Pacific Community
Communauté du Pacifique

Volume 1 | No. 1 | 2025

Journal of Agriculture and Forestry in the Pacific

Volume 1 | No. 1 | 2025

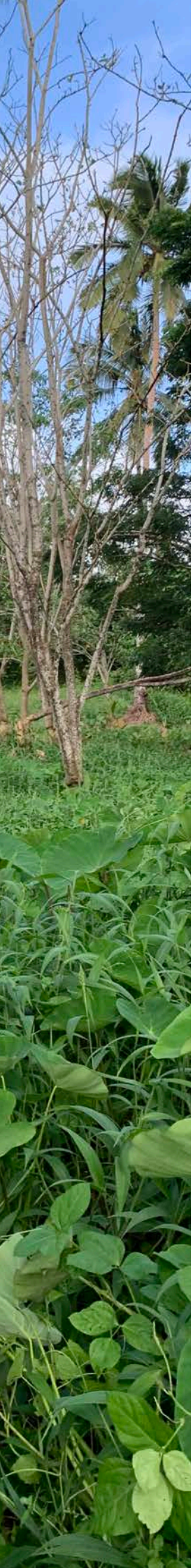
Journal of Agriculture and Forestry in the Pacific

Pacific Community
Communauté du Pacifique

Suva, Fiji, 2025

Prepared for publication at SPC's Suva Regional Office, Private Mail Bag, Suva, Fiji, 2025

www.spc.int | spc@spc.int



Contents


©SPC

Foreword

Journal of Agriculture and Forestry in the Pacific
Volume 1 | Issue 1 | 2025

Why a *Journal of Agriculture and Forestry in the Pacific*?

The need was identified during the Pacific Heads of Agriculture and Forestry Services (PHOAFS) in 2021 for Pacific Island countries and territories (PICTs) to drive, coordinate and share resources to implement research aimed at achieving regional impact. At the request of the PHOAFS, the Pacific Community (SPC), in collaboration with member countries, developed and tested the framework of the Pacific Regional Research Agenda (RRA).

To lead on the testing of the framework, a group of peer reviewers were nominated by the PHOAFS to work with SPC as the Secretariat to test the framework. The testing of the RRA framework was carried out on each of the framework's components and elements, including 'Hearing Pacific Voices', 'Peer Review' and 'Partners in Research'.

During the testing process it was identified that there was the lack of knowledge-sharing platforms for Pacific Islanders to share their research. Three knowledge-sharing platform initiatives were proposed by the group of peer reviewers. Regional write shops were proposed to be held annually to encourage the analysis and writing of research results from Pacific researchers. A regional conference or symposium was proposed to be held every two years prior to the Pacific Week of Agriculture and Forestry (PWAF) to share research, build on lessons learned from existing research and develop networks among Pacific researchers, and a journal to support in sharing knowledge from the Pacific.

As the founding members of the Peer Reviewers, tasks were allocated to team members to support with putting into action the knowledge-sharing platforms. We became the co-editors of the newly established *Journal of Agriculture and Forestry in the Pacific* (*JAFPac*) and it gives us great pleasure to share with you the very first issue.

We hope that *JAFPac* will be an avenue that encourages knowledge-sharing by the Pacific and for the Pacific to build the research platform for our region.

JAFPac supports in realising the vision that the PHOAFS have for the region, and it is our goal to have the journal sustained through collaboration and partnership. We would like to thank all our partners who made this first issue possible. The Australian Centre for International Agriculture Research (ACIAR) not only funded the testing of the framework of the Pacific RRA but also the printing of the journal for distribution. The Ministry of Foreign Affairs and Trade, New Zealand also contributed to the printing costs through their Funding with Intent (FiT) programme. We also acknowledge all our researchers from around the world and the region who volunteered to read and provide comments to the first set of articles in *JAFPac*. A big appreciation to the SPC Publications team that worked tirelessly against a tight deadline to realise this dream. Most of all, we wish to thank all our Pacific Island researchers who contributed the first articles for this issue: thank you for taking the time to write and share your research.

This is the first issue, and we intend to continue publishing at least two issues every year. We hope that *JAFPac* will be an avenue that encourages knowledge-sharing by the Pacific and for the Pacific to build the research platform for our region.

Le *Journal of Agriculture and Forestry in the Pacific* a vocation à accueillir les articles en anglais et en français, de recherche, d'expérimentations réalisées dans ou sur des sujets impliquant directement les pays du Pacifique et permettant de faire rayonner la recherche océanienne.

Thank you and merci!

Dr Maurice Wong and Dr Shalendra Prasad

Journal of Agriculture and Forestry in the Pacific

Co-Editors
April 2025

Declining giant swamp taro production on Kayangel Atoll, Palau

Soil salinity and sustainable management strategies

Rohit Lal,[1]* Andreas Antoniou,[2] Binesh Prasad,[3] John Carreon,[4] Mary Hingst,[5] Marson Anthony Aderiano[6] and Larry Mamis[7]

Abstract

Cyrtosperma merkusii (Hassk.) Schott, commonly known as giant swamp taro, is a culturally and nutritionally important crop in Micronesia, but its production has declined on atolls. This study investigates the causes of this decline on Kayangel Atoll, Palau. Soil sampling revealed elevated sodium (Na^+) levels in taro pits, likely due to increased groundwater salinity. High sodium concentrations negatively impact soil structure, permeability and fertility, challenging taro cultivation. Porewater analysis showed consistently low sulphide concentrations, ruling out elevated sulphide as a cause of the decline. This research examines the characteristics of Kayangel's taro pits, explores the causes of high sodium levels and proposes management strategies to support sustainable taro cultivation within these fragile atoll ecosystems.

Introduction

Palau, a nation of more than 340 islands in the Pacific, is celebrated for its biodiversity, marine environments and unique cultural heritage. Kayangel, the northernmost atoll in Palau, plays a crucial role in local agriculture, particularly the cultivation of traditional crops like giant swamp taro (GST).

Keywords: Atoll agriculture, Giant swamp taro, Micronesian food security, Palau, Soil salinity, Sustainable agriculture taro pit management.

Food production on atolls like Kayangel is challenged by several factors, including: saltwater intrusion, flooding, and drought; limited arable land, urbanisation, and lifestyle changes; declining outer island populations; and poor access to local and export markets. These challenges are expected to intensify with climate change, impacting crop production and further reducing available farmland.

For atoll communities, subsistence food gathering and production through fishing and farming are the primary sources of both food and income. Commonly cultivated crops include coconut, breadfruit, pandanus, banana, and root crops like swamp taro, ground taro, sweet potato, cassava and yam. These crops are typically grown on small (much less than an acre), communally-owned farms. While copra is a major agricultural export, its production is limited.

Food crop production on atolls requires significant effort due to the porous, alkaline soils with limited fertility, which restricts the range of suitable crops. Improving soil fertility to enhance food production and address food and nutrition insecurity is a common challenge, hindered by a lack of appropriate technologies.

On Kayangel Atoll, the cultivation of GST has declined, especially among younger generations. This decline, coupled with a reduction in local food supply, has led to increased consumption of imported processed foods, which has negative economic impacts and contributes to the rise of non-communicable diseases in the region (Taylor et al., 2016; FAO, 2022).

1 Soil Scientist, Pacific Community (SPC); rohitl@spc.int; *Corresponding author: rohitl@spc.int
2 Senior Hydrogeologist, Pacific Community (SPC); andreasa@spc.int
3 Pacific Soils Partnership Coordinator, Pacific Community (SPC); bineshp@spc.int
4 Technical Officer, Pacific Community (SPC); johnc@spc.int
5 Hydrogeologist, Pacific Community (SPC); maryh@spc.int
6 Outlying States Supervisor, Palau Public Utilities Corporation; marson.a.aderiano@gmail.com
7 Chief of Forestry, Palau; larrymamis@gmail.com

While research highlights the importance of GST as a subsistence crop and food security resource in Pacific Island nations (Raynor & Fownes, 1991), its declining cultivation due to soil degradation and changing dietary preferences poses risks to local food systems (FAO, 2022).

This study investigates the factors contributing to decline in GST production on Kayangel Atoll and explores potential management strategies to restore soil health and promote sustainable agricultural practices in Palau.

Research methodology

Soil sampling

Soil samples (Figure 1) were collected from three giant swamp taro farms (Figure 2) at depths of 0–5 cm and 0–20 cm to assess soil fertility. Composite l samples, each consisting of five individual cores, were taken from the periphery, centre, and areas exhibiting suboptimal taro growth within each farm. These samples were air-dried, sieved, and sent to the Palau Bureau of Agriculture for phytosanitary certification before being exported to Fiji for chemical analysis.

The analysed parameters included pH, total nitrogen, Olsen phosphorus, exchangeable potassium, calcium, magnesium, sodium and phosphorus retention. Soil fertility status was then assessed by comparing these measured values against established critical or optimal guideline levels and taro nutrient uptake requirements (Blakemore et al., 1987).

Porewater sampling

To investigate the potential link between declining crop production and elevated sulphide levels in groundwater, porewater samples were collected and analysed. MacroRhizons samplers (Edaphic Scientific) were installed in the same three taro pits. Within each pit, three MacroRhizons were placed along the edge where taro plants were still growing, and another three were placed towards the centre where taro plants were absent. At each location, samplers were inserted to depth of 20–30 cm, 30–40 cm, and 40–50 cm. After an overnight rest to ensure filter saturation, syringes were attached to each sampler and a vacuum was applied using wooden sticks. Filled syringes were collected in the afternoon. Before detaching the syringes, the flow valve was closed to prevent sulphide oxidation.

Sample vials were pre-filled with 2 or 3 mL of a zinc acetate and sodium hydroxide solution, following the Standards Methods for the Examination and Wastewater (4500-S2-Sulfide) for sulphide preservation. Needles were attached to the syringes, submerged in the zinc acetate solution, and porewater was injected to fill the vial. Caps were immediately secured to minimise oxidation risks. These samples were then shipped to the University of Delaware for analysis.

FIGURE 1. Soil sampling within a taro cultivation pit.

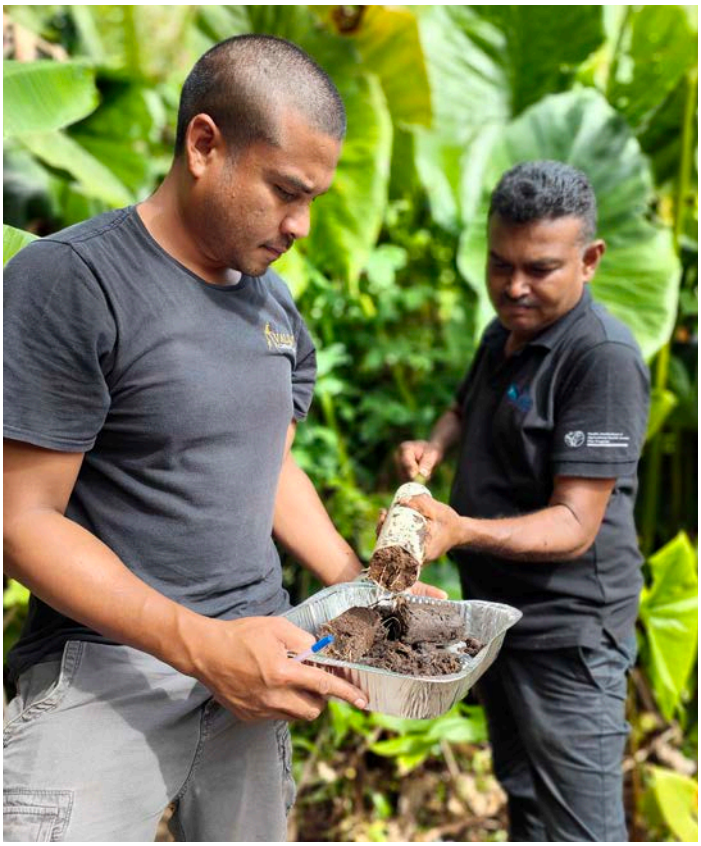


FIGURE 2. Soil sampling within a taro cultivation pit.

Groundwater/saltwater intrusion

Given the dependence of GST farming on groundwater for soil moisture, the potential impact of groundwater quality perturbations was also investigated. Shallow monitoring wells were installed in the three taro pits to enable measurements of water level and electrical conductivity (a proxy for salinity). In each pit, one well was installed along the edge where taro was growing, and another was installed in the centre where taro was absent. Constructed from 3-inch PVC pipe, the wells were approximately 1 m tall, with holes drilled into the bottom third. The pipes were inserted approximately 0.5 m into the ground, and the tops were sealed with screw-on caps.

Schlumberger Divers were deployed in each monitoring well to automatically record pressure, electrical conductivity, and temperature every 15 minutes. Two additional loggers recorded barometric pressure at 15-minute intervals. The loggers were deployed for approximately seven months.

Results

Field observations

Observations at the third site revealed a dense proliferation of water hyacinth concentrated in the swamp's centre. Water hyacinth (*Eichhornia crassipes*), a freshwater species, is recognised as one of the world's most invasive aquatic plants due to its rapid reproduction (Guezo et al., 2019). However, its growth is typically limited in coastal and estuarine environments by salinity, as it cannot tolerate levels exceeding 9 ppt. Salinity beyond the oligosaline range (0.5–5 ppt) is known to weaken and damage the plant. The substantial presence of *E. crassipes* at this site suggests the presence of stagnant freshwater conditions in the middle area of the swamp.

TABLE 1. Morphological characteristics of the three taro pit sites.

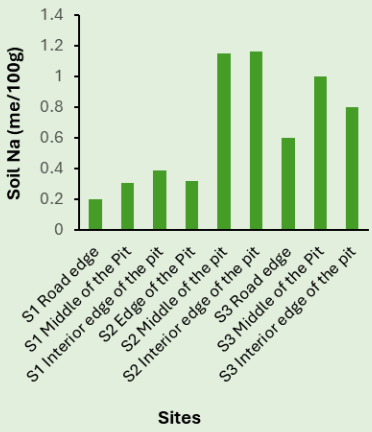
SITE	GPS COORDINATES	AREA (M^2)	% OF SWAMP WITHOUT TARO	REMARKS
1	8°05′02″N 134°43′06″E	4169	50%	GST is primarily found along the parameters of the pit, especially in areas where water is not stagnant.
2	8°05′09″N 134°43′03″E	3198	60%	There are no taro plants in the centre of the swamp, water is stagnant.
3	8°04′42″N 134°43′10″E	3071	90%	Water is stagnant in the field. GST is only found at the end of the pit. Water hyacinth grows throughout the swamp area.

FIGURE 3. Areas of poor taro growth due to encroachment by water hyacinth (Eichhornia crassipes).

Taro growth observations

Observations of taro growth across the three sites are summarised in Table 1. At site 1, encompassing 4169 m^2, approximately 50% of the swamp area lacked taro plants. Giant swamp taro (GST) was primarily observed along the periphery of the pit, particularly in areas where water was not stagnant. Site 2, covering 3198 m^2, showed a greater proportion (60%) of the swamp without taro. Here, no taro plants were found in the centre of the swamp, where water was stagnant. Site 3, the smallest at 3071 m^2,

FIGURE 4. Soil sodium concentrations.



exhibited the most extensive decline in taro cultivation, with 90% of the swamp lacking taro plants. Water stagnation was observed throughout this field, and GST was only found at one end of the pit. *E. crassipes* growth was prevalent throughout the swamp area at this site (Figure 3).

Soil characteristics of Palau taro pit

Figure 4 illustrates exchangeable soil Na levels, while Figure 5 presents the total Na percentage in giant swamp taro leaves. Samples collected from the centre of Pits 2 and 3 exhibited Na levels exceeding 1. Similarly, taro leaf samples from all sites contained Na levels above 0.4%. Ideally, the Na concentration in taro leaves should range between 0.1% and 0.3%. The elevated Na levels in the soil may have contributed to the increased Na uptake in the leaves.

This excessive sodium adversely impacts soil structure, reduces permeability, and diminishes fertility, posing challenges for cultivation. Key aspects of sodic soils, including their features, underlying causes, and potential management strategies, are critical to addressing these issues and ensuring sustainable taro production in the atolls.

Figure 6 shows Olsen P levels in taro pits. All sites had Olsen P levels of above 20 mg/kg, indicating that P levels are sufficient in these soils.

Figure 8 shows soil exchangeable K levels in taro pits. Six out of the nine sampled sites had exchangeable soil K levels below 0.3 me/100g, indicating that potassium (K) is a yield-limiting nutrient. K deficiency in taro can significantly affect plant growth and yield. Key symptoms include chlorosis (yellowing) of older leaves, followed by necrosis (browning and drying), particularly along the leaf margins (Figure 10).

Porewater sulphide

Porewater analysis showed consistently low sulphide concentrations across all samples, ranged from 0.371 to 0.499 mg/L. This suggests that the decline in

FIGURE 5. Sodium concentrations in taro leaves.

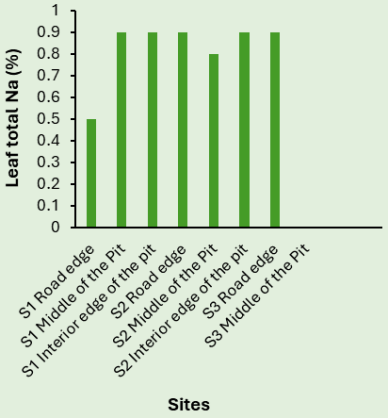


FIGURE 6. Soil available phosphorous

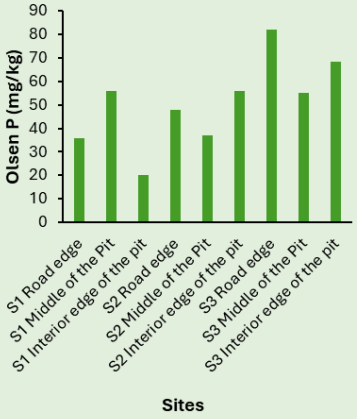


FIGURE 7. Phosphorous concentrations in taro leaves.

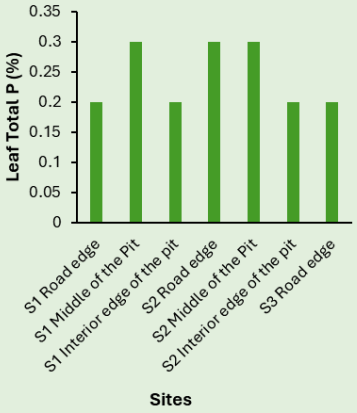


FIGURE 8. Soil potassium concentrations.

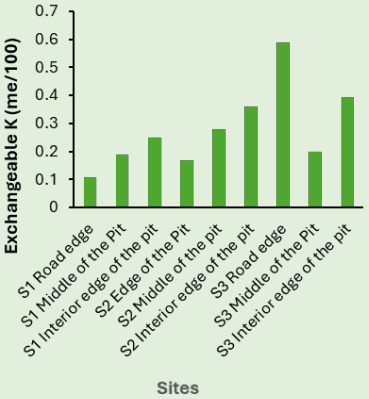


FIGURE 9. Potassium concentrations in taro leaves.

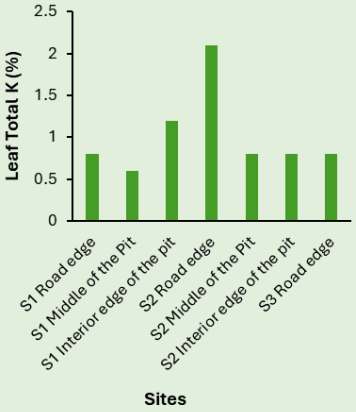
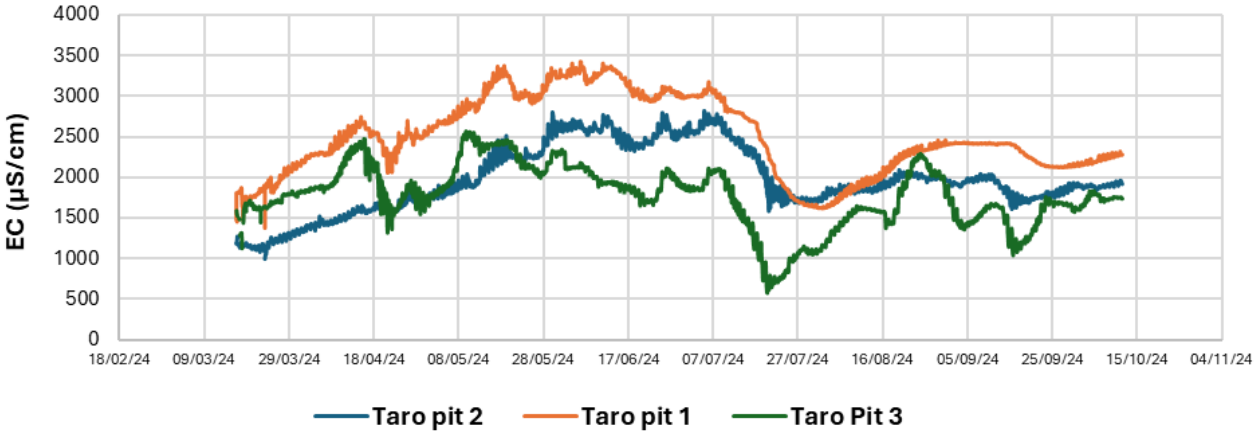


FIGURE 10. Leaf yellowing and edge burning, indicative of potassium deficiency.

FIGURE 11. Groundwater electrical conductivity in the three taro pits.



taro crop production is unlikely to be caused by elevated sulphide levels. Notably, the highest sulphide concentration was measured in the pure zinc acetate solution, indicating that the detected sulphide in the porewater samples likely originated from the preservative solution itself, rather than the porewater.

Groundwater salinity

Groundwater salinity, as indicated by electrical conductivity (EC), generally responded to climatic conditions in all three taro pits. Rainfall events typically led to a decrease in salinity, followed by a gradual increase during dry periods. Taro Pit 3 exhibited the greatest sensitivity to rainfall, showing the largest fluctuations in EC over time. This pit was also assessed as the least productive based on field observations. Conversely, Pit 2 appeared most resilient to external climatic influences, demonstrating the least variation in EC throughout the monitoring period. Field observations indicated that Pit 2 was the most productive of the three (Figure 10).

Discussion

Key features of taro pits

The taro pits of Kayangel Atoll exhibit several key features that contribute to the challenges faced by local farmers. Over the past decade, Palau has experienced several devastating Category 4 and 5 typhoons, including Bopha, Haiyan and Lan in 2012, 2013 and 2017, respectively (Merrifield et al., 2019). These typhoons, passing directly over the islands, caused widespread inundation and devastation, including salt spray damage to shoreline vegetation and reef damage.

The high sodium and chlorine levels observed in the taro pit soils may be a consequence of saltwater intrusion and salt spray during these typhoon events. The elevated sodium concentrations contribute to poor soil structure, leading to soil particle dispersion, weak aggregation, and compaction.

High sodicity causes excessive clay swelling when wet, leading to particle dispersion and weakening soil aggregates, ultimately resulting in structural collapse and pore closure. Consequently, water and air movement are severely restricted, leading to low permeability, stagnant water, and the high pH levels (often above 8.5) characteristic of sodic soils. Surface crusting further impedes seedling emergence. Root damage due to poor aeration and toxic sodium concentrations is also observed in declining plants.

Furthermore, the soils exhibit low fertility, exacerbated by reduced aeration and restricted water movement, which limit root development and nutrient availability. Potassium levels, an essential plant nutrient required in larger amounts, are particularly low across most sites. Ideal exchangeable potassium levels should be between 0.3 and 0.7 meq/100g, comprising 3 to 8% of total cations. However, two-thirds of the pit areas showed exchangeable potassium levels below 0.3 meq/100g. This potassium deficiency, along with other nutrient imbalances and poor water uptake due to compacted soil, results in taro plants exhibiting symptoms such as yellowing and burning of leaf edges (Qadir & Schubert, 2002).

Management strategies for soils with high sodium content

Managing soils with high sodium content, particularly in the context of Kayangel Atoll, requires a multifaceted approach due to the unique challenges posed by the environment, such as limited freshwater availability and frequent droughts. One effective strategy is leaching, which involves applying excess irrigation water to flush out sodium from the root zone. However, this method requires adequate drainage to prevent waterlogging and is challenging to implement consistently on Kayangel Atoll due to frequent droughts and limited freshwater resources (Rengasamy, 2010). To adapt, alternative water sources such as treated wastewater or rainwater harvesting systems could

be explored to supplement irrigation during dry periods.

Another viable approach is the use of organic amendments, such as compost or manure, which improve soil structure, increase permeability, and enhance nutrient availability. This helps mitigate the negative effects of sodium by promoting better water infiltration and root growth (Sumner, 1995). The atoll's abundance of dried leaves and branches provides a readily available resource for composting, making this a cost-effective and sustainable solution. Regularly incorporating organic matter into the soil is essential to maintain its benefits over time.

Mulching with organic materials offers additional benefits by reducing evaporation, preventing surface crusting and improving drainage. It also helps regulate soil temperature and suppress weeds (Gopal, 1987). Applying a thick layer of mulch around taro plants, using locally available materials like coconut husks or dried leaves, can create a more favourable environment for taro growth. Replenishing mulch as needed ensures its continued effectiveness.

Cultivating taro in raised beds or planting baskets filled with organic mulch is another promising strategy. This method enhances drainage, provides essential nutrients, and keeps plant roots within the fresher, upper layer of the thin groundwater lens. Planting baskets can be constructed from locally available materials like pandanus leaves and filled with a mixture of compost and soil to create a nutrient-rich growing medium. This approach is particularly useful in areas with high sodium content, as it allows for better control over soil conditions.

Selecting and cultivating salt-tolerant or sodicity-tolerant taro varieties offers a practical and sustainable approach for managing sodic soils. These varieties are naturally resilient to high sodium levels and can thrive in challenging soil conditions, reducing the need for extensive soil amendments (Raynor & Fownes, 1991). Collaborating with agricultural extension services or research institutions to identify and source suitable varieties for the atoll's specific conditions is crucial. Focusing on breeding and propagating these varieties will ensure long-term sustainability.

FIGURE 12. Taro cultivation using raised beds constructed from pandanus leaf baskets filled with compost.

Conclusion

This study reveals that the high sodium content in the taro pits of Kayangel Atoll poses a significant challenge to sustainable taro cultivation. Understanding the specific characteristics of these pits, along with the causes of elevated sodium levels, is essential for developing and implementing effective management strategies. By adopting appropriate strategies, such as raising planting beds, incorporating organic amendments, improving drainage systems, and selecting suitable crop varieties, farmers can mitigate the adverse effects of sodicity. These combined efforts can enhance taro productivity and bolster the resilience of these unique and vital agricultural systems on Kayangel Atoll.

References

Blakemore, L. C., Searle, P. L., & Daly, B. K. (1987). *Methods for chemical analysis of soils.* New Zealand Soil Bureau Scientific Report No.80, p.103. Department of Scientific and Industrial Research.

Food and Agriculture Organization (FAO). (2022). The state of food security and nutrition in the world. Food and Agriculture Organization of the United Nations.

Gopal, B. (1987). *Water Hyacinth.* Elsevier Science Publishers, Amsterdam, 1987, p.471.

Guezo, A., Hughes, L., & Simmons, A. (2019). Impacts of salinity on the growth of water hyacinth. *Journal of Aquatic Plant Management,* 57(1), 45-50.

Merrifield, M. A., Wang, J., Becker, J. M., Firing, Y. L., & Quilty, P. G. (2019). Impacts of tropical cyclones on coastal ecosystems and communities in the Pacific Islands. *Journal of Coastal Research, 35*(5), 1026–1041.

Qadir, M., & Schubert, S. (2002). Degradation processes and nutrient constraints in sodic soils. *Land Degradation & Development,* 13(4), 275-294.

Rengasamy, P. (2010). Soil processes affecting crop production in salt-affected soils. *Functional Plant Biology,* 37(7), 613-620.

Raynor, W., & Fownes, J. (1991). Giant swamp taro: A traditional Polynesian crop. *Economic Botany,* 45(3), 320-335.

Sumner, M. E. (1995). Sodic soils: New perspectives. *Australian Journal of Soil Research*, 33(6), 683–750.

Taylor, R., et al. (2016). Effects of Extreme Weather & Climate Change on Palau's Key Sectors. [PDF document]. Retrieved from https://www.jstor.org/stable/pdf/resrep28813.8.pdf

Adult coconut rhinoceros beetles collected from Bukura, Devil's Point Road, Efate. Photo, Matilda Simmons, PARC Programme, SPC.

Global management of coconut rhinoceros beetle (*Oryctes rhinoceros* L.)

Perceived or proven effectiveness of standard treatments

Bob Macfarlane[1]

Abstract

The adult of the coconut rhinoceros beetle (CRB), *Oryctes rhinoceros*, is a serious pest of many palms, especially the coconut palm. The young life stages live in rotting plant material, especially rotting palm logs and compost, assisting decomposition and release of nutrients. Over the past 120+ years, the spread of CRB from its centre of origin in central Southeast Asia has been documented west to Samoa and many island countries between and east across the Indian Ocean and to Israel. It is now recorded in about 47 countries.

Biosecurity remains the primary tool for preventing further spread of the pest to the eight remaining CRB-free Pacific Island countries and the Americas. CRB was recorded recently for the first time in the Americas, in Mexico (Jiménez Quiroz et al., 2017), but this record awaits validation. *O. monoceros* and *O. boas* are present in Africa.

Many control mechanisms against CRB have been tried, including sanitation, trapping, pesticides and biological control with insects, fungi and viruses. To date only a mix of two to three of these have shown any effective control. An integrated pest management (IPM) approach using sanitation and biological control is currently recommended. In particular, the use of the nudivirus, *Oryctes rhinoceros* NudiVirus (OrNV) and the fungus *Metarhizium majus* have shown efficacy in some areas but variable results in others. Research is continuing to develop mechanisms to improve the efficacy of these treatments.

Keywords: Coconut rhinoceros beetle, *Oryctes rhinoceros* NudiVirus, Integrated pest management

Introduction

The adult coconut rhinoceros beetle (CRB), *Oryctes rhinoceros*, is arguably the most important pest of the coconut and many other palms in the Southeast Asian and the Pacific regions. It attacks the crown of palms of all ages and in important cases can kill seedling and mature palms alike. In new invasions or outbreaks following cyclones, more than 50% of palms have been killed. Such attacks have significant impacts on the economies of countries, particularly small island countries, that rely on coconuts for food, building materials and foreign exchange. The larvae are not pests, they benefit farmers by aiding the process of plant decomposition. Frequently farmers do not recognise the link between the larvae in a dead coconut log or compost and the adult beetle in the crown of the palm; this makes farmer training more complicated.

Global issues

The centre of origin of *Oryctes* spp. (Coleoptera, Scarabaeidae, Dynastinae) is thought to be Madagascar where 13 of the 42 described species have been recorded (Catley, 1969). Several species of *Oryctes* are known pests of palms including *Oryctes centaurus*, O. *boas, O. monoceros* and *O. rhinoceros*.

Waterhouse and Norris (1987) suggest that the natural range of *O. rhinoceros* includes: the Indian subcontinent, Indonesia, Malaysia, Philippines, Sri Lanka and Taiwan. Oryctes centaurus is only recorded in Papua New Guinea (including Indonesian West Papua) and Vanuatu, and *O. monoceros* is recorded in most countries in Africa plus Mauritius and Reunion in the Indian Ocean. They all attack coconuts but only Oryctes rhinoceros is recognised internationally as the true coconut rhinoceros beetle (CRB).

The distribution of *O. centaurus* is curious as it is only reported on the island of New Guinea, the Bismarck Archipelago (Papua New Guinea and Indonesia) and Vanuatu (CoL, 2024). It seems to have leapfrogged Solomon Islands entirely as it has never been recorded there. Its primary host appears to be sago palm, but it has been recorded to attack coconut and betelnut palms. It is larger than *O. rhinoceros* with a very long horn on its head which curves back over the pronotum almost to the elytra.

1. Consultant Entomologist, Ivoro Jongo, Gizo, Solomon Islands, scapanese@gmail.com

Pest status of *Oryctes rhinoceros*

The larvae of CRB live in rotting vegetation, preferably rotting coconut logs, where they assist the logs break down into compost, increasing soil nutrients. In other words, the larvae are mostly beneficial. Only the adult is a pest, digging its way into the crown of palms and, if the numbers are high enough or if an individual reaches the growing point, killing the palms and creating more rotting logs for the larvae. What many do not know is that it is the legs of the adult that tear through the very tough fibres of the frond stems, the mouthparts of the adult are adapted for lapping plant sap, not biting or chewing.

CRB has been nicknamed the 'Palm Killer' because in outbreak situations it can cause devastating damage within palm plantations. It has been estimated to kill or severely damage 50% or more of palms on some islands. It should be noted also that CRB damage increases the risk of secondary infections and infestations, for example, by bacteria, fungi, viroids, viruses and weevils in the palm.

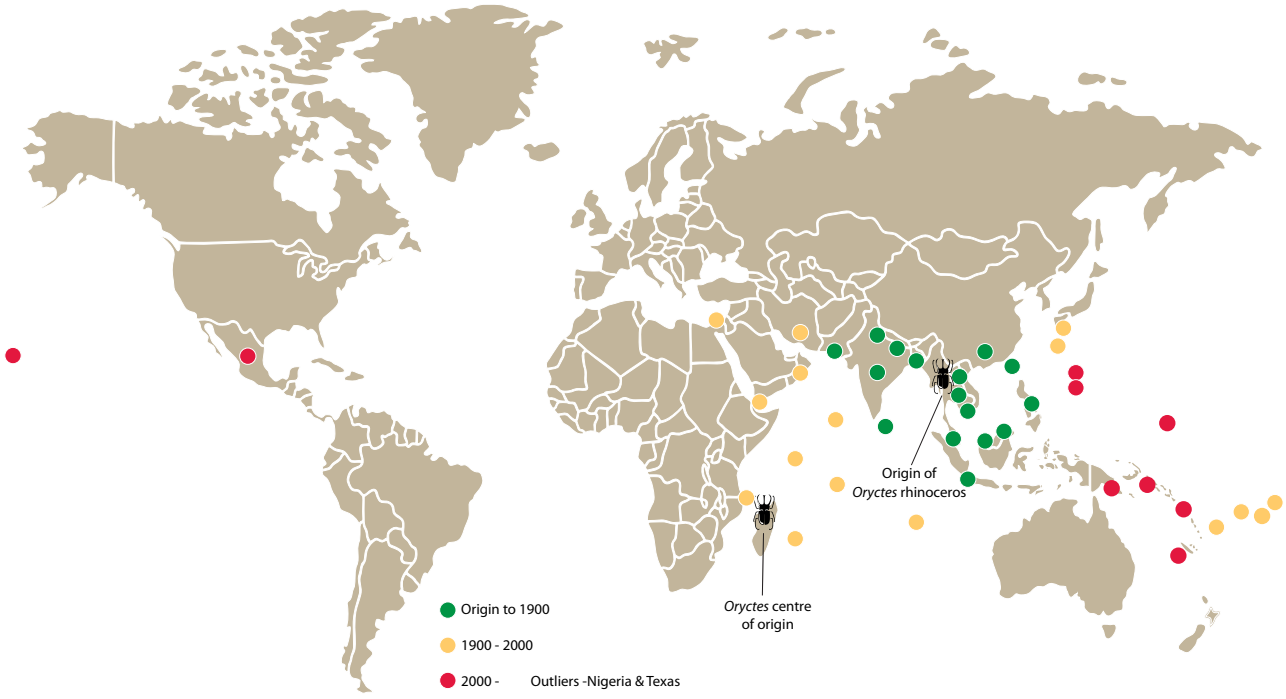
Coconut rhinoceros beetle has been nicknamed the 'Palm Killer' because in outbreak situations it can cause devastating damage within palm plantations. It has been estimated to kill or severely damage 50% or more of palms on some islands.

Gressitt (1953) recognised 31 genera of palms as hosts of CRB including: *Areca catechu* (betelnut palm), *Cocos nucifera* (coconut), *Elaeis guineensis* (African oil palm), *Metroxylon sagu* (sago palm), *Pandanus* (screw-pine), *Phoenix dactylifera* (date-palm) and *Wodyetia bifurcata* (foxtail palm). Several other plants are also recorded hosts including *Agave sisalana* (sisal hemp), *Ananas comosus* (pineapple), *Carica papaya* (pawpaw), *Colocasia esculenta* (taro), *Lantana* spp., *Musa x paradisiaca* (plantain), *Saccharum officinarum* (sugarcane), *Xanthosoma sagittifolium* (elephant ear).

Spread

Oryctes rhinoceros is recorded in 47 countries, mostly in Asia and the Pacific. Its centre of origin is believed to be central SE Asia. McKenna and Shroff (1911) reported that the pest first appeared in the extreme south of Myanmar, probably from Malaysia in 1895, and worked its way through to the north. It then spread over land to Pakistan and eventually to Iran and Israel, and across the Indian Ocean island-hopping to Mauritius and Reunion.

FIGURE 1. World distribution of the coconut rhinoceros beetle.



The spread of *O. rhinoceros* from Asia into and around the Pacific has been well documented (Figure 1) beginning with a "giant leap" from Sri Lanka to Samoa. Likely arriving in 1908 in potting mix with a consignment of rubber plantlets (*Hevea brasiliensis*) from Sri Lanka but not recognised from palm damage until 1910 (Jepson, 1912, Doane, 1913, Paudel et al., 2022). This was followed by a slower spread to American Samoa, Tonga, Wallis, Tokelau and Fiji, probably via the movement of people and cargoes on ships. It was also recorded from the southern Ryuku Islands, Japan, in 1921. The second "giant leap" took place during World War II (WWII) when it was recorded in the Bismarck Archipelago (Papua New Guinea) and Palau following the uncontrolled wartime movement of military material.

A third "giant leap" took place more recently when it was recorded in Guam, Hawaii, Port Moresby (Papua New Guinea), Solomon Islands, New Caledonia and Vanuatu, and even more recently in the Northern Marianas and the Marshall Islands. The initial incursions, at least, are likely to have occurred through direct transfer from Asia with subsequent spread between islands. The incursion coincided with the identification of strains of *O. rhinoceros* different to the one already in the region (Marshall et al., 2017). The strain issues are fully discussed elsewhere in this volume.

The mechanism of transfer to most places was most likely by sea. In the case of Guam (2007), it is reported to have been with building materials from the Philippines. But for Hawaii (2013), where it was first detected in Hickam Air Force base, Oahu, it possibly arrived by aircraft from Guam or Asia. For Port Moresby (Papua New Guinea) (2009), Solomon Islands (2015) and Vanuatu (2019) it was first detected some distance from the airport and neither Solomon Islands nor Vanuatu have regular air connections with Asia. For Solomon Islands, it is possible to speculate that it could have arrived among the quantities of artifacts (mats, etc.) imported from either or both Guam and Papua New Guinea for the Festival of Pacific Arts and Culture in July 2012, that is three-plus years (several life cycles) before the first positive detection in January 2016 near the main festival facilities.

There are now only eight island countries in the region free of this pest: Easter Island, Federated States of Micronesia, French Polynesia, Kiribati, Nauru, Niue, Pitcairn and Tuvalu. For all, except perhaps Easter Island and Pitcairn, coconuts are a crop of major importance, and it is recommended that biosecurity barriers be strengthened in each of these as a matter of urgency.

It is worthy of note that CRB was recorded as present in Niue in 1980 by Edwin Dharmaraju of the University of the South Pacific (Dharmaraju, 1980). However, New Aue, the current Chief of Biosecurity in Niue, confirms that it is not there now so it is unlikely to have been there in 1980 (New Aue, pers. comm.). Unfortunately, this record is mentioned in both the Centre for Agriculture and Biosciences International (CABI) and European and Mediterranean Plant Protection Organization (EPPO) pest databases and action is being taken to have it removed.

Elsewhere there are outlier records of *O. rhinoceros*. For example, it was recorded in Texas, USA, in 1916 (CABI, 2024) but not since, and in Nigeria in 2005 (CABI, 2024) but there are no subsequent reports of pest problems in either location. These records merit further examination. The recent report from Mexico (Jiménez Quiroz et al., 2017), the first in the Americas, is more credible but so far, to my knowledge, no actual specimens have been validated. The pictures online show something like CRB but, I suggest, not *O. rhinoceros*.

Oryctes monoceros and O. boas are present in the African continent but apart from the Mexican record (Jiménez Quiroz et al., 2017 and Jackson et al., 2022) no palm-growing country on the American continent appears to have a pest like CRB. Furthermore, Aidoo et al. (2022) suggest the Caribbean and all of South and Central America north of the equator are vulnerable to CRB invasion. Perhaps it is time to ring the alarm bells in the Americas and the Caribbean and warn them of the potential of this pest.

The USA defines its country status of CRB as "Present, Transient under eradication". This International Plant Protection Convention (IPPC) definition is based on the 2014 incursion in Hawaii as it allows the USA to submit that *O. rhinoceros* is under official control within the USA and consequently remains a quarantine pest for the whole country (The USDA/APHIS website makes no mention of the Texas record).

It is salutary that the USA has been unable to eradicate this pest even from the highly controlled area of a naval base in the 10-plus years it has been present. It has now spread to surrounding areas and is affecting ornamental and cosmetic palms in national parks and residential areas so much so that spraying of palm crowns with pesticides is being recommended to protect those palms (FIDL-191, 2023).

Control/management systems

Biosecurity/regulation

Biosecurity is the first line of defence for all countries, particularly island countries, seeking to prevent entry and establishment (introduction) of quarantine pests, or even to just restrict their internal movement. Biosecurity actions can be taken at the international border (seaports or airports) or internally between islands or between biological regions of a country. These actions are managed through regulations of various kinds, the most common in the Pacific used to be a requirement for ships from CRB-infested countries to

lay five miles offshore during the hours of darkness. This was a severe constraint on vessels wishing to unload and load cargoes as quickly as possible. It probably was not strictly imposed in most countries and now most do not impose it at all. The strictest control was the compulsory fumigation with methyl bromide of all cargoes and baggage from CRB-infested countries arriving in French Polynesia. I am advised that this regulation is not currently imposed.

There is no doubt that CRB is attracted to light so loading and unloading of ships at night is to be strongly discouraged. Recently it was reported that CRB has made its way from Efate to Espiritu Santo in Vanuatu (M. Ero, pers. comm.). It is highly probable that this occurred due to inadequate control over the movement of cargoes by ship between islands.

Movement of CRB by aircraft has never been documented but it must be possible, particularly if the aircraft are serviced overnight in well-lit open hangars. There are few domestic nighttime services in any Pacific countries and loading at night is rare.

It might be suggested that biosecurity has failed in all countries invaded during the past century. I prefer to say biosecurity has succeeded by delaying the arrival of the pest. For example, CRB was reported in Bougainville in 1989 (Moxon and Hela, 1989) but was not reported in Honiara, Solomon Islands, 550 km from Bougainville, until 2016; it arrived in Fiji in March 1953 (O'Connor, 1953) but did not get to the next nearest country, Vanuatu, until 2019, possibly from Papua New Guinea not Fiji, and is still not recorded in Tuvalu.

FIGURE 2. Rolled oil palm log (left) with CRB larvae in rotting wood underneath.

It is clear that CRB spread slowly in the Pacific between 1910 and 1953 (from Samoa to Fiji) but has spread very quickly over the past 20-plus years (Guam, Hawaii, Papua New Guinea, Solomon Islands, Vanuatu, New Caledonia, Northern Marianas and Marshall Islands). Is this purely due to the huge increase in trade in the region post-WWII or is it because, as some suggest, the new virus-resistant haplotype is more aggressive in colonising new habitats, or is it another negative result of climate change? Why did CRB not move in the region for 54 years (1953–2007) until the resistant haplotype arrived?

Only a few pathways for CRB entry and establishment have been confirmed, for example, soil around rubber plants from Sri Lanka to Samoa, building materials from the Philippines to Guam, and possibly aggregate contaminated with host plant material from Papua New Guinea to Vanuatu. Theoretically one gravid CRB female should be sufficient to start a colony. I suggest, however, that such a colony might not be sufficiently genetically diverse to be able to establish a population robust enough to create a pest outbreak even if the niche is vacant. It seems more probable that a small colony of adults (or several larvae) is required before a new robust population of CRB can be established in a new niche.

Countries currently free from CRB will no doubt experience significant harm to their economy, tourism, culture and livelihoods should the pest be introduced. It is perhaps timely to consider the most likely means and pathways of entry and establishment and provide advice to each of these countries on mechanisms to block the pathways. Can we develop early warning techniques to alert biosecurity staff to a new introduction before symptoms become obvious and soon enough to ensure eradication is possible?

FIGURE 3. Rhino beetle trapped in Tekken netting in Guam (© University of Guam).

Integrated pest management (IPM)

IPM refers to the integration of two or more pest management procedures to reduce populations of pests to below an acceptable economic threshold. For CRB, it applies when two or more of the methods discussed below are used to manage populations. For CRB, IPM almost always applies as no single method has ever completely managed a pest population. Each method will be discussed individually here but invariably they work best in combinations of two or three.

Sanitation

Sanitation has been the primary method of CRB control since controls began, particularly as it has always proven impractical to kill adults in the crowns of tall palms. Sanitation refers to the elimination of oviposition, larval food and pupation sites throughout or close to coconut or oil palm plantations. These sites include rotting palm logs (standing or fallen), heaps of dead fronds or other plant material (oil palm fruit bunches), sawdust (especially palm sawdust), compost and chicken manure. These latter two might be successfully managed by regular turning of the heaps and exposing any CRB life stages to sunlight, pigs and chickens.

In new outbreaks it is especially important to ensure farmers understand the link between rotting vegetation on the ground and the damage seen in the crown. This is particularly true where farmers were never required in the past to remove or destroy rotting vegetation from a plantation. For example, in palm replanting programmes or after cyclones or lightning strikes, where dead palms were previously just left to rot slowly. A change to managing dead palms and other rotting vegetation is to change a habit of centuries; it is a cultural change. In the village situation it will require significant extension and other inputs. Not only will the farmer have to clean up the plantation today, but they will also have to do it every day from now on. This situation applied with the oil palm plantation on Guadalcanal, Solomon Islands, where a major replanting programme had just begun when CRB was first reported in Honiara. Fallen oil palm logs are massive and create notable oviposition and larval food sites (Figure 2). It was essential to get them to break down quickly and become incorporated in the soil, several methods were suggested and ultimately a massive rotary disc plough was imported and successfully used to break up the logs and speed up rotting followed by harrowing after three months, before planting of new seedlings.

Palm debris should be spread among the palms to break down rapidly and release nutrients rather than being piled in heaps. Compost or farmyard manure should be turned regularly, and all life stages removed, or exposed to sunlight, pigs and chickens.

Where feasible, heaps of rotting vegetation can be covered with gill netting (Tekken brand has been recommended) to trap emerging adults (Figure 3).

Included in sanitation is any method that can remove the dead palm trunk from the planation. In this regard keeping them dry and using them to build houses, furniture or to make charcoal have been used successfully in Solomon Islands. The use of coconut logs as fence posts in contact with the ground is not recommended as they will rot quickly in this situation. A coconut log fence around the Festival of Pacific Arts site in Honiara was of this type and its destruction was a very early part of the management programme in Solomon Islands.

Felled palms leave a stump, even if cut flush with the ground, and as they rot become suitable for development of all stages of CRB. In the management of oil palm plantations, where a zero-burning policy is in operation, ground cover is planted shortly after felling to cover the debris and make it less attractive to the flying beetles. The legumes *Mucuna spp*. and *Pueraria javanica* are commonly used, as they will add nitrogen to the soil and cover decaying stumps and trunks. There is no doubt about the value of legumes for palm production, but the author is not aware of any definitive study to confirm that the use of cover crops protects rotting palm logs from CRB oviposition.

Sanitation is a slow, methodical process. A major emergency programme of sanitation began in Solomon Islands two years after the initial discovery, funded by New Zealand and supported by Australia. It was designed to help farmers with the initial clean-up of affected plantations, but the logistics proved hard to maintain in such a highly dispersed country. The governments of New Zealand and Australia must be commended for their support for the Solomon Islands CRB management programme. The fact that the effects of CRB infestations outside North Guadalcanal and North Malaita are not yet as bad as feared, may be one reason why farmers are slow to take up the assistance. Apparently, work is ongoing in Guam to improve sanitation techniques by using acoustic technology to help detect CRB within plant material.

Trapping

A wide of range of trap types, including pitfall, barrier, panel and PVC pipe and bucket, have been trialled to monitor or manage CRB outbreaks with varying success. One of the first was the Hoyt trap (Hoyt, 1963), developed during the FAO/UNDP Regional CRB project in the South Pacific. This essentially consisted of a piece of coconut log with a hole drilled down the centre seated upon a large open can, Figure 4. These worked well to provide an early warning of CRB presence; presumably their attraction improved as the log rotted down.

FIGURE 4. A Hoyt trap. Courtesy of Trevor Jackson.

FIGURE 5. A vaned bucket. Lure is red. Photo by Aubrey Moore.

The design and efficacy of traps improved further when the first CRB pheromones were discovered and became available in commercial quantities. The pheromone is an aggregation pheromone that attracts both sexes. In essence these traps consist of a pheromone dispensing source (a plastic septum) suspended (with or without wind vanes) above or within a collecting receptacle (e.g. a plastic bucket) with some mechanism to allow beetles to enter but not exit the receptacle (Figure 5). Usually, they are suspended two metres or more above the ground in trees/bushes or in a long PVC pipe. The latter were used successfully by the Guadalcanal Oil Palm Plantations Limited (GPPOL) and collected many thousands of adults.

Primarily these traps are used for delimitation surveys, that is, early detection and to determine the boundaries and the intensity of a CRB infestation. For delimitation surveys in Guam, a trap density of about one trap per 1,340 acres – approximately 542 hectares – is used with traps located along roadsides throughout the island. For mass trapping exercises to reduce or eliminate adult beetles a density of at least one trap per acre is recommended but to be genuinely effective, even at this density improvements in attraction over natural hosts are needed.

In 2015, Moore and Quitugua (2015) did a considerable amount of work on trapping of CRB. Primarily, they wanted to see if it was possible to use trapping for population suppression rather than just monitoring. They examined all the above traps and added refinements. They got the best results with a "pan" trap (Figure 6) and a "DeFence" trap (Figure 7).

The results showed that the pan trap and the DeFence trap were many more times effective at collecting

FIGURE 6. DeFence trap with Tekken gill netting, a UVLED and pheromone lure. Photo A. Mooe.

FIGURE 7. Pan trap 220L drum, white inside with chicken wire on top and a UVLED light. Photo, A. Moore.

FIGURE 8. A heap of vegetation covered with gill netting. Photo. A. Moore, University of Guam.

adult beetles than any of the other trap types, but none were sufficiently effective to be useful in population suppression by mass trapping.

Another form of trapping are sentinel logs. These are palm logs split lengthways and placed, strategically, flat on the ground to rot in groups of four to six. Monthly inspection of such logs for any life stage may provide an early warning of the presence of CRB in a plantation before damage is noticed in the fronds. They could also be treated with insecticides or *Metarhizium* fungus and become part of an "attract and kill" system.

Moore and Quitugua (2015) also demonstrated that the use of gill netting to cover heaps of rotting vegetation (Figure 8). were many more times as effective at collecting CRB adults than pheromone traps. However, it must be pointed out that while all the traps are useful in monitoring or delimiting CRB populations, none are sufficiently effective to be useful in population management. They also come with other constraints:

- They must be visited and maintained at least every one to two months.
- They must be located where idle hands cannot interfere with them.
- The pheromone lures are expensive and consequently are unlikely to be used by village farmers.
- Expectations of farmers must be managed;
  - they are not for control,
  - they are for monitoring not protection,
  - they do not cause more damage by attracting CRB.

Biological control

In their magnum opus, *Biological Control: Pacific Prospects,* Waterhouse and Norris (1987) list 77 insect natural enemies, seven mites, five nematodes, two protozoa, two fungi, two bacteria and two viruses as potential biological control agents against CRB. But the authors point out that only one insect, a fungus and a virus have had any success at that date (Waterhouse and Norris, 1987). I do not believe much has changed since and most current work focusses on the fungus and the virus.

The one insect is the wasp parasite *Scolia ruficornis*, which has established in most countries where introduction has been attempted. But nowhere has effective control of CRB been claimed. The best recorded was 30% parasitism in Samoa but this was in larvae living in loose rotting materials such as sawdust, not in rotting logs (Catley, 1969).

The fungus is *Metarhizium majus* (formerly *M. anisopliae* var. *majus*) which has been commercialised into a biopesticide that can be applied to CRB breeding sites (Bedford, 2013). Its use in commercial plantations in Asia has been strongly recommended but results of its use in the Pacific region have been mixed.

More recently a new more effective strain of *M. majus* has been selected in Solomon Islands, and work is in hand to bulk this up and make it available to farmers (Mansfield et al., 2024). Work is also continuing to improve infection rates in CRB populations using artificial breeding sites.

The virus is *Oryctes rhinoceros* NudiVirus (OrNV). It was originally discovered in Malaysia but has since been reported from Philippines and Indonesia, it is likely present in most other countries where CRB is endemic. Its discovery, transfer to and use in the Pacific region is well documented (Huger 2005, Bedford 1976, 1980, 2013, Marshall et al., 2017, Jackson and Marshall, 2017).

The use of OrNV has been so successful in the South Pacific and elsewhere that it is often the first management tool recommended whenever a CRB outbreak is discovered in a new place. Complications have, however, arisen recently (Marshall *et al.*, 2017) with the identification of a new strain/haplotype of CRB which may not be susceptible to the original strain of OrNV. This issue is still evolving, but Mansfield et al. (2024) claim that useful control is being achieved in Vanuatu with this haplotype of CRB but not yet in Papua New Guinea or Solomon Islands.

FIGURE 9. Young oil palm severely damaged by CRB, July 2017.

Chemical protection

Several different pesticides have been used to try to directly protect both tall and young palms. Chemical protection is, however, only useful on younger palms before they flower and produce fruit. There are concerns that the chemicals may interfere with insect pollination and may leave unacceptable levels of pesticide residues in the fruit.

On Guadalcanal, GPPOL, the company was at risk of losing a high proportion of newly replanted oil palms from CRB attack (Fig. 9). They began to treat with easily available, but very toxic, Furadan and quickly moved to the much safer pyrethroid, Icon, after trials showed a high success rate at 128 grams in 10 litres of water to spray 128 palms. Spray was directed to the base of the spear of newly formed fronds, i.e. the preferred area of attack by the adult (Alfred Pokana, pers, comm.). GPPOL has also had good results with trunk injections using 20 ml Dymehypo, per hole drilled at the base of the palm. But this is not recommended as holes drilled in monocots do not heal well. Alfred Pokana also reports that their IPM programme of sanitation by chipping of trunks after felling, extensive trapping and the above insecticide use has significantly reduced the CRB population and damage within their plantations. Mansfield et al. (2024) advise that population numbers are currently below the GPPOL treatment threshold and that chemical treatments have ceased.

In Guam and Hawaii, trunk injection with systemic insecticides is being evaluated to protect high-value ornamental palms, e.g. those in hotel grounds or parks, but they also report the same problem with healing of holes drilled in palm trunks as also reported earlier by Howard et al., 2001. Soil/root drenches or spraying boles of high-value palms, with a systemic insecticide may be an additional strategy and may be less damaging than injection. For example, in Florida a single root drench of Imidacloprid has been found to protect royal palms (*Roystonea regia*), from damage by the royal palm bug (*Xylastodoris luteolus,* Thaumastocoridae), for up to two seasons (Howard and Stopek, 1999). Soil and root applications have the added disadvantage that leaching of the chemical into water sources must be carefully managed.

Unusual control options

In Guam and Hawaii high value ornamental palms are being protected using nylon gill netting (the brand Tekken has been recommended) either bundled into the space between frond bases or tied in bows around the trunk below the frond bases. Both these techniques are intended to trap adult CRB in the netting before it starts to dig its way into the palm.

It has been suggested farming of CRB might have potential in some situations. For example, in Mozambique, following a severe outbreak of lethal yellowing disease which produced increased numbers of *Oryctes monoceros* from the breeding sites provided by the dead rotting palms. In this situation farmers might make money from either using the CRB larvae as a protein source for chickens and pigs or perhaps even selling dead adults to tourists as novelties (PestNet, 2012). My opinion of this is that the potential for causing even more damage to healthy palms by the large numbers of adult CRB created would likely outweigh any income benefits.

A programme of paying a bounty for all adult beetles presented to authorities was attempted recently in Vanuatu. Unfortunately, it was not sustainable due to rising costs and difficulties in administration.

Final note

Early on in new pest outbreaks people like to talk about the possibility of eradication of the newly established pest. I want to stress that for CRB at least, true eradication is extremely difficult unless the outbreak is found very soon after initial introduction or perhaps if the outbreak occurs on a very small remote island. In all the outbreaks since the first introduction of CRB to the Pacific, eradication has been confirmed only once.

This was in 1921 when the beetle was recorded in the tiny remote island of Niuatoputapu (Keppel) Island in the Kingdom of Tonga, 200 km south of Samoa. The campaign was done by hand collection and field sanitation and took from 1922 to 1930 (Dumbleton, 1952). In Hawaii where CRB was first accidentally introduced into a highly controlled US Air Force Base and millions of dollars have been spent, CRB has still not been eradicated. The beetle has now spread to the other islands of Hawaii and eradication must now be impossible without spending millions more or there is some amazing technological breakthrough.

Conclusion

As always, the first line of defence against any new pest is biosecurity. This is designed to keep a pest out of the country for as long as possible through pre-border restrictions, border inspections and post-border monitoring with speedy response action should a new pest introduction be detected.

Once CRB arrives in a new place an IPM approach is strongly recommended. This alone has the highest chances of reducing CRB populations to below an economic threshold. Foundation methods in any IPM approach are sanitation and the release and distribution of the virus OrNV. All the other methods mentioned here, while useful, have much smaller impact on CRB populations.

References

Aidoo, O.F., Ding, F., Ma, T., Jiang, D., Wang, D., Hao, M., Tettey, E., Andoh-Mensah, S., Ninsin K.D., Borgemeister, C. (2022). Determining the potential distribution of *Oryctes monoceros* and *Oryctes rhinoceros* by combining machine-learning with high-dimensional multidisciplinary environmental variables. *Nature Portfolio.* https://doi.org/10.1038/s41598-022-21367-1

Bedford G.O. (1976). Use of a virus against the coconut palm rhinoceros beetle in Fiji. *PANS 22: 11-25.*

Bedford G.O. (1980). Biology, ecology, and control of palm rhinoceros beetles. Annual Review of Entomology 25: 309-339.

Bedford G.O. (2013). Biology and management of palm dynastid beetles: recent advances. Annual Review of Entomology 58: 353-372.

CABI (2024). https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.37974#REF-DDB-186907

Catley, A. (1969). The coconut rhinoceros beetle Oryctes rhinoceros (L) (Coleoptera: Scarabaeidae: Dynatinae). *Pest Articles & News Summaries. A, 15: 18-30.*

CoL. (2024). https://www.catalogueoflife.org/data/dataset/1027

Dharmaraju, E. (1980). Pest problems in Niue. *Alafua Agricultural Bulletin 5: 24-26.*

Doane, R.W. (1913). The rhinoceros beetle (Oryctes rhinoceros L.) in Samoa. J. Econ. Entomol. 1913, 6, 437–442.

Dumbleton, L.J. (1952). Rhinoceros Beetle in the Kingdom of Tonga; *South Pacific Commission: Suva, Fiji.*

Eduardo, J.Q., Oscar, M.M., Oscar, T.R., Gustavo, G.V., Eugenia, G.A.M., Oscar, C.N. (2017). First intercept of the Asiatic coconut rhinoceros beetle *Oryctes rhinoceros (Linnaeus, 1758) in Mexico. Revista Mexicana de Ciencias Forestales Vol. 8 (39): 99-105.*

Gressitt, J.L. (1953). The coconut rhinoceros beetle (*Oryctes rhinoceros*) with particular reference to the Palau Islands. *Bernice P Bishop Museum Bulletin* 212, 82 pp.

Howard, F.W., Moore, D., Giblin-Davis, R.M., Abad, R.G. (2001). Insects on Palms. *CABI Publications, Wallingford, UK.*

Howard, F.W., Stopek, A. (1999). Control of royal palm bug, Xylastodoris luteolus (Hemiptera: Thaumastocoridae) with imidacloprid: a refinement in the method. *Palms* 43, 174–176.

Hoyt, C.P. (1963). Investigations of rhinoceros beetles in West Africa. *Pacific Science* 17: 444-451.

Huger, A.M. (2005). The Oryctes virus: its detection, identification, and implementation in biological control of the coconut palm rhinoceros beetle, *Oryctes rhinoceros* (Coleoptera: Scarabaeidae). Journal of Invertebrate Pathology 89: 78-84.

Jackson, G. (2012). *Farming insects – a way of controlling them?* PestNet https://www.pestnet.org/pests-pests-entities-insects-beetles-oryctes-rhinoceros-farming-insects-a-way-of-controlling-them-3/.

Jackson, T.A. and Marshall, S.D.G. (2017). Managing the threat of CRB-G, a new variant of the coconut rhinoceros beetle, in the Asia-Pacific region. Proceedings of the PIPOC 2017 International Palm Oil Conference. *Agriculture, Biotechnology and Sustainability*, Vol. 1, pp. 25-30.

Jackson, T.A., Rincón, M.N., Villamizar, L.F., Paudel, S. (2022). Social media posts suggest that coconut rhinoceros beetle has established in the Western hemisphere. Journal of Applied Entomology. https://doi.org/10.1111/jen.13083

Jepson, F. (1912). The Rhinoceros Beetle (Oryctes rhinoceros) in Samoa. Department of Agriculture Suva, Fiji. *Government Printer. Suva, Fiji.*

Mansfield, S. Marshall, S., Jackson, T., Villamizar, L. and Paudel, S. (2024). IPM for CRB: Review of stakeholder practices in Papua New Guinea, Solomon Islands and Vanuatu. Report for MFAT & CRB project partners. *AgResearch Ltd. New Zealand*. pp. 35.

Marshall, S.D.G, Moore, A., Vaqalo, M., Noble, A. and Jackson, T.A. (2017). A new haplotype of the coconut rhinoceros beetle, *Oryctes rhinoceros*, has escaped biological control by Oryctes rhinoceros nudivirus and is invading Pacific Islands. *Journal of Invertebrate Pathology* 149: 127-134.

McKenna, J. and Schroff, K.D. (1911). The Rhinoceros Beetle (*Oryctes rhinoceros*) (Linn.) and its ravages in Burma. Burma Department of Agriculture Bulletin 4. In Bedford 1980 and Waterhouse 1987.

Moore, A. and Quitugua, R. (2015). Improved traps for the coconut rhinoceros beetle, *Oryctes rhinoceros.* Pacific Entomology Conference, Honolulu, Hawaii. April 2015.

Moxon, J. and Hela, F.E. (1989). A new report in North Solomons Province of Oryctes rhinoceros. Department of Agriculture and Livestock, Agricultural Research Division, 1989 Annual Research Report. Konedobu, NCD. *Department of Agriculture and Livestock, Agricultural Research Division. pp. 45.*

O'Connor, B.A. 1953. The rhinoceros beetle (*Oryctes rhinoceros L.) in Fiji. 1. History. Agricultural Journal (Fiji)*. 24 (1/2), pp. 35-46.

Paudel, S., Marshall, S.D.G., Richards, N.K., Hazelman, G., Tanielu, P., Jackson, T.A. (2022). Coconut Rhinoceros Beetle in Samoa: Review of a Century-Old Invasion and Prospects for Control in a Changing Future. *Insects, 13, 487.*

Waterhouse, D.F. and Norris K.R. (1987). *Biological Control: Pacific Prospects.* The Australian Centre for International Agricultural Research. Inkata Press, Melbourne. 454 pp.

Effects of intercropping and chilli aqueous crude extract application on slippery cabbage shoot borer (*Earias vittella* Fab.) damage

John Bosco Sulifoa,[1]* Ruth Selo, [1]
Catherine Diana Rorodo [1] and Lawrence Atu[1]

Abstract

The trial was conducted at the Solomon Islands National University farm investigating the effect of intercropping slippery cabbage with maize and dwarf bean and the combination of intercropping with chilli plant aqueous crude extract application on infestation and incidence of damage by *E. vittella*. Six treatments were laid out in a randomised complete block design with three replicates: (1.) monocrop slippery cabbage, not sprayed; (2.) monocrop, slippery cabbage sprayed; (3.) slippery cabbage–bean intercrop, not sprayed; (4.) slippery cabbage–bean intercrop, sprayed; (5.) slippery cabbage–maize intercrop, not sprayed; and (6.) slippery cabbage–maize, sprayed). The results from the trial showed that intercropping reduced *E. vittella* incidence and minimised the level of damage compared to the control treatment (unsprayed) and the chilli plant aqueous crude extract sprayed slippery cabbage monocrop plots. Between the intercropping treatments, the slippery cabbage–dwarf bean intercrop treatment better reduced *E. vittella* incidence than the slippery cabbage–maize intercrop treatment. Combining intercropping with chilli plant aqueous crude extract application resulted in lower incidence and damage by *E. vittella* compared to the individual treatments. There is no significant difference in yield between the monocrop spray and the intercropping sprayed treatments.

Keywords: *Abelmoschus manihot*, Intercropping, Pest Management, Lepidoptera, Monocrop, Noctuidae

Introduction

Slippery Cabbage (*Abelmoschus manihot* (L.) Medikus) is an essential leafy vegetable in the Solomon Islands, and its demand is high in the market. The daily volume traded in Honiara market is approximately 0.5 tons higher than any other leafy vegetables (Jansen *et al*. 2016). Many families in rural and urban areas depend on it for food and income. However, the yield of slippery cabbage has decreased due to diseases and pest problems. Slippery cabbage shoot borer, *Earias vittella (Fab.) (Lepidoptera: Noctuidae)*, is one of the major pests that affect its production in the Solomon Islands (Tsatsia and Jackson 2010). *Earias vittella* larvae feed inside the stems of slippery cabbage and cause substantial damage to tips and leaves, which consequently leads to wilt and death of the shoot (Tsatsia and Jackson 2010).

In commercial production areas, the crop is heavily sprayed with synthetic insecticides such as Orthene (Jansen et al. 2006). Continuous use of synthetic insecticides can result in pest resistance, reduce the population of natural enemies, harm the health of farmers and contaminate the environment (Pereze *et al*. 2010; Wong et al. 2011). Therefore, a viable alternative to reliance on chemical insecticides is a synergistic approach that integrates several sustainable management strategies such as intercropping and the use of botanical pesticides that can be adopted by subsistence and small-scale commercial farmers who lack financial resources.

Therefore, the broad aim of this research project was to investigate the effectiveness of some non-synthetic pesticide methods (i.e., methods other than the use of synthetic pesticides) for the sustainable management of the *E. vittella* pest of slippery cabbage in the Solomon Islands. The main areas for investigation were intercropping systems and the use of plant-aqueous crude extract as an organic pesticide. The specific objective is to investigate the effect of intercropping slippery cabbage with maize and dwarf bean

1 Faculty of Agriculture, Fisheries and Forestry, Solomon Islands National University
* Corresponding Author: jbsulifoa@gmail.com

and of combining intercropping with chilli plant aqueous crude extract application on the incidence of damage by *E. vittella*.

Materials and methods

The trial was conducted at the Solomon Islands National University in the Faculty of Agriculture Forestry and Fisheries farm in Honiara, Solomon Islands. Various slippery cabbage (*Abelmoschus manihot*) intercropped systems combined with chilli plant aqueous crude extract on *E. vittella* were studied in this trial. Slippery cabbage was intercropped with maize (*Zea mays*) or dwarf bean (*Phaseolus vulgaris* L.). The choice of crop combinations in the intercrop and chilli plant aqueous extract was based on crops commonly grown in the Solomon Islands.

Experimental set-up and treatment application

The experimental set-up was a randomised complete block design with six treatments and three replicates. The six treatments were as follows:

- **Treatment 1 (Control):** Slippery cabbage monocrop, not sprayed with chilli plant aqueous crude extract (monocrop, not sprayed)
- **Treatment 2:** Slippery cabbage monocrop, sprayed with chilli plant aqueous crude extract (monocrop, sprayed)
- **Treatment 3:** One row of slippery cabbage alternated with one row of dwarf bean, not sprayed with chilli plant aqueous crude extract (slippery cabbage–bean, not sprayed)
- **Treatment 4:** One row of slippery cabbage alternated with one row of dwarf beans, sprayed with chilli plant aqueous crude extract (slippery cabbage–bean, sprayed)
- **Treatment 5:** One row of slippery cabbage alternated with one row of maize, not sprayed with chilli plant aqueous crude extract (slippery cabbage–maize, not sprayed)
- **Treatment 6:** One row of slippery cabbage alternated with one row of maize, sprayed with chilli plant aqueous crude extract (slippery cabbage–maize, sprayed).

The alternate row arrangement is selected because of the ease of application of management practices required for each crop. In sprayed treatments (2, 4 and 6), chilli plant aqueous crude extracts were applied at the rate of 3 ml to 1 litre of water (Tsatsia and Jackson 2012). The chilli extract was sprayed directly onto slippery cabbage plants using a knapsack sprayer. Plants were sprayed until runoff. The spraying was done two weeks after planting, then once a week until harvest.

Land preparation

An area of 23 m x 14 m (322m^2) was used. The trial site was cleared and ploughed with a rotary cultivar two weeks before planting the crops. The tillage was done mainly to loosen the soil. The experiment site was marked out, blocked, and divided into 16 plots of 4 m x 3 m, with 1 m spacing between adjacent plots. The plots were made into 10 cm beds by tilling them with spades and rakes. A total of 18 beds were established for the six treatments.

The plant spacing between rows was 60 cm, and within rows, 50 cm in slippery cabbage monocrop. In the intercrop plots, spacing between slippery cabbage, maize and bean was 60 cm between rows and within rows of maize and bean was 40 cm and slippery cabbage 50 cm.

Agronomic practices

After the land was cleared and beds were made, maize and bean seeds were sown two weeks before the slippery cabbage. Slippery cabbage cuttings (30 cm long from the shoot) were used for planting. One slippery cabbage cutting was planted per hole. Chicken manure was applied as organic fertilizer to the soil at 200 kg/ha at the time of planting. Cultural practices such as watering and weeding were done as required. Slug bait was applied around the plots to control slug and snail damage. The pest (*E. vittella*) population was allowed to establish in the trial plots after planting. The crop was harvested eight weeks after planting, which is the normal cropping period of slippery cabbage.

Chilli plant aqueous crude extracts preparation

The chilli plant aqueous crude extract was prepared following the preparation protocol provided by Tsatsia and Jackson (2012). Five hundred grams of freshly ripe chilli pods were smashed to fine pieces, soaked in a bucket filled with one litre of water, and rubbed with hands (hands were covered with waterproof gloves). After one hour from extraction, the mixture was squeezed and filtered using a cloth to collect the fruit extracts. Before the extract was used, 30 g of grated hand soap was added.

Data collection

Data collection started two weeks after the planting of the slippery cabbage, at which time the pest started establishing in the field. The following data were collected from 12 slippery cabbage plants located in the middle of each plot, excluding the edge rows to avoid the edge effect influence on the data:

- Weekly incidence of damage by slippery cabbage shoot borer (number of damaged plants per plot), regardless of incidence of infestation were recorded at two weeks after planting until harvest.
- Incidence of damage by slippery cabbage shoot borer (at harvest).
- The average weight of slippery cabbage leaves (at harvest).

The rate of *E. vittella slippery* cabbage infestation (mean ± SD) was calculated as a percentage ratio of infested plants per plot to the total number of plants. The sample size for one treatment was 36 slippery cabbage plants and for the total was 216 plants.

$$\text{Slippery cabbage infestation by } E.\ vittella\ (\%) = \frac{\text{number of infested plants per plot} \times 100}{\text{total number of plants per plot}}$$

Data analysis

Data obtained were analysed by analysis of variance (ANOVA) using the Statistic 8 statistical package. Tukey's honestly significant difference (HSD) pairwise comparison test compared the differences among means where the F-ration was significant (at $P \leq 0.05$).

Results

Incidence of shoot damage caused to slippery cabbage by *Earias vittella*

Figure 1 illustrates that the incidence of damage caused by *E. vittella* was low from week 2 to week 5, and it began to rise from week 6 to week 8. The damage from *E. vittella* was greater in the slippery cabbage monocrop plot without chilli plant aqueous crude extract spray compared to the other treatments from week 4 to week 8. Among the treatments with chilli plant aqueous crude extract spray, the intercrop plots experienced lower incidences of *E. vittella* damage than the sprayed monocrop plot. The slippery cabbage–bean intercrop that received the spray recorded the lowest incidence of damage from week 4 until harvest (week 8). However, the treatments exhibited no significant differences throughout all weeks after planting (week 4: $F_{5,12}=0.80$; $P=0.571$; week 5: $F_{5,12}=2.10$; $P=0.136$; week 6: $F_{5,12}=1.96$; $P=0.157$; week 7: $F_{5,12}=1.10$; $P=0.412$; and week 8: $F_{5,12}=1.99$; $P=0.152$).

FIGURE 1. Incidence of damage by *Earias vittella* in different cropping patterns over the trial period.

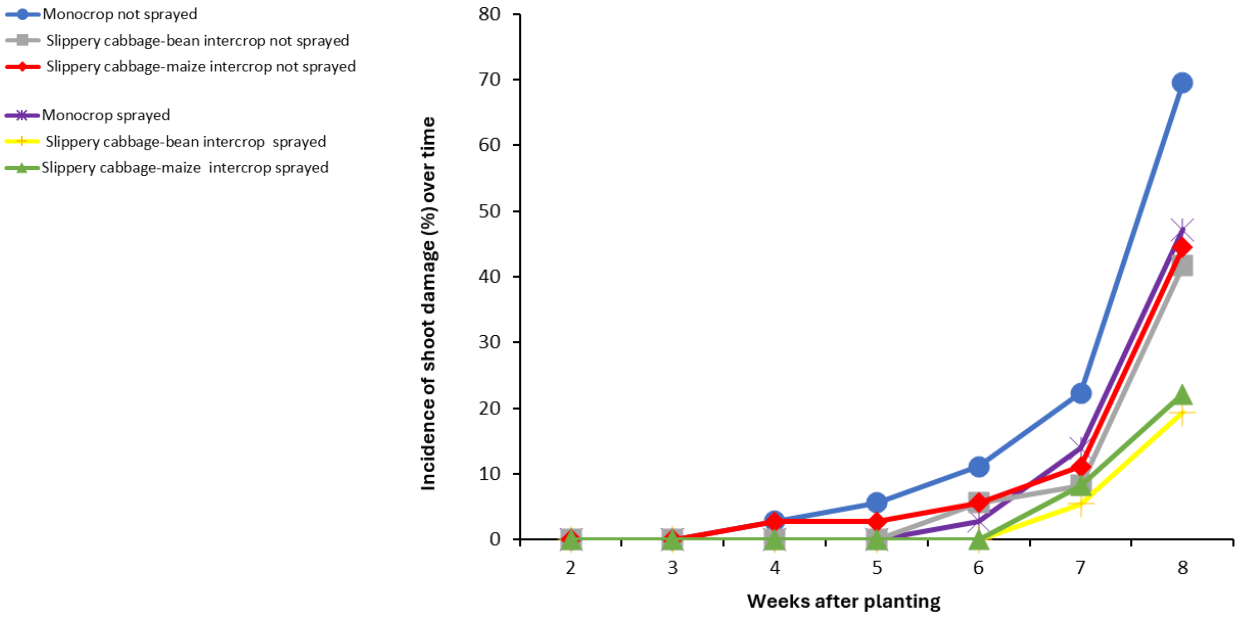
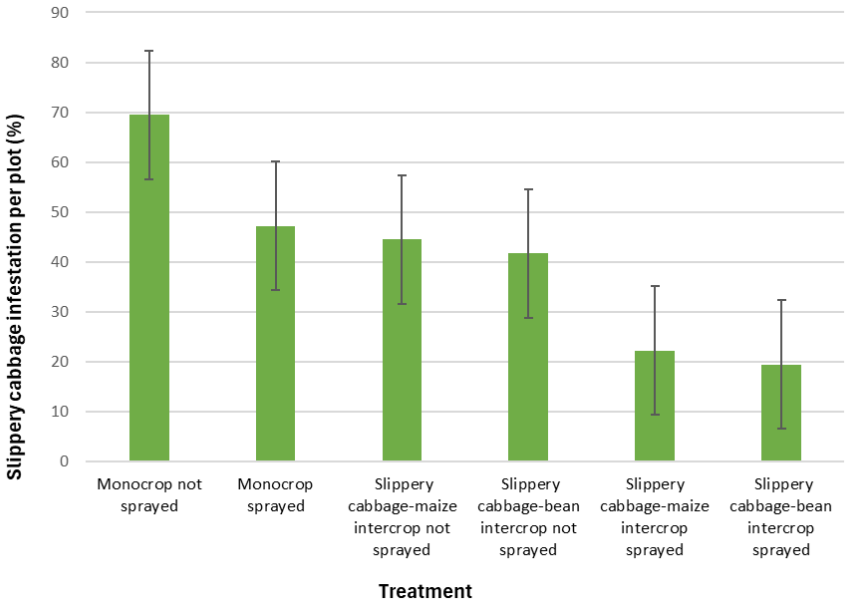


FIGURE 2. Effects of treatments on slippery cabbage infestation by *Earias vittella* at harvest.



Slippery cabbage infestation by *Earias vittella* at harvest

It was observed that the slippery cabbage–bean intercrop plot sprayed with chilli plant aqueous crude extract had the lowest percentage of shoot damage by *E. vittella* compared to the other treatments. The highest percentage of shoot damage (69.5%) was caused on slippery cabbage in the monocrop plot not sprayed with chilli plant aqueous crude extract, followed by slippery cabbage in the monocrop plot sprayed with the solution (47.2%). Among the intercrop plots, the slippery cabbage-bean intercrop but not sprayed with chilli plant aqueous crude extract (44.5%), slippery cabbage-maize intercrop not sprayed (41.7%), slippery cabbage–maize intercrop sprayed (22.2%) and slippery cabbage–bean sprayed (19.4%) (Figure 2). However, the treatments have no significant difference (at $F_{5,12}$=1.99; P=0.152).

Total weight (g) of slippery cabbage harvested per plot at the end of the trial

Figure 3 shows the mean total weight (g) of slippery cabbage harvested per plot from the various treatments. The slippery cabbage in the monocrop plot sprayed with chilli plant aqueous crude extract had significantly (at $F_{5,12}$=6.489; P=0.004) higher weight of slippery cabbage leaves than the other treatments, except the sprayed slippery cabbage–bean intercrop and sprayed slippery cabbage–maize intercrop where the weight did not differ significantly.

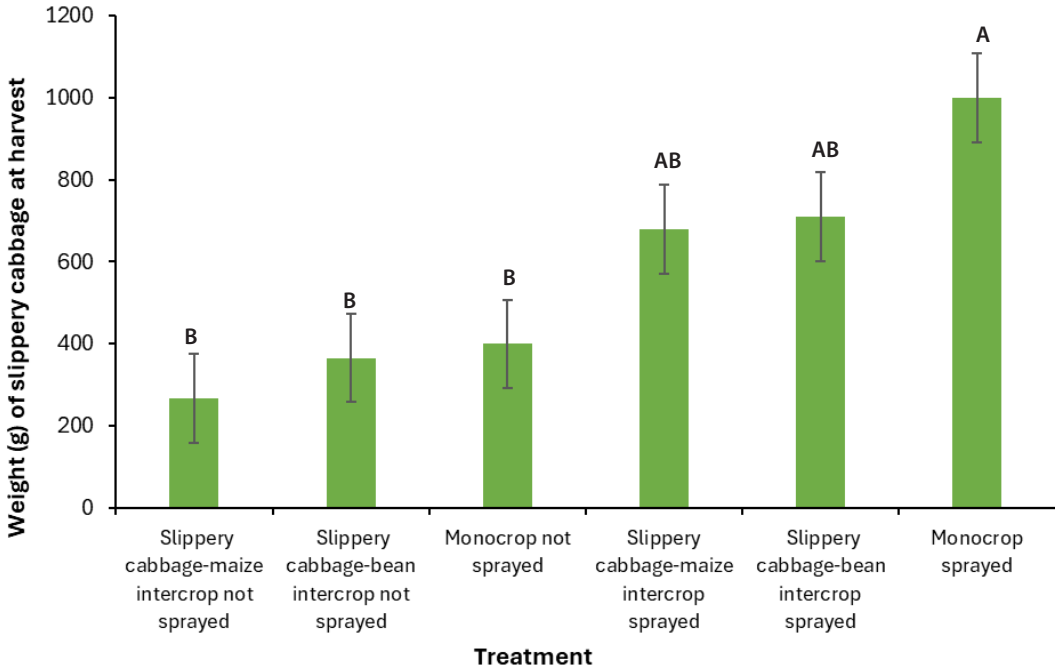
Discussion

This study investigated the effect of intercropping slippery cabbage with maize and dwarf bean and of integrating intercropping with chilli plant aqueous crude extract application on the incidence of *E. vittella* in slippery cabbage. The results indicated that intercropping reduced the incidence and damage levels of *E. vittella* on slippery cabbage compared to both slippery cabbage monocrop treatments (i.e. no spray and spray of chilli plant aqueous crude extract). Previous studies have shown that intercropping can reduce infestation and damage levels by insect pests (Jankowska et al. 2009; Lithourgidis et al. 2011). According to Andow (1991), out of 209 studies involving 287 insect pest species, the population of pest insects in intercropping systems was lower in 52% of the studies and higher in only 15%, compared to monoculture systems. Various research findings demonstrate the mechanism responsible for pest suppression in intercropping systems. For instance, physical barriers and chemical smells of non-host crops partly hide the host crop, affecting the pest's host-finding ability and thus limiting the pest's food source (Stoll, 2000). CABI (2000) and Stoll (2000) have also highlighted that greater diversity of the vegetation improves the condition for the development and survival of natural enemies, thus increasing their population. For example, many natural enemies of insect pests require a supply of nectar and pollen to complete their life cycle (Dent, 1991; Lithourgidis et al. 2011) and the cultivation of beneficial weeds adjacent to cropping systems is encouraged.

Secondly, combining intercropping with chilli plant aqueous crude extract application produced slightly better control of the *E. vittella* than monocrop cabbage sprayed. The finding shows that chilli plant aqueous crude extract affects *E. vittella* infestation through stomach poison, insecticidal, repellent and antifeedant (Stoll, 2000). This helps to reduce the infestation and incidence of damage caused by *E. vittella* on slippery cabbage. Similar observations were reported by Facknath (1999), who noted that combining cabbage/tomato intercropping with the application of neem seed kernel extracts reduced infestation by diamondback moths on cabbage plants. It was observed that intercropping might help reduce the population of caterpillars to a level that spraying plant aqueous crude extract could be more effective against *E. vittella*.

Despite the generally lower infestation and incidence of damage observed in unsprayed and sprayed intercropping treatments compared to sprayed monocrop slippery cabbage, a low yield was obtained from the intercrop treatments (Figure 3). This observation agrees with Srinivasan (1984), who noted that reduced larval incidence does not significantly increase cabbage

Figure 3: Total weight (g) of slippery cabbage leaves harvested per plot at the end of the trial. Error bars represent respective standard errors.



yield in unsprayed cabbage–tomato intercrop. Potential explanations for the low yield in the intercropping plots are because of the competition for nutrient, water and light between the slippery cabbage, dwarf bean and maize. Ratnadass et al. (2012) reported that competition in intercropping systems strongly reduce yields than insect pests. According to Lithourgidis et al. (2011), in intercropping systems, crops compete for physical space, nutrients, water and light. For example, maize–leek intercrops can reduce infestation of thrips on leeks, while also eventually leading to yield reduction in leeks because they are poor competitors for light relative to rapidly growing maize (Santillano-Cázares et al. 2019).

The result obtained in this study demonstrated that intercropping (dwarf bean or maize with slippery cabbage) alone cannot not sufficiently protect slippery cabbage against *E. vittella* when infestations are high. However, the synergetic use of chilli plant aqueous crude extract effectively reduces the damage level.

The study indicates that combining intercropping and plant aqueous crude extract can help manage the *E. vittella* in slippery cabbage fields in the Solomon Islands. However, other non-chemical control alternatives will need to be investigated for integration into the integrated pest management (IPM) package for the pest. The observation that intercropping treatments, with plant aqueous crude extract application, produced relatively better control of the pests than monocrops with similar plant extract regimes suggests that intercropping could play a role in the integrated management of this pest.

Conclusions

The findings and significance of the study include the following:

- Intercropping slowed down the incidence of *E. vittella* and reduced the damage levels compared to the unsprayed and sprayed monocrop treatments.
- The slippery cabbage–dwarf bean intercrop controlled the *E. vittella* better than the slippery cabbage–maize intercrop.
- Intercropping combined with chilli plant aqueous crude extract application controlled the *E. vittella* better than slippery cabbage intercrop with no spray and both monocrop with no spray and spray treatments.
- Monocrop spray produced a slightly higher yields than intercrop spray.

This study has demonstrated that intercropping slippery cabbage with bean or maize has some influence on the incidence *E. vittella* and the infestation levels. However, intercropping alone did not significantly improve slippery cabbage yield. Combining intercropping with plant aqueous crude extract further suppresses the infestation and incidence of attack by *E. vittella* compared to plant aqueous crude extract application alone and monocrop. Therefore, this strategy might be helpful in an integrated management programme against *E. vittella.*

Lastly, it is essential to note that other non-chemical pest control tools can be investigated for inclusion in an integrated pest management system against *E. vittella* in the Solomon Islands, e.g., natural enemies, trap cropping and selection of planting time.

Acknowledgements

The authors are grateful to the office of Research and Postgraduate studies at the Solomon Islands National University (SINU) for funding the research.

References

Abro, G.H., Memon, A.J., Syed, T.S., and Shaikh, A.A. (2004). Infestation of *Earias* spp. Cotton and okra grown as mono and mix crops. *Pakistan Journal of Biological Sciences* 7(6), 937–942.

Altieri, M.A. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture Ecosystems and Environment* 74, 19 – 31.

Andow, D.A. (1991). Vegetational diversity and arthropod population responses. *Annual Review of Entomology* 36, 561 – 568.

AVRDC, (2008). Vegetable Production Systems in Guadalcanal, Makira and Malaita, Solomon Islands. A Report on Participatory Rural Appraisal (PRA). AVRDC - The World Vegetable Center.30pp.

Blaser, B.C., Signer, J.W., and Gibson, L.R. (2007). Winter cereal, seeding rate, and intercrop seeding rate effect on red clover yield and quality. *Agronomy Journal* 99, 723–729.

Bokosou, J., and Schuhbeck, A. (1999). *How to produce homemade pesticides*. LAES Information Bulletin No.1/99.

Dent, D. (1991). Insect pest management. CAB International. 604pp.

El-Swaify, S.A., Lo, A.K.F., Joy, R., Shinshiro, L., and Yost, R.S. (1988). Achieving conservation effectiveness in the tropics using legume intercrops. *Soil Technology* 1, 1–12.

Fa'anunu, H. (2009). Report on the application for market access of island cabbage (Abelmoschus manihot) from Fiji, Vanuatu, Samoa, Cook Islands and Tonga to New Zealand. Food and Agriculture Organisation of the United Nations. 53pp.

Facknath, S. (1996). Application of neem extract and intercropping for the control of some cabbage pests in Mauritius. In *Azadirachata indica A. Juss*. (Eds R.I. Singh and R.C. Saxena) pp. 165–175. Oxford and IBH Publishing Co. Pvt. Ltd., England.

Gautam, H.K., Singh, N.N., and Rai, A.B. (2015). Effect of some plant extract and an insecticide on the incidence of *Earias vittella* in okra. *Indian Journal of Agriculture Research* 49 (2), 175-179.

Gontijo, L. M. (2019). Engineering natural enemy shelters to enhance conservation biological control in field crops. *Biological Control* 130, 155–163.

Gurr, G.M., Wratten, S.D., Landis, D.A., and You, M. (2017). Habitat management to suppress pest populations: progress and prospects. *Annual Review Entomology* 62, 91–109.

Hassama, U.A., Gulzara, A., Rasoolb, B., Zafarc, S., Younisb, T., Shakeeld, M., Khana, D., Ullaha, S., Khaliqa, S., Ahmada, S.F., and Hafeeze, M. (2021). Efficacy of Citrullus colocynthis seed extract on Earias vittella, Fabricius, (Lepidoptera: Noctuidae): *environment sustainable approach.*

Jansen, T., Mullen, B.F., Pollard, A.A., Maemouri, R.K., Watoto, C., and Iramu, E. (2006). Solomon Islands Smallholder Agriculture Study, Volume 2. Subsistence Production, Livestock and Social Analysis. Commonwealth of Australia, Canberra, Australia. 62pp.

Kremer, R.J., and Kussman, R. (2008). Intercropping with kura clover improves soil quality in a pecan agroforestry system. Soil and Water Conservation Society Annual Meeting, Tuszan, AZ, July 26- 30, 2008.

Lithourgidis, A.S., Dordas, C.A., Damalas, C.A., and Vlachostergios, D.N. (2011). Annual intercrops: an alternative pathway for sustainable agriculture. *Australian Journal of Crop Science*, 5(4), 396-410.

Pavunraj, M., Baskar, K., Paulkumar, K., Janarthanan, S., and Rajendran, P. (2016). Antifeedant activity of crude extracts and fractions isolated from Catharanthus roseus leaf against spotted bollworm. *Phytoparasitica* 44 (3), 3-6.

Preston, S.R. (1998). Aibika/Bele: *Abelmoschus manihot* (L.) Medik. International Plant Genetic Resource Institute, Rome, Italy.

Preston, S.R. (2007). Aibika/Bele *Abelmoschus manihot* (L.) Medikb. IPGRI Neglected Crops Series. 68pp.

Ratnadass, A., Fernandes, P., Avelino, J., and Habib, R. (2012). Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review. *Agronom. Sustainable Development* 32, 273–303.

Santillano-Cázares, J., Mendoza-Gómez, A., Vázquez-Angulo, J. C., Medina- Espinoza, E., Ail-Catzim, C.E., and Núñez-Ramírez, F. (2019). The compromise of intercropping: biological pest control versus competition by crop species. *Southwestern Entomology* 44, 393–402.

Sardana, H.R., and Kumar, N.K.K. (1989). Effectiveness of plant oils against leaf hopper and shoot fruit borer on okra. *Indian Journal of* Entomology 51(2), 167-171.

Singer, J.W. (2008). Corn Belt assessment of cover crop management and preferences. *Agronomy Journal* 100, 1670 – 1672.

Sowei, J.W. (1993). Aibika. *Harvest* 15 (1), 42–47.

Stoll, G. (2000). Natural crop protection in the tropics, letting information come to life. Margraf Vellag Publishers, Germany. 376pp.

Sujayanand, G.K., Sharma, R.K., and Shankarganesh K. (2016). Impact of intercrops and border crops on pest incidence in okra. *Indian Journal of Horticulture* 73(2), 219-223.

Tsatsia, H. and Jackson, G. (2010). Pest and disease manual. Ministry of Agriculture and Livestock, Honiara, Solomon Islands. 100pp.

Wang, W., Yao, J., Li, H.B., Zhang, Y., Wang, D., and Ma, G.L. (2011). Comparative study on conservation of natural enemy in the cotton field by different rapes in Xinjiang. *Plant Protection* 37, 142–145.

You, M.S., Liu, Y.F., and Xu, Q.Y. (2000). Species composition, richness and diversity of insect communities in cruciferous fields in Fuzhous's Suburb. *Journal of Fujian Agriculture University* 29, 444- 452.

You, M.S., and Hu, Y.M. (2004). Biodiversity and integrated pest management in agroecosystem. *Acta Ecological Sinica* 24(1), 190-195

The Kokonut Pacific Solomon Islands response to the fight against the coconut rhinoceros beetle (*Oryctes rhinoceros*) in Solomon Islands

Victoria Varoro Vigulu,[1] Ishmael Kwasamanu,[1] Cecilia Vakisoro[2] and Melannie Faleia[2]

Abstract

With the discovery of coconut rhinoceros beetle or CRB (*Oryctes rhinoceros*) in Solomon Islands during 2015, the country's Ministry of Agriculture and Livestock (MAL) embarked on a joint containment plan with support from AgResearch in the New Zealand Ministry of Foreign Affairs and Trade. As CRB eradication was deemed impossible, containment measures were implemented with stakeholders. Kokonut Pacific Solomon Islands (KPSI) assisted with the CRB containment plan under a joint memorandum signed on 22 June 2022, with work commencing in January 2023. KPSI is the largest coconut oil-producing company, exporting virgin coconut oil internationally, while also producing handmade soaps and essential body oils.

This paper highlights the work KPSI has undertaken in support of farmers and coconut oil producers who joined the fight to contain the CRB incursion in Malaita and Central Provinces. The paper also describes challenges the KPSI extension team faced in working with farmers and producers during project implementation. In addition, it outlines recommendations for a better CRB control plan in the future.

A total of 17 producers using Direct Micro Expelling (DME) units were selected with their cluster of coconut suppliers. KPSI's role in this collaborative project included support for farmers as well as for MAL in monitoring and responding to the CRB incursion, in preparing a report on data collection, in delivering pheromone traps, in providing farmer training, in raising awareness, and in providing tools to support sanitation.

The challenges faced included timely reporting of data collected (due to inadequate telecommunications network coverage), consistency in the supply of synthetic pheromone, replacement of bucket traps, and coconut farmers' participation.

The authors recommend reallocation of pheromone traps according to the number of farmers per hectare and taking into consideration the synthetic pheromone attractant's capacity as well as site coordinates for mapping and monitoring. Application of the self-replicating biological control fungal agent, *Metarhizium majus*, is also highly

1 Kokonut Pacific, Solomon Islands ICS coordinator
2 Kokonut Pacific, Solomon Islands extension team

recommended to enhance sanitation for pest control, thus suppressing CRB populations. Despite the efforts of KPSI, CRB damage has continued in both Malaita and Central Provinces.

Introduction

Kokonut Pacific Solomon Islands (KPSI), established in 2004, works closely with coconut farmers, exporting virgin coconut oil (VCO) to international markets, while also selling it domestically for essential body oils and soap.

A total of 34 active Direct Micro Expelling (DME) units supplied VCO to KPSI in 2023. The highest VCO producers were from Malaita Province, producing an estimated total of 94,792.34 kg (94.79 t) in 2023 and 50,892 kg (5.09 t) from January to August 2024 (KPSI, 2024). Other provinces produced an estimated volume of 23,291.80 kg (23.29 t) in 2023. The nuts were supplied by 1,000 coconut farmers on 3,371.7 hectares (ha) to VCO producers for milling, drying, and oil extraction (KPSI, 2024).

The network of farmers, VCO producers and KPSI generates cash income for rural people in remote areas of Solomon Islands, delivering important social and economic benefits. The network creates employment for large numbers of people directly and indirectly in rural areas where employment opportunities are limited, while also providing food for rural people and feed for livestock. In addition, the network contributes to the nation's GDP through sustainable production (Young & Pelomo, 2014).

Coconut rhinoceros beetle or CRB (*Oryctes rhinoceros*) was observed at Honiara in January 2015, causing estimated losses of 50% palm mortality. Adult beetles were collected to determine their identity, as the indigenous beetle *Scapanes australis* causes similar damage to young palms (Marshall, Paudel, Mansfield, & et al, 2023).

After identifying CRB symptoms in 2015, Biosecurity Solomon Islands (BSI) and the Ministry of Agriculture and Livestock (MAL) put in place an emergency response plan and conducted a delimiting survey based on frond damage. This clearly demonstrated that the CRB incursion was already underway, and that eradication was impossible.

Therefore, the plan's focus was switched to containment, since the beetle had already spread 60+ km east and west along the coast of Guadalcanal Province, with damaged palm frond losses estimated at 50–100% from 2016 to 2019. During 2019–2020, frond damage symptoms were observed on five additional islands. In 2019, two of the Russel Islands had frond damage loss of 20–50%, and in 2020, Savo, Nigella, Malaita, and Ulawa Islands had a CRB incursion causing losses of 20–50% (Marshall, Paudel, Mansfield, & Richards, 2023).

After signing a memorandum of understanding on 22 June 2022, KPSI and MAL's Biosecurity department began their collaborative effort to control the CRB population in January 2023, effective for one year. It was vital KPSI to participate as well, since the pest affects coconut production indirectly, with a major impact on the company's production of VCO. Its core responsibility as a partner is to work with MAL to provide information along with specific deliverables, as follows:

- Number of coconut farmers to receive support from MAL.
- Location of these farmers/villages.
- Support for MAL in monitoring and responding to CRB incursions.
- Reporting of data collected on a monthly basis, as the work progresses.
- Efforts of the KPSI extension office in delivering pheromone for trapping beetles, in training and awareness raising, in cleaning up infected palms with producers and farmers, and in cutting and burning of dead coconut logs for charcoal production.

Monitoring and collection of data on treated plantations, trees cut down, number of beetles trapped, and number of time traps checked, and sharing of beetles caught for the delimiting survey.

Key highlights from this work include effective engagement of coconut producers and farmers for monitoring and surveillance as well as data collection, sanitation demonstration, and distribution of tools. The Pacific Community (SPC) and MAL provided capacity building for KPSI officers to assist coconut producers and farmers in Malaita and Central Provinces.

This paper highlights the work done by the project in those provinces. It also discusses the control measures carried out, indicating the number of training and field events. It further documents the number of traps established and data collected to determine the distribution and spread of the CRB population in the two provinces. In addition, the paper outlines challenges and recommendations for future control management strategies and identifies gaps requiring further study.

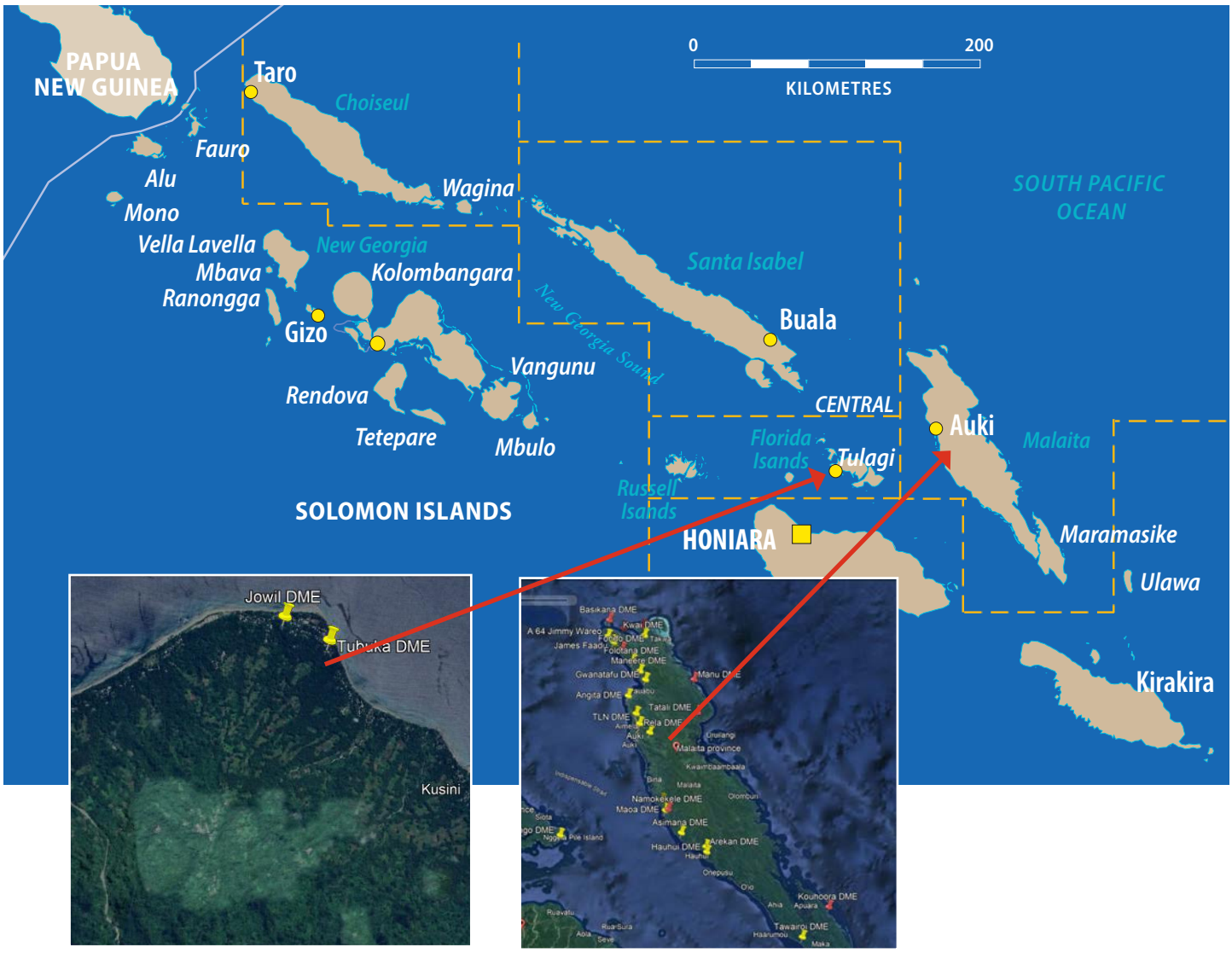
Methodology

Location of the CRB project site

The project's focal sites were located in Malaita and Central Provinces, where coconut farmers earn income through the DME unit established by KPSI in 2017–2018.

Malaita Province has the highest population, with about 172,740 people (Kimi, 2019), and a land area of 4,225 km^2, making it the second largest province after Guadalcanal. Central Province has a population of 30,326 and a land area of 615 km2 located 22 minutes from the nation's capital Honiara (Wikipedia contributors, 2024).

FIGURE 1. The two provinces in Solomon Islands with pheromone trap sites. Map: SPC. Satellite images: Google Earth.



As in other provinces of Solomon Islands, coconut (*Cocos nucifera*) and cocoa (*Theobroma cacao*) serve as a valuable resource for people in Malaita and Central Provinces, providing income for local livelihoods and the national economy.

Method of CRB management

After the memorandum of understanding for collaboration was signed in January 2022, the KPSI extension team provided a number of coconut farm sites where farmers were to receive support in confronting the CRB incursion in Malaita and Central Provinces.

The KPSI team travelled to infested sites, where they placed pheromone traps with *oryctalure ethy1 4-methyloctanote* supplied by MAL's Biosecurity department in Honiara.

A sanitation programme was carried out on selected coconut farms in the two provinces. Along with awareness and field training, producers learned how to identify the biological cycle and sex of adult beetles. This training enabled producers to assist in data collection, especially on beetle counts in the pheromone traps.

VCO producers worked closely with the KPSI extension team in reporting numbers of beetles trapped along with their sex. The data were entered on forms filled fortnightly and sent to MAL. It proved impossible to send live beetles to Honiara due to the geographical location of the two provinces.

During this phase of the project, farm tools were delivered to producers and farmers for enhanced plantation management and sanitation.

Physical control is the only control measure that the KPSI extension team can implement in these provinces.

Data collection

This study used the cluster sampling method to collect data from VCO producers in different regions of Malaita and Central Provinces. There are 17 DME units in West ʻAreʻare, South Malaita, West Kwaio, and Dorio Asimane. Also, VCO producers in West Kwaraáe, West Baegu/Fataleka, Baelealea, and To'abaita constituencies were randomly selected. In Central Province, a total of four DME units were selected in Panueli and Sisiaka wards.

From the 17 VCO producers, a total cluster of 378 farmers supply coconuts to the producers, and 322 farmers participated in project implementation.

A total of 23 bucket traps baited with the synthetic attractant *oryctalure ethyl 4–methyloctanoate* were established during the project period. The pheromone lures were replaced every two to three months, and VCO producers reported the numbers of captured beetles. Segregated data on male and female counts were sent fortnightly to KPSI's head office via mobile phone, and VCO producers then destroyed the beetles in the field.

The study also relied on secondary data obtained from KPSI extension reports on the company's Microsoft OneDrive.

Data analysis

Several approaches were used to analyse the data collected for determining CRB population spread and its impact on coconut farms in selected sites. The graphical information collected was analysed using Microsoft Excel. Photographs of frond damage were also used to determine losses caused by beetles in the plantations visited. Through informal interviews and visits with farmers and VCO producers at the site, the extension team obtained information about the impact of CRB on coconut farmers.

Secondary information from the extension officers was placed in a table indicating the number of training events, field activities, and visits carried out with selected producers during the project period.

Results

As indicated in Table 1, farmers supplying the VCO producers practised integrated pest management to control CRB.

Applied biological control and chemical controls were not implemented during the project period in Malaita and Central Provinces. Mechanical control, sanitation, and trapping proved to be the most practical and affordable pest control measures for farmers. They cleaned their plantations through disposal of organic matter sources, removal of standing dead stumps, and management of organic matter and compost. Trapping was used for different purposes, including surveillance for early detection and population monitoring as well as mass trapping to reduce the CRB population. A key gap identified in this study is limited knowledge of natural predators of CRB, although one report indicates that red ants can feed on first instar grubs, pointing to the need for further study in this area.

Table 2 shows the number of VCO producers that took part in the project. Seventeen producers joined the KPSI team in collaborating with MAL on the control and management programme.

Central Province has a total area of 120.5 ha and Malaita Province a total of 963.8 ha. As shown in the table, 13 producers were selected in Malaita Province and four in Central Province.

Gwuanatafu VCO producer from West Fataleka had the largest cluster of 60 farmers with a total of 92.5 ha. Compared with 1,307.2 ha in Asimana, 154.5 ha in Rela, and 156 ha in TLN, these producers had the largest total area of coconut farms in Malaita Province, with one bucket trap established for each, except Asimana with two bucket traps. In Central Province, two traps were established for VCO producers.

The bucket traps allocated for all the selected VCO producers ranged from one to two traps, and the pheromone lure for the traps was sent every three months.

The table above shows the number of days extension officers were at the site to conduct training, raise awareness, oversee cleanup campaigns, and deliver tools during the project period as well as the total number of farmers participating in the training and field exercises.

A total of 32 field trips was conducted in 79 days, and a total of 279 farmers took part in the project. In Central Province, farmers and producers were invited for training and field work on the same day, since they are located at the same site. In Malaita Province, field trips, and training were held at different times.

Figure 2 shows the trapped beetle count reported to the KPSI head office, Honiara. Blue bars indicate the total number of live female beetles observed in the trap; orange bars indicate live male beetles; green bars indicate dead females; and light blue bars are for dead male beetles.

The beetle counts took place from January to September 2023 and indicated that only male adult beetles are trapped, with the highest count from Kwa'a producer in West Kwaio, Malaita Province, followed by Folotana producer in Baelelea, West Northern region in Malaita Province.

In Central Province, Sol-entrepreneur producer had the highest live male and female count, compared to other VCO producers. The absence of a bar indicates no record of beetles of either sex counted.

TABLE 1. CRB control measures.

PROVINCE	DME SITE	PHYSICAL CONTROL	BIOLOGICAL CONTROL	CHEMICAL CONTROL
Malaita Province	Angita	• Cleaning of plantation • Pheromone traps & bait • Handpicking	None	None
Malaita Province	Arekan	• Cleaning of plantation • Pheromone traps & bait • Handpicking	None	None
Malaita Province	Asimina	• Cleaning of plantation • Pheromone traps & bait • Handpicking	None	None
Malaita Province	Folotana	• Cleaning of plantation • Pheromone traps & bait • Handpicking	None	None
Malaita Province	Gwuanatafu	• Cleaning of plantation • Pheromone traps & bait • Handpicking	None	None
Malaita Province	Kwa 'a	• Cleaning of plantation • Pheromone traps & bait • Handpicking	None	None
Malaita Province	Kwai	• Cleaning of plantation • Pheromone traps • Handpicking	None	None
Malaita Province	Maneére	• Cleaning of plantation • Pheromone traps • Handpicking	None	None
Malaita Province	Mao	• Cleaning of plantation • Pheromone traps • Handpicking	1st Viral BCA	None
Malaita Province	Rela	• Cleaning of plantation • Pheromone traps • Handpicking	None	None
Malaita Province	TLN	• Cleaning of plantation • Pheromone traps • Handpicking	None	None
Malaita Province	Namokekele	• Cleaning of plantation • Pheromone traps • Handpicking	None	None
Central Province	Sol-entrepreneur	• Cleaning of plantation • Pheromone traps • Handpicking	Red ants attacking the adult beetle	None
Central Province	Tubuka	• Cleaning of plantation • Pheromone traps • Handpicking	None	None
Central Province	Jowil	• Cleaning of plantation • Pheromone traps • Handpicking	None	None
Central Province	Tongo	• Cleaning of plantation • Pheromone traps • Handpicking	None	None

TABLE 2. Summary table on placement of traps

No. of producer	Province	DME site	Total number of farmers	Total hectares (ha)	Number of traps
1	Malaita Province	Angita	10	15.9	1
2	Malaita province	Arekan	23	97.3	2
3	Malaita Province	Asimana	38	1,307.2	2
4	Malaita province	Folotana	20	27.5	1
5	Malaita Province	Gwuanatafu	60	92.5	1
6	Malaita Province	Kwa'a	21	112	2
7	Malaita Province	Kwai	13	48.3	1
8	Malaita Province	Mane 'ere	28	77	1
9	Malaita Province	Mao	11	22.6	1
10	Malaita Province	Rela	20	154.5	1
11	Malaita Province	TLN	24	156.3	1
12	Malaita Province	Namokekele	4	13.7	1
13	Central Provine	Sol-entrepreneur	25	36.5	2
14	Central Province	Tubuka	21	23.1	2
15	Central Province	Jowil	26	26.9	2
16	Central Province	Tongo	14	34	2
17	Malaita province	Tawairoi	20	16	2

FIGURE 2. Trapped beetle counts for selected VCO producers in Central and Malaita Provinces.

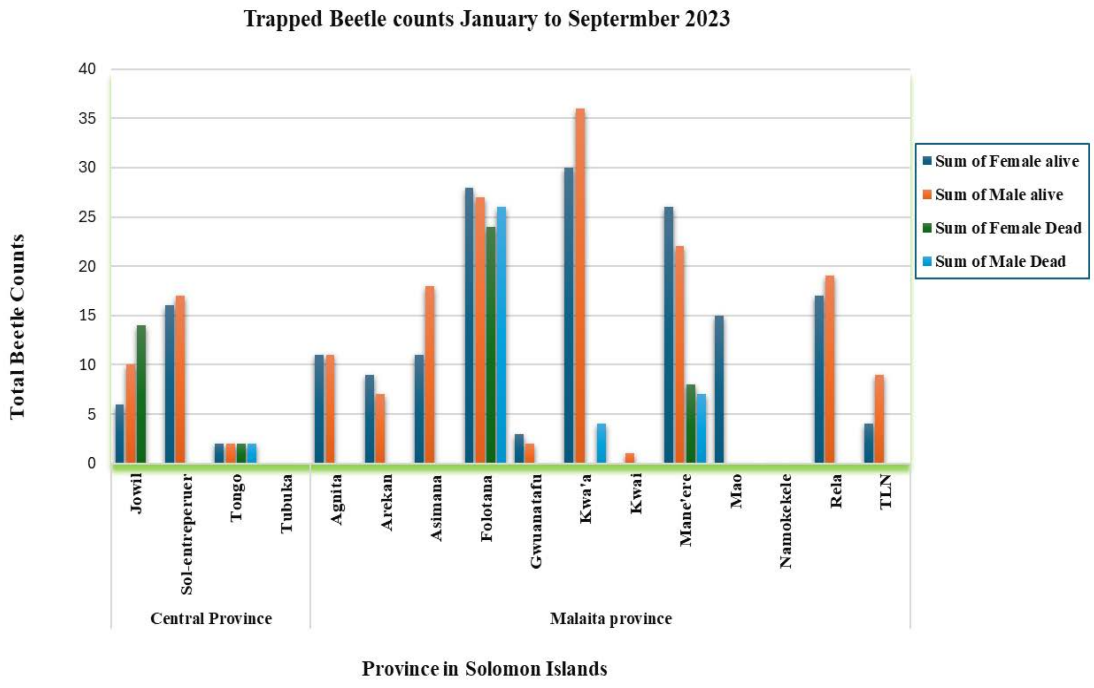


TABLE 3. Field work done by KPSI officers during the CRB project

No. of DME	Province	DME site	Number of field trips	Days of field work	No. of trainings	Number of farmers attending
1	Malaita	Angita	2	7	2	10
2	Malaita	Arekan	2	6	2	20
3	Malaita	Asimana	2	6	2	23
4	Malaita	Folotana	2	7	2	15
5	Malaita	Gwuanatafu	2	7	2	50
6	Malaita	Kwa'a	2	5	2	20
7	Malaita	Kwai	2	1	2	10
8	Malaita	Mane'ere	2	7	2	20
9	Malaita	Mao	2	3	2	11
10	Malaita	Rela	2	6	2	15
11	Malaita	TLN	2	6	2	22
12	Malaita	Namokekele	2	2	2	4
13	Malaita	Tawairoi	2	4	2	20
14	Central	Sol-entrepreneur	3	4	3	23
15	Central	Tubuka				
16	Central	Jowil				
17	Central	Tongo	3	4	3	16
Total			32	79	32	279

Discussion

CRB control measures

CRB populations increase at breeding sites and can be active in a wide variety of decaying plant materials, pile compost, and manure or sawdust (Gressitt, 1953). Sanitation is a practical method for suppressing CRB populations, as outlined in the SPC manual for control and management.[2] This method helps prevent newly, established breeding sites and disrupts the beetles' life cycle (Trevor, Marshall, Mansfield, & Atumurirava, 2020).

During the project, KPSI extension officers partnered with VCO producers and farmers to remove and burn decayed plant materials from coconut farms, cut down dead standing palm trees, and destroy the larva and adult beetles in the dead logs. This helped supress and eradicate CRB populations. Several methods were used to detect CRB at obscure breeding sites during past outbreaks. Detector dogs were used during a CRB outbreak in Guam (Moore & Siderhurst, 2002); this method is suited specifically to obscure breeding sites. A cheaper detection method involves the use of harmonic radar tags (Moore & Siderhurst, 2002). Drones have been used as well, though with the disadvantage that it is difficult to differentiate the crown and texture of the soil and any plants beneath ground level. The accuracy of this method is 94.4%, making it applicable only for large plantations (Kadethankar, Sinha, Burma, & Hegde, 2021).

Another method for suppressing CRB populations involves establishing bucket traps with synthetic pheromone *(oryctalure ethyl 4-methytoctanoaate)*. The purpose of pheromone traps is to collect CRB samples to determine the haplotype and OrNV infection status. Pheromone is also used for research on CRB ecology and migration as well as to monitor pest populations for economic management (Paudel, et al., 2023).

Installing networks of pheromone traps during the project period helped suppress the CRB population and indicated its rate of infection in Malaita and Central Provinces. This step is vital for monitoring the pest and initiating control strategies (Sulav, Marshell, Tsatsia, & et al, 2021).

2 This publication, *Coconut rhinoceros beetle* (Oryctes rhinoceros): *a manual for control and management of the pest in Pacific Island countries and territories* (2020) is available in the SPC Digital Library at: https://www.spc.int/digitallibrary/get/bs47c

Since farmers and producers are scattered across the provinces, it is challenging to keep data collection up to date, particularly in areas without network communications (Telekom or B-mobile coverage). As a result, beetle counts are sometimes not timely or reliable. Other challenges include ensuring consistency in supplying synthetic pheromone and replacing damaged bucket traps.

Oryctes rhinoceros nudivirus was the biological control agent released during the CRB outbreak in the 1960s and 1970s (Marshalet et al., 2017). The recent outbreak in the Pacific region was discovered to result from an unrecognised haplotype (CRB-G) that is resistant to OrNV (Mansfield, Marshall, Jackson, Villamizar, & Paudel, 2024) (Marshal, et al., 2017). This prompted MAL to conduct research under the direction of AgResearch (Ministry of Foreign Affairs and Trade, New Zealand) in Gizo, Western Province. Another biological control method under research involves *Metarhizium*. A further natural predator, fire ant (*Solenopsis invicta*), was reportedly seen in Central Province, pointing to the need for more research on this natural biological control species in the province.

Throughout the project, sanitation and mechanical control measures were carried out.

Number of traps per hectare for farmers

In KPSI's VCO supply chain, producers purchase nuts from coconut farmers for the extraction of virgin oil, which is stored in barrels and sent to Honiara.

As indicated in Table 2, 17 VCO producers took part in the joint programme for CRB containment and monitoring along with a delimitating survey for damage assessment. The farmers supplying coconuts for each oil producer vary in number and farm size. As shown in Table 2 on the allocation of pheromone traps, Gwuanatafu DME in West Fataleka, in the northern Malaita Province had the largest cluster of 60 farmers with one trap. Farmers in Asimane, West Kwaio, had the largest coconut plantation area, with two traps for a total of 1,307.2 ha. VCO producers in Kwaraáe, West Baegu, and Fataleka similarly had two traps for a total area of 572 ha. According to (Paudel, et al., 2023), a density of five traps per hectare is recommended for achieving the highest trap catches in oil palm plantations. A key question is whether this trap allocation is well suited for a similar area of coconut plantation. Beetle counts were possibly biased for coconut plantations. However, the main objectives of the partnership were to conduct a delimiting survey and monitor the CRB incursion.

Beetle counts of VCO producers

When the CRB incursion was detected in the Solomon Islands during 2015, the pheromone bucket traps were used to monitor the beetle's spread and abundance (Sulavet et al., 2021). KPSI, in collaboration with MAL, played a vital role in distributing bucket traps with synthetic bait and prepared KPSI extension officers to train producers and farmers in CRB morphology. This helped producers make beetle counts and collect information. Data on beetle counts were sent to KPSI headquarters in Honiara and later to MAL Biosecurity for further analysis. This indicated that both CRB strains (CRB-S/CRB-G) were present in in Malaita and Central Provinces (Sulavet et al., 2021).

The presence of the biotypes in different regions of Malaita Province is still unknown. This is not so relevant for Central Province with its small land mass compared to that of Malaita Province. Since Central Province is closer to Guadalcanal Province, it possibly has biotypes similar to CRB-S, CRB-G, and OrNV.

According to data collected on beetles in Malaita Province, Kwa'a producer reported the highest count of male live adult beetles trapped, stating that the chemical used was a male- produced aggregation pheromone of CRB (Sulav, et al., 2021). The second highest count was for producers in Folotana, Baelelea constituency in North Malaita. Sol-entrepreneur producer in Central Province reported the highest male and female adult beetle count. The summary counts indicate that adult male beetles were more attracted to *oryctalure ethyl 4-methytoctanoaate* on the bucket traps. Timely documentation of weather conditions, ecological background, and other factors affecting the counts were not fully considered during beetle counting and placement of the bucket traps. Moreover, the data does not indicate the strain type and OrNV infection status. Nor does the count include an analysis of whether the sanitation implemented by farmers on their farms was effective in suppressing the CRB population.

In the assessment of coconut frond damage, the CRB strains CRB-S and CRB-G showed similar damage with a V-shape (Mansfield , et al., 2023). How severely this damage affects coconut yield capacity in the two provinces is still unclear. Frond damage assessment was not compared with beetle counts on farmers' coconut plantations. Extension officers took photos of damaged fronds in the areas visited and sent these to MAL. One shortcoming of this study is that it did not fully implement frond damage assessment using the binary three- and five-point scale frond assessment method (Sulav, et al., 2021) (Mansfield, et al., 2023). It is vital to assess the intensity of CRB impact, comparing data on estimated pest population between every producer in the two provinces. This can help devise the best integrated pest management strategies for producers or famers to apply on coconut farms and in rehabilitation programmes.

Challenges and recommendations

- Telecommunications network coverage was inadequate in some remote areas of the project site, limiting the ability of farmers and producers to share surveillance and monitoring reports.
- Replacement of damaged buckets traps was inconsistent in some locations because of extreme weather conditions and difficulty in getting supplies of pheromone lures to producers and farmers, resulting from limited availability of these materials as well as the high cost of transport and poor road conditions.
- It proved difficult to obtain adequate data on the number of trees cut down and number of times traps were checked as well as photos from monitored and treated coconut farms.
- Some farmers proved reluctant to take part in the sanitation programme and capacity building because of other commitments. Moreover, ineffective communication may have made it more difficult for these farmers to adapt to project innovations. Non-participating farms can become breeding sites for CRB, undermining the project's efforts.

Recommendations

Bucket traps containing the synthetic attractant *oryctalure ethyl 4-methytoctanoaate* should be distributed according to the land area of the coconut farms, considering the range of the synthetic lures and the beetles' sensitivity to them. Moreover, the bucket traps should be better adapted to weather conditions in the Solomon Islands.

Site coordinates of the distributed bucket traps should be recaptured, using KoboToolbox and QGIS software for improved visual monitoring and control.

Fungal (*Metarhizium majus*) and viral (*Oryctes nudivirus strain V23B* control should be applied in these provinces to further strengthen the management of CRB.

Frond damage assessment should be conducted using the binary three - to five-point scale to determine the impacts and management required for each region of the two provinces.

It is necessary to collect more data on beetle counts and conduct further data analysis, using a generalised linear model or RStudio as well as Minitab or KoboToolbox software.

Conclusion

RCB was discovered in the Solomon Islands during 2015, causing estimated losses of 50% palm mortality in coconut plantations. MAL collaboration with KPSI to address the problem came into effect on 22 June 2022 with the signing of a memorandum of understanding. KPSI was assigned to provide MAL with information on numbers of coconut farmers and their location as well as to assist in training farmers and producers for engagement in a sanitation programme.

KPSI, as the prime exporter of VCO, supported MAL by conducting surveillance, delimiting, and monitoring of the invasive CRB. This paper discusses the monthly reports of beetle count data provided by oil producers to KPSI extension officers. It also reports on the awareness, sanitation, and training activities conducted by the KPSI team with producers and famers in Malaita and Central Provinces. Sanitation included the production of charcoal for cooking from dead palms that had been cut down.

KPSI has a total of 34 producers extracting oil in the Solomon Islands. In Malaita Province, 17 VCO producers with DME units involve a total of 363 farmers, whose coconut farms have a total area of 2,387.1 ha. Central Province has four DME units involving a total of 86 farmers with a total of 120.5 ha. Seventeen producers took part in the joint effort to combat CRB from 2022 to 2023. Twelve VCO producers are from Malaita Province and four from Central Province. These producers have clusters of farmers, who supply coconuts for production and participate in the CRB project.

During the project, KPSI distributed 27 bucket traps with the synthetic attractant *oryctalure ethyl 4-methytoctanoaate*. Every three months, synthetic bait was sent to producers for replacement. Awareness and field training were conducted as well, including annual awareness raising for farmers taking part in annual organic management training for organic certification.

Data collection relied on information obtained from the VCO producers, who shared it via telecommunications to the KPSI extension team in Honiara. Producers provided fortnightly counts of live or dead beetles, differentiated by sex of the adult beetles found in the traps. KPSI extension officers entered the data on forms and sent it to MAL. Frond damage assessment was not fully completed, but photos were taken and sent to MAL.

The control measures conducted involved sanitation, use of pheromone traps, and handpicking. Sanitation helps destroy breeding sites to suppress the pest population. Farm tools were provided to help ensure continuous sanitation for enhanced farm management. MAL is conducting research on application of the fungus *Metarhizium majus*, which is recommended to strengthen management strategies for disrupting the biological cycle of CRB and thus supressing the population.

Placement of bucket traps with the synthetic attractant *oryctalure ethyl 4-methytoctanoaate* was used to monitor the status of beetle strains CRB-S/CRB-G and OrNV. These pheromone traps also helped suppress the CRB population in Malaita and Central Provinces. One to two traps

were provided per producer, with variation in the total area for each farmer. A key question is whether this number of bucket traps per hectare is consistent with the range of the synthetic attractant.

The data on adult beetles indicates their responses to *oryctalure ethyl 4-methytoctanoaate*, with adult male beetles dominating. The accuracy of this data is uncertain, however, due to inconsistency in the supply of *oryctalure ethyl 4-methytoctanoaate*, in the replacement of damaged pheromone traps, in network coverage for timely reporting of data, and in the producers and farmers' ability to count and determine the sex of beetles. Moreover, the binary three- to five-point scale for damage assessment was not fully implemented to determine damage severity for management strategies in the two provinces.

In conclusion, KPSI can help coconut farmers replace damaged bucket traps and send them *oryctalure ethyl 4-methytoctanoaate* sachets obtained from MAL. This depends, however, on the availability of pheromone traps and synthetic pheromone bait as well as on the budget for transporting these items to farmers in the two provinces.

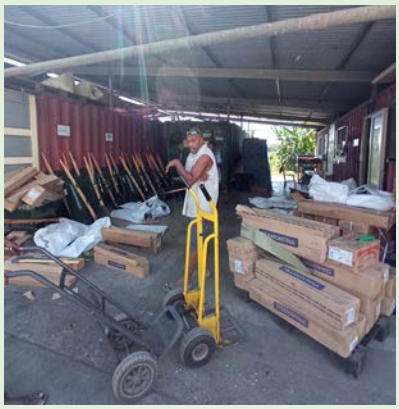
Appendix

Bucket traps established on Savo Island, Central Province. Hung in the tree canopy at 1.5–1.8 m above ground, they were operational for about three months (photos courtesy of Cecilia Vakisoro).

James Ramo in Kwaraáe, Rela DME, conducting sanitation and cutting down dead stumps on his coconut farm (left) and training for farmers to identify CRB's biological cycle and the sex of adult beetle (photos courtesy of Ishmael Kwasamanu).

Frond damage, estimated at 20-50%, resulting from CRB *(CRB-S /CRB-G)* on coconut farms in Rela, Malaita Province (photos courtesy of Ishmael Kwasamanu).

Frond damage (estimated at 50-100%) resulting from CRB on coconut farms in Agnita, Kwaraáe (photos courtesy of Ishmael Kwasamanu).



Farm tools delivered to the KPSI headquarter warehouse (**A)** and KPSI extension officers distributing tools for farmers in West 'Are'are (Arekan DME) and West Kwaio (Kwaá DME) (**B**), Malaita Province (photos courtesy of Victoria Varoro Vigulu, **A**, and Melannie Faleia, **B**).

Acknowledgments

We thank the following stakeholders and team members:

- MFAT (New Zealand) for funding the project for five years.
- SPC for capacity building and technical assistance throughout the project.
- AgResearch New Zealand for scientific analysis and technical assistance.
- MAL of Solomon Islands for collaborating with KPSI in training and capacity building.
- Producers and farmers who took part in the field work and data collection throughout the project.
- KPSI management for providing support throughout the project period.
- The KPSI extension team for their efforts in achieving the project objective.

References

Gressitt, L.J. (1953). The coconut rhinoceros beetle *(Oryctes rhinoceros)* with particular reference to the Palau Island. Bernice P. Bishop Museum. Retrieved from http://hbs.bishopmuseum.org/pubs-online/bpbm_buttetins.html

Kadethankar, A., Sinha, N., Burma, A., & Hegde, V. (2021). Deep learning based detection of rhinoceros beetle infestation in coconut trees using drone imagery. *Computer vision and image processing*.

Kimi, D. (2019). Report on 2019 population and housing census, volume 2. Honiara, Solomon Islands: Ministry of Finance and Treasury, Solomon Islands National Statistics Office.

KPSI, K. (2024). Operation coconut virgin oil blending and receiving record 2023. Honiara.

Mansfield, S., Asigau, B., Koten, C.V., Paudel, S., Bowie, M., Jackson, T.A., & Marshall, D.S. (2023). Assesment of coconut palm damage caused by coconut rhinoceros beetle *Oryctes rhinoceros* (Coleoptera: Scarabaeidae). *New Zealand Journal of Crop and Horticultural Science*, 335-357.

Mansfield, S., Marshall, S., Jackson, T., Villamizar, L., & Paudel, S. (2024). IPM for CRB: Review of stakeholder practises in Papua New Guinea, Solomon Islands and Vanuatu. Report for MFAT and CRB project partners.

Marshal, S.D., Moore, A., Vagalo, M., Noble, A., & Jackson, T.A. (2017). A new haplotype of the coconut rhinoceros beetle, *Oryctes rhinoceroses*, has escaped biological control by *Oryctes rhinoceros nudivirus* and is invading Pacific islands. *Journal of Invertebrate Pathology*, 127-134.

Marshall, S.D., Paudel, S., Mansfield, S., & et al. (2023). Coconut rhinoceros beetle in the Solomon Islands: A tale of two invasions. 2659-2678.

Marshall, S., Mansfield, S., Paudel, S., & et al. (2023). Evaluation of OrNV impact against CRB on Guadacanal Solomon Islands. *(2018-2023)*.

Moore, A., & Siderhurst, M. (22 August 2002). Proposal for detecting coconut rhinoceros beetle breeding sites using hanonic radar. Retrieved from https://doi.org/10.3897/rio.8.e86422

Paudel, S., Jackson A.T., Mansfield, S., Ero, M., Moore, A., & Marshall, S. (2023). Use of pheromone for monitoring and control stratergies of coconut rhinoceros beetle (*Orycte rhinoceros*): A review. *Crop Protection*, 106400.

Sulav, P., Marshell, S.D., Tsatsia, F., & et al. (26 July 2021). Monitoring an invasive coconut rhinoceros beetle population using phremone traps in Honiara Solomon Islands. Retrieved from https:doi.org/10.30843/nzpp.2021.74

Trevor, J., Marshall, S., Mansfield, S., & Atumurirava, F. (2020). *Coconut rhinoceros beetle (Oryctes rhinoceros): A manual for control and management of the pest in Pacific Islands countries and territories.* Suva, Fiji: SPC.

Wikipedia contributors. (12 June 2024). *Georgraphy of the Solomon Islands.* Retrieved from Wikipedia, the free encyclopedia: https://en.wikipedia.org/w/index.php?tittle=Geography_of_the_Solomon_Islands&oldid=1228721361

Young, D., & Pelomo, M. (2014). *Solomon Island coconut value chain anlaysis.* World Bank, Australian Department of Foreign Affairs and Trade.

Understanding the socioeconomic aspects of coconut agribusiness in rural areas in Fiji

Luisa Wara,[1*] Rohit Lal[1] and Sonny Lameta[2]

Abstract

The coconut (*Cocos nucifera*) is the tree of life, contributing to both food and income security. Socioeconomic factors are among the various factors that influence coconut business in rural areas. The study examined the relationships between rural households' participation in coconut business and socioeconomic factors such as family composition, household spending and sources of income. Family composition in this case was represented by family arrangement (nuclear, extended or living alone) and the number of members per household. Through purposive sampling, five districts were selected from a population of 4,178 rural households, who were actively engaged in coconut production in Fiji. A target response of 100 households was set for each district. The responses were analysed using R software for three main relationships: (i) family composition and coconut income per week; (ii) households' expenses and coconut income; and (iii) the number of coconut enterprises households were involved in and family composition as well as their location. The findings reflected on the significance of the coconut to rural livelihood. Furthermore, the coconut industry operates in a diverse environment; thus, other factors needed to be considered alongside household composition when assessing rural households' participation in the coconut business.

Keywords: Coconut agribusiness, Rural livelihood, Fiji, Socioeconomics

Introduction

The coconut (*Cocos nucifera*) has sustained livelihoods for generations, contributing to both food and income security – earning the title of "King of the Islands and Emperor of the Seas" (Bennett, 2018). The coconut provides employment for 30 million farmers through production and marketing along the supply chain, supporting 60 million households worldwide (Zainol *et al.*, 2023). The tree crop constitutes 3,512 hectares (ha) of land in Fiji of which 90% are within 0.5–4 ha of landholding – meaning that the majority are smallholders (Ministry of Agriculture, 2021, Lin, 2020). The rural economy is reliant on natural resources, namely, agriculture and marine resources. The coconut alone cannot sustain livelihoods but it acts as a safety net for households (Nenci et al., 2023, Vijayakumar, 2020). The government and partners have invested resources in reviving the coconut industry – an industry that could contribute to sustainable development.

The socioeconomic contributions of coconut agribusiness are primarily linked to employment opportunities, income generation and wealth accumulation. Additionally, the coconut tree supports and contributes to sustainable agricultural practices through the provision of ecological, socioeconomic and cultural services enabling sustainable management of resources (Kumar and Kunhamu, 2022). Coconut activities are also characterised by shared responsibilities in the overall production and marketing of coconuts (Heince and Sofilda, 2024). The agribusiness operates in a dynamic environment and is labour-intensive in nature (Nor et al., 2020). Technological progress in the industry will require a holistic approach that taps into all facets of production and marketing, across stakeholders and institutions, and across resources (Zainol *et al.*, 2023, Lin, 2020, Lin et al., 2021). Empowerment of women and the rural communities, as a whole is essential in the adoption and sustainability of the coconut industry. Peer-to-peer learning among farmers offers better chances of the adoption of knowledge and skills disseminated in rural communities (Heince and Sofilda, 2024). Sociocultural elements such as trust, kinship and communal-owned resources offer strengths and opportunities for rural agribusiness (Vunibola and Scheyvens, 2023; Bryceson and Ross, 2020). Thus, optimising the benefits of informal institutions is key in the success of

1 Land Resources Division, Pacific Community. *Corresponding author: waraluisa@gmail.com, luisaw@spc.int
2 Discipline of Agriculture and Food Technology, School of Agriculture, Geography, Environment, Ocean and Natural Sciences, University of the South Pacific

coconut business in rural areas in Fiji. This study examined socioeconomic factors such as family composition, household spending and sources of income and their relationship with coconut agribusiness in the rural areas.

Methodology

The study adopted a mixed-methods approach. A sample size of 500 households was selected from a population of 4,178 households actively engaged in coconut business in Fiji. The sampling method used was convenience sampling in which the sample had to include or satisfy the following conditions: The sites were to have coconut as one of the top five agriculture commodities they relied on for income generation and, secondly, the sites had to be located in either of the two main islands, Vanua Levu and Viti Levu. Additionally, gross margins for commodities from the kernel and palm fronds (broom production) were estimated from field observations carried out in Mua Research Station. The figures for coconut stems were estimated from secondary sources.

Data collection involved participant observation, field site visits, questionnaire survey and informant interviews. The data collected was analysed using cross tabulation, case studies, thematic analysis, gross margin and breakeven analysis and use of R statistical software to conduct non-parametric tests such as chi-square and Kruskal-Wallis.

Results

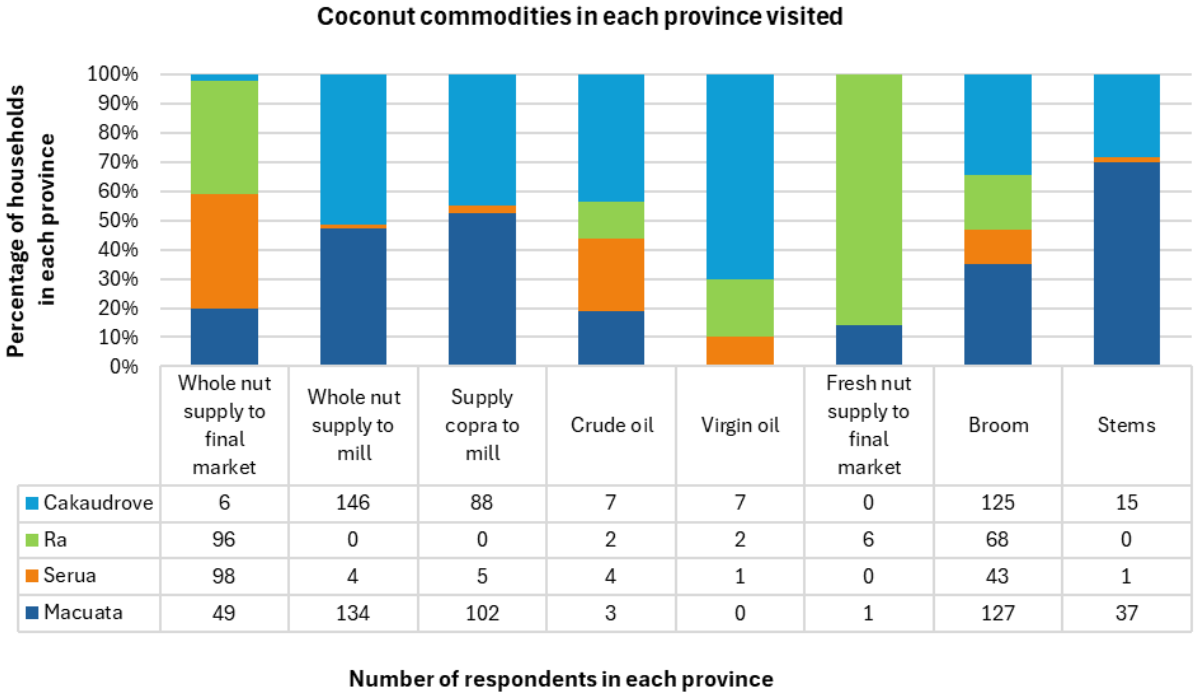
The findings revealed that a vast majority of the households were headed by a male, as indicated in Table 1. The most common family arrangement was nuclear, comprising the parents and the children. Around half of the households in each site had between four to six household members with an exception for Ra where the household size was mainly between one to three members. An average of one person would be engaged in formal work in Serua but not in the other three. This could be mainly due to the geographical location of the sites. Out of the four sites, Serua was the closest to the town centre with accessible roads and consistent transport services throughout the day. There were some chances of household members being involved in casual labour (non-contract basis). A fair number of household members from all the sites have received or were currently receiving formal education at the time of the study. Further, an average of two members in each household were below the age of 18 years, which is within the age group whereby the members were most likely to live with, and thus still depend on, older adults. In the villages visited in Cakaudrove, approximately one member was within the dependency age group of under 18 years.

Eight coconut enterprises were identified from the survey (refer to Figure 1). These enterprises included whole nut supply to final market, whole nut supply to mill, copra supply to the mill, crude oil production, virgin coconut oil (VCO) production, fresh nut supply to final market, broom production, and utilising stems for building construction purposes. The choice of coconut enterprise was determined by various factors of availability of markets, accessibility to the markets, costs and the existence of other income sources. The market in this case referred to either a physical location or an intangible mechanism that enabled the sale of coconuts to buyers – both for final and intermediate goods. In

TABLE 1. Summary of household composition in each study site (by province).

Province	Gender of Head of Household		Family Arrangement (Percentage)			Number of Household Members (Percentage)				Average no. of household members involved in formal work	Average no. of household members involved in informal work	Average no. household members received/ receiving formal education	Average no. household members below 18 years
	Male (%)	Female (%)	Alone (%)	Nuclear (%)	Extended (%)	1 to 3 (%)	4 to 6 (%)	7 to 9 (%)	≥10 (%)				
Cakaudrove	85	15	1	86	13	27	56	15	2	0	0	3	1
Macuata	78	22	1	78	21	28	54	13	5	0	0	3	2
Ra	84	16	5	74	21	47	39	14	0	0	1	3	2
Serua	83	17	0	49	51	21	57	15	7	1	1	4	2

FIGURE 1. Different types of coconut enterprises rural households are involved in.



	Whole nut supply to final market	Whole nut supply to mill	Supply copra to mill	Crude oil	Virgin oil	Fresh nut supply to final market	Broom	Stems
Cakaudrove	6	146	88	7	7	0	125	15
Ra	96	0	0	2	2	6	68	0
Serua	98	4	5	4	1	0	43	1
Macuata	49	134	102	3	0	1	127	37

the case of the sites in Vanua Levu, the mill was the main marketplace that the households supplied whole nuts and copra to. The sites on Viti Levu mainly supplied whole nuts to the municipal market. Coconuts in the latter were either sold to end customers or sold first to market vendors who would then sell the coconuts to end customers. The decision to either sell to vendors or directly to end customers was mainly influenced by the return for efforts. The coconut suppliers in Ra would sell the coconuts to the vendors and then carry out household errands before returning to the village. The limited transportation determined how much time the households could spend in town on each visit. Serua, on the other hand, was a different story: the consistent and frequent transportation services encouraged ease of travel. There were some instances where wholesale buyers would visit the village for the coconuts. This saved the households the trouble of paying for additional transportation to deliver the coconut to the market.

Households could be involved in a maximum of six core coconut enterprises – the most popular being the sale of matured whole kernels to the end market, as indicated in Figure 1. There was also the option of supplying whole kernels or copra (either dry or wet) to the nearest mill – as in the case of the sites in Vanua Levu. The coconut enterprises were mainly marketed as raw product or in semi-processed form. The absence of adequate capital and the labour-intensive nature of production could be two key contributing factors to the nature of coconut production.

Table 2 provides an estimate of the profitability of the coconut commodities identified from the sites visited. The calculations were based on the following: 123 coconut trees in a hectare, producing 6,000 kernels and 3,075 fronds (25 fronds per coconut tree) per hectare annually. Further, the fixed cost was calculated as 5% of total variable cost. The breakdown of costs is further elaborated at the end of this paper; refer to *Appendix 1*. Based on the analysis, the three commodities with

TABLE 2. Cost-effective analysis for coconut commodities.

Commodity	Matured kernels	Green (young) kernels	Wet copra	Dry copra	Virgin oil	Crude oil (homemade)	Broom	Stem
Gross Income (FJD)	1,860.00	12,000.00	1,260.00	1,260.00	6,060.00	3,260.00	15,375.00	1,771.20
Total Variable Cost (FJD)	960.00	160.00	630.00	750.00	2,413.00	2,413.00	12,620.00	3,667.44
Gross Margin (FJD)	900.00	11,840.00	630.00	510.00	3,647.00	847.00	2,755.00	(1,896.24)
Fixed Cost (FJD)	48.00	8.00	31.50	37.50	120.65	120.65	631.00	183.37
Total Cost (FJD)	1,008.00	168.00	661.50	787.50	2,533.65	2,533.65	13,251.00	(1,712.87)
Return for cost (FJD)	1.85	71.43	1.90	1.60	2.39	1.29	1.16	(1.03)
Unit (kernels/ fronds/logs)	6,000 kernels	6,000 kernels	6,000 kernels	6,000 kernels	6,000 kernels	6,000 kernels	3,075 fronds	221 logs
Selling price per unit (FJD)	0.31	2.00	0.21	0.21	1.01	0.54	5.00	8.01
Variable cost per unit (FJD)	0.16	0.03	0.11	0.13	0.40	0.40	4.10	16.59
Breakeven point (kernels/ fronds/ logs)	320 kernels	4 kernels	300 kernels	441 kernels	198 kernels	855 kernels	704 fronds	21 logs

the highest gross margins were young green kernels or coconuts, VCO and brooms. Upon calculating return of cost (ratio of gross income to total cost), it was discovered that green kernels had the highest return, followed by VCO and then wet copra. The breakeven analysis was calculated with the following formula:

$$\frac{\text{fixed cost}}{\text{[selling price per unit-variable cost per unit]}}$$

with each unit referring to kernels or nuts, fronds and logs, respectively. The analysis indicated that green coconuts could operate at a minimum of four kernels to remain viable whereas 300–350 kernels were needed for matured kernels and wet copra. Dry copra required 441 kernels and homemade crude oil required 855 kernels to operate at breakeven. The breakeven point for broom production was 704 coconut fronds (approximately 28 trees).

The figures for coconut stem were based on the possibility of felling senile trees, estimated to be 60% of total trees in one hectare of palms, with 123 trees per hectare (Venn et al., 2023). The variable costs were calculated per cubic-metre (m^3) with one log estimated to constitute 0.118 m^3 and a length of 2.4 metres. A tree was likely to produce a maximum of three logs (0.35 m^3 per tree). The costs and revenue were calculated at farm gate (McGregor and Tawake, 2018). The calculated negative gross margin indicated a loss for rural households. The breakeven point was 21 logs, which is equivalent to felling three senile trees. The breakeven point in this case is preferable for conditions where the costs were either shared or fully covered by the coco wood processor.

A Kruskal-Wallis test was conducted on family arrangement, number of household members and income given the violation of the assumptions for one-way ANOVA. The null hypothesis, H_0 was that there was no difference in the mean income among family

TABLE 3. Number of coconut business enterprises households are involved in.

Number of members in each family arrangement according to number of members in each household	Number of coconut businesses involved in						
	1	2	3	4	5	6	Grand total
Alone	5	2	0	1	0	0	8
1–3	5	2	0	1	0	0	8
Extended	109	14	1	0	0	0	124**
> 10	22	1	0	0	0	0	23**
1–3	14	1	0	0	0	0	15
4–6	50	7	1	0	0	0	58
7–9	23	5	0	0	0	0	28
Nuclear	168	166	36	1	1	1	373**
1–3	73	41	14	0	0	0	128
4–6	78	104	19	1	0	1	203
7–9	17	21	3	0	1	0	42
Grand total	282	182	37	2	1	1	505

** Significant at $p \leq 0.01$

arrangements and among number of household members. The alternative hypothesis, H_A would be accepted if the test was significant at $p \leq 0.05$. There was sufficient statistical evidence to reject H_0 and conclude that a difference exists in the mean income among the family arrangement, $H(41) = 132.62$, $p \leq 0.001$. The pairwise Wilcoxon test indicated significant difference between nuclear arrangement and extended arrangement. There was also sufficient statistical evidence to reject H_0 and conclude that a difference exists in mean income among the number of household members: $H(41) = 87.45$, $p \leq 0.001$. The pairwise Wilcoxon test indicated significant differences for households with more than 10 members and in between households with 1–3 members and 7–9 members (refer to Table 3).

A similar test was conducted with the dependent variable being the number of enterprises households were involved in. There was sufficient statistical evidence to reject the H_0 and conclude that the mean number of enterprises differed among family arrangements [$H(5) = 69.1$, $p \leq 0.001$] and among number of members in a household [$H(5) = 12.86$, $p \leq 0.05$]. A pairwise comparison indicated significant difference between nuclear and extended arrangement. Similarly, a significant difference was evident for households with more than 10 members. Furthermore, households were mostly involved in one form of coconut business (56% of total households) and around 36% were involved in two coconut businesses. There was one household that was involved in a maximum of six coconut enterprises.

The households were mainly reliant on natural resources for food and income security. The survey indicated that coconut barely constituted half (44%) of total household earnings in a week; refer to Figure 2. Further, the income generated from coconut agribusiness could not cover the entire family expenses, with mean expenses of FJD 122.60 exceeding mean coconut income of FJD 99.51 by FJD 23.09. However, it is important to note that although coconut income could not fully meet household expenses, it did provide a safety net. The "fast cash" received from coconut acted as an insurance for households when other forms of income were delayed. A Spearman's test was conducted to examine any correlation between expenses and coconut income. The test was selected because of the non-parametric nature of the data. The result proved significant at $p \leq 0.001$ with a weak positive correlation between expenses and coconut income: rho = 0.3.

The coconut satisfies dietary requirements for households when it is incorporated into meals. The presence of coconut oil and brooms saves households from purchasing these products. Figure 3 presents an estimate of coconut uses in a week for households. An average household collected an average of 285 coconuts in a week – 87% for income generation, 7% for home consumption and the remaining 6% given away for free. Households would occasionally send coconuts to relatives residing in the urban areas – collecting enough nuts to send in one batch to provide sufficient return for efforts of sending coconuts via public transport. Further, an average household would consume 21 coconuts in a week – three nuts in a day and at least one nut in every meal (with three meals in a day for seven days in a week).

There were three main activities identified from the coconut production – collect nuts, prepare nut for final production and delivery of nuts to next selling point, as illustrated in Figure 4. There appeared to be shared responsibilities between males and females among households. However, a chi-square test of independence reported insignificant finding ($p > 0.05$). The null hypothesis was accepted and the conclusion made that there was no relationship between gender involvement and the type of activity in coconut business.

FIGURE 2. Average family expenses and income estimated for a week.

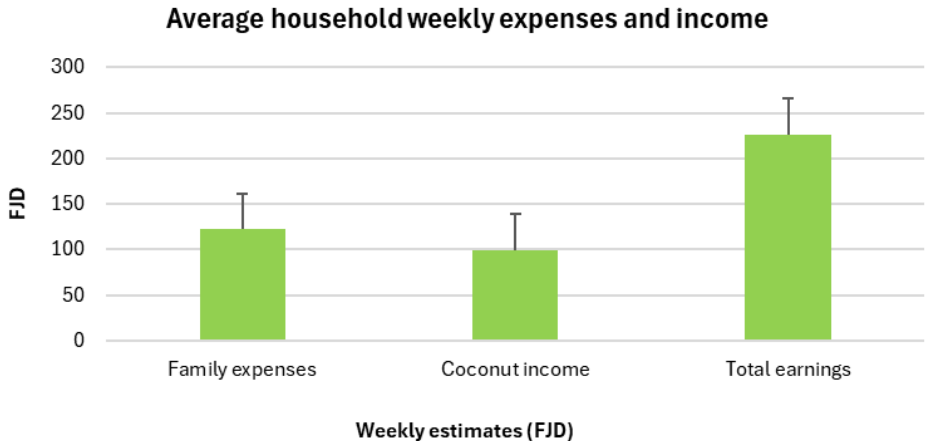


FIGURE 3. Average number of coconuts used by households in a week.

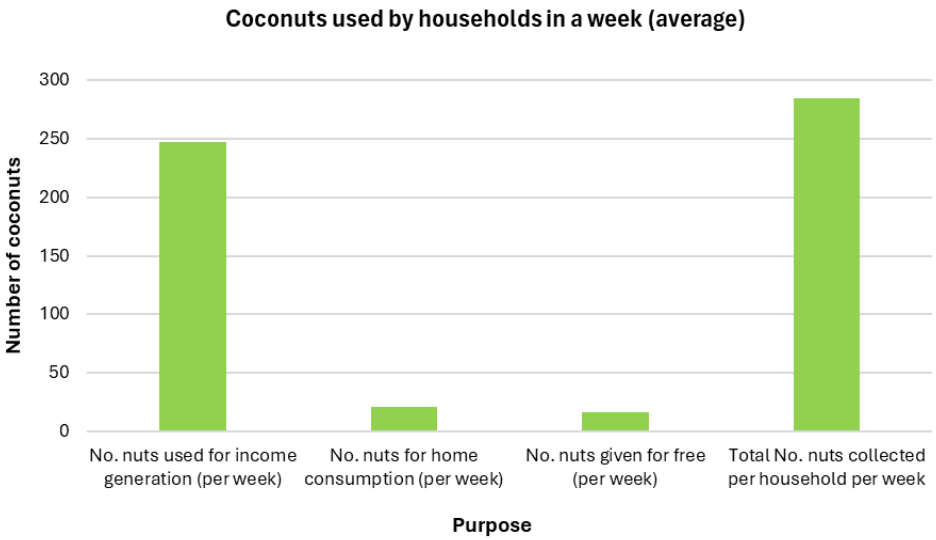
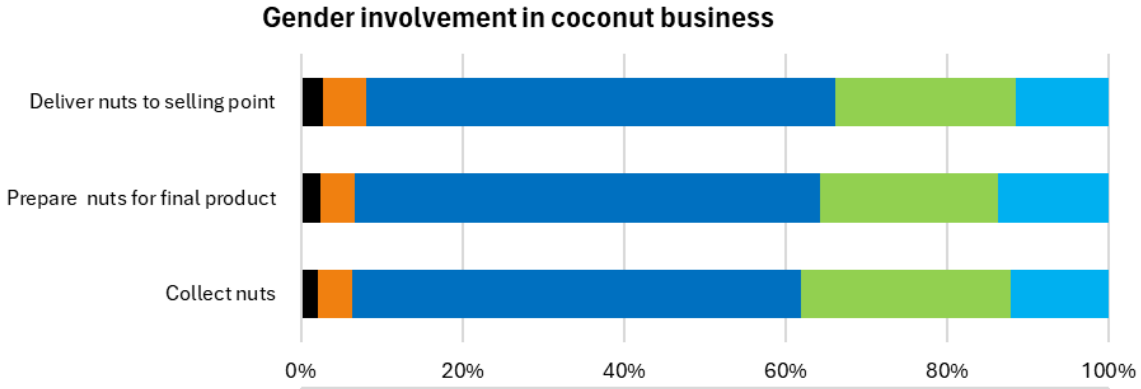


FIGURE 4. Gender participation in household coconut production.



	Collect nuts	Prepare nuts for final product	Deliver nuts to selling point
Female (100%)	11	12	14
Female (75%)	21	22	27
Male & Female (50%)	281	291	293
Male (75%)	131	111	113
Male (100%)	61	69	58

Discussion

The rural community is often challenged by limited economic opportunities. Thus, natural resources primarily contributed to income and food security for households living in rural areas. One such natural resource contributing to wellbeing was the coconut – meeting basic necessities and generating income for households in the rural areas of Fiji. This study was conducted to examine the socioeconomic aspects of coconut livelihood in rural areas in the country. In doing so, three key relationships were examined and documented.

The geographical locations of the sites seemed to influence the socioeconomic aspects of households. Certain aspects of household sizes, arrangement, employment and education were influenced by the distance to the nearest main centres and the availability of essential services such as schools, hospitals and ease of transportation – to name a few. The households were reliant on other income generating opportunities from the sea and land. Sale of root crops, kava, fish and other crustaceans were evident. Informal work existed for the sites but there was limited formal work. The former in this case referred to casual labour that would be demanded when needed. Informal work also included operating community canteens. There were instances where sale turnover and efforts from other activities were delayed due to unforeseen circumstances. For instance, delayed harvest from longer-term crops, unavailable markets, social obligations – among other factors associated with living in rural areas – may contribute to slow income generation from other economic activities. In these cases, the sale of whole nuts at the market and to the mill provided fast cash to sustain households. Households could be involved in a maximum of six different types of coconut enterprises, mainly sold in raw or semi-processed form. Semi-processed coconut enterprises such as copra were converted into final products, mainly by the mill. The sale of whole nuts at municipal markets was also an opportunity for buyers to purchase coconuts as intermediate goods. These intermediate goods could also provide opportunities for downstream production.

The study identified two key factors that could address supply/value chain challenges and strengthen market linkages – efficient transport arrangements and digital marketing. A lesson learnt from Ra province was the surety of sale once the villagers reached the next selling point – whether it was sale to middlemen or directly to the end customer. In the communities visited in Cakaudrove, the delivery truck to the mill should fix days in the week for a specific village. The current challenge in this is that nut collection starts at the furthest village and the collection atthe next village was determined by how many coconuts could fill up the truck in those multiple stops. Nevertheless, certain copra suppliers (wet or dry form) would deliver their product in their personal vehicles – and receive a special pay package from the mill. The key lesson learnt from these experiences was the surety of the sale or high turnover rate from fixed agreement and trust between buyer and seller along the supply chain.

Digital marketing is another avenue that can improve marketing of coconut products – linking the villagers or producers to potential customers via social media. Similar to the efficient sale and delivery arrangement, the trust between customer and seller was crucial in the success of such form of business. The timeliness and quality of products plays an important role in keeping the business functioning. Support services such as reliable mobile networks in remote areas cannot be emphasised enough. Village-based producers can take advantage of the internet bundles available by their mobile providers. Similar bundles exist for telecommunication (SMS and voice plans). However, there remains the need for training on how rural communities could make best use of such opportunities.

Income generated from coconut constituted 44% of household total income – and was unable to meet 100% of household expenses. Nevertheless, the coconut provided insurance for household incomes as highlighted by Nenci et al. (2023) and Vijaykumar (2020). Apart from income security, the coconut also provided food security for households. An average of 21 coconuts consumed per week (seven days) at home meant that on average, households were consuming at least one coconut in every meal. On average, 100 grams of flesh from a matured kernel contained 7.3 grams of dietary fibre (Pacific Community, 2021). Furthermore, the average weight of a dry coconut was 0.98 kg (Varghese et al., 2016). Thus, one coconut consumed per meal would contribute approximately 72 grams of dietary fibre. It was also discovered that coconut income had a positive correlation with expenses – signifying the increased purchasing power of households.

The coconut agribusiness remained labour-intensive and thus provided low return for efforts for households. The labour hours would be divided up among activities that offered more returns in cash and intrinsic benefits to the individual household and the community as a whole. Further, the shared responsibilities and roles between gender emphasised the importance of family labour and collectivism. The strength of the coconut agribusiness was centred on the values, norms, beliefs and customs of the sites visited, as highlighted by Vunibola and Scheyvens (2023). Communal sharing of resources overflowed into the sharing of responsibilities first at the family level and then to the broader community.

Further, young green coconuts sold in raw form summoned higher gross margins. Aside from this, value-added products such as VCO and stem sold at the farm gate for further processing proved viable. Nevertheless, the nature of production meant that the costs were to be shared among the households (through community-based agribusiness) or covered by another intermediate actor in the value chain. The return for efforts, thus remained an important factor in rural agribusiness, specifically in coconut enterprises. Although green coconuts offered higher gross margins compared to matured kernels, they did not possess long shelf life and transporting them to the next market was essential. Broom production although viable remained unsustainable, the reason being that households had to forego kernel production for the palm fronds. The continuous cutting of palm fronds could severely impeded kernel production.

The coconut agribusiness remained underutilised – with more potential to be realised. Research and development might be challenged with the adoption rate by rural households. Further, the absence of markets, inadequate infrastructure, lack of capital (financial, human and physical) hindered household involvement in coconut production. The study offered valuable insight that would be beneficial in reviving the coconut industry, particularly in Fiji. One key finding was that long-term benefits in coconut business needed to be realised and clearly disseminated in the short run for better acceptance of innovation. The households were confident in providing future plans for coconut production within a three-year forecast. However, the level of uncertainty in production and marketing increased as the forecast period was extended. Another key finding was the need for a holistic approach in addressing issues affecting the coconut industry. The approach ought to take advantage of the enabling environment for coconut agribusiness in rural areas in Fiji. Understanding the enabling environment would better inform research and policy development. The three key components of understanding the enabling environment identified from this study were:

i. Acknowledgement of various governing institutions
ii. Sustainable use of resources
iii. Support services throughout the value chain (technical, infrastructure, market access, digital marketing, communication and, research and development).

The adoption of research and acceptance of policies by households, who were target beneficiaries, was crucial as failure to do so would exacerbate issues ailing the coconut industry. Households ought to remain at the core of all activities associated with research innovation in the coconut industry. Rural empowerment is crucial in the adoption of research innovation. This study noted the importance of leadership, capacity building and social capital as forms of empowerment. Firstly, understanding and working with influential individuals representing governing institutions (both informal and formal) in rural settings was vital in carrying out work (Lin et al., 2019, Bryceson and Ross, 2020).

Secondly, capacity building through peer-to-peer learning not only improved knowledge and skills but provided motivation for households. For instance, a training on VCO production, which was facilitated by a VCO entrepreneur was intended for women's associations in rural settings. The main goal was to provide technical and moral support for the women to start their own VCO business. The training was conducted in various rural communities in Fiji. Some of the communities went on to establish their own coconut downstream business. Moreover, social capital was a strength and an opportunity that needed to be tapped into. The communal way of living emphasised shared ownership of natural resources and shared responsibilities in utilising these resources. Such communal ways of life upheld values of kinship, working together (*solesolevaki*), trust and accountability. Understanding these values or social capital was crucial in synthesising research innovation into the local communities across Fiji and across the region.

Conclusion

This study reaffirmed the significant role of the coconut in food and income security in rural areas in Fiji. Although income from coconut may not fully satisfy household expenses, the crop continued to provide insurance against inconsistent income flow from other economic activities that households are involved in. There were eight coconut enterprises or agribusiness discovered in the survey – the majority of the households were involved in at least one enterprise; one household was involved in a maximum of six enterprises. These enterprises were mainly marketed either in raw or semi-processed form. Moreover, coconut agribusiness in the sites visited were mainly labour-intensive and adversely affected by various factors. The lack of market opportunities, inaccessible roads, inadequate infrastructure and lack of capital would hinder household participation in the agribusiness.

There was a need to realise the significance of coconuts to rural communities in the effort to revive the industry. Reviving the coconut industry requires a holistic approach – acknowledging the enabling environment, placing rural households at the centre of research and policy development, optimising leadership in the various governing institutions. The study also highlighted that the coconut agribusiness in rural areas operated in a dynamic environment. Thus, there were various confounding factors that needed to be acknowledged in understanding the socioeconomics of coconut business in such areas. Further research is encouraged to better understand the underlying factors related to, and influenced by, socioeconomic aspects of coconut in rural areas in Fiji and the region.

Acknowledgements

This study was supported by the Australian Centre of International Agricultural Research (ACIAR) through the Pacific Agriculture Scholarships and Support and Climate Resilience Program (PASS-CR). Also, special thanks to Dr Ramona Sulifoa for the guidance received in writing this article.

References

Bennett, J. A. (2018). Pacific Coconut: Comestible, Comfort and Commodity. *The Journal of Pacific History,* 53**,** 353-374.

Bryson, K. P. & Ross, A. (2020). Habitus of informality in small scale society agrifood chains - filling the knowledge gap using a socio-culturally focused value chain analysis tool. *Journal of the Asia Pacific economy,* 25**,** 545-570.

Heince & Sofilda, E. (2024). Impact of sustainable intensification of coconut toward women farmer's empowerment in Sarmi Papua. *American Journal of Economic and Management Business,* 3**,** 242-253.

Kumar, M. B. & Kunhamu, T. K. (2022). Nature-based solutions in agriculture: A review of the coconut (Cocos nucifera L.)-based farming systems in Kerala, "the Land of Coconut Trees". *Nature-Based Solutions,* 2**,** 100012.

Lin, J. (2020). *The role of institutions on modern agricultural value chains.* PhD Dissertation, Georg-August University.

Lin, J., Bourdeix, R. & Alasia, J. P. (2021). Investment in Coconut Research and Replanting. *Coconut Risk Management and Mitigation Manual for the Pacific Region.* Suva, Fiji: Pacific Community.

Lin, J., Flachsbarth, I. & Cramon-Taubadel, S. V. (2019). The role of institutional quality on the performance in the export of coconut products. *International Studies of Economics,* 51**,** 237-258.

McGregor, A. & Tawake, S. (2018). The Coco Veneer Value Chain: the Fiji case study. Suva, Fiji: Pacific Community.

Ministry of Agriculture. (2021). Volume I: General Table & Descriptive Analysis Report. *2020 Fiji Agriculture Census.* Suva, Fiji: Ministry of Agriculture Fiji.

Nenci, S., Pietrobelli, C., De Angelis, M. & Manson, H. (2023). Coconut productivity in the Caribbean: Relational value chains in traditional farming. Kiel, Hamburg.

Nor, A. A. M., Arrif, E. E. E., Omar, N. R. N., Abidin, A. Z. Z., Muhammad, R. M., Rahim, H., Nazmi, M. S. & Sulaiman, N. H. (2020). Total productivity and technical efficiency of coconuts in Malaysia. *Economic and Technology Management Review,* 15**,** 11-22.

Pacific Community. (2021). There is 7.3 grams of dietary fibre in 100g of coconut flesh. *Stat of the week* [Online]. Available from: https://www.spc.int/updates/blog/did-you-know/2021/08/stat-of-the-week-there-is-73-grams-of-dietary-fibre-in-100g-of [Accessed 24 January 2024].

Varghese, A., K, F. & Jacob, J. (2016). A study of physical and mechanical properties of the Indian coconut for efficient dehusking. *Journal of Natural Fibers,* 14**,** 1-10.

Venn, T. J., Dorries, J. W. & McGavin, R. L. (2023). Financial and Economic Modelling Report 6: Fijian application of the 'Forest to Mill' Module for the mathematical programming model to support engineered wood product manufacturing decisions. Canberra: Australian Centre for International Agricultural Research.

Vijayakumar, A. (2020). Coconut farmer producer organisation in socio-economic transformation of rural economy in Karnataka. *International Journal of Agricultural Resources, Governance and Ecology,* 16**,** 301-319.

Vijayakumar, A. N. (2020). Coconut farmer producer organisation in socio-economic transformation of rural economy in Karnataka. *International Journal of Agricultural Resources, Governance and Ecology,* 16.

Vunibola, S. & Scheyvens, R. (2023). Strategies for success of indigenous businesses on customary land: case studies of three Itaukei (indigenous Fijian) enterprises. *AlterNative: An International Journal of Indigenous Peoples,* 19**,** 646-655.

Zainol, F. A., Arumugam, N., Daud, W. N. W., Suhaimi, N. A. M., Ishola, B. D., Ishak, A. Z. & Afthanorhan, A. (2023). Coconut Value Chain Analysis: A Systematic Review. *Agriculture,* 13**,** 1379.

Appendix 1

Gross margin analysis for matured whole nuts or kernels

GROSS MARGIN OF 6,000 HUSKED COCONUTS				
Husked nuts from own plantation at farm gate sales				
Details	**Unit**	**Amount**	**Rate (FJD)**	**Total (FJD)**
Sale of coconut (husked)	no.	6000	$0.30	$1,800.00
Husks*	no.	6000	$0.01	$60.00
Gross income				**$1,860.00**
Expenditure				
Variable costs				
Collection	man-days	4	$20.00	$80.00
Husking	man-days	40	$20.00	$800.00
Marketing	man-days	4	$20.00	$80.00
Total variable costs				**$960.00**
Gross margin				**$900.00**
*Opportunity costs of coconut husks				

Gross margin analysis for green (young) nuts or kernels

GROSS MARGIN OF 6,000 GREEN COCONUTS				
Green nuts from own plantation at farm gate sales				
Details	**Unit**	**Amount**	**Rate (FJD)**	**Total (FJD)**
Sale of coconut (husked)	no.	6000	$2.00	$12,000.00
Gross income				**$12,000.00**
Expenditure				
Variable costs				
Collection	man-days	8	$20.00	$160.00
Marketing	man-days	4	$20.00	$80.00
Total variable costs				$240.00
Gross margin				**$11,760.00**

Gross margin analysis for wet copra

COCONUT GROSS MARGIN – WET (GREEN) COPRA EQUIVALENT				
Using traditional farming systems at minimal input at 123 plants per hectare				
INCOME	**UNIT**	**AMOUNT**	**RATE (FJD)**	**TOTAL (FJD)**
Coconuts	no.	6000		
Copra dry	tonne	1	1200	$1,200.00
Husks*	no.	6000	0.01	$60.00
Shells	no.			
Leaves	no.			
TOTAL				**$1,260.00**
VARIABLE COSTS				
Labour				
Clearing of weeds	times	4	100	$400.00
Collecting of nuts	person-days	4	15	$60.00
Cutting of coconuts and de-flesh	person-days	4	15	$60.00
Bagging of Copra	person-days	1	15	$15.00
Other Costs				$0.00
Empty bags	no.	24	1	$24.00
Miscellaneous Costs				$71.00
TOTAL VARIABLE COSTS				**$630.00**
GROSS MARGIN				**$630.00**

Gross margin analysis for dry copra

COCONUT GROSS MARGIN - DRY COPRA EQUIVALENT				
Using traditional farming systems at minimal input at 123 plants per hectare				
INCOME	**UNIT**	**AMOUNT**	**RATE (FJD)**	**TOTAL (FJD)**
Coconuts	no.	6000		
Copra dry	tonne	1	1200	$1,200.00
Husks*	no.	6000	0.01	$60.00
Shells	no.			
Leaves	no.			
TOTAL				**$1,260.00**
VARIABLE COSTS				
Labour				
Clearing of weeds	times	4	100	$400.00
Collecting of nuts	man-days	4	15	$60.00
Cutting of coconuts and de-flesh	man-days	4	15	$60.00
Firewood cutting and collection	man-days	2	15	$30.00
Fireman costs	man-days	4	15	$60.00
Cartage of firewood & husks to drier	man-days	1	15	$15.00
Turning of copra after 2 days	man-days	1	15	$15.00
Bagging of copra	man-days	1	15	$15.00
Other costs				$0.00
Empty bags	no.	24	1	$24.00
Miscellaneous costs				$71.00
TOTAL VARIABLE COSTS				**$750.00**
GROSS MARGIN				**$510.00**

Gross margin analysis for VCO

GROSS MARGIN OF VCO 6,000 HUSKED COCONUTS				
Manual VCO production from own plantation				
Details	Unit	Amount	Rate (FJD, $)	Total (FJD,$)
Sale of VCO	litres	400	$10.00	$4,000.00
Husks*	no	6000	$0.01	$60.00
Shell*	no	12000	$0.01	$120.00
Coconut crude oil	litres	100	$3.00	$300.00
Coconut meal	kg	520	$0.75	$390.00
Gross income				**$4,060.00**
Expenditure				
Variable costs				
Collection	man-days	4	$20.00	$80.00
Husking	man-days	40	$20.00	$800.00
Scraping	man-days	15	$20.00	$300.00
Pressing & coco meal prep	man-days	15	$20.00	$300.00
Harvesting & filtering	man-days	15	$20.00	$300.00
Drying	man-days	15	$20.00	$300.00
Bottling & labelling	man-days	2	$20.00	$40.00
Empty bottles – 1 Litre	no	400	$0.45	$180.00
Label	no	400	$0.05	$20.00
Empty bags	no.	13	$1.00	$13.00
Marketing	man-days	4	$20.00	$80.00
Total variable costs				**$2,413.00**
Gross margin				**$1,647.00**
*Opportunity costs of coconut husks				

Gross margin analysis for homemade crude oil

GROSS MARGIN OF CRUDE OIL 6,000 HUSKED COCONUTS				
Homemade crude oil production from own plantation				
Details	Unit	Amount	Rate (FJD)	Total (FJD)
Sale of crude oil	litres	400	$8.00	$3,200.00
Husks*	no	6000	$0.01	$60.00
Shell*	no	12000	$0.01	$120.00
Coconut meal	kg	520	$0.75	$390.00
Gross income				**$3,260.00**
Expenditure				
Variable costs				
Collection	man-days	4	$20.00	$80.00
Husking	man-days	40	$20.00	$800.00
Scraping	man-days	15	$20.00	$300.00
Pressing & coco meal prep	man-days	15	$20.00	$300.00
Harvesting & filtering	man-days	15	$20.00	$300.00
Cooking	man-days	15	$20.00	$300.00
Bottling & labelling	man-days	2	$20.00	$40.00
Empty bottles – 1 Litre	no	400	$0.45	$180.00
Label	no	400	$0.05	$20.00
Empty bags	no.	13	$1.00	$13.00
Marketing	man-days	4	$20.00	$80.00
Total variable costs				**$2,413.00**
Gross margin				**$847.00**
*Opportunity costs of coconut husks				

Gross margin analysis for brooms

GROSS MARGIN OF BROOMS				
Brooms from own plantation at farm gate sales				
Details	**Unit**	**Amount**	**Rate (FJD)**	**Total (FJD)**
Sale of broom	no	3075	$5.00	$15,375.00
Gross income				**$15,375.00**
Expenditure				
Variable costs				
Collection	man-days	8	$20.00	$160.00
Broom preparation	man-days	4	$20.00	$80.00
Coconut coir (tie)	metres	6150	2	$12,300.00
Marketing	man-days	4	$20.00	$80.00
Total variable costs				**$12,620.00**
Gross margin				**$2,755.00**

Gross margin analysis for coconut stems (logs)

GROSS MARGIN OF COCONUT LOGS				
Coconut logs from senile trees (own plantation) at farm gate sales				
Details	**Unit**	**Amount**	**Rate (FJD)**	**Total (FJD)**
Sale of coconut logs	logs	221	$8.00	$1,771.20
Gross income				**$1,771.20**
Expenditure				
Variable costs				
Cut, snig and load	m^3	26	$100.00	$2,619.60
Transport cost	m^3	26	$40.00	$1,047.84
Total variable costs				**$3,667.44**
Gross margin				**-$1,896.24**

Produced by the Pacific Community (SPC)
Suva Regional Office
Private Mail Bag Suva, Fiji
+679 337 0733 spc@spc.int | spc.int