# Root and tuber crops of the Pacific: A resource for meeting the challenges of the 21st century

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## Abstract

The Pacific Island Countries and Territories, home to an estimated 9.5 million people, are geographically, ecologically, sociologically and economically diverse. This region faces numerous social and physical challenges simply by nature of the size of the islands, and their geographical isolation. The 21st century, however, has brought new challenges from climate change to increasing food prices to the alarming increase in lifestyle-related diseases, which is strongly associated with the over-consumption of nutritionally poor foods, often imported. The response to the increasing food prices has been to strengthen local food production. Increasing local food production and promoting local food consumption provides an excellent opportunity to address the nutrition-related health problems. However, local food production has to be sustained in the light of climate change.

This paper describes the work of the Secretariat of the Pacific Community (SPC) in promoting and supporting the conservation and utilization of root and tuber diversity, as one of the solutions to manage these many challenges. For example, the SPC Centre for Pacific Crops and Trees (CePaCT), which houses a unique collection of over 850 accessions of taro (*Colocasia esculenta*), as well as other crops and trees of importance to the region, is building a "climate-ready" collection, consisting of local crops and varieties selected because such diversity will provide the farmers in this region with the traits, such as drought and salt tolerance. Evaluation, participatory crop improvement and value-adding programmes all encourage utilization of the root and tuber diversity conserved in the CePaCT.

Keywords: Pacific, Aroids, diversity, taro, root and tuber.

## Introduction

Pacific Island countries cover a land area of only 553,959 km$^2$ spread in the world's largest ocean (33 million km$^2$), with Papua New Guinea (PNG) accounting for 83% of the land area. The Pacific is home to about 8 million people, speaking 50% of the world's languages, with over 800 in PNG alone. The population is predominantly rural; however urbanization is occurring at a rapid rate, resulting in more than 40% of the population residing in urban areas in a few countries (Secretariat of the Pacific Community, 2004). Pacific Island countries face many challenges, including small populations and economies; weak institutional capacity in both the public and private sector; remoteness from international markets; susceptibility to natural disasters and climate change; fragility of land and marine ecosystems; limited fresh water supply; high costs of transportation; limited diversification in production and exports; dependence on international markets; export concentration; and income volatility and vulnerability to exogenous economic shocks such as cost of fossil fuels.

Traditionally, the Pacific Islands have depended on local staples, such as root and tubers for food and nutritional security. However, increasing urbanization, the introduction of modern plantation systems, the opening up of Pacific Island markets to global trade and the promotional prowess of the modern food companies have contributed to the decline of traditional crop production and an increased dependence on imported foods. The food crisis that was experienced globally in 2007 highlighted the level of vulnerability of many countries in the region. The extent to which individual countries are reliant on imported foodstuffs varies across the Pacific with the countries of western Melanesia having the lowest dependency on imported foods. On the other hand, countries such as Kiribati, Marshall Islands and the Federated States of Micronesia are very reliant on imported foods and as such extremely vulnerable to global crises. A UNICEF report highlighted the significant increase in consumer prices in Kiribati in the 12 months leading up to July 2008. Rice prices increased by 30%, flour by 20% and sugar by 20%. (UNICEF, 2008)

The dependence on imported food, often nutritionally poor, has also impacted severely on the health of the Pacific people. Rice and flour have now replaced root crops as the single most important source of starch and energy. Despite the nutritional superiority of traditional root crops (Parkinson, 2004), all Pacific Island countries and territories, apart from Fiji, Papua New Guinea and Solomon Islands, rely exclusively on cereal imports. The low nutritional value of these imported foods is a major factor contributing to food-related chronic disease and mortality in the Pacific, such that the people of the Pacific have some of the highest rates of obesity in the world. This in turn leads to elevated rates of non-communicable diseases (NCDs). Pacific Island countries and territories have the highest death rates from ischaemic heart disease, cerebrovascular disease and diabetes. (WHO, 2006)

The Pacific Island region generally has historically managed to avoid acute food shortages, through strong local food production systems, traditional food preservation techniques and supplementation of diets with wild crops. However, these coping mechanisms are not as resilient as they have been in the past. Knowledge of traditional farming practices and food preservation techniques have been and are being lost with the rural-urban drift experienced in the Pacific. The poor investment in agriculture over the years has significantly weakened research and extension systems in most agriculture ministries in the Pacific, with a predictable impact on local food production. The over-inflated status of imported foods and the poor status of traditional foodstuffs have also served to discourage interest in local food production and consumption. This decrease in the utilization of traditional food crops, in particular the root and tuber crops has presented a significant threat to the genetic diversity of these crops in the Pacific. Genetic erosion has been exacerbated by market forces. For example, Fiji is the largest exporter of taro – an export market that is based on largely one variety. The influence this market has had is visible in the limited diversity that exists in taro gardens in Fiji. A recent study carried out on the New Zealand market for taro found that it is currently under-supplied, which could pose further threats for taro diversity (Thomson, pers.comm.)

This loss of diversity and an associated lack of the traditional knowledge associated with these crops also undermine the capacity of the Pacific region to manage climate change. As the Stern Review highlighted "adaptation is essential to manage the impacts of climate change that have already been locked into the system" and the development of "more climate-resilient crops" is one of the main strategies for adaptation (Stern, 2006). Losing diversity reduces the options available with which to modify an agriculture production system, that is, to adapt. Having at hand a range of crops and varieties is similar to having a well-equipped toolbox – the tools being diversity that can either be used directly or in crop improvement programmes.

In summary, the increasing dependence of Pacific Island countries on imported foods has rendered the people of the Pacific vulnerable to non-communicable diseases and food insecurity. Is it therefore now time to return to our traditional food crops, in particular our root and tuber crops and to give them the attention they deserve? Can a focus on these crops assist the Pacific in meeting the many challenges it faces?

## Diversity of root and tuber crops in the Pacific

The diversity of root and tuber crops in the Pacific varies both for the crop and also across the Pacific. For taro (*Colocasia esculenta*) and giant swamp taro (*Cyrtosperma merkusii*) the Pacific is a primary centre of diversity whereas for sweet potato it is a secondary centre of diversity. Diversity in the Pacific in general declines markedly from west to east, due to the history of colonization, and the fact that the crops in question are vegetatively propagated.

## Aroids

Of the aroids used in the Pacific, *Colocasia esculenta* (taro) is the most important. The question of the centre of origin of taro remains unanswered and has been the focus of many discussions (Lebot, 2009). The Asian origin of taro has been well-documented (Matthews, 2002a). There is now circumstantial evidence that *Colocasia* may have been domesticated in western Melanesia. Thus, most cultivars found throughout the Pacific were not brought by the first settlers from the Indo-Malayan region as previously thought (Plucknett *et al.* 1970; Leon 1977; Kuruvilla and Singh 1981), but were domesticated from wild sources existing in Melanesia. Two independent domestications of taro in Southeast Asia and Melanesia have been confirmed using AFLP markers, as has the relatively limited genetic diversity existing in Polynesia compared to Melanesia (Kreike, 2004)

Attention was focused on taro in the early 90s when production in Samoa was severely affected by taro leaf blight. This event highlighted the role diversity can play in managing diseases and reminded scientists, researchers and to some extent, policy makers, as to the importance of genetic diversity. As a result AusAID funded a regional project - TaroGen (Taro Genetic Resources: Conservation and Utilization), which commenced in mid-1998 and ended in late 2003. The objectives were to complete the description and conservation of the bulk of taro genetic diversity in the Pacific Region; and to provide growers in Pacific Island countries with taro varieties with improved resistance to taro leaf blight. Some 2199 accessions were collected and described by partners, and 211 accessions were recommended for inclusion in a regional core collection based on phenotype and molecular characterization (Mace, *et al.*, 2006). The majority of these are safely stored at the Secretariat of the Pacific Community Centre for Pacific Crops and Trees (SPC CePaCT). The Taro Network for Southeast Asia and Oceania (TANSAO) also began in 1998, funded by the European Commission. Its objective was to improve taro in Southeast Asia by selecting varieties with high commercial potential as a table food and for processing. The project was completed in December 2001, having successfully established taro genebanks in all seven member countries complete with passport and characterization data. From the 2,298 accessions collected, a core of 168 was selected based on morphological and isozyme data, representative of the genetic diversity of the countries involved (Lebot *et al.,* 2004). The TANSAO core is conserved in the SPC CePaCT for sharing with other countries

Three other aroids are cultivated to varying extent in the Pacific – *Alocasia macrorrhiza* (giant taro), *Cyrtosperma merkusii* (giant swamp taro) and *Xanthosoma sagittifolium* (cocoyam). Compared to *Colocasia*, these species have attracted very little research and development attention. *Alocasia* is important, in some Pacific islands, notably American Samoa, Samoa, Tonga and Wallis and Futuna The number of varieties is low and it is presumed that the species has a narrow genetic base (Lebot 1992). *Xanthosoma* was introduced to West Africa, Oceania and Asia in the 19$^{th}$ century (Coursey 1968; Wilson 1984). Compared to the other aroids, it is of least importance in the region in general.

An Indo-Malay centre of origin has been proposed for *Cyrtosperma* (giant swamp taro), however "coastal New Guinea region" has also been suggested because of the variation in wild forms found in that region (Lebot, 1999). *Cyrtosperma* is cultivated in most Pacific Island countries, more rarely today as a staple food but, nevertheless, still retained for its important cultural uses, especially in the atoll islands (Iese 2006). A recent study carried out in four Pacific Island countries, identified the number of accessions; Federated States of Micronesia (48), Fiji (5), Kiribati (18) and Tuvalu (12) (Englberger *et al.* 2003; Iese 2006). Morphological and molecular comparisons were made, traditional knowledge collected and dendrograms of morphological characters drawn to show that some varieties were closely related between countries, while others were unique. Preliminary DNA fingerprinting studies supported the view that some varieties were rare and needed attention to prevent their loss (Iese 2006).

## Sweetpotato

There are a number of suggestions as to how this crop arrived in the Pacific. One hypothesis suggests there was a direct prehistoric transfer by Peruvian or Polynesian voyagers from South America to Polynesia (Yen, 1974, 1982a). Alternatively sweet potato could have been introduced to the Pacific during Spanish voyages from Mexico to the Philippines which traded across the Pacific. DNA fingerprinting shows little relationship between Oceania germplasm and that of Peru-Ecuador, suggesting that human dispersal from Mesoamerica is more likely (Rossel *et al.*, 2001). Based on DNA fingerprinting, it is quite clear that there are two major groups of cultivars, those from New Guinea and those from South America. The genetic base of the New Guinea cultivars appears to be narrower than the South American base. DNA analysis shows that New Guinea cultivars after a long, isolated evolution in a specific agro-ecological environment have significantly diverged from their ancestors, confirming their ancient presence on the big island (Zhang *et al.*, 1998a).

The SPC CePaCT holds a number of sweet potato varieties selected from a fairly rigorous and extensive varietal screening programme conducted under the European Union funded Pacific Regional Agriculture Programme (PRAP) sweet potato project (June 1990 to December 1998). The varieties were selected from a total of 1,167 varieties, which included material accessed from within PNG and also introduced from overseas (Pacific and elsewhere). The CePaCT now conserves and distributes the top varieties from this selection programme

## Yams

*Dioscorea* spp are found throughout the tropics and different species of edible yams have been domesticated independently in America, Africa, Madagascar, South and Southeast Asia, Australia and Melanesia. Of more than 600 *Dioscorea* species, *D. alata, D. cayensis* and *D. rotundata* are the most cultivated species. AFLP markers have shown that *D.alata* shares a common genetic background with *D. nummelaria* and *D. transversa* (Malapa *et al.*, 2005a, b). It is suggested that *D. alata* was domesticated 60,000 years ago, after the arrival of the Australoids, in the present New Guinea, or in Melanesia (Lebot, 1999). This geographic region is also the centre of diversity of the species (Lebot *et al.*, 1998). *D. esculenta* is an ancient crop in the Pacific, as found by the dating of starch grains in Fiji, 3050-2500BP (Horrocks and Nunn, 2006). Other yams with their origin in the Pacific include *D. bulbifera, D. nummelaria, D. pentaphylla and D. transversa.*

The South Pacific Yam Network (SPYN), a regional project funded by the European Commission focused on *D. alata*, recognizing that this species has potential for increased commercial exploitation. SPYN, a four-year project, was established to enhance the competitive position of yam in traditional cropping systems of five Pacific Island countries. Cultivars were selected for desired agronomic characteristics, such as tuber shape and tolerance/resistance to anthracnose. A core sample from the final collection made during this project is now conserved at the SPC CePaCT.

## Cassava

The debate on the origin of cassava is complex but it is likely that it was introduced into the Pacific in the late 19$^{th}$ – early 20$^{th}$ century (Lebot, 2009). Cassava accessions are conserved in the CePaCT, but these are largely accessions obtained from CIAT, to date only five varieties have been collected from the Pacific, namely Fiji. However there has been increasing interest in cassava from a food security standpoint. The food crisis in 2007 saw increased plantings of cassava in Fiji, and enthusiasm for new varieties, especially early-maturing. Its ability to stay for long periods in the ground and its adaptability to marginal areas also adds value as a food security crop. Commercial interest also exists; for biofuel and frozen cassava as an export product.

The numbers of accessions of root and tuber crops conserved in the SPC CePaCT are shown in Table 1.

**Table 1. Root and tuber crops conserved in SPC CePaCT (September 2009)**

| Crop | Species | Number of accessions |
|---|---|---|
| Taro | *Colocasia esculenta* | 852 |
| Giant taro | *Alocasia macrorrhiza* | 10 |
| Cocoyam | *Xanthosoma sagittifolium* | 8 |
| Giant Swamp Taro | *Cyrtosperma merkusii* | 17 |
| Sweet potato | *Ipomoea batatas* | 230 |
| Yams (*Dioscorea* spp) | *D. alata* | 164 |
| | *D. esculenta* | 4 |
| | *D. nummelaria* | 2 |
| Cassava | *Manihot esculenta* | 31 |

## Nutritional value of root and tuber crops

The poor nutritional value of many of the imported foods consumed in the Pacific has been discussed, which begs the question as to the value of some of the traditional food crops. Significant work has been carried out on some crops, in particular, banana, (Englberger, 2004) but less attention has been focused on the root and tubers. However, what is recognized is that these food crops provide superior nutrition to the white rice and flour products consumed today in the Pacific (Parkinson, 2004). Nutritional studies conducted on swamp taro have shown, as with banana, that the nutritional value is often linked to the variety. A study carried out by Englberger *et al.*, (2008) showed that the carotenoid contents of giant swamp taro varieties in Micronesia varied across a range from zero to 4,000µg/100g, with at least four varieties with beta-carotene contents well over 1000µ/100g.

## Securing and utilizing the root and tuber diverstiy of the pacific: activities within the SPC genetic resources programme

The Pacific is home to a wealth of root and tuber diversity however, as previously stated this diversity is under threat. The threat to diversity and the limited resources for diversity conservation at the national level was acknowledged in 1996 when Pacific Ministers of Agriculture resolved to put in place, both in their countries and through regional cooperation, policies and programmes to conserve, protect and use Pacific plant genetic resources effectively and efficiently for development. In response to this resolution from the Ministers of Agriculture, the Secretariat of the Pacific Community (SPC), an inter-governmental agency with a membership of 22 Pacific Island countries and territories, established the Centre for Pacific Crops and Trees (CePaCT) in 1998. The basic aim of the CePaCT is to provide the region with the means to safely and effectively conserve crop diversity, and to facilitate access to useful diversity, both within and outside the region. *In vitro* techniques are used, and collections exist for taro and other aroids, yam, sweet potato, banana, breadfruit, cassava, pandanus, aibika (*Abelmoschus manihot*) and kava (*Piper nigrum*).

The response of SPC to the ministerial decision in 1996 did not stop with CePaCT. In May 2001, Pacific Directors of Agriculture recommended that a Pacific Agricultural Plant Genetic Resource Network (PAPGREN) be established. The overall objectives of PAPGREN are to strengthen national plant genetic resources programmes and collaboration among them, so as to use scarce resources more effectively to solve common problems. Both CePaCT and PAPGREN are the major components of the Genetic Resources programme within SPC.

The core business of the Genetic Resources programme is to conserve and promote the use of diversity, in particular the root and tuber crops. This focus has been not only a conservation effort, but importantly a response to the serious challenges facing the region. How to ensure food security despite adverse climatic conditions? How to meet existing market demands, such as taro for export, and find and secure new markets? How to raise the status of these crops so that they are in demand locally and are not put to one side in preference to white rice?

Efforts over the past ten years have focused very much on building up the collection of aroids, and promoting utilization. This effort has been supported by the previous work of the two taro networks (TANSAO and TaroGen), and the absence of a Consultative Group for International Agricultural Research (CGIAR) Centre with a mandate to cover edible aroids. The taro collection is particularly unique, being the largest *in vitro* collection of taro diversity globally – over 850 accessions (Pacific and Southeast Asian in origin). In fact the uniqueness of both the taro and yam collections, and the role these collections can play in ensuring food security has been acknowledged at the international level with the recent signing of a long-term agreement with the Global Crop Diversity Trust. The Trust has agreed to provide funding support *ad infinitum* for these collections – this agreement is the **first** to be signed with a genebank outside of the CGIAR Centres.

The CePaCT has developed virus testing expertise for taro and yams in order to ensure safe utilization of the collection. Research is on-going to determine the optimum virus elimination technique (with regards to effectiveness and speed with which a usable plant is available) for the more common taro viruses, such as DsMV (Dasheen Mosaic Virus) and TaBV (Taro badnavirus), both of which occur relatively frequently in the Pacific, but impact on distribution of germplasm. Another area of study linked to viruses is investigating the impact of DsMV infection on the yield of the crop in two countries, namely Fiji and Samoa.

The size of the taro collection has also prompted research into more resource-effective conservation systems. With this in mind, a cryopreservation technique (droplet vitrification) has been developed to enable those accessions of currently limited interest to be cryopreserved (Sant *et al.*, 2007). This technique has proved successful with a number of accessions from the collection; it is currently being evaluated for its applicability across a wider range of accessions from the taro collection and also to include the other edible aroids (*Alocasia, Xanthosoma* and *Cyrtosperma*).

The TaroGen project in its efforts to develop cultivars with tolerance/resistance to taro leaf blight supported two breeding programmes in Papua New Guinea and in Samoa. The programme in Samoa, which continues to be supported by SPC in collaboration with the University of the South Pacific (USP) is of particular interest, because of its participatory approach. This Taro Improvement Programme has worked with farmers since its inception, breeding and selecting lines which have good taste, yield and importantly are tolerant/resistant to taro leaf blight. The farmers are currently evaluating Cycle 6 of the breeding programme, the result of crossing lines obtained as a result of the two taro networks from Asia and the Pacific. These Cycle 6 lines have received excellent feedback in Samoa and are currently being virus-tested in CePaCT for wider distribution and evaluation. This participatory programme has recently expanded its breeding programme to include selection for drought tolerance.

To date work on the other aroids has focused on collecting and at the same time virus testing these new accessions so they can be made available. Their ability to tolerate more marginal conditions has made them very suitable for the climate-ready collection. Some preliminary salt tolerance evaluation work is in progress, with taro and swamp taro, using a simple culture system on medium containing sodium chloride and identifying toxicity levels. It is hoped that this work will expand soon to include drought tolerance investigations as well.

The sweet potato work within the Genetic Resources programme is largely concerned with maintaining the existing collection, which consists of Pacific and non-Pacific germplasm. More recently material has been imported from CIP – these accessions, all orange-fleshed sweet potato (OFSP) have demonstrated salt and drought tolerance in Asia. These are extremely interesting accessions for evaluation in the Pacific with the double benefit of nutritional and climate-ready value. Early reports from some countries indicate that some OFSP varieties have performed well and are liked for their taste, texture and yield.

The work on yams is very similar to that of sweet potatoes. With the exception of the SPYN project, there has been very little focus on yams. However, CePaCT is endeavoring to increase the diversity of the yam collection, which currently consists mainly of *D. alata*, to include other yam species, especially *D. esculenta*, which is a hardier yam that appears to perform well in atoll conditions. *D. nummelaria* is another yam species of interest, known because it is very hardy, resistant to diseases and high yielding.

The conservation focus of the SPC Genetic Resources Programme has been *ex situ*. Some studies have conducted on *in situ* conservation (Jansen, 2002; Maemouri and Jansen, 2004). This work is being continued with some countries, for example, Papua New Guinea through the network (PAPGREN, and the need to link these two methodologies and to have in place a complementary approach to conservation is acknowledged (Taylor *et al.*, 2004).

## Root and tuber crop diversity: helping to address the challenges

The SPC Genetic Resources programme considers diversity to be essential in managing the many challenges facing the Pacific, not least, climate change. Scientists have shown that diversity provides a natural insurance policy against major ecosystem changes, be it in the wild or agriculture (McNaughton, 1977, Chapin *et al.*, 2000, Diaz *et al.*, 2006). With this in mind a major activity within the Genetic Resources programme is the establishment of a 'climate-ready' collection within CePaCT. The collection currently consists of 107 accessions of a range of crops, of which 93 are roots and tubers, sourced from within and outside the region, recognized for their climate-tolerant traits, such as, the salt and drought tolerant sweet potato accessions from CIP. This collection will provide the farmers of the region with a range of diversity required to sustain food production in a changing climate. As the nature of climate change is dynamic, this collection will also be dynamic, with collections being evaluated and constantly updated. Germplasm is collected, virus tested and then made available through the PAPGREN for evaluation in the different countries and different agro-ecological environments. Consideration is given to evaluating this material in challenging environments, such as on atoll islands.

The root and tuber crops, and the diversity this group provides, can also assist the region in addressing the problem of lifestyle related diseases. The Centre promotes varieties with known nutritional value, such as the orange fleshed sweet potatoes from the CIP collection. Interestingly some of Cycle 6 lines from the participatory breeding programme in Samoa are orange-fleshed, and have attracted interest from farmers and consumers. In collecting missions, nutritional traits are also considered, and targeted. The Genetic Resources programme works closely with the Island Food Community of Pohnpei, a NGO based in the Federated States of Micronesia promoting local food consumption, and in particular emphasizes the importance of diversity in achieving nutritional needs. Pohnpei is the location for an interesting collection of over 60 accessions of swamp taro, which will shortly be characterized and duplicated in CePaCT.

Finally with the urgent need to establish new markets for trade, the root and tuber crops offer considerable potential. The Genetic Resources programme is working with an EU-funded project "Facilitating Agricultural Trade in the Pacific" to source and identify varieties which have potential for local and overseas markets, whether fresh or processed. The bulk of the *D. alata* accessions in CePaCT were selected for their commercially-suitable shape. More recently there has been interest from a local grower and exporter in purple-fleshed yams, for both nutritional value and consumer-attractiveness. The New Zealand and Australia markets are strong markets because of the population of Pacific Islanders and Asian immigrants, though quarantine regulations can be restricting, reducing the price competitiveness of crops, such as taro. However, small volumes of partially processed and flash-frozen taro are currently being exported, for example by Fiji, but the size of the market and its profitability has not yet been determined (Thomson, pers.comm.). For all the root and tuber crops, snack foods, vacuum packed products and speciality flours are a possibility. As "convenience" is admittedly another factor contributing to the poor attraction of root and tuber crops, processing these crops so that they are available in convenient supermarket style packages can only improve demand. For taro, speciality starch is an area of promise (Lebot, 2009). The nutritional benefits of these crops are yet to be exploited, for example, their low glycaemic index.

The Centre for Pacific Crops and Trees (CePaCT) is one of a kind in the Pacific and is a resource that has been built up over the years through the commitment of donors and SPC. Importantly it is a resource the Pacific region now truly values for its role in conserving traditional crop and tree diversity, and providing "new" material to fulfill all the functions required of diversity. With the challenges of the 21st century this role is becoming increasingly important. The demands are huge on the fragile resources of the Pacific, maintain food security with the unpredictability of climate change, address the problems of nutritional security, and respond to the needs of the markets, but with the diversity of traditional food crops, in particular the root and tuber crops, these challenges will be more easily addressed.

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