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SPC Land Resources Division

TARO BEETLE MANAGEMENT IN PAPUA NEW GUINEA AND FIJI

FINAL PROJECT REPORT

(ACIAR PROJECT NUMBER CS2/2000/044)

Compiled by:

Sada N. Lal

SPC Land Resources Division

Contributors:

J. Moxon, M. L. Autar, R. J. Milner, D. Hunter, S. Hazelman, F. Atumurirava, K. Kurika and T. Vasuidreketi

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Secretariat of the Pacific Community
BP D5 98848 Noumea Cedex, New Caledonia
Tel: +687 26 2000 Fax: +687 26 3818
Web: http://www.spc.int

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1 EXECUTIVE SUMMARY

The Australian Centre for International Agricultural Research (ACIAR) funded a six-year project for the management of taro beetle in Papua New Guinea (PNG) and Fiji. The Secretariat of the Pacific Community (SPC) was commissioned to lead the project. SPC also used funds from the European Union's project on 'Plant Protection in the Pacific' to extend its activities to Kiribati, New Caledonia, Solomon Islands and Vanuatu, which also faced taro beetle problems.

The project ran from January 2002 to December 2007 and comprised four years of laboratory and field research and two years of participatory research. It succeeded in finding methods to control taro beetle, a serious pest of taro, which is a staple Pacific food crop. Recommendations for control of taro beetle, and packages of best practices for taro management were developed and transferred to Pacific Island growers, who previously had no suitable methods for controlling the pest. The achievements of the programme are particularly notable given many earlier but unsuccessful attempts to develop control methods for taro beetle.

In the two ACIAR project countries, taro beetle was causing losses of up to 30% of the yields which amounted to AUD 40 million per year in PNG (Gaupu et al 1992) whilst in Fiji research field losses showed yield losses of up to 33% amounting to AUD 10-12 million. In Fiji, commercial growing of export quality taro had to be shifted to the outer islands, resulting in increased production costs and transportation problems. In PNG, taro growing was only possible on new areas of land opened up by clearing virgin forest. In Vanuatu and Solomon Islands, it was virtually impossible to grow taro without beetle damage.

The objective of the Taro Beetle Management (TBM) project was to develop environmentally sustainable taro beetle management practices that could be incorporated in cropping systems and to transfer these to taro growers in the Pacific Islands. The desired outcomes were to increase production, thus restoring the supply of a major staple food, and to raise the economic value of taro through improving its quality.

In the first four years of the project, extensive laboratory and field experiments were conducted to evaluate bioagents and insecticides. Potential bioagents and insecticides were selected from the Pacific Regional Agriculture Project, which had conducted initial studies but had not obtained conclusive results.

In this project, studies found that the fungus *Metarhizium anisopliae* (Ma) when applied to soil in taro planting holes gave about a 30% marketable yield of taro corms. Although beetle mortality rates due to Ma infection were high, the infected beetles took some time to die. As a result, damage to corms still occurred. Applying the insecticide, imidacloprid, to soil in planting holes at the time of planting and three months after planting resulted in marketable yields of up to 90%. Bifenthrin applied in the same way as imidacloprid gave similar results. Imidacloprid used in low dosages with Ma also gave good control of beetles, but not as high as when used alone. Residue analysis showed no trace of bifenthrin in harvested taro corms, while imidacloprid was recorded at below maximum residue levels (MRL) in harvested corms.

Using the results of the first four years work, recommendations were drawn up for safe use, dosages, frequency and methods of application of the selected insecticides, imidacloprid and bifenthrin. These recommendations, and other taro growing practices, were demonstrated to taro growers in farmer field schools (FFS) in PNG, Fiji, Vanuatu and Solomon Islands. The synergistic use of low dosages of imidacloprid with Ma was also demonstrated to taro growers. In addition, TBM packages were developed and launched at field days in PNG, Fiji and Vanuatu.

The results of the project have increased the confidence of taro-growing communities in PNG, Fiji, Vanuatu and Solomon Islands. There has been a rise in sales of the recommended insecticides and an increase in taro production in beetle-infested areas. Growing taro on flat land and repeated planting are now possible, which reduces the need to clear virgin forest for taro plantations. High-quality taro can be produced for food and as a cash crop with higher returns for growers.

1.1 Future work

The project has developed effective methods of controlling taro beetle, but reliance on insecticides may not be a long-term solution for this very persistent pest. There is also the problem of resistance developing. Research into better management of taro beetles must therefore continue. There is a need to evaluate the effectiveness of new insecticides with lower environmental impacts and to study the use of pheromones. Pheromones can play a vital role in dissemination of the *Oryctes virus*, an important pathogen of the beetle. Laboratory studies have shown that the virus is very effective in controlling taro beetle and could be particularly useful in breeding grounds that are difficult to access. Evaluations of locally available, plant-derived pesticides should also be pursued. It is believed that before the advent of pesticides, taro farmers used plant extracts to manage taro beetles in their plantations. Cultural practices used by farmers could be harnessed and combined with modern pest control approaches to develop holistic pest management practices for taro growers.

2 INTRODUCTION

Taro, *Colocasia esculenta (*L.), belongs to the family Aracaceae and is cultivated along with several other edible species in the genera *Colocasia*, *Xanthosoma, Alocasia, Cyrtosperma* and *Amorphophallus*. *Colocasia* is the most widely cultivated aroid, a root crop grown throughout the tropics and in most Pacific Island countries and territories.

Taro has great ceremonial and cultural significance in the Pacific region. Giving and sharing taro when visiting relatives or holding a feast is an important social obligation. In parts of some Pacific Islands, taro is usually included in the 'bride price' or payment made to the bride's family to compensate for the loss of her presence and loss of her contribution to the household when she marries. Special varieties of taro are grown for such occasions. Taro is also widely used to barter for fish or other products not readily available to the farmer.

Some countries, notably Fiji, Tonga, Niue and Cook Islands, also export taro to New Zealand and Australia. In PNG, it is a staple food in the lowland and intermediate altitude areas where rainfall is well distributed throughout the year. Taro is a livelihood earner for many Pacific Islanders and contributes greatly to national economies. In Fiji, taro known as 'dalo' is a major agricultural export. The main markets are Australia and New Zealand, where it is sought by Pacific Island communities. These exports are worth AUD $25 million–$30 million per year.

2.1 The taro beetle pest

Taro beetles, *Papuana* and *Eucopidocaulus* species (Coleoptera: Scarabaeidae), are important pests of taro in the South Pacific (Thistleton 1984; Macfarlane 1987; Waterhouse and Norris 1987). Most species of taro beetle belong to the genus *Papuana*. Of the 19 known species (Endrodi 1971, 1985), eight are recorded as major pests of taro. In addition, another species, *Eucopidocaulus tridentipes* (previously *Papuana tridentipes*) has recently also been shown to be a major pest of taro. The beetles are native to the Indo-Pacific Region with 14 of the 19 species occurring on the island of New Guinea (Endrodi 1971, 1985).

The beetles are the main constraint to improving the yield and quality of taro production in PNG, Solomon Islands and Vanuatu. Repeated taro growing in the same field is not possible in these countries and as a result, forest areas are cleared for new plantings. Taro fields therefore tend to be in isolated bush areas, a long way from dwellings, which causes considerable hardship to taro farmers. Over the years, this has led to less interest in taro growing and a shift in dietary habits. In Fiji, taro beetle resulted in production of export taro being shifted to the island of Taveuni. The taro beetle is therefore of great concern to affected countries.

2.1.1 Host plants

The main host plants of adult beetles are aroids of the genera *Colocasia*, *Alocasia, Xanthosoma, Cyrtosperma, Amorphophallus*, banana *Musa* spp. and the ferns *Angiopteris* spp. and *Marattia* spp. Taro beetles can also infest sweet potato (*Ipomoea batatas)*, Irish potato (*Solanum tuberosum)*, yams (*Dioscorea* spp.), sugarcane (*Saccharum officinarum)*, pineapple (*Ananas comosus)*, peanuts (*Arachis hypogea),* cocoa (*Theobroma cacao),* coffee *(Coffea arabica)*, betel nut *(Areca catechu),* coconut *(Cocos nucifera),* oil palm *(Elaeis guineensis),* tea (*Camellia sinensis)*, *Crinium* spp., wandering jew (*Commelina diffusa)* and Pandanus (*Pandanus odoratissimus*) (Thistleton 1984, Macfarlane 1987, Sar et al. 1990, Thistleton et al. 2001). The wide host range of adult beetles enables them to survive in the wild when *C. esculenta* and other cultivated aroids are not available.

2.1.2 Damage

Adult taro beetles burrow into the corms of taro and other aroids, making smooth-sided tunnels of the same width as the beetles. In severely damaged plants, the tunnels run together to form large cavities and secondary rots often develop. Damage to other root crops such as sweet potato, yam and potato takes a similar form. When populations are high, the beetles move into the taro gardens at an early stage and subsequent feeding at the base of plants leads to wilting and plant death. Plant death can also occur in newly planted taro, while plant vigor and growth is retarded in established plants. The beetles rarely feed on corms exposed above the soil. Severely damaged taro is unmarketable. No damage is tolerated for export markets. Damage to other commercial crops, such as sweet potato and yam, is relatively low. The beetles occasionally ringbark young tea, cocoa and coffee plants in the field and bore into seedlings of oil palm and coconut. This does not cause any major problem but may set back plant growth.

2.1.3 Description, biology and life cycle of taro beetles

The biology and ecology of taro beetles, and control using pathogens, chemicals and cultural means were studied by the EU/SPC TBM project. These studies and their results have been presented in a number of papers and reports (Aloali'i et al. 1993; Anon. 1991–2000a, b, 1996, 1997a, b; Beaudoin 1992; Jackson 1997; Jackson and Masamdu 1998; Jackson and Richards 2000; Masamdu 2000; Masamdu in press a, b, c; Masamdu et al. 2000; Penney 1992; Richards et al. 1999; Simbiken in prep.; Taisau in prep.; Theunis 1997a, b, c, d, e, 1998; Theunis and Aloali'i 1997, 1998, 1999; Theunis and Simbiken 1997; Theunis and Teuriaria 1998; Theunis et al. 1993, 1997a, b, c; Thistleton 1995a, b; Thistleton and Masamdu 1996, 1997; Thistleton et al. 1993, 1995).

The adult beetles are black to dark coloured with miniature single horns like that of the rhinoceros beetle, or sometimes two horns. The female beetles lay eggs in debris of decaying organic matter such as heaps of animal dung, chicken manure, rotten grass and wood, crop refuse, kitchen refuse, sawdust, etc. Previous studies on taro beetle (Perry 1977) and coconut rhinoceros beetle (Bedford 1974) have used a 1:1 mixture of cow dung and sawdust for culturing larvae. Cultures were used by the EU/SPC project to study the taro beetle life cycle. The eggs when freshly laid are white and oval shaped, changing to off-white during the incubation period of about 2 weeks. The larvae are translucent on hatching and become the colour of the surrounding debris as they start feeding. The first instars take about 2 weeks before moulting into second instars – a period lasting up to 4–5 weeks. The third and final instars last for up to 3–4 months. The larvae are found in the curled 'C' shape typical of Scarabaeidae. Fully grown larvae turn into pre-pupae and to pupae by making pupal chambers in the breeding places. Upon emergence, the adult beetles are light brown with soft elytra. The elytron hardens within 1–2 weeks when they glide to feeding places and for mating at dusk. Males are usually territorial and stay within the host plant for a long period. After mating, the females glide to nearby breeding places for egg laying. The total life-cycle takes from 17 to 28 weeks depending on temperature, moisture and abundance of organic matter. For *Papuana uninodis* there is a 4–6 week pre-oviposition period, after which around 140 eggs are laid over a period of 27 weeks. Adults live for up to 22 months. The life cycle of this species lasted for 19 weeks in the laboratory in Solomon Islands. This compares with other studies on *P. uninodis* in Fiji (22–25 weeks; Autar and Singh 1988), and *P. huebneri* and *P. woodlarkiana* in PNG (20 and 28 weeks respectively; Perry 1977).

2.2 Control of taro beetle

Previously, control measures for taro beetle were based on the use of chemicals. However, due to the soil-dwelling habits of the pest, the insecticides that give effective control are often persistent organochlorine compounds, such as lindane, which are no longer considered acceptable due to their long-term environmental effects. Indeed, in many areas, e.g. Australia (Rath 1992) and Europe (Zimmerman 1992), environmental concerns over residues and toxicity have led to deregistration of so many chemicals that Jackson et al. (1992) reported that at that time there were no registered chemicals for the control of scarabs. While newer products (e.g. slow release granules of less persistent chemicals) are filling this gap, there has also been much interest in finding biological control methods for a range of scarabs worldwide. In almost all cases, these methods rely on the use of pathogens.

There have been few parasites and predators recorded. Barrett (1966) recorded a scoliid wasp, while Perry (1977) and Thistleton (1984) recorded a Tachinidae (*Formosia* sp.) from *P. woodlarkiana* in Rabaul and Mt Hagen respectively. The EU/SPC project found two tachinid parasites (Diptera: Tachinidae), *Formosia solomonicola* Baranov, from *P. uninodis* and *P. huebneri*, and *Formosia* sp. nov. near, *complicate* Walker, from *P. uninodis.* A scoliid wasp (Hymenoptera: Scoliidae), *Austrocolia nitida punctassima* (Kirby) was recorded from *P. huebneri* in Solomon Islands and *Palpastoma* sp. was recorded from *P. woodlarkiana* larvae at Ramu Sugar Estate, PNG.

A natural parasitism rate of 2% by *P. solomonicola* on *P. uninodis* breeding in *Saccharum* stumps along a riverbank near Aoela, Guadalcanal, Solomon Islands, was recorded. In artificially created breeding sites consisting of logs placed around taro plots at a field experimental station at Ringi, 17% parasitism was recorded on larvae of *P. huebneri*. An increase in pupal numbers of *A. nitida punctassima* at Ringi was evident during sampling in the artificially created breeding sites (Thistleton 1995). Pippet (1975) recorded the cane toad *Bufo marinus* feeding on scarab beetles and the EU/SPC project recorded predation on *Papuana* sp. in Solomon Islands and PNG. Rats feed on larvae in sugarcane trash in PNG. Pigs also dig around in beetle breeding sites and feed on the larvae.

Around the world, there is great emphasis on development of control methods for scarabs using pathogens and there have been a series of international workshops on this topic (Jackson and Glare 1992, 1996; Jackson and 0'Callaghan 1998). Projects involve control of sugarcane white grub (Australia and Zimbabwe), grass grub (New Zealand), white grub on corn (Mexico), Melanesian rhinoceros beetle (PNG), common cockchafer (several countries in Europe), Japanese beetle (USA) and turf grass pests (Canada) using viruses, fungi, bacteria and entomopathogenic nematodes sometimes integrated with the use of pheromones and insecticides (Garcia-Martinez et al. 2000; Jackson et al. 1992; Karunakar et al. 2000; Klein 1992, 2000; Ruiz et al. 2000; Najera-Rincon et al. 2000; Mazodze and Zvoutete 2000; Milner 1992; Milner and Samson 2000; Simard et al. 2000; Villalobos 2000; Villalobos et al. 2000, Wahid et al. 2000; Zimmerman 1992). A newsletter (Scarab Biocontrol News) is also produced and a Scarab Biocontrol Network has been formed.

2.2.1 Viruses

Oryctes virus (OrV) was originally isolated from *Oryctes rhinoceros* in Malaysia, (Huger 1966). Later it was also found in the Philippines and Indonesia (Zelazny 1977). The virus was successfully introduced into the South Pacific as a biological control agent for *Oryctes rhinoceros* (Bedford 1986). In the 1970s, following many years of research and introductions of biocontrol agents (Waterhouse and Norris 1987), *Oryctes rhinoceros* was successfully brought under control in several Pacific Island countries using OrV (Bedford 1980, 1986; Young 1986). Tests with this virus in Fiji on *Papuana uninodis* gave positive results (Zelazny et al. 1988).

The EU/SPC project confirmed in laboratory tests that several strains of OrV killed both adults and larvae of taro beetle, but dead insects often did not exhibit the symptoms found in *Oryctes rhinoceros*. In early releases in Solomon Islands, it was difficult to diagnose infected beetles, but in later releases, a PCR technique (Richards et al. 1999) was used to detect the presence of virus in the beetles. This indicated that that there was rapid adult-to-adult transmission but low persistence of the virus.

2.2.2 Fungi

The fungi *Metarhizium anisopliae* and *Beauveria* spp. are important pathogens of scarabs; *M. anisopliae* has been described from over 200 species of insects including at least 70 Scarabaeidae (Veen 1986). *Metarhizium anisopliae* var. *anisopliae* was the only pathogen mentioned in association with *Papuana* spp. by Shaw (1984) and Prior (1986). It has been used successfully in Brazil to control spittlebugs on sugar cane (Ferron 1981), and recently against scarabs in pasture and sugarcane (Rath 1992; Milner 1992). The long-spored variety, *M. anisopliae* var. *major,* is used in parts of the Pacific and South-East Asia, together with a baculovirus, for control of the coconut pest, *Oryctes rhinoceros*.

Several studies have shown that *M. anisopliae* can remain infective in soil for well over one year and some strains can grow saprophytically in soil. (Latch and Falloon 1976; Milner and Lutton 1976, Muller-Kogler and Stein 1976; Rath 1992). *Beauveria* conidia do not survive as long in soil (Muller-Kogler and Stein 1976) but Gotwald and Tedders (1983) consider *B. bassiana* superior to *M. anisopliae* because of higher pathogenicity, higher spore production and the ability to grow saprophytically through soil.

In Australia, *M. anisopliae* strains from the redheaded pasture cockchafer *Adoryphorus couloni* (Rath 1992) and from greyback canegrub *Dermolepida albohirtum* (Milner 1992; Milner and Samson 2000) are now available as commercial products (BioGreen™ and BioCane™, respectively), and another strain for control of Negatoria cane grub *Lepidiota negatoria* has also been selected for commercial development (Milner and Samson 2000). In India, *M. anisopliae, B. brongniartii* and *B. bassiana* are used for the control of white grubs (*Holotrichia* sp. and *Leucopholis* sp.) (Yadava and Chandrika 1992; Shashi et al. 2000), and *M. anisopliae* is a candidate for control of sugarcane grubs in Zimbabwe (Mazodze and Zvoutete 2000) and in peanuts in Burma (Milner et al. 1992).

The EU/SPC project selected a highly virulent strain of the fungus (Theunis and Aloali'i 1998) using a four-tiered bioassay system from laboratory screening to field trials (Theunis 1997a). Theunis (1997b) gives details of techniques and media for isolation, culture, storage and bioassay of *Metarhizium* and *Beauveria*.

2.2.3 Bacteria

Bacteria are important biocontrol agents for insects. *Bacillus thuringiensis* and *Paenibacillus* (previously *Bacillus*) *popilliae*, both spore formers, have been used for decades in biological control. Recently, *Serratia entomophila* has been developed as a control agent for *Costelytra zealandica* (Jackson et al. 1992) and produced as a commercial product (Invade™). *P. popilliae* has been isolated from at least 29 species of scarab (Klein and Jackson 1992) and has been reported causing epizootics in *Popillia japonica*, *Cyclocephala parallela* and *C. zealandica* (Klein 1992). The EU/SPC project discovered several strains of *P. popilliae* from taro beetles in PNG and Solomon Islands (Theunis and Simbiken 1997; Theunis and Aloali'i 1999) and field tested the use of *P. popilliae* in PNG and Solomon Islands. It has also been introduced into Kiribati (Theunis and Teuriaria 1998). Theunis (1997c) gives techniques and media for diagnosis, isolation, culture, storage and bioassay of *B. popilliae*, *B. thuringiensis* and *Serratia* sp.

2.2.4 Nematodes

Nematodes (steinernematids and heterorhabditids) have been found to be effective biocontrol agents for larvae of scarabs (Klein 1990; Poinar and O'Callaghan 1992). Most effective against taro beetles was a strain of *Steinernema glasseri.* However, the method was not found to be suitable for use in the field as the nematodes did not establish in a field trial against adult beetles (Theunis et al. 1996) and it would also be difficult to introduce them into beetle breeding habitats. Theunis (1997d) gives techniques and media for isolation, culture, storage, mounting and bioassay of entomopathogenic steinernematid and heterorhabditid nematodes.

2.2.5 Lure, infect and disperse method

If an attractant for taro beetles is discovered, a lure, infect and disperse system could be used for disseminating the pathogens (Jackson and O'Callaghan 1998; Klein 2000; Klein and Lacey 1999; Vega et al. 2000).

2.2.6 Cultural and physical methods

Cultural techniques used by farmers in PNG, Solomon Islands and Vanuatu differ considerably. They include manipulating planting time, flooding gardens, keeping taro gardens free of weeds, manipulating planting depth, mixed cropping, planting new gardens further away from old gardens, applying wood ash, crop rotation, planting repellent plants, hand collecting adult beetles, and slashing and burning vegetation. However, the only method found to give good control of the beetle was planting taro away from old gardens in bush locations. The EU/SPC project evaluated potentially resistant or tolerant taro cultivars, but no suitable varieties were identified.

2.2.7 Chemical control of taro beetles

Since the first record of the taro beetle in Fiji in 1984, studies have been carried out by the Ministry of Agriculture to evaluate suitable insecticides. The EU/SPC project later assisted with these studies and extended the work to PNG and Solomon Islands.

Prior to the EU/SPC project, chemical control was obtained with the use of persistent and toxic organochlorine insecticides such as 6% Lindane (Gamma BHC). However, the control levels were variable. This insecticide was later banned and so was not available for commercial use.

Initiation of insecticide evaluation experiments by the EU/SPC project identified imidacloprid as a promising insecticide against the beetle in Fiji. Although experimental results were not conclusive, in the first year of field experiments, harvested yields of taro corms in Vanuatu clearly indicated the effectiveness of imidacloprid. In the second year of field experiments, bifenthrin was included in trials in PNG and Fiji. It proved to be as effective as imidacloprid against the beetle in the field. In subsequent years of field experiments, the two insecticides were tested for appropriate dosages and frequency of application. Both are now recommended for use against the beetle, bringing relief to taro growers in their fight against this menace.

3 OBJECTIVES OF TBM PROJECT

To develop and promote taro beetle management packages in sustainable farming systems in PNG and Fiji for commercial, semi-commercial and subsistence farmers.

The project aimed to develop at least one technique that would reduce taro beetle damage in farmers' fields and would be suitable for integration into a sustainable IPM (integrated pest management) system adapted to local conditions.

Previous research had identified several options with the potential to become efficient control methods:

- *Metarhizium anisopliae* had been shown to be effective to some extent in the field.
- Taro beetles were easily infected with *Oryctes virus* in the laboratory and when released, they transmitted the virus to other taro beetles.
- Formulations of chlorpyriphos and imidacloprid reduced taro beetle damage in the field.

This project aimed to further develop these control options, especially through:

- improving the effectiveness of *M. anisopliae* applications by conducting trials to establish optimal dosage and timing;
- developing a cost-effective local production technique for *M. anisopliae*;
- improving the effectiveness of *O. virus* by trialing different dosages to increasing its persistence in field beetle populations;
- assessing the effect of *O. virus* in reducing taro beetle damage;
- evaluating effective insecticides and their application in taro plantations;
- conducting pesticide residue analysis for identified insecticides on harvested taro corms.

The output table at the end of this section shows in more detail how these objectives were undertaken. The continuation of research on one component depended on the success of the previous step, with the emphasis shifting to components that showed the most promise.

Since taro beetle species vary between countries, it was also necessary to conduct trials of the same control option in several countries.

The risk of low adoption of the final product was reduced by the project's participatory approach, which meant that stakeholders were involved during the trial period.

4 METHODOLOGY

4.1 Feasibility of biocontrol using Metarhizium anisopliae

The EU/SPC taro beetle project demonstrated that certain strains of *M. anisopliae* (Ma) – especially TB 101 – resulted in high mortality of both adults and larvae in the laboratory and in field trials. To test Ma on a larger scale, two options were used. Ma was applied directly to taro fields to protect the crop and indirectly to other host plants and breeding habitats within the surrounds of plantations to decrease the total population.

4.1.1 Application of Ma to taro fields to provide direct crop protection

In earlier trials, Ma killed adult beetles throughout the growing period of the crop, but the death rate was too slow to reduce damage to corms. However, trials in PNG showed a statistically significant reduction in damage.

Field experiments using standard experimental designs with sufficient replications and large enough plots to give meaningful results were conducted. Ma was applied at various rates and treatments were monitored at different stages of the crop in these large plots. Damage was assessed according to two methods. The first gave an estimate of the amount of corm lost to beetle damage. Each corm was weighed and a visual assessment made of the percentage of the corm removed. This allowed calculation of the weight of the corm removed and the weight the corm would have been had it not been damaged. The second method was an assessment of quality on a scale of 0–4:

0	no damage
1	damaged but saleable
2	damaged, not saleable but edible
3	damaged, not saleable, not edible, but fit for animal consumption
4	damaged, completely riddled, unfit for even animal consumption

Populations of adult beetles were recorded at harvest and beetles were brought to the laboratory to assess rates of infection by Ma.

Laboratory-cultured Ma at 0, 10, 50 and 150 g per planting hole at the time of planting was tested in replicated field experiments at Bubia, Situm and Keravat. The trial was progressively harvested and evaluated.

4.1.2 Application of Ma to other host plants and breeding habitats

The use of *Ma* in breeding habitats and on other host plants was assessed for its effectiveness in reducing overall beetle populations and migration of beetles to taro crops.

As the aim was to achieve population reduction by applying Ma to a range of adult and larval breeding habitats in the wider area, the use of standard replicated experimental designs for these trials was less appropriate. The success of the interventions was therefore assessed by comparing pest populations and crop damage before and after release of the agent, or between areas where the agent had been released and areas where it was not present.

The previous project collected a large amount of baseline information on populations of both taro beetle adults and larvae and damage levels over a number of years. These data were based on counts of adults from taro fields and of larvae from various habitats using 0.25 m^2 and 1 m^2 quadrants, and mark/recapture data over several years. The Ringi Field Experiment Station had high beetle populations and damage levels and the previous project had collected extensive data on this over several years. Ringi was therefore one of the sites chosen for the Ma releases.

The following possibilities were considered in conducting the Ma trials:

- Taro beetle breeding sites and adult habitats are often widespread, making it difficult to apply Ma to a high proportion of these habitats. However, artificial breeding habitats established near taro fields had comparatively high numbers of larvae. Adults could be similarly attracted to trap crops.
- Application of Ma to breeding habitats could give direct control of larvae, while application to trap crops would kill adults. Some adults could be killed in the trap crop before they could breed; others might migrate to the breeding habitat but also carry the Ma and kill any larvae there.
- Since taro is one of the beetle's most attractive adult host plants, application of Ma to plots of taro in the area would give direct protection and reduce populations.

Adult and larval beetle populations were monitored using the sampling techniques developed by the EU/SPC project, including mark/recapture methods. Taro plots were established at intervals in the trial areas to monitor fluctuations in damage. The persistence of Ma was estimated by assessing the proportion of infected beetles in samples and by caging fresh adults and larvae at release sites.

4.1.3 Ma strain from PNG highlands

Jackson (1997) reported widespread occurrence of Ma in the PNG highlands. The highland strain appeared to be highly pathogenic to taro beetle larvae in feeding tests. There also seemed to be a different mode of sporulation between Ma from the highlands and lowlands.

A survey was conducted in the highlands of PNG and samples of suspected Ma-infected beetles (adults and larvae) were collected. Ma from these collections was labeled as FI-1472. The lowland Ma strain in PNG is TB 101. The highlands have much lower temperatures than the lowlands in PNG. Bioassays were conducted on mortality and infection rates and compared with those resulting from the lowland strain, TB 101. Field studies were also carried out.

4.1.4 Development of low-cost production method for Ma

All isolates of *Metarhizium* can be produced on simple substrates. The main requirements are a source of utilisable carbohydrate, some protein, trace elements, moisture and air exchange as well as maintenance of an aseptic environment. Temperature is also very important, with most isolates producing an optimum number of conidia at 28^{o}C and few conidia above 30^{o}C or below about 22^{o}C. The ratio of carbohydrate to protein is important, as is the moisture content. Adequate aeration is essential. In practice, rice (human food-type, long-grain) seems to have the necessary nutrients (7% protein) and can be moistened so that it retains a loose structure, thereby allowing good aeration. Experience has shown that different isolates of *Metarhizium* may require different conditions in terms of moisture and nutrients added to the rice. In many countries, rice is expensive and this is often used to justify the use of other substrates. However, before this is accepted, consideration needs to be given to the cost of the rice as a proportion of the total cost of production and the reduction in yield when using other substrates. For this reason, the initial aim of the project was to optimise production on rice and then to test other cheaper substrates to see if they could be used to lower production costs.

During the first year of the project, mass production was done in the participating countries using the existing methodology, while, research on production was undertaken in Canberra with the aim of optimising a system that could be readily transferred to the countries. For example, existing methods for substrate sterilisation in Australia are gamma radiation or autoclaving. These were not available in participating countries, but CSIRO devised a novel chemical sterilisation method that could be used instead.

The production process developed by CSIRO is as follows:

- The initial culture is in the form of a sporulating colony on an agar plate, or an aseptic vial of viable conidia.
- A shake flask of a sugar/yeast medium is inoculated in a laminar flow cabinet and the mycelium is grown for about 5 days.

- 2 kg of long-grain rice is placed in a self-aerating, autoclavable, clear plastic bag (Unicorn Bags Texas USA) and 500 ml water added. The bag is heat-sealed and autoclaved.
- After autoclaving and when cool, a corner is cut off the bag in a laminar flow cabinet and the flask inoculum of mycelium is added, together with additional water and nutrients (if needed). The bag is re-sealed.
- The bags are incubated at 25°C for about 2 weeks. The rice is massaged every couple of days initially to prevent caking during the mycelial growth phase.
- The bags are placed in a drying room at 30°C and 20–30% RH, cut open and left to air dry for 7 days. When dry, the conidia are removed by sieving in an electric reciprocating sieve.
- The conidia can then be stored, formulated in talc as a dust or formulated in water or oil for spraying.

It may be that (as with BioCane) the rice/conidia mixture could be used directly without drying. Research was needed to test various formulations and application strategies to ensure the most efficient use of the *Metarhizium* conidia.

After perfecting the methodology for mass production of Ma, the technology was transferred to participating countries from year 2 of the project onwards.

4.2 Feasibility of biocontrol with Oryctes virus

In 1998, beetles were artificially infected with *Oryctes virus* (OrV) and released once at three sites in Solomon Islands and one site in PNG. A newly developed PCR technique was used to check adult and larval samples for infection with OrV. After three months, a large proportion of beetles in all Solomon Islands sites were infected, which indicated rapid adult-to-adult transmission of the virus. The alternative proposition – that the released, infected beetles made up a considerable proportion of the total population – was disproved as all released beetles had been marked and no marked beetles were recovered. However, six months after the release, the virus was recovered from only one site.

There were plans to repeat the release to see if more frequent releases increased the persistence of the virus and if reductions in damage and populations occurred. The following methodology was planned (and is reported here for information purposes):

- The beetles required for an initial infection in the laboratory will be bought from villagers. This method is more efficient than labour intensive breeding of beetles in the laboratory.

- Beetles will be infected using simple feeding or swim techniques and marked. The mark could be a simple 'X', a notch on the elytra or a specific number if more detailed monitoring is required. That way, artificially infected beetles can be recognised in later samples from the field.

- Then the beetles will be released in taro plots and surrounding areas, preferably under various environmental conditions. Since the aim will be to achieve a reduction in the pest population in the release area, the importance of selecting sites with good baseline data is also relevant here.

- Artificial breeding sites will be established around the taro plots. These will increase the chance of transmission to larvae and allow the monitoring of trends in larval populations.

- At intervals, samples of adults and larvae will be collected, dissected and sent to CSIRO. Fluctuations of the population and damage levels will be assessed. Samples will also be taken from natural breeding habitats in the area.

- CSIRO will improve the currently used PCR technique and diagnose the sent specimens for infection with OrV.

- Beetles infected with high dosages of OrV can die within a week. In the laboratory, different dosages

should be tested to find a rate that maximises the life span of infected beetles and thus also the number of – still deadly – virus transmissions in the field. There may also be differences between virus strains. Cage trials could be carried out to investigate field transmission from adults to larvae.

- A separately funded project will be looking for attractants of taro beetles. If the project is successful, the above investigations will also provide data on the usefulness of the virus in a lure/infect/release system.

- Even if the virus does not persist in the field but significantly reduces damage, the simple infection technique and low costs involved could justify simple releases in areas with high pest populations as a temporary control measure.

- Technology transfer will start in year 3 but will mainly take place in year 4 of the project, focusing on station a staff that has the skills to infect and release beetles.

However, due to lack of resources, the planned virus activities were not carried out. Only testing of the virus infection on field-collected beetles using PCR was carried out.

4.3 Chemical control

In Fiji, the methods used to conduct research on chemical control were based on the understanding gained from previous local work and the EU/SPC project. The main objectives of the research were to evaluate the effectiveness of insecticides that were cost effective and environmentally safe to use in Pacific Island situations.

Initially, laboratory and field experiments were conducted in Fiji and Vanuatu to select the most promising insecticides. The field experiments were repeated in PNG. Once the selection of the insecticides had been narrowed down to imidacloprid and bifenthrin, laboratory and field experiments were conducted on dosages and frequency of applications. All experiments were designed and replicated to suit the conditions of the experimental sites. At harvest, samples were collected from different treatments for pesticide residue analysis. In the last two years of the project, field trials were also conducted in the Solomon Islands to demonstrate the effectiveness of imidacloprid and bifenthrin.

At harvest, the taro corms were rated. The number and weight of corms harvested from each plot were recorded and the corms were then grouped, according to severity of damage (SOD), into five levels using a scale of 0 to 4:

0 no damage
1 damaged but saleable
2 damaged, not saleable but edible
3 damaged, not saleable, not edible but fit for animal consumption
4 damaged, completely riddled, unfit even for animal consumption

The five levels were collapsed in two ways: number and weight of corms per plot suitable for the export market –level 0; and number and weight of corms per plot suitable for the local market – combination of levels 0 and 1. The total number and weight of corms per plot combined all five levels.

The yield of marketable corms was also costed out against inputs, specifically insecticide costs.

The recommended usage of the insecticides was demonstrated to taro growers by forming farmer field schools in taro growing areas in PNG, Fiji and Vanuatu.

PROJECT ACHIEVEMENTS AGAINST ACTIVITIES AND OUTPUTS/ MILESTONES

Sub-project: Increasing the effectiveness of Metarhizium anisopliae (Ma).

Objective 1: To increase large-scale taro beetle control using Ma.

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1	Ma applications to field scale (rates/times/strains)	Large-scale trial results from different ecological regions in PNG and Fiji.	December 2004	Field trials with Ma strain TB 101 with rates of 0, 2, 10, 50 and 150 g/planting hole were conducted at different locations in PNG and Fiji. Rates of 10 g and above gave 30% yield of marketable corms at trial sites.
1.2	MA applications to modified breeding sites (rates/ times/strains/ sites)	Large-scale trial results from range of modified cropping habitats.	December 2005	Laboratory-cultured Ma strain TB 101 was seeded in artificial breeding sites in taro plots. No conclusive result was obtained from these trials because not enough beetles were attracted to the breeding sites.
1.3	Develop low-cost production method	Production method at a reasonable cost	December 2005	Ma can be cheaply produced on rice and chemically sterilised by sodium meta-bisulphate.
1.4	Adapt low cost production of Ma in PI	Cost effective local production	December 2005	Local skills in low-cost production of Ma developed in PI. However, not very practical for farmers as process still requires a laboratory.

PI = Pacific Islands

Sub-project: Increasing the effectiveness of OrV in PNG to enhance transmission in the field.

Objective 2: To enhance transmission of OrV in PNG.

No.	Activity	Outputs/ milestones	Completion date	Comments
2.1	PNG refines infection and release technique on reared taro beetle	Taro beetles infected/ released with different dosages (small scale)	December 2004	Attempt was made to infect beetles and release them in field, but no results could be obtained.
2.2	CSIRO tests new improved PCR methods for detection	Improved methodology	December 2004	Taro beetles were infected and sent to AgResearch for PCR studies. No conclusive results could be obtained.
2.3	Small and large-scale trials of infected beetles	Rates/extent of transmission and persistence data in large trials/different sites	Not pursued	Virus collection and production was difficult; therefore, this work was not pursued.

Sub-project: Pesticide control measures for sustainable management of taro beetle in PNG and Fiji.

Objective 3: To develop application rates for IPM compatible insecticides.

No.	Activity	Outputs/ milestones	Completion date	Comments
2.1	Select suitable insecticides. (chlorpyriphos, imidacloprid, others)	Data on reduction of corm damages and rates of insecticides; cost effectiveness; pesticides registered	December 2005	Assistance was provided to PI for registration of recommended insecticides imidacloprid and bifenthrin on dosages, frequency of application, safety and production of labels.
2.2	Trials on application techniques	Appropriate techniques for PI	December 2005	Use of the recommended insecticides was demonstrated to taro growers in modified farmer field schools set up in taro growing areas of PI.
2.3	Residue analysis	Residue levels and persistence in soil taro at different rates	December 2005	Residue analysis was conducted from samples of harvested taro for the 2 recommended insecticides.

Sub-project: Synergy between insecticides and biocontrol agents

Objective 4: To shift the population balance to biocontrol agents.

No.	Activity	outputs/ milestones	completion date	Comments
2.1	Combinations of Ma and low insecticide rates	Corm damage data from insecticide rates and Ma rates in infestation sites and breeding habitats	December 2006	Several trials were conducted with low dosages of imidacloprid and Ma. imidacloprid at .75 ml/litre of water applied with 10 g of Ma yielded over 80% of marketable corms. Work on low dosages of imidacloprid with Ma could not be pursued.

PI = Pacific Islands

Sub-project: Participatory implementation of integrated taro beetle management in sustainable cropping systems.

Objective 2: To develop IPM packages for taro growers.

No.	Activity	Outputs/ milestones	Completion date	Comments
2.1	Develop extension materials/methods for participatory transfer of Ma production to PI	Materials/methods for implementation of field-scale mass production of Ma and adoption by taro farmers	December 2004	Hands-on training and a regional training workshop were held on Ma production procedures. Ma can be cheaply produced on rice with chemical sterilisation. However, this is only possible in PI with laboratory facilities. Adoption of the technology by farmers is still not possible.
2.2	Develop means for transfer of skills to taro growers on use of recommended insecticides	Participatory methods/materials for safe and effective use of pesticides by taro growers.	December 2007	Application of the recommended insecticides was demonstrated to taro growers in several locations in PNG, Fiji, Vanuatu and Solomon Islands in modified farmer field schools.
2.3	Develop with target groups means to transfer *OrV*, Ma or Ma x recommended insecticides in taro IPM systems	Means of transfer of skills to taro community as a practical component of applied IPM of taro	December 2007	Use of Ma, and Ma with low dosages of imidacloprid was demonstrated to taro growers in modified farmer field schools.

RESULTS AND DISCUSSION

Use of MA on taro

5.1.1 MA field trial 1

Field experiments carried out in PNG at Bubia, Situm and Keravat showed that at Keravat, a 150 g dosage of the fungus produced significantly ($P < 0.05$) more marketable corms than the 50 g dosage, untreated control and use of chlorpyriphos insecticide. However, this high percentage was not significantly ($P > 0.05$) different from the 10 g dosage of the fungus (Table 1). Ma (10 g) and Ma (150 g) produced significantly more exportable corms and higher corm weight than the no-treatment control at all three sites. It therefore gave a degree of control. At Bubia and Situm, this was around 30% but less at Keravat. Ma was effective on both species of taro beetle – *P. huebneri* and *P. woodlarkiana* – and in two different islands with respect to these two parameters. Thus, the technology may also be applicable to other countries. There were no significant differences between sites for export corm number and weight. Severity of damage was significant at Bubia and Situm but not at Keravat. There were no significant interactions between the experimental treatments and sites for corm weight and exportable corm number.

Two different experimental methodologies were tested in two PNG provinces. In the two trials at Lae (Bubia and Situm), the treatments and trial reps were planted close to each other, whilst at Keravat they were separated from each other by some 60 meters. This was done to determine if treatment plots that were close together would have interference due to the high mobility of the beetles (walking or flying). That is, would beetles subjected to one treatment move to and damage taro in another nearby treatment and so distort the results. Damage produced in the trials at Lae was significantly different for the Ma treatments (as compared with the control) but not at Keravat. That is, the Ma seemed to be more effective at Lae than at Keravat. This is believed to be largely due to differences in the experimental design. This result supports the theory on male /female feeding and mating behaviour detailed below and presents opportunities for control strategies. It is recommended, therefore, that for further Ma and chemical rate trials, treatments should be at one location to minimise site variability. As the lowest rate Ma (10 g) treatment worked, any further trial perhaps should examine rates lower than 10 g.

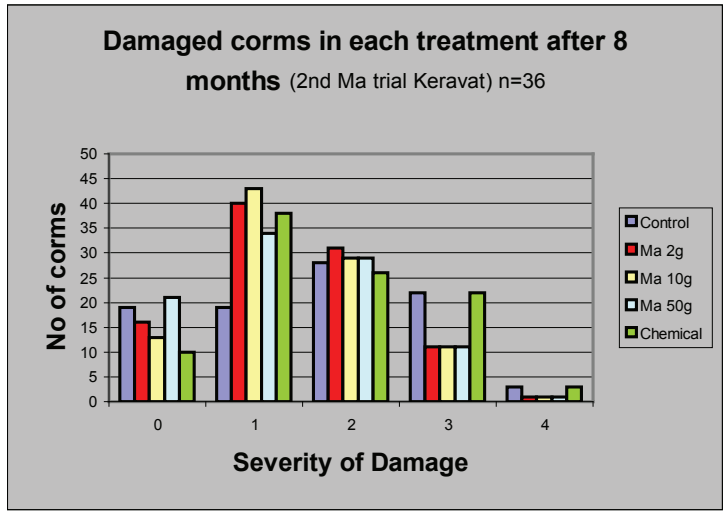
Table 1: Mean (%) marketable numbers and weights of taro corms as affected by the experimental treatments in each of the three sites – Bubia, Situm and Keravat.

Treatment	% exportable number			% exportable weight		
	Bubia	Situm	Keravat	Bubia	Situm	Keravat
Control	124a[1]	39a	35b	28.7a	36.2a	35.6a
Chlorpyriphos	72a	85a	40b	70.5a	84.1a	43.6a
10 g *M. anisopliae*	72a	89a	61ab	77.4a	90.3a	59.4a
50 g *M. anisopliae*	48a	59a	46b	45.4a	58.4a	45.1a
150 g *M. anisopliae*	70a	87a	67a	71.3a	89.0a	66.9a
300 g *M. anisopliae*	54a	-	-	58.1a	-	-
F-ratio	1.19	2.51	3.90	1.03	3.00	2.85
Probability (P)	0.361	0.097	0.030	0.433	0.063	0.071

[1] Means in the same column followed by the same letter are not different ($P > 0.05$) using an LSD value.

5.1.2 Ma field trial 2 (Keravat)

Trial 1 was subject to a severe drought, which adversely affected the taro plants. Trial 2 was therefore conducted to repeat Trial 1 and check the results (Fig. 1). It followed the same experimental design but the Ma rates were changed. The trial treatments were Ma 2 g, Ma 10 g, Ma 50 g, chlorpyriphos (standard) and the control. The trial was planted in August 2003 and harvested in April 2004.



Dead corms were invariably due to severe taro beetle damage and thus were counted as SOD 4. , which increased the control treatment count a little. As in Field Trial 1 at Keravat, neither the Ma nor Chorpyriphos are protectinged taro well at any application rate. ,This further indicating Ma's limitations when applied as a single application.

5.1.3 Ring test

Two strains of Ma were collected in PNG. They were FI 1452 (the standard) and FI 1472, which was collected from the PNG highlands.

An experiment was done to determine the rate of decline of Ma (conidia) of each strain in the top soil (volcanic derived) under natural conditions over a one-year period at Keravat. Annual rainfall at Lae, Keravat, is around 3,000 mm/per annum with an average temperature of about 31°C. Ma solution was mixed with soil and placed into 16 plastic rings for each Ma strain. Four rings (replicates) for each strain were dug up and Ma conidia counted every three months. The experiment showed that the highland strain deteriorated more quickly than the lowland strain, FI 1452.

5.1.4 Bioassay

Bioassay experiments carried out in PNG on two species of taro beetle (*P. woodlarkiana* and *P. huebneri*) showed that both Ma strains (TB 101 and FI 1452) killed both sexes of both species of the beetle. FI 452 was better on *P. huebneri* at a lower rate but not on *P. woodlarkiana*. As expected, the higher doses killed more quickly and resulted in the greatest mortality (Fig. 2). At Bubia, the top three doses (equivalent to 100, 10 and 1 g per taro plant) gave over 75% mortality after 5 weeks, while the fungus caused very little mortality at the lowest two doses. In contrast, at Keravat, only the two highest doses gave over 50% mortality after 5 weeks. Mortality at the higher doses commenced after 7 days at Bubia but not until after 14 days at Keravat. The more rapid effect seen at Bubia was also enhanced by the high proportion of beetles that stopped feeding prior to death. For example, at doses 1, 2 and 3 almost all the beetles were either dead or had stopped feeding by day 21, while at Keravat over half the beetles were both alive and feeding on day 21 (Fig. 3). Most of the dead beetles at Bubia sporulated, while less than half of the beetles killed by the fungus at Keravat sporulated (Fig. 4).

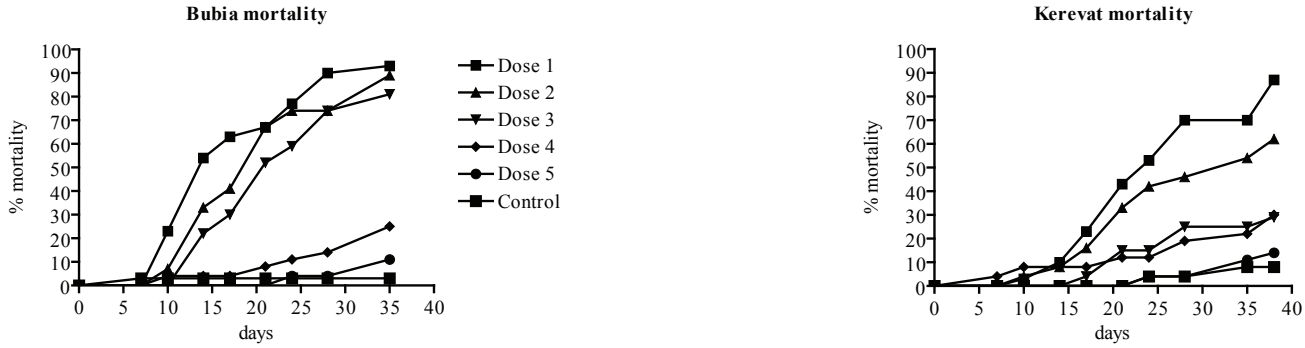


Figure 2. Effect of dose (Ma) and time on mortality of taro beetles.

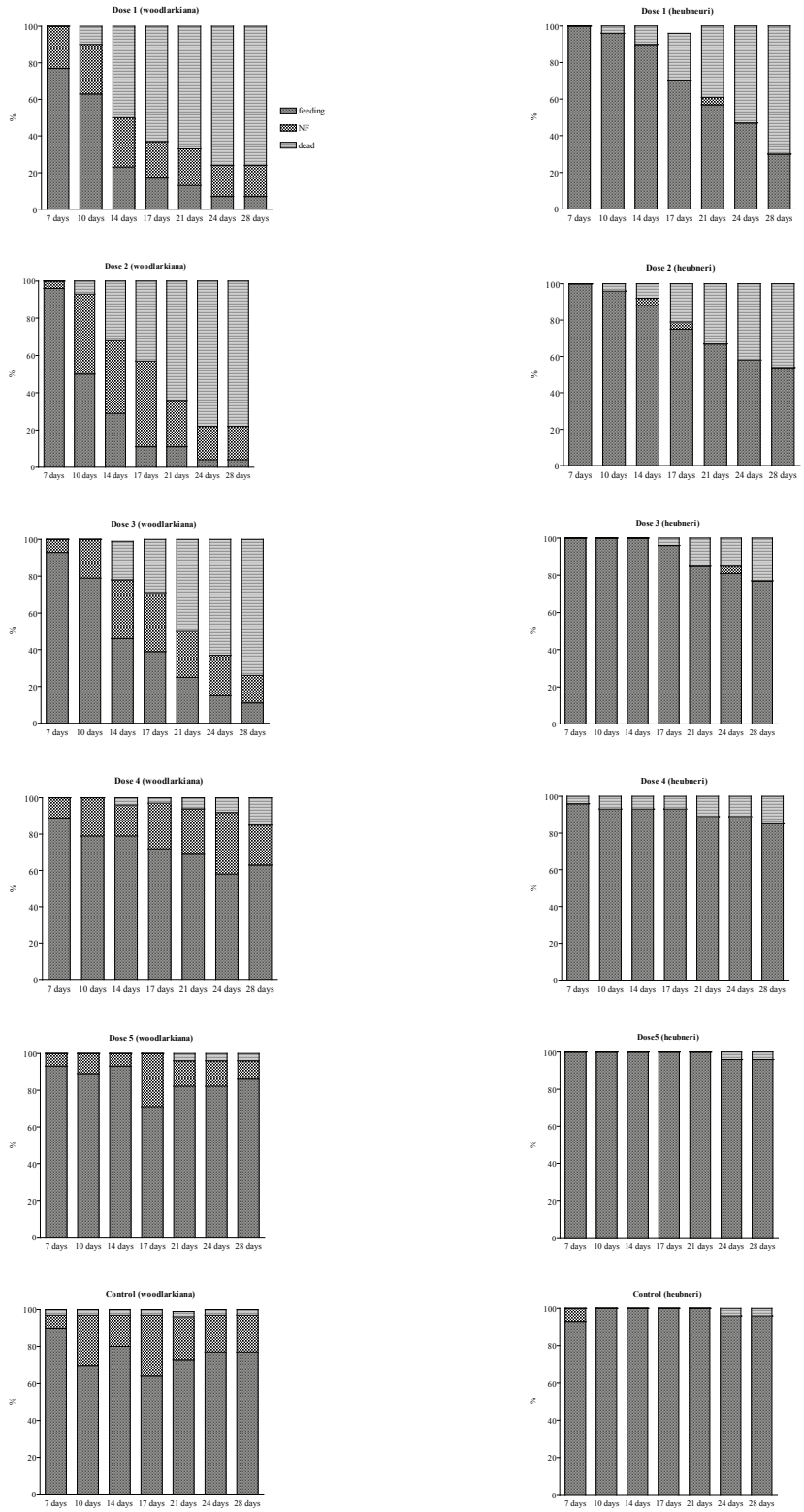


Figure 3. Effect of dose (MA) and time on the proportion of taro beetles feeding, not feeding or dead.

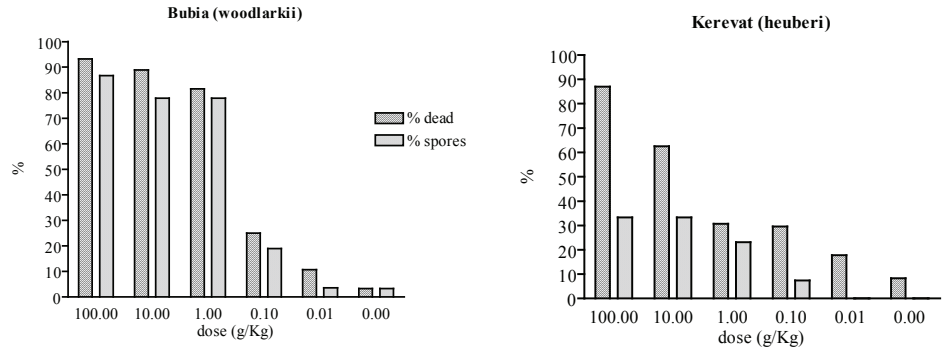


Figure 4. Effect of dose (Ma) on final percentage mortality and proportion of beetles sporulating.

Probit analysis (Table 2) of the results confirmed that the Keravat beetles were significantly less susceptible than those at Bubia.

Table 2: Probit analysis of the results of the bioassay of taro beetles.

Species	LD_{50} (95% confidence limits) in g /kg at 21 days	LD_{50} (95% confidence limits) in g /kg at 28 days	Common slope $\pm$ standard error
w*oodlarkiana* (Bubia)	6.3 (1.7 – 26.4)	0.32 (0.08 – 1.27)	0.63 ± 0.56
huebneri (Keravat)	61.9 (14.3 – 367.0)	3.54 (0.70 – 17.42)	

This analysis suggests that the beetles at Bubia were about 10 fold more susceptible. The data on sporulation confirmed that the TB 101 (FI 1452) strain of the fungus was better adapted to killing P woodlarkiana (which it was isolated from) than P. huebneri. It seems to be a general rule that isolates of Metarhizium are more pathogenic and best adapted to the original host from which they were isolated, than to other hosts, even when the other hosts are closely related. Nevertheless, this result needs to be confirmed by further bioassays.

These results show the importance of undertaking detailed laboratory bioassays of the different species and local races of the beetle as a guide to field trials, as failure in a field trial may be due to the innate susceptibility to this particular isolate rather than to problems with the quality of the material used in the field trial or the application methods.

5.1.5 Low-cost Ma production

The protocol for mass spore production using autoclave or oven methods was followed and shown to work well in both PNG and Fiji. The technique has been mastered by technicians and successful Ma cultures now can be produced without difficulty. Where autoclaving is not available, an alternative method using sodium metabisulphite is used for sterilisation of the culture media

5.1.6 Storage of Ma

Milner et al. (1992) showed that addition of Benlate (a fungicide) to the medium inhibited germ tube growth but not the germination viability of FI 1452.

This method was therefore tested on a batch of rice-produced conidia and found to give 98–100% germination after 48 hrs. The standard method had given germinations of 75-80% on these conidia. The main steps in this new method are as follows:

1. Use thin plates of SDA with 0.001% Benlate added before autoclaving.

2. Mix 1 g rice/conidia mixture with 100 ml 0.1% Tween 80. Shake well (resulting suspension should be just discoloured green; if darker, dilute further).

3. Place a small droplet on to the agar and press a large cover slip (22 x 50 mm) over it to spread the droplet out.

4. Incubate for 48 hrs at 25°C and check germination at x 400 (ideally with phase contrast). Count 100 conidia on transects. Germination is a visible germ tube.

The new method was tested on a range of rice/conidia batches stored at 4°C for various periods of time (Fig. 5). Stored conidia gave significantly higher rates of germination with this method.

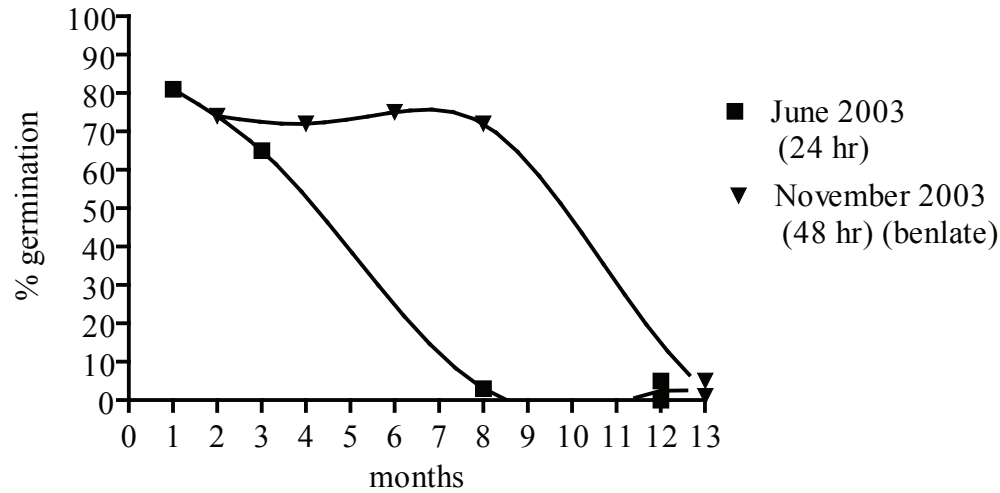


Figure 5. Storage of FI-1452 on rice at 4°C: effect of time on storage as assessed by a 24 hr germination test compared with a 48 hr germination test.

The graph based on a 48 hr germination test suggests that the conidia can in fact be stored for about 10 months without significant loss of viability compared with about 3 months as previously determined. However, the stored conidia are much slower to germinate and this may be reflected in a loss of pathogenicity. To maximise the chances of success in field trials, it is suggested that the material is used as soon as possible and certainly not stored for longer than 6 months in the fridge.

5.2 Oryctes virus

An experiment was conducted to determine the pathogenicity of the virus collected from a naturally occurring population of the Dynastid beetle, *Oryctes rhinoceros*, on taro beetle *P. huebneri* adults at NARI, Keravat. DNA in the beetle specimens could not be detected due to an improper preservation method. The experiment was repeated and specimens sent to AgResearch, Lincoln, New Zealand. Virus was detected in most of the specimens. No further work on the virus was pursued.

5.3 Insecticides

5.3.1 Testing of potential insecticides and two rates of MA

At harvest, the highest total corm weights were detected in taro plants receiving 5 g Confidor and 1-% v/v chlorpyriphos insecticides, with the lowest observed in untreated plants (control), and those receiving 0.027-% v/v Ascend and 10 g of the TB 101 strain of Ma (Table 3). However, the differences between these treatments were not significant ($P > 0.05$), as indicated by the computed F value from the ANOVA.

Table 3: Total yield of corms (in kg/plot) as affected by the experimental treatments evaluated in the Vanuatu field trial.

Treatment	Total yield of corms Kg/plot
Untreated control	52.98a[1]
5 g Suscon blu /plant	56.52a
5 g Grubguard/plant	57.60a
1-% v/v chlorpyriphos	64.78a
5 g Confidor/plant	67.35a
0.027-% v/v Ascend	52.05a
10 g TB101 strain of Ma/plant	52.53a
50 g TB101 strain of Ma/plant	61.15a
Error df	21
F value	0.49
Probability of F	> 0.05
S.E.M.	8.270
Coefficient of variation (%)	29

[1]Means with the same letter(s) are not different at $P = 0.05$ using Tuckey's critical w value.

The highest marketable corm weights were found with taro plants treated with 5 g Confidor per plant, which was higher ($P < 0.05$) than the other seven treatments. On the other hand, no differences ($P > 0.05$) were found between the other seven treatments (Table 4). Similar results were observed in terms of per cent market yield over total yield (Table 5), where about 95% of the total yield was considered marketable for corms harvested from taro plants treated with 5 g Confidor per plant. This per cent marketable yield over total yield was higher ($P < 0.05$) than in the other seven treatments, with no differences ($P > 0.05$) between the latter treatments.

Table 4: Marketable yield of corms (kg/plot) as affected by the experimental treatments evaluated in the Vanuatu field trial.

Treatment	Marketable yield of corms (kg/plot)
Untreated control	16.23b[1]
5 g Suscon blu/plant	27.03b
5 g Grubguard/plant	28.35b
1-% v/v chlorpyrifos	19.93b
5 g Confidor/plant	64.10a
0.027-% v/v Ascend	26.78b
10 g TB101 strain of Ma/plant	20.25b
50 g TB101 strain of Ma/plant	16.57b
Error df	21
F value	8.91
Probability of F	< 0.001
S.E.M.	5.217
Coefficient of variation (%)	38

[1]Means with the same letter(s) are not different at P = 0.05 using Tukey's critical w value.

Table 5: Per cent marketable yield over total yield of corms as affected by the experimental treatments evaluated in the Vanuatu field trial.

Treatment	% marketable yield over total yield of corms
Untreated control	30b[1]
5 g Suscon blu/plant	48b
5 g Grubguard/plant	44b
1-% v/v chlorpyrifos	31b
5 g Confidor/plant	95a
0.027-% v/v Ascend	50b
10 g TB101 strain of Ma/plant	31b
50 g TB101 strain of Ma/plant	29b
Error df	21
F value	9.08
Probability of F	< 0.001
S.E.M.	7.306
Coefficient of variation (%)	33

[1]Means with the same letter(s) are not different at P = 0.05 using Tukey's critical w value.

Treating taro plants with 5 g Confidor insecticide per plant resulted in higher corm yield and the per cent of total yield considered marketable. It is suggested that the application rate of 5 g per plant of the Confidor insecticide be evaluated further in one or two other beetle-infested areas in Vanuatu to verify its effectiveness in controlling/reducing beetle damage on taro corms.

5.3.2 Evaluation of Confidor, bifenthrin and Ma

Beetle damage was quite evident with corms treated with the fungus or not treated at all, as indicated by the low per cent (48–70%) and weight (50–74%) of both exportable and marketable corms (Table 6).

On the other hand, both of the two chemical insecticide treatments significantly reduced beetle damage, as indicated by both the high per cent (77–97%) and weight (79–96%) of both marketable and exportable corms (Table 6).

Although the average numbers of beetles found in the four treatments were low, the numbers of beetle-made tunnels in corms were significantly higher in the untreated and Ma-treated plants (Table 7). Beetle tunnels were mostly present in the middle and lower parts of the corms in all four treatments (Table 8). This suggests that the fungus is not an effective treatment, as compared to the two chemical insecticides, in controlling taro beetle damage to taro corms, at least in the 7 months duration of taro growth.

Table 6: Mean per cent of total number and weight of corms harvested that were considered exportable and marketable, as affected by the four treatments.

Treatment	Export market		Local market	
	% number	% weight	% number	% weight
Control	50b[1]	52b	65b	67b
10 g Ma	48b	51b	68b	72b
5 ml L^{-1} Confidor	77a	79a	87ab	88a
2.5 ml L^{-1} Bifenthrin	88a	88a	97a	96a

[1]Means in the same column followed by the same letter(s) are not different at P = 0.05 using an LSD value.

Table 7: Average number of beetles and beetle-made tunnels on corms harvested, as affected by the four treatments.

Treatment	Mean number of beetle-made tunnels	Mean number of beetles
Control	91a[1]	4.8a
10 g Ma	87a	4.7a
5 ml L^{-1} Confidor	36b	4.6a
2.5 ml L^{-1} bifenthrin	13b	2.5a

[1]Means in the same column followed by the same letter(s) are not different at P = 0.05 using an LSD value.

Table 8: Location of beetle-made tunnels on corms at harvest, as affected by the four treatments.

Treatment	Mean number (rounded) of beetle-made tunnels		
	Top part of corm	Middle part of corm	Bottom part of corm
Control	4a[1]	34a	53a
10 g Ma	3a	32ab	52a
5 ml L^{-1} Confidor	1a	16bc	19b
2.5 ml L^{-1} bifenthrin	2a	5c	7b

[1]Means in the same column followed by the same letter(s) are not different at P = 0.05 using an LSD value.

5.3.3 Results of chemical x synergy trial in Keravat, Papua New Guinea

The highest per cent exportable number and weight of corms, and per cent marketable number and weight of corms, were observed in plots receiving two rates of bifenthrin applied twice, two rates of Confidor applied twice, and 10 g Ma in combination with the standard rate of Confidor applied twice. Severe beetle damage was observed in corms treated twice with Ma alone or not treated at all (Table 9).

On average, treating taro with Ma in combination with Confidor increased ($P < 0.05$) per cent exportable number and weight of corms, and per cent marketable number and weight of corms compared to treating with Ma alone (per cent exportable number by 36%, per cent exportable weight by 37%, per cent marketable number by 38%, per cent marketable weight by 43%).

On the other hand, per cent exportable number and weight of corms, and per cent marketable number and weight of corms were lower ($P < 0.05$) on average in plots receiving Ma in combination with Confidor compared to those receiving only the insecticide (per cent exportable number by 40%, per cent exportable weight by 39%, per cent marketable number by 47%, per cent marketable weight by 47%), confirming that Confidor was much more effective than Ma in controlling beetle damage.

On average, two applications of Ma in combination with Confidor increased ($P < 0.05$) per cent exportable number and weight of corms, and per cent marketable number and weight of corms, compared to a one-off application (per cent exportable number by 54%, per cent exportable weight by 54%, per cent marketable number by 64%, per cent marketable weight by 65%), confirming the ineffectiveness of a one-off application of Confidor in controlling taro beetle damage to taro corms.

The number of beetle-made tunnels on corms was higher ($P < 0.05$) in the untreated and Ma-treated plants, and those treated with a one-off application of Ma in combination with any of the three rates of Confidor.

Treating taro with Ma in combination with Confidor decreased ($P < 0.05$) the number of tunnels by about three per corm compared to treating with Ma alone, while the number was higher ($P < 0.05$) by about two per corm in plots receiving Ma in combination with Confidor compared to those receiving only the insecticide. This result confirmed the ineffectiveness of the Ma fungus in controlling beetle damage.

Two applications of Ma in combination with Confidor decreased ($P < 0.05$) the number of beetle-made tunnels by about four per corm compared to a one-off application.

Table 9: Mean per cent exportable and marketable number, exportable and marketable weight, and number of beetle-made tunnels per corm as affected by the 12 treatments.

Treatment	% exportable number[1]	% marketable number[1]	% exportable weight[1]	% marketable weight[1]	Number of beetle-made tunnels/corm[2]
Control	0e[3]	5.8d	0e	6.8d	9.4a
10 g Ma applied twice	6.5de	13.2cd	5.9de	8.3cd	5.5b
½ standard rate Confidor applied twice	80.9ab	98.4a	81.8a	98.1a	0.29d
Standard rate Confidor applied twice	84.1ab	98.4a	82.0a	98.7a	0.32d
10 g Ma + standard rate Confidor applied once	4.9de	9.7cd	5.3de	9.5cd	5.78b
10 g Ma + standard rate Confidor applied twice	88.2ab	100.0a	88.4a	100.0a	0.39d
10 g Ma + 1/5 standard rate Confidor applied once	25.1d	28.3c	24.5d	26.3c	3.97c
10 g Ma + 1/5 standard rate Confidor applied twice	71.1bc	82.8b	71.2b	83.1b	0.74d
10 g Ma + 1/10 standard rate Confidor applied once	17.7d	21.1c	17.2d	19.9c	3.37c
10 g Ma + 1/10 standard rate Confidor applied twice	50.0c	67.9b	48.7c	67.2b	1.27d
½ standard rate bifenthrin applied twice	81.6ab	100.0a	81.5a	100.0a	0.28d
Standard rate bifenthrin applied twice	92.0a	100.0a	93.7a	100.0a	0.08d

[1]Arc sine transformed data subjected to ANOVA. [2]Logarithmic transformed data subjected to ANOVA. [3]Means in the same column followed by the same letter(s) are not different at P = 0.05 using an LSD value.

6 PROJECT IMPACT

The results of the TBM project represent an important solution to the menace of taro beetle, which is a major threat to a staple food crop in beetle-infested countries. Notably, the project succeeded in developing economically viable methods for taro beetle control after decades of previous attempts, including the 10-year EU PRAP project.

6.1 Scientific impacts

The recommended control technology fits appropriately with national policies to increase food and income security for rural people in affected countries. The development of innovative methods to control taro beetle provides an impetus for taro production and will help accelerate agricultural diversification. However, it must be understood that the recommended systemic insecticides only serve to suppress taro beetle populations and protect taro corms from damage. They will not eradicate taro beetle.
Beetles are killed when they come in contact with the insecticides. Therefore, the recommended dose and method of application must be followed strictly to prevent development of resistance. Following the recommendations will also increase the market value of taro and boost income generation.

Noteworthy aspects of the project included the following:

- The use of a parallel approach to research implementation to save time.
- Sequential harvesting and recording of root crops for information generation.
- Value of Ma bioassay work for developing pest control strategies.
- Value of farmer surveys to research and to monitoring and assessment of impacts in tropical developing countries.
- Potential value of Ma (pathogenic fungi) and its synergism with selected insecticides in developing pest control strategies and reducing environmental impacts of pesticide use.
  Potential of pheromones and trapping for economic control of taro beetles.

6.1.1 Capacity building

The project developed and enhanced capacities in the following areas:

Human resource development

- Research and development capacities
- Hands-on training, attachments and training workshops on –
  - insect survey, collection, rearing and preservation
  - mass rearing, storage and use of pathogenic fungi for biocontrol
  - insecticide rates, application and safety
  - planning, design and conduct of laboratory and field experiments
  - data collection, processing and interpretation
  - extension techniques and participatory R&D approaches
  - conducting field demonstrations
  - conducting meetings
  - farmer survey design, data collection and interpretation
  - project administration and management

Infrastructure development

- Improved laboratory facilities
- Acquisition of laboratory and field equipment

6.2 Economic impact

For communities in taro beetle affected countries, improved taro quality and quantity per unit area will bring major economic and social benefits, with enhanced food security, income generation and export earnings. In Fiji, taro is one of the leading export crops, earning millions of dollars (more than FJ $20 million) in foreign revenue every year. The beetle is the biggest threat to taro production and is estimated to cause 40% loss of harvested corms. The taro industry stands to gain greatly from the project's findings and could increase its export earnings by 20% in the next 5 years. Higher production for export is targeted to return up to FJ $30 million in this period. Currently, most of the export taro is grown on Taveuni, which is a long way from exporting facilities. This brings extra costs in transport and handling of this perishable produce. Taro on Taveuni is also grown on hills and slopes, and forest areas are being cleared for taro plantations. The recommendations on taro beetle management practices are restoring farmers' confidence in growing taro on flat land and in beetle-infested areas in other parts of Fiji that are closer to marketing facilities.

In PNG, Vanuatu and Solomon Islands, taro could only be reliably produced in newly cleared forest/bush areas. Peri-urban families and institutions will now be able to grow taro successfully for food and income. Taro production is thus expected to increase significantly throughout these countries. For the first time, taro is a potentially viable export cash crop in PNG. It can now be grown on land near villages, thus reducing farmers' time and labour inputs and enabling the establishment of gardens based on crop rotation. With improved agronomic inputs, taro in PNG can be produced on the same land, year after year, which should discourage the practice of clearing forest areas for taro plantations.

In addition, businesses relevant to taro growing will expand. There are already increased sales of insecticides and application equipment and more local entrepreneurship is likely in taro beetle infested islands.

6.3 Social impact

Taro is culturally very important and is the preferred food crop in many Pacific Islands. Social events such as funerals, weddings and family gatherings include taro. Taro is a key crop in farming systems for many Pacific Island families, providing essential cash flow for households. It will now be possible to produce taro successfully with higher yields, increasing its availability for social events.

In most Pacific Islands, taro gardens are managed by women and other family members. Many of these families are located in relatively remote areas and cash crops are essential. Thus, income generation possibilities will be improved for both semi-subsistence and peri-urban/village families. This in turn will lead to more land being available for other crops, less labour being required for production, improved incomes and generally improved well-being. Increased production may also provide surplus taro for export, contributing to sustainable community livelihoods. However, all of this will require an active approach to implementation of pest management strategies.

6.4 Health impact

Taro has a much higher nutritional value than other staple crops such as cassava or tapioca. It is high in complex carbohydrate, fibre and other nutrients that are essential for good health. The physical activity needed to grow taro for family use, particularly by women, and consumption of good quality complex carbohydrate by the family can contribute towards controlling the epidemic of obesity in the Pacific region. Although highly recommended by nutritionists, and also preferred by Pacific communities, many families cannot afford to buy taro as a regular staple food due to high prices and short supply in local markets. By promoting taro growing in backyards, the TBM project will also be providing added health benefits in terms of physical activity and improved fitness.

6.5 Gender impact

A successful method of control for taro beetle will enable increased yields of a traditional and preferred root crop, which will most certainly have a positive impact on women and children in rural areas of Melanesia. Women supply most of the farming labour in Melanesia and any reduction in their workload will be welcomed. Less field work for women will give them more time to care for their children. The time saved may also be used to do other types of farming.

6.6 Environmental impacts

Taro garden can be established closer to households, reducing the need to clear and fell primary forest and regrowth for new taro gardens. Farmers will be able to increase the crop rotation cycle and reduce the area of land farmed. The major focus of the TBM project was to develop environmentally friendly management strategies. The insecticides recommended are biodegradable and break down soon after application, as shown in the residue analysis of soils from field trials. This suggests that the recommended methods of beetle control pose no danger to the environment. The use of chemicals in small quantities and by topical application will have minimal effect on other wildlife on large land masses. Synthetic pyrethroids are extremely safe for humans. Use of chemicals in fragile environments (e.g. in Kiribati) with high water tables remains a concern however. There is thus a need to pursue work on the synergistic use of Ma x very low dose Confidor, and OrV, in a strategy such as pheromone/trapping.

6.7 Communication and dissemination of information

Well set-up research and extension services and established social structures in affected countries have provided avenues for delivering both general information and training on taro management packages. Emphasis has been placed on the crucial need to prevent the taro beetle developing resistance to recommended insecticides through incorrect use. The general public and taro producers are regularly provided with information on the newly developed technology through farmers' meetings, farm visits, radio talks, leaflets and posters.

7 CONCLUSION

The TBM project has been a good example of the value of pooling resources and working in partnership to achieve targets within a desired time frame. In terms of efficiency, the project initially had a wide scope, which after initial work was narrowed down to concentrate on developing effective and sustainable use of Ma and insecticides for taro beetle management. As a result of this work, recommendations for control of taro beetle and packages of best practices for taro management have been successfully developed and transferred to Pacific Island growers. Previously, there were no recommended measures for control of taro beetle in affected islands.

The outcomes of the project are summarised below.

7.1 Recommendations for taro beetle management

Two insecticides, imidacloprid and bifenthrin, on their own or in combination, were found to provide good control of taro beetle and to give marketable yields of taro corms of up to 95%. Both are common insecticides, widely used for managing other pests worldwide.

- Imidacloprid at a dose of 1.5 ml per litre of water and Bifenthrin at a dose of 2.5 m/s applied at 125mls formulation per plant at planting and three months after planting is recommended for taro beetle control.

- Research found that Ma is a potentially useful bioagent in managing taro beetle but did not give the required level of control of the beetles in taro plantations.

- However, a very low dosage of 0.75 ml of imidacloprid per litre of water applied at planting with 10 g of Ma yielded marketable yields of taro corms similar to yields obtained using the two insecticides on their own.

- The use of the two insecticides should be alternated to avoid resistance, which also requires that growers adhere closely to resistance management practices.

- A package of best practices for the management of taro beetles was developed and demonstrated to taro growers through a modified version of a farmer field school. The demonstrations focused on methods of application and safety, correct usage rates, and frequency of applications.

7.2 Recommendations for further work

OrV is potentially a good bioagent for control of taro beetle. Laboratory tests conducted during the project showed that the virus was effective against taro beetle, as previously found by Zelazny et al. (1988). However, considerable work is required to produce pure cultures of the virus and to develop suitable methods of transmitting it to beetle populations in the field. Further work should be pursued.

Evaluation of insecticides, especially of new ones as they come to market, is a continuous process and should be built into the work plans of countries affected by taro beetle.

New insecticides may not have residue data for taro. During the project, good collaboration on residue analysis was developed with the Chemistry Department of the University of the South Pacific (USP). New analysis work could continue to be done in collaboration with USP.

The identification of sex pheromones could be contracted to a competent agency. Research should focus on practical use of pheromones as a component of an IPM approach to managing taro beetle. Taro beetle are similar in behaviour to other scarabaeids such as rhinoceros (*Oryctes rhinoceros*) and *Scapanes* beetles and, like them, may use sex pheromones in communication. This research component could be considered initially as a separate sub-component, supported in advance of other work.

Extension activities should be strengthened considerably to ensure wide and well-informed uptake of taro beetle management strategies. Consideration should be given to the involvement of the private sector/NGOs rather than using the services of a specialist agency.

There is a need to correctly identify the beetle species present in the Pacific Islands region, possibly utilising DNA analysis (fingerprinting) techniques.

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