to fertiliser treatments either. This is possibly due to cultivar yield variation (*Balekana ne Samoa* had farm yield potential of around 200 kg/tree or 20 tonne/ha at maturity, whereas *Uto Dina* productivity is much lower at 5 tonne/ha). Further experiments targeting the interaction of soil type and cultivar are required to accurately assess any benefit of fertiliser regime on breadfruit growth and fruiting with/without pruning.

**Investigate the genetic diversity of breadfruit to identify potential low tree form traits** (Objective 2.2.1)
Breadfruit stem elongation could be manipulated by gibberellin (GA)-related regulators, with the genes related to GA biosynthesis, degradation and signal repression isolated. These genes displayed differential expression pattern across green vegetative, root and reproductive organs. Under the treatment of GA or Paclobutrazol, there was different response from individual members in these gene families. Interestingly, treatments of drought or high salinity down regulated the expression of some GA biosynthetic genes, but increased the expression of GA catabolic genes. These results suggest that drought and high salinity could contribute to the dwarf phenotype in breadfruit trees. Our results showed genetic variation in GA biosynthetic genes, *AaGA20ox2* and *AaGA20ox3* across the field survey samples is low, the Samoa *AaGA20ox2* showing 96% identity to the *AaGA20ox2* of all other pacific regions tested while the rest of *AaGA20ox2* genes, together with all the *AaGA20ox3* genes share 99% similarity with each other at protein level. The aim of this work was to screen GA biosynthetic mutants as a tool to discover dwarf alleles. Our results suggest all the surveyed varieties have functional GA biosynthetic genes, consistent with the fact that no dwarf phenotype was discovered during the field survey.

Breadfruit scions have been successfully grafted onto interspecific rootstocks, *Pedalai*, *Marang* and *Lakoccha*. For the first time, we showed there was a positive correlation between graft success and the levels of plasma membrane (PM) $H^+$-ATPase activity measured from rootstocks before grafting (Zhou and Underhill, 2018). Rootstocks with low PM $H^+$-ATPase activity in leaf microsomes before grafting had lower graft survival than those with high enzyme activity, with graft success of 10% versus 60% and 0% versus 30% for marang and pedalai rootstocks, respectively. There was also a positive correlation between graft success and the PM $H^+$-ATPase activity measured from the rootstock stem microsomes at 2 months after grafting [marang, $r(7) = 0.9203$, $P = 0.0004$; pedalai ($r(7) = 0.8820$, $P = 0.0017$; Zhou and Underhill, 2018]. While the information may provide an opportunity to improve the graft success of *Artocarpus* species, the current assay protocol for PM $H^+$-ATPase activity is not straight forward for use in fields or labs without appropriate equipment. Future work is required to investigate solutions, perhaps in combination with commercial products to develop a simple and cost-effective method for large-scale application.

A dwarf phenotype with over 50% reduction in plant height was identified when *Marang* or *Lakooc*ha rootstocks were used (Zhou and Underhill, 2019). The dwarf phenotype on marang rootstocks was characterized by shorter stems, reduced stem thickness and fewer branches, with 73% shorter internode length, 51% fewer and 40% smaller leaves compared to the standard size of breadfruit trees. Further molecular analysis suggested GA might play a role in the marang rootstock-induced dwarfing. Recently, an RNA-sequencing study of breadfruit scions at 22 months after grafting identified 5409 differentially expressed genes of which 2069 were upregulated and 3339 were downregulated in scion stems on marang rootstocks compared to those on self-graft (Zhou and Underhill, 2021). These differentially expressed genes were predominantly enriched for biological processes involved in carbon metabolism, cell wall organization, plant hormone signal transduction and redox homeostasis. Signalling pathways of auxin and gibberellin, along with strigolacton and brassinosteroid biosynthetic genes dominated the down-regulated genes. Signalling pathways of salicylic acid, jasmonic acid and ethylene were significantly upregulated. These results suggest that networks of multiple pathways integrated with carbon partitioning disrupt the balance of growth and defence leading to inhibition of cell elongation growth on *Marang* rootstocks. Assessment for the long-term effect of *Marang* rootstocks on breadfruit phenotype is required in the future. The information provides opportunity to design screening strategies to assist in breeding and selection of potential size-controlling rootstocks (Zhou and Underhill, 2021).

For the intraspecific grafts, preliminary results from CePaCT indicated that self-grafting regardless of variety type (seedless or seeded) reduced plant height. *Balekana*, being a normal low growing variety, appeared to have an effective impact on reducing plant height when using as a scion regardless of rootstock type. Unfortunately, effect of *balekana* as a rootstock could not be determined from the current trial. The sample size was also too small ($n < 3$) to have statistically significant results. Future expansive trials are required to confirm these grafting effects, and particularly the effect of *balekana* rootstock. CePaCT is going to proceed with the grafting trials using jackfruit. Where possible, CePaCT will also continue to find ways to source *Marang* seeds to include in the trials.

**Breadfruit fruiting calendar**

To allow farmers to select cultivars that could provide year-round fruit supply, the fruiting behaviour of 31 different breadfruit varieties currently in the CePaCT field collection was documented. CePaCT has developed a preliminary breadfruit fruiting calendar (Table 1). Breadfruit varieties that have just started fruiting but are yet to complete the fruiting year calendar are shown in Table 2 Some varieties are yet to produce fruits. Multiple seasonal assessment and supplemental information on peak fruiting periods for each variety is needed, so these data have been gathered from years of observation and are continuously being updated. Climate change, such as shifting temperature and annual rainfall has created limitation for data interpretation. Breadfruit fruit yield and nutrition levels are impacted by climate factors, including annual precipitation, abiotic environmental factors and soil parameters (Liu *et al.*, 2014; Needham *et al.*, 2020). It is not known whether the fruiting pattern of each variety is conserved across different climates and geographic regions. This data will provide opportunity to improve food productivity and accessibility through careful selection of breadfruit cultivars to extend season or to help plan for fruit processing.

Table 1: Breadfruit fruiting calendar for CePaCT field collection.

| | Variety and source country | J | F | M | A | M | J | J | A | S | O | N | D | D/O/P* | D/1st/Fruit** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Dreu lo (Fiji) | | | | | | | | | | | | | 22/09/2011 | 21/11/2014 |
| 2 | Ulu peti (Samoa) | | | | | | | | | | | | | 22/09/2011 | 14/02/2015 |
| 3 | Votovoto (Fiji) | | | | | | | | | | | | | 22/09/2011 | 21/11/2014 |
| 4 | Ulu fiti (Samoa) | | | | | | | | | | | | | 22/09/2011 | 21/11/2014 |
| 5 | Uto dina (Fiji) | | | | | | | | | | | | | 22/09/2011 | 23/01/2014 |
| 6 | Samoa Soke (Fiji) | | | | | | | | | | | | | 22/09/2011 | 23/12/2014 |
| 7 | Maopo (Samoa) | | | | | | | | | | | | | 22/09/2011 | 21/11/2014 |
| 8 | Maireena (Kiribati) | | | | | | | | | | | | | 22/09/2011 | 1/10/2012 |
| 9 | Moamoalega (Samoa) | | | | | | | | | | | | | 22/09/2011 | 17/03/2015 |
| 10 | Motiniwae (Kiribati) | | | | | | | | | | | | | 22/09/2011 | 22/04/2014 |
| 11 | Puou (Samoa)TC | | | | | | | | | | | | | 22/09/2011 | 17/03/2015 |
| 12 | Koqo (Fiji) | | | | | | | | | | | | | 22/09/2011 | 23/12/2014 |
| 13 | Samoa balavu (Fiji) | | | | | | | | | | | | | 22/09/2011 | 11/12/2014 |
| 14 | Balekana (Fiji) | | | | | | | | | | | | | 22/09/2011 | 14/08/2016 |
| 15 | VUT 109 (Vanuatu) | | | | | | | | | | | | | 22/09/2011 | 29/10/2015 |
| 16 | Ulu Faloa (Samoa) | | | | | | | | | | | | | 22/09/2011 | 24/07/2016 |
| 17 | Koqo Bioreactor (Fiji) Experiment | | | | | | | | | | | | | 25/11/2014 | 20/08/2018 |
| 18 | Koqo TC (Fiji) Experiment | | | | | | | | | | | | | 25/11/2014 | 20/08/2018 |
| 19 | Ma'afala Bioreactor (Fiji) Experiment | | | | | | | | | | | | | 25/11/2014 | 20/01/2018 |
| 20 | Ma'afala TC (Fiji) Experiment | | | | | | | | | | | | | 25/11/2014 | 21/01/2018 |
| 21 | Ma'afala (Samoa) | | | | | | | | | | | | | 22/09/2011 | 13/02/2015 |
| 22 | Ma'afala (Samoa) TC | | | | | | | | | | | | | 22/09/2011 | 23/12/2014 |

*DOP, Date of planting ** D/1st/Fruit, Date for first fruit set.

Table 2: Breadfruit varieties started fruiting (Incomplete calendar)

| | Variety and source country | J | F | M | A | M | J | J | A | S | O | N | D | D/O/P | D/1st/Fruit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Sagosago (Samoa) | | | | | | | | | | | | | 22/09/2011 | 20/01/2021 |
| 2 | Ulu Pu'upu'u (Samoa) | | | | | | | | | | | | | 22/09/2011 | 28/05/2020 |
| 3 | VUT 127 (Vanuatu) | | | | | | | | | | | | | 03/12/2012 | 20/01/2021 |

*DOP, Date of planting ** D/1st/Fruit, Date for first fruit set.

## Pineapple

**Preharvest and postharvest interventions** (Objective 1.3).
Four agronomic and postharvest pineapple farmer workshops were undertaken in Fiji providing technical and hands-on training to 108 pineapple farmers and MoA extension staff. Thirty-eight people attended the Natovi workshop in February 2017, with most farmers from the Vulagi pineapple farmers association and surrounding villages (Natovi workshop - 12 Women, 26 men. Ba workshop – 3 woman, 22 men. Vulagi workshop – 6 woman, 16 men). Twenty-five pineapple farmers participated in the Ba workshop held in March 2017, including eight MoA extension staff from Ba and Ra Province. Twenty-three Fiji MoA staff and two industry representatives attended the Seaqaqa pineapple master class held in early June 2017. A further twenty-two farmers at the Vulagi settlement attended a postharvest and value-adding workshop in June 2018. Fijian pineapple farmers have now received training in land preparation[33] (Suppl. 13, 14, 15), erosion control, crop rotation, identifying nutritional deficiencies, fertiliser application, floral induction and postharvest handling. Farmers recognised significant issues with soil erosion and declining productivity. Extensive technical resource material was provided to attendees.

Three postharvest pineapple value chain studies were conducted between 2016 and 2018 to document the impact that current harvesting, handling, transport and market practice had on fruit quality and loss We found that if fruits were consumed within 4 days of harvesting, postharvest loss was 10%, but losses increased to 40% if market storage was extended to seven days (Suppl. 16). Pineapple postharvest loss can be halved if more care is taken at specific points along the supply chain (specifically between the field and the packing shed), and if farmers alternatively harvested fruit at ¾ peel colour[34]. To support farmers to reduce commercial loss and improve fruit quality, a farmer workshop was held at the Vulagi settlement where research findings were discussed and possible remediation strategies identified. As a result of these dialogues[35] (Suppl. 17), we developed preliminary designed options to improve existing harvesting equipment, prepared a pineapple harvest colour chart and provided travel assistance for farmers to visit the MoA pineapple cultivar trials at the Seaqaqa agricultural research station on Vanua Levu Island. Construction and field evaluation of new postharvest equipment (due to occur in 2020) was not progressed due to difficulties in sourcing local agricultural engineering support, and COVID-19 impacts.

In Samoa, postharvest pineapple supply chain studies for the Alesia to Fugalei municipal market were undertaken in late 2016. We found that Samoan pineapple farmers experienced difficulties in accessing suitable transport and were often forced to use overcrowded local buses to access markets. High transport costs, and limited space, led many smallholder farmers to limit the volume of product transported. Farmers also incurred extra costs to transport empty plastic crates back to the farm. To improve packaging and reduce transport costs, we imported 200 collapsible plastic crates and distributed them to Samoan farmers in May 2018. The one key benefit of the collapsible crate was that farmers were not charged to transport crates back to the farm, effectively halving transport costs. In partnership with FAO, we also undertook a series of postharvest training workshops throughout Samoa in early 2018 to improve farmer awareness of good postharvest handling practice. A postharvest manual was also prepared, and 200 copies distributed to farmers.

[33] Includes an assessment of training benefit.
[34] As opposed to the current practice of harvest at full peel colour.
[35] Supply chain dialogues included farmers, vendors, MoA staff, researchers from FNU and USC.

In Tonga, a rapid assessment of pineapple production and postharvest handling practice was undertaken in Vava'u Island in November 2018 and February 2019[36]**.** One key concern identified, was possible poor temperature management associated with small steel sea-freight containers to ship produce between Vava'u and Tongatapu.

**Optimise sea-freight storage protocols for Samoan pineapple** (objective 1.3.5). In discussion with SROS we have decided not to undertake this activity[37]**.** While niche export opportunities for Samoan pineapples into New Zealand have been identified (Macgregor, 2017), domestic pineapple production in Samoa has remained small and limited to a few medium-scale farmers. Effort to establish the Samoan pineapple export pathway into New Zealand is also ongoing. We therefore believe it is premature (at this stage) to undertake trials to develop an optimised sea freight storage protocol for Samoa pineapples. *In lieu* of this output, additional research has been undertaken to explore hot water treatments for breadfruit as a possible lower cost alternative to HTFA.

[36] This work was qualitative and observation based. No report was prepared.

[37] This action was endorsed by the Mid-term project review.

## Mango

**Mango flowering** (*objective 1.4.1*).
The effect of paclobutrazol in promoting flowering in mango trees is well documented (Tongumpai *et al*., 1991; Winston, 1992; Wongsrisakulkaew, 2017). In this project, paclobutrazol was evaluated as a possible method to improve mango crop uniform in Fiji. These experiments had varied results, depending on season, cultivar, and location variables. The initial response (in 2016/2017) was poor possibly due to unfavourable flowering conditions. In the 2017/2018 season, Paclobutrazol treatment appeared to increase the amount of flowering for *cvs. Tommy Atkins* (3 sites), *Mango Dina* (1 site), *Kensington Pride* (1 site), *Tahitian* (1 site), and *Nang Klang* (1 site). Flowering intensity was increased by around 50% with flowering observed two weeks earlier than in control trees. However, treatment did not have a similar effect on cvs. *Nang Klan* or *Nam Dok Mai*

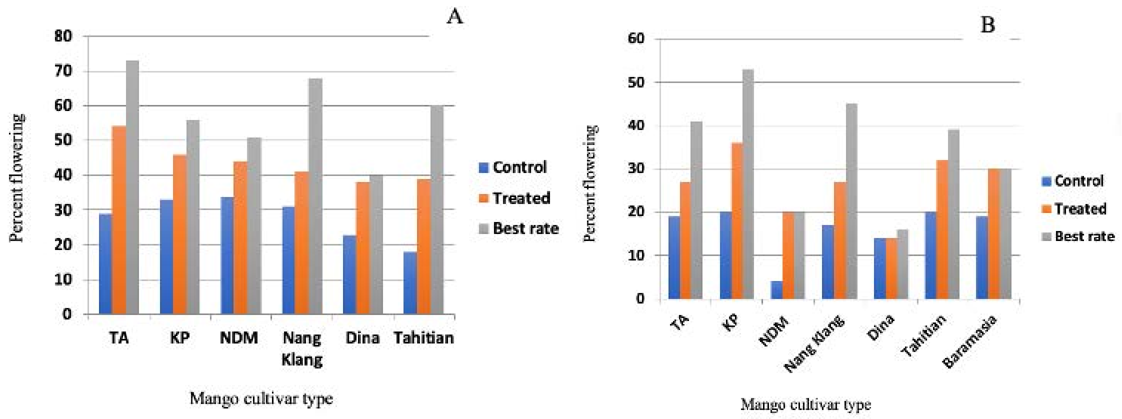


Figure 16. Effect of Paclobutrazol on mango flowering for key cultivars grown in Fiji

at 1 site (N

However, in the 2018/2019, paclobutrazol appeared to increase flowering incidence for *cvs. Tahitian* and *Nang Klang* at Legalega Research station; *cv. Kensington Pride* at Korovutu; *cv. Tommy Atkins* at Jack's Farm; *cv. Nam Dok Mai* at Momi farm and *cv. Baramasia* at Saioko. Poor treatment response was observed for *cv. Tommy Atkins* at Korovutu and Legalega Research Station, contrary to results in 2017; and for *Nang Klang* at Momi farm. Generally, a paclobutrazol application rate of 20 mL ai / tree tended to be more effective in most trials and most cultivars. Unfortunately, due to the small number of sites ranged in different locations, the results were not statistically significant. Further experiment is required to confirm the effect of paclobutrazol in mango flowering uniformity in Fiji. Future work should focus on refining the dosage rates and scheduling of each location, and cultivar, with an aim to provide pratical recommendation to Fijian mango farmers.

**Mango fruit bagging trials** (Objective 1.4.2) were undertaken by MoA to evaluate the commercial potential of this technique to improve fruit quality. While single bagged fruits produced excellent quality, if fruit clusters were bagged (i.e. fruit were touching each other in the bag), this led to an increased incidence of disease and caterpillar damage. In 2018, a further trial design using *cv. Tahitian* with 100 fruits of the following; single fruits not in clusters, clusters of 2 or 3 fruit in 1 bag, fruit with no bags, delayed bagging (approx. 50 days after fruit set) was established. We found that fruit bagging improved fruit quality based on the incidence of skin blemish being reduced from 38% in the control, to 13 to 19% depending (Suppl. 11) on the number of fruits per bag (2 fruit per bag @ 13% skin blemish incidence gave the best result). However, based on the time and labour cost to effectively bag fruit during the trials relative to the benefit gain (Ali *et al.*, 2021, del Pino *et al.*, 2021) this technique is not considered commercially viable in Fiji at the present time.

**Research on postharvest diseases** of mango in Fiji (Objective 1.4.3) was undertaken by Dr Mereia Fong Lomavatu (MoA) as part of her now successfully completed JAF-PhD scholarship linked to the project. Over two mango seasons postharvest disease assessments were conducted on five local Fijian cultivars at each of five major growing areas in Fiji, along with fruit from five exotic cultivars at one growing area. Fungi that were associated with symptoms of anthracnose and stem end rot in these studies were cultured and identified using current molecular techniques.

Fungi found to be associated with mango anthracnose symptoms in Fiji were *Colletotrichum asianum, C. gloeosporioides, C. acutatum* and *C. siamense*. *C. asianum* was by far the predominant species of *Colletotrichum* isolated from these symptoms, accounting for 84% of the total number of *Colletotrichum* isolates recovered from symptoms. *C. asianum*, *C. acutatum* and *C. siamense* represent new reports for Fiji. Host range studies showed that a *C. asianum* isolate from mango was highly pathogenic on unwounded, detached mango fruit, but non-pathogenic on papaya or banana fruit. Conversely, *Colletotrichum* isolates obtained from anthracnose symptoms on papaya (*Colletotrichum brevisporum*) and banana (*Colletotrichum musae*) were both pathogenic on the host fruit that they were isolated from, but non-pathogenic on unwounded, non-host fruit.

Fungi associated with stem-end rot symptoms were identified as *Lasiodiplodia theobromae, L. pseudotheobromae, Neofusicoccum parvum, Pestalotiopsis* sp., *Botryosphaeria* sp. and *Phomopsis mangiferae.* All these are new records for mango in Fiji. Four isolates of the stem end rot fungi, each representing one of the four species *Lasiodiplodia theobromae, L. pseudotheobromae, Neofusicoccum parvum and Phomopsis mangiferae*, were found to be highly pathogenic on detached mango fruits following inoculation (Lomavatu, 2018, Ph.D dissertation[38]).

Significant cultivar difference was observed in response to inoculation with the anthracnose pathogen. The local *cv*. *Maqo Loa'* was found to be the most susceptible to anthracnose at eating ripe, and the exotic cultivar, 'Tahitian' was also more susceptible than other cultivars (Lomavatu, 2018, Ph.D dissertation). The results highlight the importance of future strategy to target different pathogens and cultivars to reduce mango postharvest loss.

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**38** Thesis can be sourced from: https://research.usc.edu.au/discovery/fulldisplay?docid=alma99451453602621&context=L&vid=61USC_INST:ResearchRepository&lang=en&search_scope=Research&adaptor=Local%20Search%20Engine&tab=Research&query=any,contains,mango&offset=0

Figure 17.  Mango being evaluated at the Fiji MoA laboratories, Koronivia Research Station.

**Mango pre-harvest pest risk** (Objective 1.4.3). Research to document pre-harvest pests of mango in Fiji was not completed due to a series of staff resignations and staff changes at FNU. A further attempt to initiate this work through University of the South Pacific (USP) was also not successful. While FNU re-commenced the mango pest survey with initial sampling undertaken in February 2019 based at 11 sites (around Nadi and Tavua) further sampling in 2020 and 2021 did not occur. A lack of research capacity in horticultural entomology at FNU remains unresolved.

**Mango cultivars evaluation** (Objective 1.4.4). In late 2018, a site at the Legalega Research Station, Nadi was cleared in preparation for planting. The preparation of planting material was also undertaken at Sigatoka Research Station. However, low initial grafting success (now resolved), and a request from MoA to expand the field plot to also include other mango cultivars delayed planting. A variety trial of 10 selected mango-types in 5 replications was established by MoA at Legalega Research Station, Nadi between 2019 and April 2021.

**Mango training workshop** (Objective 1.4.6) A mini mango workshop to communicate research findings to farmers (and other stakeholders) was held in Fiji in December 2019.[39]

## Citrus

**Citrus industry development in Tonga** (Objectives 1.7, 3.2, 4.1 and 4.2).
Given limited domestic citrus production in Tonga (current supply is sourced from small low-input orchards or wild harvested plantings primarily located on one Island) our initial priority was on sourcing and importing commercial grafted citrus genetics into Tonga. In November 2016, 373 citrus trees were imported including 60 Washington Navel. 60 Valencia Orange, 58 Imperial Mandarin, 58 Emperor Mandarin, 58 Afourer Mandarin, 45 Ellendale Mandarin, 14 Meyer Lemon and 14 Tahitian Lime, all of which were on Troyer Citrange rootstock except for the Imperial and Emperor that were on Cox hybrid rootstock to avoid the mature tree incompatibility with Imperial that can lead to fruit dryness and granulation[40]. Trees were planted at three main sites; at the Houma community and at the Ha'atu'a community on `Eua Island, and at Nishi Trading, Utulau, on Tongatapu Island. A Category 5 cyclone hit Tonga in March 2018, initially inflicting minimal damage to the citrus orchards on `Eua and Tongatapu. However, around a quarter of the trees began showing very severe leafy yellowing in the following weeks, which was attributed to Phytophthora root rot caused by damage to the root sheaths during the cyclone, allowing the Phytophthora spores to enter the roots. Soil applications of Ridomil and subsequent Phosphorus acid spray limited loss and assisted with orchard recovery, providing a remediation strategy against future cyclone damage.

In April 2019, a further 269 citrus trees were imported into Tonga including 220 Tahitian limes, 15 Imperial mandarin, 11 Meyer lemon, 5 Emperor mandarin, 5 Afourer mandarin, 3 Valencia orange, 3 Washington navel and 7 Cox Hybrid rootstock as a future rootstock source. The importation of Tahitian limes sought to capitalise on a pending export pathway for Tahitian limes into New Zealand (B. Wiseman *pers com.* 2018), with a Tahitian Limes orchard now established at the MORDI complex and Nishi farm both on Tongatapu island.

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[39] Extension material in support of the mango farmers is now needed. Since late 2020, MoA has been progressively preparing youtube-based farmer extension material (including pineapple), with mango material also proposed. SPC LDR has recently undertaken a value chain reviews on mango value-adding (Brown, 2021).
[40]An explanation of why specific citrus varieties were selected is provided in the method section (see Page 17)

Collectively, the project has established four citrus orchards that includes +600 grafted citrus trees into Tonga. In February 2020, the Tongan Government funded the further importation of 1500 additional grafted citrus trees into Tonga, with trees subsequently distributed throughout Tongatapu and the outer islands (in support of home garden production).

We developed a citrus fertiliser protocol for Tonga to account for the predominant vaini soils in the orchard sites (which originated from volcanic and coral reef weathering). These friable reddish-brown clays' have an extremely high cation exchange capacity that can lead to severe calcium deficiency despite high levels of soil calcium (Suppl. 18). A protocol has also been developed using agronomic methods plus soil and foliar sprays to prevent phytophthora causing tree deaths after cyclone damage that occurs regularly in Tonga. Wind breaking has also been employed to reduce the impact of cyclones. Of particular interest is native species such as Tani Tani already used for hedging. A supplementary experiment to compare the standard traditional leaf analysis with new portable light technology from France, was delayed due to COVID-19 travel restrictions. Traditional leaf analysis has to be done in laboratories in New Zealand or Australia and this light technology offers the prospect of affordability and portability in the Pacific Islands for all crops not just citrus.

Information on citrus fruit yielding and orchard status is separately presented in sections 8.1 and 8.3.

Tree monitoring and maintenance continued through 2021, coordinated by MORDI and staff at Nishi Trading and supported by USC. Information is being captured and collated with the expectation of preparing a citrus extension manual for Tongan (and Samoan) smallholder farmers through HORT/2019/165.

**Community engagement with a community of subsistence farmers in Savai′i, Samoa.** (Objective 4.2). Community consultation and a rapid value chain assessment highlighted that domestic citrus production in Samoa was currently sourced from a small area with few cultivars leading to short periods of market over-supply, and that farmers were sourcing from old trees with little agronomic management. The prevalence of local seed-sourced cultivars has resulted in a very short and highly concentrated fruit supply season (4 to 6 weeks annually; elsewhere domestic citrus production can be up to 6 months; and in Tonga domestic citrus supply is around 4 months[41]). Depressed farm-gate price due to a short supply spike, appeared to create few incentives for smallholder farmers to increase production. Low tree productivity (due to seed-sourced planting material) further limits farm returns. Those farmers reliant on third-party transport to the markets in Apia, Upolu Island were disadvantaged by high transport costs.

Further consultation with farmers indicated strong interest to participate in a citrus industry development, however, COVID-19 travel restriction and local travel curfews in Samoa during 2020 negated further in-community engagement.

[41] The disparity between domestically-grown citrus supply in Samoa and Tonga is possibly due to a wider diversity of citrus species present in Tonga, enabling an extended seasonal supply-window. Underhill and Peterson (2017) reported at least seven citrus species in Tonga [prior to the current project] based on a review of historical reports. Anecdotally, Samoan citrus production is based on few cultivar-types. Production conditions in Samoa are also quite different to Tonga with localised semi-commercial small scale citrus farms (compared to predominately amenity-based scattered plantings in Tonga).

# 8 Impacts

## 8.1 Scientific impacts – now and in 5 years

This project resulted in 18 peered reviewed academic publications (see section 10.2), and some notable key research findings.

**Papaya**

The isolate of *Colletotrichum* obtained from papaya anthracnose in this study (*C. brevisporum*) represents a first record for this pathogen on papaya in Fiji.

**Breadfruit**

We have undertaken the first detailed molecular-based study of breadfruit tree form, producing several peer-reviewed academic papers (Zhou and Underhill, 2016, 2017, 2018, 2020). This research demonstrated that breadfruit stem elongation could be manipulated by gibberellin (GA)-related regulators[42], with genes related to GA biosynthesis, degradation and signal repression isolated. Concurrent research on inter-species grafting, as a possible strategy to support low tree form, also showed positive results (Zhou and Underhill, 2019, 2020), providing an important platform for future breadfruit research. The RNA-sequencing work (Zhou and Underhill, 2021) provided insight into the signal transduction pathways regulating breadfruit dwarfing by interspecific rootstocks, also generated a valuable gene resource for functional study and rootstock breeding for dwarfism of the species. Based on academic citations these findings have stimulated further work by other research groups.

Paclobutrazol was shown to reduce breadfruit tree height under glasshouse condition (Zhou and Underhill, 2015). In field experiment, we also showed that the chemical was effective in stimulating early flowering/fruiting following tree pruning. While further trials to refine treatment protocols, local chemical registration and farmer extension are required, we anticipate this practice will be commercially adopted in Fiji and Samoa orchards as a post-cyclone tree recovery strategy.

Trials on HWT as a possible alternative disinfestation strategy to HTFA are anticipated to stimulate further research by SROS and Plant and Food Research New Zealand.

**Mango**

Postharvest hot water treatments (HWT) (55°C for 5 mins) were shown to be effective in reducing the incidence of postharvest diseases in mango *cvs. Maqo Dina*, *Tommy Atkins* and *Tahitian*, grown in Fiji (Lomavatu et al., 2015; Lomavatu 2018 [43]). HWT has the potential to be commercially used in Fiji's export mango industry[44]**.** Through MoA we are currently endeavouring to raise awareness of the benefits of HWT amongst Fiji mango exporters.

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[42] Breadfruit tree heights were manipulated by applying growth hormones, with tree height reduced by up to 30% in glasshouse conditions.

[43] Thesis and associated data can be sourced from: *https://research.usc.edu.au/discovery/fulldisplay?docid=alma99451453602621&context=L&vid=61USC_INST:ResearchRepository&lang=en&search_scope=Research&adaptor=Local%20Search%20Engine&tab=Research&query=any,contains,mango&offset=0*

[44] AGB/2015/015 reported that Fiji currently exports between 20 and 45 Tonnes of mangoes annually, primarily to New Zealand, with poor fruit quality and inconsistent supply eroding market demand.

With mango cultivar trials now established at Legalega Research Station this provides MoA with the research capacity to undertake long-term cultivar performance trials, improving future extension recommendations to mango farmers, especially in terms of cultivar performance and site suitability.

Paclobutrazol shown to be effective in promoting flowering and increasing fruit yield in mango cultivars grown in Fiji. This result was consistent with prior published results (Winston, 1992; Nafees *et al.*, 2010).

**Citrus**

We developed a fertiliser and irrigation schedule, and orchard monitoring protocols tailored to Tonga's citrus production conditions. This involved overcoming the challenge of severe calcium and copper deficiencies in the young citrus due to Tonga's challenging soils. We have also developed a remediation strategy to reduce loss to aid tree recovery following wind damage. These recommendations and protocols[45] are now being commercially used in citrus orchards in Tongatapu and `Eua Islands.

**Other scientific impacts**

Horticultural food loss research undertaken in Fiji, Tonga and Samoa (Kumar and Underhill 2019; Underhill et al., 2017, 2020; Underhill and Kumar, 2018) has provided a better understanding of Pacific food systems and their relative vulnerability to food loss. This research has resulted in an increased public awareness of food loss in the region (Fig. 18),


stimulated policy reform[46], there is tangible evidence of vendor practice change[47], and has resulted in increased international donor investment in Pacific food loss[48].

## 8.2 Capacity impacts – now and in 5 years

This project has achieved several significant institutional and individual capacity building impacts. During stakeholder interviews undertaken at the conclusion of HORT/2014/077 to quantify impact, SROS, FNU, MORDI and MoA Fiji all highlighted significant capacity building benefit.

Figure 18. Examples of public media articles in Tonga and Fiji, highlighting the importance of food loss.

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[45] Tree maintenance and monitoring protocols were communicated to Nishi Trading and MORDI based on email exchanges and ongoing WhatsAPP communications. We plan to make this information more widely available through a proposed Tongan Citrus Manual (to be prepared by pending phase -2 project - Hort 2019.165).

[46] Postharvest is now included in the Samoan and Fijian Government Fruit and Vegetable Strategies, and the Tongan Agricultural sector plan.

[47] The level of food loss in the central municipal market in Samoa decreased from 15% to 10% between 2017 and 2019, possibly in response to extensive market vendor capacity building and postharvest training.

[48] Between 2005 and 2014 there has been 3 academic published papers and 1 donor project on Pacific horticulture food loss. Since 2015 [when this grant commenced], there have been 13 academic papers and 9 donor projects (FAO [6], ACIAR [1], UNDP [2]) on Pacific horticulture food loss.

**Institutional capacity impacts**

Based on HDR training, targeted mentoring, workshops, funded attendance at key international technical fora, and hosted laboratory visits, Fiji and Samoa now have a postharvest plant pathology and postharvest research capacity. Prior to HORT/2014/077 this capacity was limited.

1. FNU (Fiji) now has expertise in postharvest horticulture[49]**,** with an ongoing capacity to supervise postharvest HDR students to PhD-level. Postharvest technology has been better incorporated into FNU's horticulture curriculum, and FNU is now actively involved in ongoing postharvest research initiatives. FNU is currently partnering with SROS on a new ACIAR and IDRC-funded food loss project and has recently completed an IFAD-funded project on smallholder farmer postharvest training.

   *"Personally, this project has been very enriching for me. It has given me experience in managing a project - conducting the research and the management of funds. I have been able to take my experiences into the classroom and am in the midst of completing some further publications."* Dr Salesh Kumar, FNU, Fiji

2. Koronivia Research Station, MoA (Fiji) now has capacity to undertake postharvest plant pathology and postharvest horticulture research. This capacity based on enhanced research expertise [50] was recently utilised by MoA to support the Fiji Government home gardens scheme.
3. SROS, (Samoa) now has a postharvest research capacity[26,51]. SROS has created a new Postharvest Research Program led by Dr Seeseei Molimau-Samasoni. Based on this increased capacity, SROS has secured several new FAO-funded postharvest research grants and leads the ACIAR and IDRC-CRDI funded project on food loss in the Pacific. SROS is now positioned to become a regional leader in postharvest horticulture research and development in the Pacific.

   *"SROS has increased capacity in its laboratories to undertake postharvest assessment of produce, procured equipment… and increased capacity of staff who have attended multiple trainings to learn more about postharvest theory & practical applications."* Dr Seeseei Molimau-Samasoni, SROS, Samoa.

4. Collaborating NGOs now have increased knowledge and technical expertise in horticultural production practice. In Tonga, MORDI has gained technical skills in tree fruit and orchard establishment and maintenance, plant propagation, and emerging expertise in pest, disease, nutrition identification and remediation. MORDI has used this capacity to subsequently establish their own plant nursery and build a fruit value adding processing facility (Fig. 19), establish a papaya seed orchard and citrus orchard, and now employs several field horticulturists. Through HORT/2014/077, USC and MORDI have developed a close research partnership, leading to further collaboration on various IFAD and FAO community development and food loss initiatives in Tonga.

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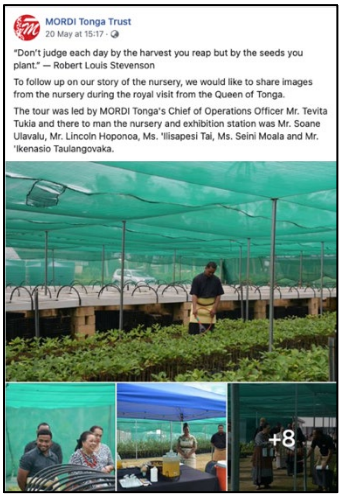
[49] The project funded three FNU staff members to attend the University of California, Davis world-class postharvest course, building capacity within the individual and the institution. Two SROS staff were also funded to attend this training.

[50] MoA staff, Mr Shalendra Prasad and Dr Mereia Fong Lomavatu [who are currently supporting the home gardens initiative] are now applying knowledge gleaned through formal higher research degree training supported by Hort 2014.077.

[51] SROS capacity building involved mentor support provided by E/Prof Ron Wills, Dr Allan Woolf and Prof Steven Underhill, laboratory training in NSW Australia and New Zealand, and UC Davis short course training.



While similar capacity building support and engagement was provided to NWC, unfortunately this was less successful. NWC was unable to retain critical staff at the completion of the grant, negating capacity building gains, and highlighting the innate challenge of creating long-term capacity impact in Pacific NGOs.

Figure 19. Social media posts illustrating the newly established MORDI nursery and processing facility in Tonga.

**Extension officer capacity building**

Given Pacific Government extension staff play a critical role in supporting smallholder farmers, we undertook a series of capacity building activities aimed specifically at local extension officers. MoA-Fiji extension staff have received capacity building in pineapple production practice (see photographs below), and mango and breadfruit tree management. MA… ive received postharvest handling capacity building. To sup… ding outcomes, extension resource material for pineapple and … and provided to MoA and MAF. As a result, MoA

Class room session at Seaqaqa Research Station

Fertilization practical at Aad'si pineapple farm Nasarawaqa

extension staff now have technical experience to better advise farmers on pineapple production practice, mango and breadfruit pruning, and potential Paclobutrazol application[52]. MoA Fiji has now taken the lead on promoting flowering induction practice to farmers in Fiji https://www.youtube.com/watch?v=bCj-UQ5nOVE

**Individual impact**

Two Pacific Island PhD students and one Pacific Island Master student (all aligned to HORT/2014/077) have successfully completed their studies. A fourth student Mr Shalendra Prasad (a JAF PhD scholar) will complete his PhD in July 2022. Dr Lomavatu,

[52] Subject to registration of Paclobutrazol in Fiji for mango applied as a trunk drench

Mr Shalendra Prasad, and Dr Salesh Kumar have all gone on to secure senior positions at MoA or FNU.

1. Dr Mereia Fong Lomavatu (Fij) undertook an assessment of mango postharvest diseases in Fiji (a JAF-funded scholar). Mereia was awarded her PhD in November 2018. On returning to Fiji, Mereia was promoted within MoA. Mereia is now using her skills to support other Pacific Island students through an active role in ACIAR's Pacific Alumni, the ACIAR-PASS program, and her ongoing horticultural research duties with MoA.
2. Dr Salesh Kumar (Fiji) undertook a study of horticultural postharvest handling practice in Fiji (an ACIAR-USP funded scholar). Since completing his PhD in 2019, Salesh has been promoted to Head of School at the Fiji National University. Salesh now leads several international donor-funded research projects, is a key collaborator on the ACIAR-funded Pacific Agricultural Scholarship and Support Program (PASSP), and active in ACIAR's Pacific Alumni.
3. Mr Shalendra Prasad (Fiji) commenced a study of pineapple postharvest handling practice in Fiji in 30th July 2018. As a senior MoA staff member, Shalendra is using his ongoing PhD studies to raise awareness of good postharvest handling practice within MoA horticulture industry development strategies. Supervisors: S. Underhill, S. Burkhart and S. Trueman.
4. Mr Kelemeni (Menny) Tavuto (Fiji) studied pineapple postharvest handling practice in Fiji and was a recipient of an ACIAR-USP Masters scholarship. Since graduating Menny has been included in an FAO-funded horticulture project.

## 8.3 Community impacts – now and in 5 years

### 8.3.1 Economic impacts

**Citrus**

> *"It has lifted my spirits and enthusiasm knowing what we know now about the trees. It has also demonstrated or confirmed that we can grow a successful citrus crop on the main island which is closer to sea level and not known to be the main supplier of citrus for the country. It has also demonstrated a difference in performance between private sector and community led projects."* Mr Minoru Nishi, Nishi Trading, Tonga

The establishment of four[53] citrus orchards in Tonga has created new opportunities for smallholder farmers of Tonga. This project has changed the local farmer and broader community perceptions of growing citrus. Mr Minoru Nishi reported that of the 100 registered smallholder growers he works with, every one of them is now interested and ready to incorporate citrus production on their lands. Another eight farmers (including one of Tonga's most prominent farmers) working closely with MORDI are also keen to try citrus in their production systems.

In the final year of the project (2021), one of the project-established citrus plots reached the significant milestone of harvesting and supplying citrus to local markets in Tonga (Fig. 21 and 22). Successful harvest seasons for 2020 and 2021 have had promising results (Table 3) for the future of citrus production in Tonga. There has been overwhelming demand for the fruit, with customers saying the product is sweet, easy-to-peel, cheaper (than imported fruits) and fresher.

[53] There is a further privately-established citrus orchard on Eua Island, Tonga.

Figure 21. Citrus fruit harvesting (from project-established orchards) in May 2021

By 2025, the annual fruit yield from the four project-established orchards plus the small private orchard is conservatively anticipated to be 150 tonnes (based on 50 tonne /ha).

Table 3. Fruit production and retail price from Nishi citrus orchard (established by the project).

| | 2020 | | 2021 | | | | | | | | TOTAL 2021 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan-Dec | | Feb | | March | | April | | May | | | |
| | Weight[1] | Value[2] | weight | value | weight | value | weight | value | weight | value | weight | value |
| Meyer lemon | 293 | $1,466 | 37 | $187 | - | - | 608 | $1,509 | 499 | $781 | 1144 | $2,477 |
| Tahitian lime | 76 | $382 | 3 | $17 | 44 | $132 | - | - | - | - | 47 | $149 |
| A[illegible] mandarin | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible]98 |
| TOTAL | 369.6 | $1,848 | 40.8 | $204 | 44 | $132 | 608 | $1,509 | 824 | $3,179 | 1516.8 | $5,024 |

[1]Weight in Kg, [2]Value in $TOP.

At the commencement of the project, citrus consumed in Tonga was exclusively bush-grown and of poor quality. The production window of this bush-grown citrus was four months of the year, with fruit described as “not sweet, and dry”. Introduced varieties

have opened the production window to six months with fruit described as “looking like the local fruit, only sweet”. With the fruit supplied to supermarkets and the local market selling out within the day.

**Pineapple**
As a result of multiple capacity building workshops provided to Fiji pineapple farmers, the Vulagi Pineapple Farmers Association, Tailevu, Viti Levu Island have increased their planting from 140 to 180 ha[54]**,** resulting in an estimated increase yield of 25% and farmer return of 10%.

*".. pineapple project activity including training of nearby farmers, more farmers in the locality have ventured into pineapple farming" Mr Singh.*

**Breadfruit**
While trials to establish a postharvest storage protocol to enable Samoan breadfruit sea-freight exports were unsuccessful, project-sponsored collaboration between SROS and NWC and Plant and Food Research New Zealand, has stimulated renewed interest in developing fresh Samoan breadfruit airfreight export supply chains. SROS has been in discussions with MAF to discuss constructing a fruit fly treatment facility for export.

There is now a greater awareness of the importance of fruit industries in Fiji. In April 2019, MoA launched its first Fiji fruit industry development initiative based on strategy of promoting and establishing fruit orchards (Suppl 19). To date this has resulted in new guava and dragonfruit orchards being established, with further MoA-sponsored breadfruit, avocado and, jackfruit orchards anticipated.

### 8.3.2 Social impacts

**Pineapple**
Before this project commenced, the Vulagi pineapple farmer association[55] were experiencing hardship due to misinformation about pineapple agronomic practices and limited varietal choices. As it was, pineapples farmers of Vulagi were being given the same agronomic advice as the farmers in Ba (northern district) where historically most of the pineapple farm had been. They had not had the privilege of Ministry advice on local varietal choices or agronomic practices due to their not being any R&D locally. As a result of this project, Vulagi pineapple farmers received significant capacity building support, are now accessing MoA extension support, and are more aware of Fiji Government farmer support initiatives. The Vulagi pineapple farmers have now secured supplementary grants[56] and assistance from the Fiji Government, which have been used to improve on-farm roads (addressing a key postharvest risk factor identified by the project), and purchase farm inputs, and they are currently building a pineapple processing shed. The association members have changed their production practice in favour of contour farming and increased their plantings by 29%[57]**.** This has provided an important social impact, strengthening community commitment to co-operative-based marketing and enabling the community to diversify into pineapple value-adding.

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**54** Information based on an interview with Mr Balbir Singh, President of the Vulagi pineapple farmers association on 23/6/2021.
* We received written permission to use and publish the image of the child shown in Figure 22, in the context of ACIAR project reporting.
**55** Located in Tailevu, Viti Levu, Fiji.
**56** Fiji financial farmer support grants to Vulagi famers was FJD$92,000,
**57** Further details provided on previous page.

## Citrus

New citrus orchards established in Tonga are anticipated to yield 150 tonnes of fruit annually by 2025. Increasing domestic citrus production in Tonga will create a social (health) impact based on providing a more reliable[58] and affordable supply of domestically grown fruit. HORT/2019/165 (phase-2), which commences in July 2021, will quantify these health impacts based on dietary and food consumption surveys.

Figure 24. Citrus trees at Nishi farm yielding high-quality fruit.

### 8.3.3 Environmental impacts

**Pineapple**

While we endeavoured to ensure sustainable horticultural production practice outcomes in all of the fruit crops involved in this project, pineapple was of particular concern given production on hill-side slopes in Fiji has resulted in significant soil erosion (particularly evident in the pineapple farms in the Ba and Natovi region, on Viti Levu Island). As a result of this project, 68 Fiji pineapple farmers were provided with hands-on and demonstration experience in how to construct water draining systems to minimise soil erosion risk and contour planting (Fig. 25 A and B). The Vulagi farmers have now transited into contour planting to reduce hill slope erosion and also received funding[59] support from the Fiji Government to improve on-farm roads (Fig. 25 C and D)


Figure. 25 Reducing soil erosion due to pineapple farming on steep slopes. (A) Demonstration water drainage systems were established on pineapple farms in Natovi and Ba to highlight simple practical strategies to minimise the risk of soil erosion. (B) Fiji farmers who attended capacity building in erosion (and agronomic production practice). (C) Severe soil erosion along internal access roads on a farm at Natovi, in Feb 2017. (D) The same farm after significant grading work of internal access roads, in August 2017

[59] FJD$165,552 was generously provided by the Fiji Government to improve the on-farm roads at the Vulagi settlement. https://www.fijitimes.com/prickly-path-to-success/

## 8.4 Communication and dissemination activities

To disseminate project findings the following activities and initiatives were undertaken:

1. Pineapple farmer training workshops (February 2017), Vulagi settlement and Ba, Fiji.
2. Pineapple production manual (February 2017).
3. Postharvest handling manual for Samoan farmers (2017 and 2019).
4. Presentations at the International Breadfruit Summit, Samoa (October 2017).
5. Postharvest farmer training workshops (October 2018), Vulagi settlement, Fiji.
6. Mango industry workshop (December 2019), Nadi, Fiji.
7. Ongoing Tonga citrus WhatsApp Group (January 2019).[60,61]
8. Postharvest training workshop (August 2019), Nuku'alofa, Tonga.
9. Citrus propagation training workshop for MORDI nursery staff, delivered by zoom™, (July 2020).
10. Regional project steering meeting (objective 3.1) was held annually (Samoa, Australia, Tonga).

Results were further communicated through 18 academic peer reviewed papers and seven technical conference presentations (see section 11- Appendices). The project also undertook extensive communications with stakeholders and partner agencies (see below).

| Date | Person and activity |
|---|---|
| April 2016 | (Singh-Peterson) Site selection in `Eua with citrus consultant and project partners, Tonga. |
| April 2016 | (Zhou) Project planning travel to CePaCT Fiji. |
| April 2016 | (Chapman) - Tonga. Assess citrus industry Tongatapu and `Eua Islands and engage `Eua community re suitable orchard sites, Tonga. |
| June 2016 | (Underhill, Baker) Fijian inception workshop. |
| June 2016 | (Underhill, Ma'asi, Prasad, Hunter) Samoan inception workshop and regional steering committee meeting. |
| June 2016 | (Singh-Peterson) Interviews with citrus growers and vendors in Savai'i, MOA crops and SROS staff members. |
| Aug. 2016 | (Zhou) Project discussion, molecular training to CePaCT Fiji. |
| Aug. 2016 | (Chapman) - Tonga. Confirm orchard sites, conduct initial training at `Eua and plan tropical fruit site at Nishi Trading, Tonga. |
| Sept. 2016 | (Singh-Peterson) Meetings with the Tonga government regarding community citrus plots, Tonga. |
| Sept. 2016 | (Singh-Peterson) Interviews with pineapple farmers and MOA extension officers in Ba and with two pineapple co-operatives located at Natovi Jetty. |
| Sept/Oct. 2016 | Dr. Seeseei Molimau-Samasoni travelled to New South Wales Australia for postharvest training at the University of Newcastle (Ourimbah Campus). |
| Oct. 2016 | (Underhill) Pineapple supply chain assessments, Samoa. |
| Nov. 2016 | (Underhill) Support for tree fruit exports to Tonga, Sydney. |
| Nov. 2016 | (Chapman) - Tonga. Assess site preparations, order equipment, receive citrus trees imported from Eyles Nursery Sydney, plant at Nishi Trading and `Eua trees potted for holding in nursery. |

[60] As of June 2021, this online team discussion forum was still being actively (almost daily) used by Nishi Trading and USC staff.
[61] *New project HORT/2019/165 will prepare extension resource material for Tongan and Samoan citrus farmers.*

| Date (cont) | Person and activity |
|---|---|
| Dec. 2016 | (Zhou, CePaCT) Breadfruit cultivar surveys and investigation on the potential of dwarf cultivar (Samoa). |
| Dec. 2016 | (Baker, MoA, NWC) Mango and breadfruit trial establishment, Fiji. |
| Dec. 2016 | (Cooke) technical assistance and support for mango postharvest disease survey, Fiji. |
| Feb. 2017 | (McGregor, Santen, Underhill) Pineapple farmer training, Fiji. |
| Feb. 2017 | (Singh-Peterson, SROS) Discussion forum held with Sataua community and follow up interviews with gender experts in country, Samoa. |
| Feb. 2017 | (Singh-Peterson, MoA) discussion forum with pineapple growers in Vanua Levu and citrus growers in Vanua Levu, Fiji. |
| April 2017 | (Singh-Peterson, MAFFF) Planting of citrus trees, community discussion forum to determine maintenance program and community governance arrangements, Tonga. |
| April 2017 | (Chapman, MAFFF) - Tonga. Transport trees from Tongatapu to `Eua mark out and plant citrus trees at Houma village and Ha'atu'a village and conduct in-field training and attended workshop. |
| June 2017 | (Singh-Peterson) Invited presentation at ACIAR’s Gender Workshop, Fiji 1 – 3rd June 2017. |
| June 2017 | (Singh-Peterson) Facilitated six gender segregated community discussion forums – Upolu, Samoa. |
| June 2017 | (Baker, MoA, NWC) Mango and breadfruit trial work and project planning, Fiji. |
| June 2017 | (Zhou, CePaCT) Breadfruit cultivar survey and investigation on the potential of dwarf cultivar, Vanuatu. |
| June 2017 | (McGregor, Santen, MoA staff) Pineapple master class, Vanua Levu, Fiji. |
| Sept 2017 | (Underhill, MORDI) stakeholder meetings and field site visits, `Eua and Tongatapu Islands, Tonga. |
| Sept 2017 | (Underhill, FNU, MoA) Stakeholder meetings in Suva, Fiji. |
| Oct 2017 | (Underhill & Zhou) presentation of project activities at the Pacific and Global breadfruit summit, Apia. |
| Oct 2017 | (Underhill, SROS, FNU, MoA) attendance at the Pacific week of Agriculture meetings/symposia in Port Vila, Vanuatu. |
| Oct 2017 | (Underhill, MoA) Fiji. Tropical fruit postharvest handing presentation. International Symposium on Tropical Fruits (ISTF): Food Security amidst a Changing Climate: Towards Sustainable and Resilient Tropical Fruits, Nadi, Fiji. 22-25 October. |
| Nov 2017 | (Chapman, McKenzie) Tonga. Citrus tree evaluation and stakeholder consultation. |
| Nov/Dec 2017 | (Underhill, Chapman, Kumar, Prasad, Zhou) attendance at the ACIAR mid-term review, Fiji. |
| Dec. 2017 | (Baker) Mango trial assessments in Fiji. |
| Feb. 2018 | (Singh-Peterson) Consultation with Naweni community and Government officers, Vanua Levu, Fiji. |
| April 2018 | (Baker) Mango trial assessments in Fiji. |
| April 2018 | (Molimau-Samasoni, SROS) Breadfruit coordination meeting travel from Samoa to Fiji. |
| April 2018 | (McKenzie) Pineapple workshop preparation and consultation meeting to Fiji. |
| April 2018 | (Zhou) Breadfruit dwarfing progress meeting in Fiji. |
| June 2018 | (Chapman, McKenzie) Tonga citrus community orchard assessments. |
| July 2018 | (Underhill, McKenzie) Pineapple postharvest workshop Fiji. |
| Aug. 2018 | (Molimau-Samasoni, Hunter, Tauati, Prasad, Manu) travel to Brisbane to attend annual project review meeting. |
| Aug. 2018 | (Underhill) Postharvest research collaboration and USP student seminars. |
| Oct. 2018 | (Molimau-Samasoni, Va’aiva-SROS) travel to Plant and Food Research New Zealand for postharvest training. |
| April 2018 | (Zhou) Breadfruit dwarfing progress meeting in Fiji. |

| Date (cont) | Person and activity |
|---|---|
| Nov 2018 | (Underhill, Kumar, Patolo) Vavau pineapple supply chain assessment in Fiji. USP student meetings in Nadi, Fiji. |
| Dec 2018 | (Baker) Fiji mango and Breadfruit trial assessments. |
| March 2019 | (Underhill) Samoa. Review project research progress. |
| March 2019 | (Chapman, McKenzie) Tonga citrus trial plot assessments on `Eua and Tongatapu. |
| March/April 2019 | (Zhou) Fiji breadfruit research review meetings with CePaCT. |
| Aug 2019 | (Molimau-Samasoni) SROS-led research on postharvest research to support sea-freight transport of fresh breadfruit from Samoa to New Zealand, was presented at New Zealand Plant Protection Society Annual Conference. |
| Sept 2019 | (SROS, Underhill) Presentations at Pacific week of agriculture & at the Regional Breadfruit Consultation in Samoa on HORT/2014/077 achievements. This was attended by local NGO’s, representatives from Pacific Ministries of Agriculture, USP staff and several Pacific farmer organisations |
| Nov 2019 | (Zhou) NWC experimental design and analysis training |
| Dec 2019 | (Underhill) Project coordination meeting with MoA and CePaCT |
| Dec 2019 | (Ian Baker) Mango industry workshop, Nadi, Fiji |
| Feb 2020 | (Underhill, Zhou) Postharvest capacity building in Fiji. |
| April 2020 | (Beyer) Commissioned review of Vanuatu citrus industry to identify learnings and challenges for Tonga. |
| July 2020 | (Chapman, McKenzie) A zoom based plant propagation workshop was undertaken with MORDI plant nursery staff (Tonga) to support local capacity building in support of local grafting of citrus. |

# 9 Conclusions and recommendations

## 9.1 Conclusions

HORT/2014/077 successfully achieved its objective of enhancing fruit industries in Fiji, Samoa and Tonga, but given the limited historical investment in fruit crops in the Pacific, multiple research questions, and the long-term nature of fruit tree research programs, further investment is needed.

The key project impacts include: the establishment of multiple citrus orchards in Tonga leading to an anticipated 150 tonne production capacity by 2025[62]; significant institutional capacity building outcomes; enhanced regional research and development partnerships; new knowledge on the potential benefit of paclobutrazol to aid breadfruit tree cyclone recovery; glasshouse trials that have potential for inter-species grafting as a strategy to create dwarfing breadfruit trees; new postharvest diseases in mango and papaya identified in Fiji; and a breadfruit cultivar fruiting calendar that supports year-round fruit supply[63].

Our success in developing citrus orchards in Tonga was due to the significant support and in-kind assistance provided by MORDI and Nishi Trading, highlighting the criticality of local NGO and private-sector partnerships. A similar partnership approach was adopted with Vulagi pineapple farmers in Fiji resulting in agronomic practice change, expanded production, and farmers gaining access to local technical and financial support services. Key learnings from the Fiji pineapple and Tonga citrus programs were the importance of consulting farming communities at the project-design phase,[64] and the benefit of platforms such as WhatsApp to maintain effective communications. In breadfruit, we achieved significant research impact but translating research findings into economic impact will require increased industry coordination, ongoing extension support and long-term research investment. Mango fresh fruit industry in Fiji is considered marginal but could be improved if project research findings were adopted. The central challenge for Fiji's mango industry is overcoming low farmer returns (due to low-input production systems, seasonal supply gluts, poor fruit quality, and vulnerability to cyclone damage).

We believe SROS has the potential to become an important regional centre of excellence in postharvest horticulture and applied food processing technology for the Pacific[65]. While the project successfully collaborated with several NGOs, the vulnerability of these agencies to loss of critical staff and technical capacity remains problematic. With NGO's playing an increasingly important role in the agriculture sectoral development across the Pacific (Anon 2020 b; Moloney, 2020; Roche et al., 2020), strategies to enable sustainable NGO capacity building needs to be identified.

Ministry of Agriculture (MAFFF, MAF and MoA) capacity to support Pacific fruit industries faces long-term challenges (due to resource and staffing constraints, limited critical research infrastructure and diverse industry service obligations). There is an emerging need to better support horticultural extension services across the Pacific, with an emphasis on improved regional collaboration (Suppl. 19).

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[62] Tonga imported 1,049 tonnes of fresh fruits in 2019, including 462 tonnes of citrus, (Anon 2019).

[63] See Table 1 - Papaya fruiting calendar, which supports this impact.

[64] Further information on the project community engagement is outlined in Suppl. 7.

[65] Based on targeted staff training and institutional network development (whereby SROS is now closely partnering with a series of Australian and New Zealand research agencies) support by ACIAR Hort 2014-077] and strategic equipment and infrastructure investment by FAO and the Samoan Government.

## 9.2 Recommendations

1. This project has identified and developed a network of highly collaborative private sector and NGO partners (Vulagi Pineapple Farmers Association [Fiji], MORDITT [Tonga], NWC [Fiji], and the Asau and Sataua[66] communities [Samoa]). These agencies and communities were central to the success of this project. However, developing robust and effective partnerships in the Pacific can be very challenging and often necessitates long-term and multifaceted engagement. We believe there is a need for more structured opportunities and processes whereby current best practice and key learnings can be effectively shared between ACIAR's Pacific project leaders (especially with new or early career project leaders) and ACIAR Research Program Managers.
2. Given limited historical research on fruit crops in the Pacific, this project focused on research-based trials, the importation of new genetics, and targeted capacity building support. While this proved highly effective (i.e. citrus orchards being established in Tonga; improved pineapple agronomy in Fiji; enhanced postharvest research capacities at SROS), there is now a need to improve local extension services and products that better support fruit-farmers in Fiji, Tonga and Samoa. This could include:
    - A review of Pacific horticultural extension services and identify approaches to enhance regional extension resource sharing and farmer support services. This review should be farmer-centric, explore how farmers currently source extension services and knowledge, the type of information being sought, and the potential need for bilingual extension products.
    - With very high mobile phone ownership across the Pacific this creates opportunities to also explore new emerging delivery platforms.
3. With NGO's having an increasing role in the delivery of ACIAR-funded Pacific projects, there is a need to undertake an analysis of these NGO's (that support Pacific farmer innovation) to identify strategies that ensure sustainable capacity building outcomes can be achieved.
4. Breadfruit
    - To date, ACIAR efforts to support breadfruit industry development in the Pacific has involved a series of targeted interventions (i.e. plant propagation, cultivar performance, annual cultivar-fruiting calendar, postharvest handling, tree form, nutrition and tree spacing) across numerous projects. While we now have a better understanding of breadfruit preharvest and postharvest handling practice, many of the key research questions remain partially resolved. Given the importance of breadfruit to Pacific food security, as well as the emergence of commercially significant value-added breadfruit products, there is a case for a future regional Pacific breadfruit initiative (as recommended by the 2019 Breadfruit Summit in Samoa).
    - Given the absence of a suitable breadfruit experimental research orchard in Fiji, further technical assist and support needs to be provided to MoA to create a statistical-designed and suitably replicated breadfruit agronomic trial plot, possibly located at the MoA Legalega Research station.

[66] These villages (both located on north-western Savai′i Island) represent Samoa's main citrus production region.

5. Mango
    - While this project has developed numerous scientific impacts potentially benefiting Fiji's mango industry, there needs to be follow-up extension effort to raise awareness amongst Fiji's mango farmers and exporters. This could be achieved by MoA gaining access to existing mango extension material produced through multiple prior and current ACIAR-funded mango projects.
    - Further trials to identify suitable mango cultivars able to withstand the high rainfall of the Fijian climate and to extend the season are required
    - MoA may wish to consider seeking chemical registration of paclobutrazol (in Fiji) as a trunk drench to increase mango fruit yield and tree recovery following cyclone impacts. Given cultivar and location variable responses, there is unlikely to be one optimal Paclobutrazol application treatment. Based on trial results and commercial application elsewhere, a potential paclobutrazol registration should be around 20 to 25 mL ai / tree applied.
    - There is a need for a mango extension manual (for distribution to farmers through extension services) with clear photos of Fiji mango varieties and their characteristics for identification.
6. Pineapple
    - Based on feedback from pineapple farmers in Fiji, there was considerable interest in exploring value-adding options based on community-scale micro processing capacity and infrastructure. Vulagi Pineapple Farmers Association is currently sourcing pineapple value adding equipment based on assistance from MOA but would significantly benefit from agribusiness technical support to develop commercially viable value-chains.
    - MoA has a significant pineapple field research site located within the Seaqaqa Research Station, Vanua Levu, Fiji. This research capacity was only fully appreciated at the latter stages of Hort 2014-077. Future ACIAR investment in support of the Fiji pineapple industry should considered inclusion of this research station and associated staff.
7. Capacity building. One common challenge many Pacific non-Government agricultural/community support organisations face, is the retention of critical skills. This challenge was evident in our capacity to undertake effective mango and breadfruit trials in Fiji, and the loss of some critical staff at the conclusion of the project. We believe there is a need to provide further technical capacity building support in the Pacific, but equally there needs to be a concurrent plan as to how these skills will be retained at the conclusion of the project. For example:
    - NWC would benefit from further assistance to improve their technical expertise in experimental design and data analysis. However, attempts to provide this training (by this project and prior ACIAR-projects) has not led to enhanced organisation capacity. An alternative approach might be to encourage greater technical skills sharing opportunities between NWC and MoA.
    - FNU would benefit from targeted capacity building in horticultural entomology (specifically tree crops). Given current ACIAR investment in pests and disease research in the Pacific (including Fiji), this could be achieved through encouraging and supporting closer links between FNU and MOA staff.
    - We believe SROS has the potential to become an important regional centre of excellence in postharvest horticulture and applied food processing technology for the Pacific

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## 9.4 List of publications produced by project

**Academic Publications**

1. Zhou, Y and Underhill, S.J.R. (2021). Differential transcription pathways associated with rootstock-induced dwarfing in breadfruit (*Artocarpus altilis*) scions. BMC Plant Biol 261:1-21. https://doi.org/10.1186/s12870-021-03013-6.
2. Underhill, S.J., Sherzad, S., Zhou, Y., Molimau-Samasoni, S. and Tagoai, S.M., 2020. Postharvest Loss in Fruit and Vegetable Markets in Samoa. In *Food Security in Small Island States* (pp. 111-131). Springer, Singapore.
3. Underhill, S.J., Patolo, S., Zhou, Y. and Burkhart, S., 2020. The Agriculture–Nutrition–Income Nexus in Tonga: Is Postharvest Loss Undermining Horticulture Market Efficiency in Tonga? *Horticulturae*, *6*(4), p.61.
4. Molimau-Samasoni S., Vaaiva, V., Wills, R.B.H (2020). Effect of low temperatures on the storage life of two Samoan breadfruit (Artocarpus altilis) cultivars. Journal of Horticulture and Postharvest Research. 3:91-96
5. Zhou, Y. and Underhill, S.J.R (2020). Expression of gibberellin metabolism genes and signalling components in dwarf phenotype of breadfruit (Artocarpus altilis) plants growing on marang (Artocarpus odoratissimus) rootstocks. Plants. 9. 634. doi: 10.3390/plants9050634
6. Kumar, S. and Underhill, S.J.R (2019). Smallholder farmer perceptions of post-harvest loss and its determinants in Fijian tomato value chains. Horticulturae, 5(4), 74. doi:10.3390/horticulturae5040074
7. Molimau-Samasoni S., Vaaiva V., Seruvakula S., Tugaga A., Ortiz G., Wallace S., Seelye M., Waddell B., Brown S., Jamieson L., Woolf A. 2019. A comparison of postharvest quality of breadfruit (*Artocarpus altilis*) after disinfestation with hot air or hot water treatments. *New Zealand Plant Protection* **72:** 67-74.
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9. Zhou, Y. and Underhill, S.J.R (2019). A dwarf phenotype identified in breadfruit (Artocarpus altilis) plants growing on marang (A. odoratissimus) rootstocks. Horticulturae 5, 40; doi:10.3390/horticulturae5020040.
10. Singh-Peterson L., and Iranacolaivalu, M. (2018). Gender perspectives on restrictions and barriers for subsistence farmers wishing to engage further in Fiji's food system. *J Rural Studies,* 60: 11-20.

11. Zhou, Y. and Underhill, S.J.R (2018). Plasma membrane H+-ATPase activity and graft success of breadfruit (Artocarpus altilis) onto interspecific rootstocks of marang (A. odoratissimus) and pedalai (A. sericicarpus). *Plant Biology* doi: 10.1111/plb.12879.
12. Kumar, S., Underhill, S. and Kumar, S. (2017). Importance of historical review of horticulture in Fiji. *Journal of South Pacific Agriculture*. 19 (1&2): 9-2.
13. Underhill, S.J.R and Kumar, S. (2017). Postharvest handling of tropical fruit in the South Pacific. *Fiji Agricultural Journal*. 57(1): 19-26.
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15. Underhill, S.J.R., and Singh-Peterson, L (2017). Improving non-communicable disease remediation outcomes in Tonga: the importance of domestic fruit production systems: an analysis. *Journal of Agriculture and Rural Development in the Tropics and Subtropics,* 118(1): 91-103
16. Underhill, S.J.R., Zhou, Y., and Kumar, S. (2017). Infrared Thermal Imaging: A Practical Educational Tool to Improve Smallholder Farmer Postharvest Practice in Fiji. *Journal of Agricultural & Food Information*, 18(2), 75-80.
17. Zhou, Y., and Underhill, S.J.R. (2017). Breadfruit (Artocarpus altilis) DELLA genes: gibberellin-regulated stem elongation and response to high salinity and drought. *Plant Growth Regulation*, 83(3), 375-383.
18. Zhou, Y., and Underhill, S.J.R. (2016). Breadfruit (*Artocarpus altilis)*: gibberellin 2-oxidase genes in stem elongation and abiotic stress response. *Plant Physiology and Biochemistry,* 98:81-88

**Technical booklet.**

1. Underhill, S.J.R. (2017). A practical guide to better postharvest handling for Samoan smallholder farmers. University of the Sunshine Coast, Qld. pp76. https://research.usc.edu.au/discovery/fulldisplay?docid=alma99450698802621&context=L&vid=61USC_INST:ResearchRepository&lang=en&search_scope=Research&adaptor=Local%20Search%20Engine&tab=Research&query=any,contains,steven%20underhill&offset=0

**Conference publications**

1. Molimau-Samasoni, S., Vaaiva, V., Seruvakula, S., Tugaga, A., Ortiz, G., Wallace, S., Seelye, M., Waddell, B.C., Brown, S.D., Jamieson, L.E. and Woolf, A., (2019). A comparison of postharvest quality of breadfruit (Artocarpus altilis) after disinfestation with hot air or hot water treatments. *New Zealand Plant Protection*, *72*, pp.67-74
2. Underhill, S.J. and Salesh, K., 2018. Postharvest handling of tropical fruits in the South Pacific. In *Proceedings, International Symposium on Tropical Fruits (ISTF2017)," Food Security amidst a Changing Climate: Towards a Sustainable and Resilient Tropical Fruit Industry", 23-25 October 2017, Nadi, Fiji* (pp. 81-88). International Tropical Fruits Network (TFNet).
3. Underhill, S.J.R. (2017). A brief overview of breadfruit research in the South Pacific. Presentation to the Global and Pacific Breadfruit Summit, Apia, Samoa. 10-12 October.
4. Underhill, S.J.R. and Kumar, S. (2017). Postharvest handling of tropical fruits in the South Pacific. Proceeding of the Iinternational *Symposium* on *Tropical Fruits* (ISTF): *Food Security amidst a Changing Climate: Towards a Sustainable and Resilient Tropical Fruits*, Nadi, Fiji. 22-25 October. (in press).
5. Zhou, Y. and Underhill, S. (2017). Breadfruit dwarfing: a strategy for climate resilience. 2017 Samoa Pacific & Global Summit, October 10-12, 2017, Apia, Samoa. (Oral presentation)
6. Zhou, Y., Underhill, S. (2017). Breadfruit (*Artocarpus altilis*) gibberellin metabolic genes: stem elongation and abiotic stress response. 3rd Global Summit on Plant Science, August 7-9, 2017, Rome, Italy. (Oral presentation)
7. Lomavatu, M. F., Coates, L., Underhill, S. (2015). Postharvest diseases of mangoes in Fiji, APPS Conference Proceedings, Fremantle, Western Australia.

**Reports**

1) Beyer, R. (2020) Rapid review of Vanuatu citrus industry to identify learnings ad challenges for Tonga.
2) McGregor, A. (2017) Pineapple Agribusiness Opportunities for Fiji, Samoa and Tonga: Report Prepared for the ACIAR Tropical Fruit Project (ACIAR HORT/2014/077). 67pp. (see Suppl. 2 to source)
3) McGregor, A. (2017) Report on Natovi pineapple farmer training. (ACIAR HORT/2014/077). 13pp. (see Suppl. 13 to source)
4) McGregor, A. (2017) Improving husbandry practices in pineapple cropping: Ba training workshop report. (ACIAR HORT/2014/077). 16pp. (see Suppl. 15 to source)
5) McGregor, A. (2017) Report on master class training for the Fiji Ministry of Agriculture in profitable and sustainable pineapple cropping. (ACIAR HORT/2014/077). 21pp. (see Suppl. 16 to source)
6) Molimau-Samasoni, S. (2016) Postharvest Training at the University of Newcastle and Department of Primary Industries New South Wales, Central Coast (September 26th – October 7th). SROS Internal Report
7) Molimau-Samasoni, S. (2016) Report on visit to Plant & Food Research New Zealand to discuss alternative quarantine treatments, Auckland (October 26th). SROS Internal Report
8) Molimau-Samasoni, S., Seruvakula, S., Tagoai, M., Vaaiva, V. and Faatuiese, S. (2016) Preliminary trial on cool storage of Puou and Ma'afala breadfruit to extend postharvest shelf-life. SROS Internal Report (see suppl. 1 to source data)

9) Molimau-Samasoni, S., Seruvakula, S., Tagoai, M., Vaaiva, V. and Faatuiese, S. (2017) Preliminary trial on cool storage of Puou and Ma'afala breadfruit to assess chilling injury scale. SROS Internal Report. (see Suppl. 1 to source data)
10) Molimau-Samasoni, S., Seruvakula, S., Tagoai, M., Vaaiva, V. and Faatuiese, S. (2017) Experimental trials 1 and 2 into cool storage of Puou and Ma'afala breadfruit to extend postharvest shelf life. SROS Internal Report. (see Suppl. 1 to source data)
11) Molimau-Samasoni, S (2018). Report on Heat Chamber Training for Dr. Seeseei Molimau-Samasoni (Cabinet Submission, Government of Samoa) (see Suppl. 1 to source data)
12) Molimau-Samasoni, S.; Tanielu, P., Vaai, A., and Seruvakula, S. (2018). Report on Study Tour of Fiji Breadfruit Industry for Dr. Seeseei Molimau-Samasoni & Semi Seruvakula (Cabinet Submission, Government of Samoa) (see Suppl. 10
13) Molimau-Samasoni, S., Tauati, S. and Hunter, TD. (2018) Travel Report on ACIAR Steering Committee Meeting, Update & Deliberations for Phase 2 of Project in Australia, (Cabinet Submission, Government of Samoa)
14) Molimau-Samasoni, S. (2018). Report on Heat Treatment Experiment Discussions & Update at Plant & Food Research New Zealand (Cabinet Submission, Government of Samoa)
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16) Singh-Peterson, L. (2017) HORT 2017/044 Objective 4: Status of Activities and Frameworks Utilised. HORT 2014/077 Project Report.
17) Singh-Peterson, L and Iranacolaivalu, M. (2018) Appraisal of a potential community-based citrus project based in Fiji. HORT 2014/077 Project Report. (see Suppl. 9 to source data)
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19) Underhill, S.J.R. (2017) Six monthly project briefing – Tonga. Report to MAFFF Tonga. 4pp.
20) Underhill, S.J.R. (2017) Six monthly project briefing – Fiji. Report to MoA Fiji. 4pp

**Supplementary List of Documents (providing links to attachments)**

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|---|---|
| Suppl. 1 | Breadfruit Technical Report.pdf (pp. 17-18) |
| Suppl. 2 | Pineapple Agribusiness Opportunities for Fiji, Samoa and Tonga.pdf |
| Suppl. 3 | Pineapple postharvest shelf-life guide.pdf |
| Suppl. 4 | Report improving vale-chains.pdf |
| Suppl. 5 | Technical report on postharvest trials.pdf |
| Suppl. 6 | Breadfruit and pineapple supply chain assessments.pdf |
| Suppl. 7 | Criteria of site and community selection for new citrus orchards in Tonga.pdf |
| Suppl. 8 | Eua citrus site selection.pdf |
| Suppl. 9 | Appraisal of a potential community-based citrus project in Fiji.pdf |
| Suppl. 10 | Breadfruit Review (Draft).pdf |
| Suppl. 11 | Ian Baker final report. pdf |
| Suppl. 12 | Field survey data breadfruit tree form and growth habit in the Pacific.xlsx |
| Suppl. 13 | Natovi Fiji Training Report.pdf |
| Suppl. 14 | Seaqaqa Fiji Training Report.pdf |
| Suppl. 15 | Ba Fiji Training Report.pdf |
| Suppl. 16 | Technical report – pineapple postharvest loss trials in Fiji.pdf |
| Suppl. 17 | Farmer Handbook – pineapple postharvest loss trials in Fiji.pdf |
| Suppl. 18 | Photos of calcium deficiency.pdf |
| Suppl. 19 | Policy Guidelines Fruit.pdf |
| Suppl. 20 | Better postharvest handling for Samoan smallholder farmers.pdf |