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Searching for sources of resistance to taro leaf blight in collections from the Pacific

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Abstract

This paper examines the vital role genebanks play in the conservation and use of plant genetic resources (PGR), highlighting the South Pacific's version of the Irish Potato Famine and the organizational interdependence necessary to respond to disastrous losses in a cultivated food crop. On Samoa in 1993, *Phytophthora colocasiae,* taro leaf blight (TLB), caused an almost 100% loss of taro—the staple "prestige" food crop of this island nation. Several international organizations were formed to conduct botanical expeditions to regather the diversity of taro, *Colocasia esculenta,* from various centers of origin. This parental material was utilized in a 10-year breeding cycle process to produce viable TLB resistant varieties and replant fallow fields of Samoa. The duty to safeguard these global accessions led to the formalization of The Centre for Pacific Crops and Trees (CePaCT) which houses this core collection as the World Centre for Taro. The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) enables access and benefit sharing of this germplasm for breeding crops adapted to changing climates that are resistant to biotic and abiotic stressors. The collection, conservation, multiplication and distribution of taro *in vitro* has a significant impact beyond the regional needs of the South Pacific. Plantlets have been deployed to countries worldwide affected by the blight, aiding in staving off potential famines and economic crises. This ancient aroid is the 14th most eaten vegetable in the world – an indispensable nutritional and caloric resource for subsistence farming nations, that carries deep cultural significance.

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Acronyms

AusAID	Australian Agency for International Development
CePaCT	The Centre for Pacific Crops and Trees
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
INEA	The International Network for Edible Aroids
IPGRI	(previously) The International Plant Genetic Resources Institute (now) Bioversity International
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
LRD	Land and Resources Division of SPC
PGR	Plant genetic resources
PICTs	Pacific Islands Countries and Territories
PPB	Participatory plant breeding
RGC	Regional Germplasm Centre (now CePaCT)
SMTA	Standard Materials Transfer Agreement
SPC	Secretariat of the Pacific Community
TANSAO	Taro Network for Southeast Asia and Oceania
TaroGen	Taro Genetic Resources: Conservation and Utilization Network
TIP	Taro Improvement Project
TLB	Taro leaf blight
UNDP/FAO	United Nations Development Program / Food and Agriculture Organization of the United Nations
USP	University of the South Pacific

Contents

1 Introduction: The "prestige" crop ancestor

1.1 The delicious and wild world of *Colocasia esculenta*

Taro, specifically *Colocasia esculenta,* is a staple food crop that is vital to the nutrition, caloric intake and culture in many humid subtropical countries around the globe. It is the fourteenth most consumed vegetable in the world grown on over 1.8 million ha (FAO 1991). This study aims to conduct an ethnobotanical fieldwork with the Centre for Pacific Crops and Trees (CePaCT), the genebank of The Secretariat of The Pacific Community (SPC) of The Land Resources Division (LRD).

On "The Trail of Taro," we focus on the Pacific's version of the Irish Potato Famine, the taro leaf blight (TLB) (*Phytophthora colocasiae*) catastrophe, that occurred on the island Independent State of Samoa in 1993. The natural disaster provided the global impetus to create an international organization to conduct botanical expeditions to re-gather genetic diversity of *Colocasia esculenta* from various centers of origin. This germplasm was then used as parental material in a breeding effort to find lines resistant to TLB. The tale of this blight is indeed also the origin story of the formalization of CePaCT as a genebank with the duty to safeguard these newly gathered core collections. Today, CePaCT is the World Centre of Taro and houses 70% of known taro diversity (Figure 1).

In this paper, we outline the germplasm flow of how, why and by whom the global diversity of taro was gathered. Through this short narrative we hope to illustrate the imperative nature of the functions that CePaCT serves for both the Pacific Islands Countries and Territories (PICTs) as well as the global community in providing clean, virus-tested taro plantlets and propagules for use by farmers, breeders and scientists- specifically in respect to their TLB tolerant lines. We will showcase the importance of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO 2019), highlighting the immense humanitarian and ecological benefit derived from the genebanks' edict to share virus-indexed germplasm accessions of global crop diversity for free with all who request it. The disaster described in the following pages serves as both a wake-up call and a call to action amongst the Pacific region and global aroid community to support the work of CePACT in order to ensure the future of food security in the face of changing climates.

1.2 The origins of taro: A plant of the canoe people

Taro is an ancient crop—often considered one of the world's oldest (Lebot 2009) with archaeological evidence that supports its utilization in the Solomon Islands an astounding 28,000 years ago (Loy 1992). It is hypothesized that *Colocasia* first emerged in the Indomalaya ecozone of Southeast Asia and Southern India, more specifically near Nepal and Bangladesh (GRIN 2015). Through human cultivation and transport taro was spread to the humid, subtropic and temperate zones of the Pacific, Egypt, Africa, the Mediterranean and Caribbean. The Austronesian People in outrigger canoes commenced a massive human migration across the Indo-Pacific including Melanesia, Micronesia and Polynesia—bringing "Canoe Plants" with them to settle the islands discovered on their seafaring explorations (Figure 2). Taro, of the family *Araceae*, is a vegetatively propagated perennial staple crop of which the entire plant including the vitamin-rich leaf, clean carbohydrate corm and petiole are all edible, highly nutritious, hypoallergenic and have medicinal applications. Due to its hardy nature and storage ability, the crop was able to fare the voyages well, ensuring sustenance wherever the intrepid explorers landed.

The cultural significance of this totem "prestige crop" cannot be overstated. The Hawaiians' Creation Chant, the Kumulipo, tells the tale of the Earth Mother (Papa) and the Sky Father (Wakea) who birthed Ho'ohokukalani. Their first child, Haloa-naka, was stillborn. When buried in the earth Haloa-naka (*ha* = breath, *loa* = long, *ka* = quivering) grew into the first taro plant with a long quivering leaf—thus the name *kalo* for taro in Hawaii (Figure 3). Haloa, the second-born son, received his sustenance from kalo. The Hawaiian people therefore trace a direct ancestral lineage to this sacred crop (Heard 2010). Similar origin stories are common in Melanesia and Micronesia, where societies that have used taro for thousands of years and the plant commands an important role in local legends, stories, chants and proverbs (Rao 2010).

The ethnobotanical significance of taro around the globe is a thesis itself. In Fiji where taro is called *dalo*, there is the cultural custom of "giving dalos," at all major life events: births, weddings, funerals and so forth. In Samoa only the largest and best corms of *talo* are presented to the chief's and kings. *Talo* is an integral part of *Fa'a Samoa* or traditional Samoan culture. "Taro is part of our heritage and a binding force for our tradition. We are Samoans, people from the sun, and throughout our ancestral migration, taro has played a vital role" (Semisi 1993). Taro feeds not only the bellies of those who caretake this plant but their spirits as well.

2 Context: The orphan crop catastrophe

2.1 An Orphan Crop

There is a consensual assessment that aroids are orphan crops of utmost importance to the poor, essential for food security and that they represent an untapped potential for further economic development - Dr. Vincent Lebot

In 1988 a young and enthusiastic Dr. Vincent Lebot[1] was delving into a largely neglected area of taro genetic analysis. Although the reliance on taro as a subsistence and staple food crop for many parts of the globe was well understood, there were virtually no breeders focusing on this "Orphan Crop." This is still the case. With UNDP/FAO funding, Dr. Lebot contacted various universities, departments of agriculture, research stations, botanical gardens, and field collections, also visiting to farmers' markets around Asia and Oceania[2]. He assembled an impressive 1,417 cultivars and wild forms of taro. Utilizing these germplasm accessions (both dry leaf matter and vegetative cuttings), he began conducting isozyme and rDNA variation analysis on this highly polymorphic species (Kreike 2004). Due to the large morphological diversity, it was assumed that many unique varieties were present – yet, little had been done to DNA fingerprint global accessions and understand genetic variation. The results presented in Lebot's (1991) seminal paper exhibited a dendrogram with a shockingly narrow genetic diversity found within *Colocasia esculenta* in the Pacific. Clonal reproduction via primarily vegetative propagation, and introduction through a "bottleneck," accounts for the lack of genetic diversity found in this genepool. At

[1] Sefra Alexandra interviewed Dr. Vincent Lebot while on expedition in Vanuatu in 2018. Dr. Lebot is a root and tuber crops breeder working for CIRAD (www.cirad.fr). He obtained his PhD in 1988 and has been working on root and tuber crops for the last 30 years. His studies focus on the chemical composition of the underground organs and their relations with quality. He was the scientific coordinator of TANSAO (the Taro Network for South East Asia and Oceania) and is now coordinating the INEA (International Network for Edible Aroids).

[2] Germplasm gathered from: Hawaii: University of Hawaii Kauai Branch Station, Harold Lyon Arboreteum, Waimea Botanical Garden, and Hawaiian Studies Institute Ethnobotanical Garden. French Polynesia: Station de Papara, Tahiti. South Pacific: South Pacific Commission tissue culture collection in Suva, Fiji, and Koronivia Research Station, Department of Agriculture in Nausori, Fiji. New Caledonia: Institut de Recherches en Agronomie Tropicale, Station de Poindimir. Vanuatu: Agriculture Department, Santo. The Solomons: Dodo Creek Research Station, Guadalcanal. Papua New Guinea: Department of Primary Industries, Bubia Research Station, Morobe Province. Indonesia: Indonesian Institute of Sciences, Bogor, Java. Japan: National Research Institute of Vegetables, Ornamental Plants and Tea, Anr, Mie. The Philippines: Rootcrop Research and Training Center, Baybay, Leyte. Accessions from India, Thailand, and Malaysia were collected in market places. Young suckers or tubers collected from New Caledonia, Tahiti, Pohnpei, the Philippines, Indonesia, Malaysia, Thailand, Japan, India, and Vanuatu and tissue cultured accessions obtained from the SPC laboratory based in Suva, Fiji, were introduced to the Horticulture Department of the University of Hawaii at Manoa, Honolulu.

the time, this was a revolutionary discovery that caused great concern to the young scientist, who called for germplasm exchange.

> *Oceanian cultivars constituted a continuum of clusters and are thought to have originated from a narrow genetic base introduced from Indonesia. If taro breeding is to have any future in Oceania, it is important to exchange genotypes to broaden the base of existing breeding programmes. (Lebot 1991)*

Unfortunately, Dr. Lebot's recommendation was largely ignored. His words of warning foreshadowed the events that would come to bear in the following years. Just two years later, in July of 1993, the fungal disease *Phytophthora colocasiae* was detected on the Southern windward side of the main island of Samoa. The recent havoc wreaked by Cyclone Val[3] which ripped vast swaths of taro out of farmers' fields led to a massive replanting effort. Tens of thousands of new planting materials were introduced to the land (a circumstance that could have easily been a vector of introduction for the pathogen from foreign material). This factor, coupled with unusually high rainfall that season caused a perfect storm that proliferated this oomycete, which spreads by raindrops and wind. Fields of taro production across the island were decimated. The climate of the island with warm nights and high relative humidity was the ideal incubation setting for this warm weather pathogen. The germination period of the zoospores and sporangia is terrifyingly quick and can be almost immediate- showing symptoms of lesions on the leaves in 2–4 days and causing a 50% corm yield loss and 95% leaf loss (Brooks 2005; Nelson 2011). Cultural and chemical remediation strategies were trialed in the aftermath with little to no avail.

The fields of Samoa were a veritable monoculture of two cultivars: Manu 'a and Niue, which were favored for their palatability, corm color and production output.[4] As the world learned with the Irish Potato Famine, relying on just two varieties is a recipe for disaster. In this instance, an estimated 97% of the national taro crop was eradicated. An agricultural economy that depended on this prestige crop[5] was heavily affected, forcing the inhabitants to embark on a frantic search for a replacement staple starch.

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[3] At this time, there was a major replanting of taro underway in the aftermath of Cyclone Val and anything up to 10,000 plants could be planted by a single farmer in a one-week period (Semisi 1993).

[4] A Rapid Rural Appraisal was conducted in American Samoa in 1989 to document traditional agricultural practices associated with the growing of taro. From this survey, 22 cultivars of taro were documented where all farmers grew either Manu 'a or Niue cultivars along with a scattering of other cultivars. https://www.ctahr.hawaii.edu/oc/freepubs/pdf/RES-140-23.pdf

[5] Taro is classified as a "prestige crop," because it is the crop of choice for royalty, gift-giving, traditional feasting, and the fulfilment of social obligations. http://www.fao.org/docrep/005/AC450E/ac450e03.htm

2.2 Economies of "tipping" the scale: Agroeconomic effects of taro leaf blight

The effects of losing their main export and staple aroid had staggering economic implications. Andrew McGregor, the agricultural economist expert on root and tuber crops in the Pacific, wrote a definitive case study in 2011 focusing specifically on the economic implications of TLB in Samoa (McGregor 2011).

> *The disease poses a serious threat to Western Samoa for not only is taro the principal root crop consumed, but Western Samoa is the major supplier of taro to the large populations of Pacific Islanders in New Zealand, Hawaii and the USA (CTA 1994).*

His analysis showcased the devastatingly detrimental effects of the agroeconomic catastrophe. The epidemic witnessed on the Island State highlighted the dangers posed by a lack of access to plant genetic resource and allelic diversity with minimal attention heeded to breeding efforts.

In a personal interview while in Fiji in 2018, McGregor stated that within the year a 12 million USD production and export industry of Western Samoa had been brought to a halt and the dinner plates of every household had changed. He calculated the estimated economic cost of loss of self-sufficiency due to TLB (Table 1) by examining the increase in grain imports as a replacement starch. An observed increase of 30 kg/yr per person was attributed to the blight, representing a 38% increase over pre TLB purchasing patterns. He estimated the economic cost of loss from 1994–2010 to be around 22 million USD. The quantifiable financial burden is substantial on subsistence households that rely heavily on their ability to produce their own staples.[6] The disruption of the quality of life on the island raised the question about the origins of the blight's arrival on Samoan shores.

2.3 How did I get here? Hypotheses of Phytophthora colocasiae's route of deliverance

It is important to consider where and how the taro leaf blight arrived. The first recorded account of this disease was in 1918. In Guam, the disease wiped out 60% of the known varieties, followed by an outbreak in Hawaii in 1920 which is hypothesized to have caused the loss of over 300 landraces, all most likely susceptible. "It is generally believed that TLB entered Samoa via unauthorized imports of infected

[6] "Prior to 1993, taro was by far the most important food staple in Samoa. At the time, over 90% of taro production was used to meet household consumption needs (Chan et.al.1999, p. 93). According to the 1989 Agricultural Census, 96% of agricultural households grew Colocasia taro of which 76% were grown as a monoculture." (McGregor 2011)

corms of planting material" (Hunter et al. 1998). Three main theories that are generally proposed to explain how the blight arrived in the South Pacific (Trujillo 1967): 1) to Hawaii via the Philippines; 2) from Taiwan to Micronesia by way of the Philippines; and 3) to Fiji by way of Papua New Guinea and the Solomon Islands where documented cases had already ravaged their local crop production[7].

These pathways illustrate that it is imperative to have clean, virus-tested propagules available for distribution and multiplication—especially for massive replanting efforts after natural disasters. This instance should have inspired the entire Pacific to diversify farmers' fields and proactively build robust and resilient strategies in an effort to be able to respond rather than react to such situations. Unfortunately, although many networks and meetings in this vein have commenced, very little has changed. What was agreed upon was the desperate need to assemble existing diversity in order to identify genetic sources of resistance to blight.

3 Germplasm: collection, conservation and use

3.1 Who you gonna call? The expeditions begin

"There is a need to conserve and characterize the taro in the region. Such a collection would not only insure against further genetic erosion of the germplasm, but would serve as a source of desired genotypes for various countries in the region. Hopefully, this will permit in vitro maintenance of the germplasm to complement accessions that are maintained in the field….

In the root crop cultures of Oceania, there is a great sentimental attachment to taro. This attachment will continue to propel and fuel taro cultivation far into the future. It will also continue to ensure a vibrant internal and external market for taro" (Onwueme 1999)

The global plant genetic resource community rallied together and formed networks that gathered, analyzed and bred new lines in search of blight-tolerant cultivars. The germplasm assembled by Dr. Lebot in the late 1980s with UNDP/FAO funding had been all but lost in the fields of farmers and research stations due to natural disasters, lack of funding and an absence of an overarching organization working to conserve and maintain these resources. Up until this point very little work had been done in this sector

[7] At this point in TLB's timeline it had been reported in: Indonesia, Papua New Guinea, Solomon Islands, Hawaii, Thailand and the Philippines.

which was devoid of a proper facility in the region to house plant material and thus varieties were rapidly being lost.[8] In 1996 a meeting was held at The Secretariat of the Pacific Community (SPC) in conjunction with the Pacific Ministers of Agriculture to address these issues.

Officials resolved to put in place—both in their countries and through regional cooperation—policies and programs to conserve, protect and use their plant genetic resources effectively and efficiently (APAARI 2011). It was time to formulate a regional collaborative approach that could organize, orchestrate and fund the work required to collect, identify and utilize leaf blight tolerant parental material to breed new hybrid lines.

3.2 Taro genetic resources: Conservation and utilization network: TaroGen: The gathering of the Pacific diversity

There was an obvious imperative to collect, analyze and safeguard the *Colocasia* found around the region to provide virus-indexed breeders' lines and traditional cultivars (Singh 2010). In 1998 Australian Aid (AusAID) funded the five-year long TaroGen Project with Graham Jackson as Technical Director. This provided the support to establish the Regional Germplasm Centre (RGC) at SPC led by Dr. Mary Taylor, which would eventually be renamed the CePaCT. This initiative not only established the genebank for the Pacific[9] but also provided funding to revitalize breeding efforts that had been halted in Papua New Guinea and Samoa. Further, TaroGen embarked on a Pacific wide botanical expedition to collect, characterize and utilize the diversity present in the region. 2,200 accessions of taro were collected and analyzed to form the Pacific Core Collection[10] of 196 accessions that are still maintained *in vitro* at the CePaCT. The International Plant Genetic Resources Institute (IPGRI, now Bioversity International) provided biotechnological assistance with the identification of core sub-sets.[11] The two main taxonomic varieties of Dasheen (*C. esculenta* var. *esculenta*) and Eddoe (*C. esculenta* var. *antiquorum*) are conserved, with agronomical preference within the Asian Pacific favoring the Dasheen type. However, this core collection

[8] With exception to few scientists who have been continuously working on taro genetics and taro breeding systems since the 1970s: Jill Wilson, Ramon de la Peña, Vincent Lebot, Eduardo Trujillo, John Cho, Susan Miyasaka, and Xiaoling.

[9] "The foundations for such germplasm conservation have been laid at the Papua New Guinea University of Technology and other locations where protocols for taro tissue culture have been developed."

[10] A core collection is the maximum amount of genetic diversity within the smallest number of samples.

[11] ACIAR, through University of Queensland (UQ), funded DNA fingerprinting and the virus-testing components. ACIAR also funded the Queensland University of Technology (QUT) to develop methods for diagnosis and detection of taro viruses.

still represented low allelic diversity and a narrow genetic base. Finally, with a proper facility to house accessions, the impetus and ability to gather and steward cultivars from outside the region was both possible and pertinent.

3.3 Taro Network for Southeast Asia and Oceania: TANSAO

This widely distributed crop is a staple food important in many localities in the humid tropics and subtropics. There is a diversity of cultivars adapted to a range of (agroecological) microenvironments, from swidden fields, rain-fed upland and home gardens, to paddy fields and swamps in China, India, Vanuatu, Guadeloupe and elsewhere" (Hunt 2013).

In 1998 the TANSAO was formed with support from the European Union and direct involvement of governments of Thailand, Philippines, Vietnam, Papua New Guinea, Malaysia and Indonesia. This network's efforts were aimed at gathering, studying, conserving and eventually distributing germplasm diversity to broaden the genetic base and gene-pool of the crop in the Pacific, as well conduct analysis on the genetic diversity of *Phytophthora colocasiae.* 120 accessions were collected and 16 were utilized in the taro breeding program at The University of the South Pacific (USP) Alafua Campus. The newly acquired diversity was virus-tested and made available through distribution by SPC to be utilized by breeders. This was a major crossroads along *The Trail of Taro*, where viable material could finally be bred and evaluated for tolerance, palatability and yield. Tolo Iosefa (who would soon become the head breeder of this effort), a true TLB hero, coordinated the Taro Improvement Project (TIP) in an effort to incentivize farmer participation and ascertain feedback during this process.

3.4 Taro Improvement Project: TIP: On farm participatory evaluation

"Recently, the Pacific and Southeast Asian regional taro networks have made excellent progress in developing cultivars resistant to taro leaf blight through enhanced utilization of taro genetic resources and close collaboration between farmers and researchers in breeding programs. These programs have secured vital taro genetic resources for future use."- Dr. Mary Taylor

In July 1999, the Taro Improvement Project (TIP) was initiated at the USP Alafua Campus in Samoa with the Ministry of Agriculture Research and Extension as a participatory plant breeding (PPB) program. This platform provided a method and audience to discuss and evaluate the newly bred TLB tolerant lines coming out of the Cycles. Taro Breeder Clubs were formed as focus groups to provide planting material, impart best practices and gain feedback utilizing crop-focused Participatory Rural Appraisals "to learn more about taro production problems, perceptions of taro cultivars and criteria important in the selection of a cultivar" (Hunter 2000). Now in its 19th year, TIP has worked with hundreds of male farmers—as it is customary for males to do the taro cultivation on Samoa—and gathered significant amount of culinary, agronomic and ethnobotanical data on selection characteristics key to the Samoan population (Table 2). Taro production has been back on the rise for the past decade and a half. From recent reports and field visits in 2018, Samoan women seem quite satisfied with the taste, elasticity and color of the new cultivars; and all of course, are fond of the man who bred these lines into existence.

3.5 University of the South Pacific: Alafua's taro breeding program: The tale of TOLO

In 1997 before TaroGen had started, Dr. Param Sivan began Cycle One of breeding TLB tolerant lines with PSB-G2 from the Philippines, a few Micronesian lines as well as some from Samoa (Guarino 2003). Once TaroGen had begun the following year and the TANSAO strains were cleared for distribution through SPC, a wide allelic diversity was introduced to the subsequent breeding cycles. Niue, although highly susceptible to the blight, was the favored line for palatability and thus was still included in the efforts. A young Mr. Moafanua Tolo Iosefa (Figure 4) had recently finished his plant breeding studies. For the next 22 years he has been coordinating TIP and championing the breeding efforts in Samoa, around the Pacific and around the World. His lines are the most successful and palatable hybrids that arose from the global rebreeding effort. His first seven cycles are illustrated in (Figure 5), and currently in 2019 he is on Cycle 9. In 2009, 13 years after he began his ethnobotanical sojourn, his lines (Samoa 1-5) were made widely available to the export market, and household production is now almost back to pre-blight era levels. The dedication and determination exhibited by Tolo and everyone in the local and international community who gathered, studied, analyzed, planted, tested, conserved, multiplied and distributed this vital plant genetic resource- ancestor- prestige crop, is what enabled the Community to overcome this catastrophe as a tale of triumph.[12]

> *We crossed our preferred Samoan varieties with varieties from Indonesia and Malaysia that had leaf blight resistance. In that way, we could keep the traits of our familiar and locally adapted varieties, and integrate disease resistance. It took time and a lot of work, but ultimately it was successful (ACIAR 2011). - Tolo Iosefa*

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[12] A brief video of Tolo explaining his breeding cycles while at the PS4L Validation Workshop in Nadi, Fiji. Nov. 2018.

The success of this story should also be heralded as a reminder that the diversity that still exists in the soils around the world must be backed up and safeguarded for future use because we may not always be able to find them again *in situ*.

Tolo's TLB resistant breeding cycles lines tells the tale of a world working together for the use and conservation of the delicious and ever adapting diversity of *Colocasia esculenta,* reminding us not to take the flora bounty that surrounds us for granted. We have been sojourning with this sacred crop for over 28,000 years as it provides us with food and medicine and creates habitat for other creatures. The crop looks after us, and as caretakers and stewards of this Earth, it is our innate duty to reciprocate and share this resource with as many countries, people and soils as possible. The success of Tolo's breeding lines was a victory for both Samoa and the rest of the planet.

3.6 The International Network for Edible Aroids: INEA: Sharing germplasm beyond the Pacific

The imperative to share this genetic resource and allelic diversity on a global scale led to the formation of the International Network for Edible Aroids (INEA) in April of 2011.[13] INEA is comprised of a cooperative network of 15 countries across Africa, Asia, Central America and the Pacific:

> *Whereby edible aroids are used as a model to improve clonally propagated root and tuber crops of tropical countries. All partners have a national mandate for the collection and conservation of taro genetic resources and documentation of accompanying information (Chaïr 2016).*

The aim of this network is three-fold: providing access to genetic diversity; assisting with best practices in breeding; and promoting effective use of modern technologies. The formal establishment of the Regional Germplasm Centre—which at this point in our timeline has transitioned to the CePaCT—provides invaluable access and resources to the world by operating under the ITPGRFA. The Standard Material Transfer Agreement (SMTA) stipulates a core mission of sharing clean, virus-tested and characterized germplasm to anyone who requests it for free. Almost all members of INEA have signed the Plant Treaty and can benefit from and enable others to benefit from the multilateral system.

[13] TaroGen & TANSAO had long since ended, and an organization was needed to support aroids.

Dr. Vincent Lebot (Figure 6) is currently the Coordinator of INEA, a role he fulfills out of his dedication to the Aroid Orphans because the funding ended in 2016. Dr. Lebot is also the root and crop breeder at the French Agricultural Research Centre for International Development (CIRAD), and is "entrusted with the genetic diversity assessment" of INEA.[14]. The demand for aroid diversity is ever-present locally and globally, and CePaCT is leading on conservation and distribution both within and beyond their region.

4 Germplasm distribution discussion: Global impact beyond the Pacific Region

4.1 Pacific Agriculture Plant Genetic Resources Network (PAPGREN): Formulating strategies for proactive seed readiness within the Pacific region

SPC's Land Resources Division (LRD) hosted the Pacific Seeds 4 Life Validation Workshop at the Tanoa International Hotel in Nadi, Fiji, 26–28 November 2018.[15] The meeting was centered around the revitalization of the regional network, the function of which is to facilitate PGR sharing under the ITPGRFA within and outside of the Pacific. Twelve island countries were brought together under the theme of "Harnessing Effective Partnerships for Sustainable Seed Systems in the Pacific." Heads of ministries of agriculture, breeders, farmers and members from the private sector joined together and participated in a design charrette to review and validate a draft of:

> *The Pacific Seed System* Roadmap*: a framework to establish priority activities to guide joint-collaboration, which increases farmers access to quality seeds of climate ready crops at CePaCT and enhances food and nutritional security. In order to create: A viable seed system, which allows access to a wide range of varieties, critical in allowing countries and communities to sustain their livelihoods and ensure swift*

[14] A total of 321 cultivars were analyzed, comprising 64 from Asia, 196 from Africa, including 5 cultivars from Madeira, 19 from America and 42 from the Pacific region. 36 cultivars from Japan, the Philippines, Malaysia, Indonesia, Thailand and Vietnam, originally collected during TANSAO are still maintained *in situ* at the Vanuatu Agronomical Research and Technical Centre (VARTC) by Dr. Lebot.

[15] In the same location where the 3rd Global Taro Symposium was held in 2003

> *post-disaster recovery. Countries in the region therefore must prioritize seed security as a sector for climate action.*[16]

Access to parental material of wild, cultivated and traditional varieties with passport data is a breeders' ideal. Yet, as we saw, no matter how well situated or prepared a nation may or may not be, the process still takes many, many years to adjust to new environmental constraints. This factor is why a proactive resilience plan needs to be implemented for crops around the world and a community of practice must be formalized in the Pacific.

PAPGREN serves island nations that are susceptible to the stressors of importation as well as the fragility of inhabiting vast swaths of coastline. The landraces must be safeguarded before they are lost to ensure continuity of culture and cuisine in shifting climatic conditions. CePaCT serves a large and vulnerable region, providing vital services to the agroecological sector.

4.2 The Centre for Pacific Crops and Trees: CePaCT: Safeguarding biodiversity for conservation and use

As this story unfolded, a genebank was funded; a worldwide community of practice was formed; and a global core collection was curated and is now available at the World Centre for Taro for distribution. The Sanky diagram (Figure 8) shows the international demand for access to the taro germplasm maintained at CePaCT. It is crucial to remember that this allelic diversity is only partially safeguarded at a handful of other germplasm repositories. The fragility of this aroid to biotic and abiotic pressures could significantly change the lives of millions of people who rely on the nourishment of this prestige crop.

4.3 Distribution beyond the Pacific: Deploying TLB resistant germplasm

The widely successful taro leaf blight tolerant lines bred by Tolo were sent back to SPC CePaCT to be conserved, regenerated and distributed to countries where *P. colocasia* is present or where preventative efforts are underway. As Andrew McGregor stated in his interview, "it's not a matter of if, but when the blight arrives."

In 2011, it did indeed arrive in West Africa, namely Nigeria, one of the top producing taro countries in the world (Mbong 2013). Nigerians experienced an equally devastating epidemic of the blight that ravaged

[16] Facebook post from Pacific Agriculture after PS4L (authored by social media network managers)

their fields. When disaster struck, Tolo's lines were ready for deployment. The germplasm received from CePaCT via ITPGRFA was indeed instrumental in their breeding efforts to overcome this threat to food security and the livelihoods of Nigerians.

The story recounted here does not begin and end with Tolo in Samoa. His dedication to TLB tolerant breeding, his country, his culture and his cuisine has created a bridge which binds the global networks of plant genetic resource institutions together. The diversity of taro safeguarded at CePaCT including the TLB resistant lines have been distributed far beyond the boundaries of the Pacific region. The global distribution of taro plant samples (Figure 7) clearly emphasizes the significance and scale of cultivation of this staple food crop worldwide. The conservation and use of taro is imperative to staving off famine and ensuring food security in numerous subsistence farming nations globally. Never knowing what pests, fungi or natural disasters may wash up on countries' shores means the preservation of this diversity is vital to global resilience.

Regional and global seed networks operating under the Plant Treaty have an all-access pass to the immense and invaluable genetic biodiversity safeguarded by the world's genebank repositories. Seeds are the greatest tools of resilience in the effort to adapt both domesticated and wild lands to ever changing climates. The vital importance of the conservation, multiplication and distribution of this shared natural resource is a global imperative and responsibility.

5 Conclusion: The confluence of efforts

This story is a story centered around an ecology of humans dedicated to overcoming obstacles for the greater good, illustrating the international effort, coordination and execution needed to find solutions to agricultural challenges. "The Global Partnerships in Taro Conservation for Breeding TLB Resistant Lines" diagram (Figure 9) attempts to illustrate the intricate inter-organizational cooperation and commitment to finding a solution.

To recap the confluence of this heroic effort, Samoa was devastated by TLB in 1993. TaroGen recollected diversity from the Pacific and TANSAO collected germplasm from Southeast Asia and other centers of origin. The need to safeguard these accessions and virus-index them for utilization in breeding efforts by Tolo Iosefa at the USP Alafua Campus and by Dr. Lebot in Vanuatu, among others, was one of the impetus that formalized CePaCT. These core collections are the basis of the World Centre of Taro and were utilized in PPB efforts led by TIP to identify palatable and high yielding varieties resistant to TLB.

These new cultivars were re-accessioned to the CePaCT and have been widely distributed to countries around the globe under the ITPGRFA who have experienced or are susceptible to the blight.

This dedicated web of successful scientific collaboration showcases the vital role genebanks play in addressing food security issues. Access to conserved, virus-indexed materials is paramount in safeguarding the genetic resources necessary to breed for climate adaptable cultivars. This is simply one tale of one crop on one island facing one blight. The loss of staple food crops has vast and detrimental effects on agricultural economies, food security and cultural legacy. This work must be supported and implemented while the resources still exist in our cultivated and wild soils.

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7 Tables

Table 1. Estimated economic crop loss of food self-sufficiency due to TLB.

Year	Est. additional per capita grain imports due to TLB (kg)	Population (‘000)	Total est. additional grain imports due to TLB (tonnes)	Average landed value per tonne (USD)	Average landed value per tonne (WST)	Estimated economic of the loss of food self sufficiency (WST)
1994	30	167	5,010	268.65	658	3,297,529
1995	30	168	5,040	278.83	705	3,555,388
1996	30	170	5,100	231.81	563	2,872,857
1997	30	172	5,160	193.24	535	2,762,078
1998	30	174	5,220	169.54	510	2,663,880
1999	29.3	175	5,119	182.59	551	2,822,577
2000	28.5	177	5,048	151.71	507	2,557,707
2001	27.8	178	4,949	150.86	536	2,650,679
2002	27.1	178	4,826	188.58	607	2,930,244
2003	26.4	179	4,731	228.14	634	3,000,818

2004	25.8	179	4,613	303.87	811	3,742,880
2005	25.1	179	4,498	189.55	523	2,353,055
2006	24.5	179	4,385	360.89	971	4,257,379
2007	23.9	179	4,276	323.97	829	3,546,223
2008	23.3	180	4,192	563.93	1,641	6,879,544
2009	22.7	180	4,087			5,000,000
2010	22.1	181	4,007			5,000,000
TOTAL						59,892,837

WST: Western Samoan currency. Source: McGregor, A (2011)

Table 2. TIP Farmer Rankings of Trialed Taro Cultivar.

Variety	Vigour	Yield	TLB resistance	Sucker Production	Palatability
PSB-G2 (taro fili)	3.1	2.4	2.0	3.4	4.0
Pastora	3.8	3.3	2.9	3.2	1.5
Pwetepwet	3.4	2.9	2.7	3.8	2.2
Toantal	3.3	2.3	1.7	2.7	3.5
Palau 3	3.3	3.0	2.6	3.1	2.9
Palau 4	3.1	2.1	2.6	3.1	2.9
Palau 7	3.5	3.0	2.8	2.8	2.4
Palau 10	3.9	3.8	3.5	3.2	3.2
Palau 20	3.7	3.5	2.6	2.9	3.6
Niue (pre 1993)**	3.9	3.9	-	3.1	4.0
Niue (post 1993)	1.9	2.0	1.1	1.9	1.9

Sources: SPC Taro Leaf Blight Manual p.13 and Hunter et al. 2007, Rankings for all criteria are based on 1= unacceptable; 2= okay, but not good; 3= good; 4= outstanding.

Farmers were asked to rank taro Niue for the criteria highlighted before and after the arrival of TLB.

8 Figures

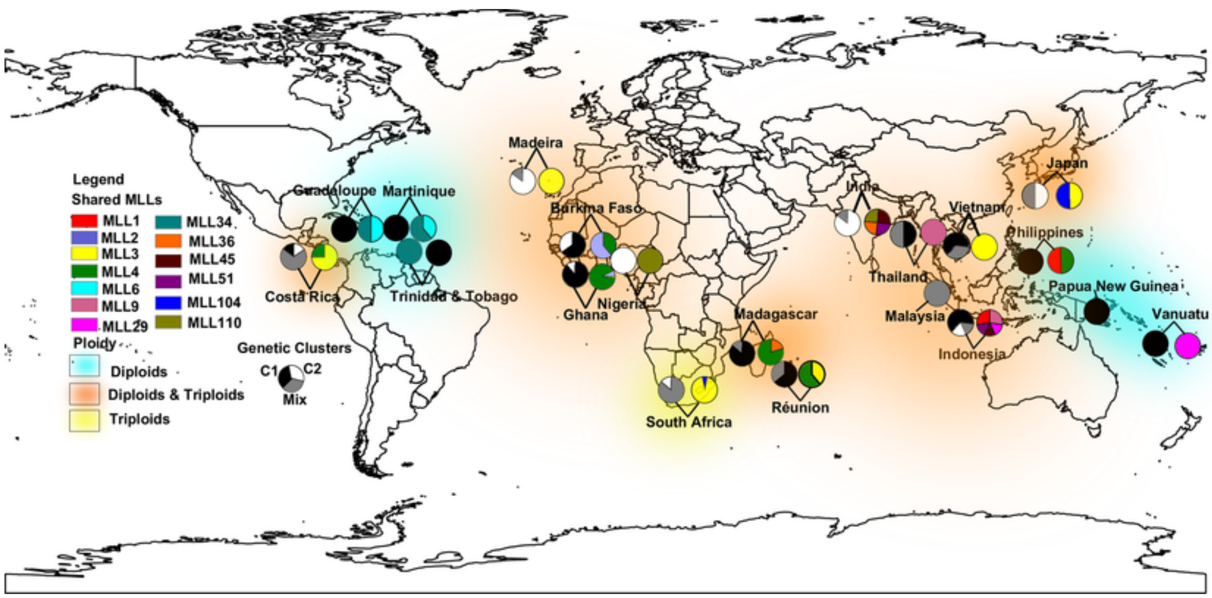

Figure 1. Geographical distribution of taro cultivars. Source: Chaïr 2016

Note: Map showing the geographical distribution of the cultivars (i) after Bayesian clustering assignment (black, grey and white pie chart in each linked pair of charts), (ii) of the ploidy levels inferred from the number of alleles per microsatellite locus, (iii) and of the multi-locus lineages (MLLs) in cultivated taro (coloured pie chart in each linked pair of charts)

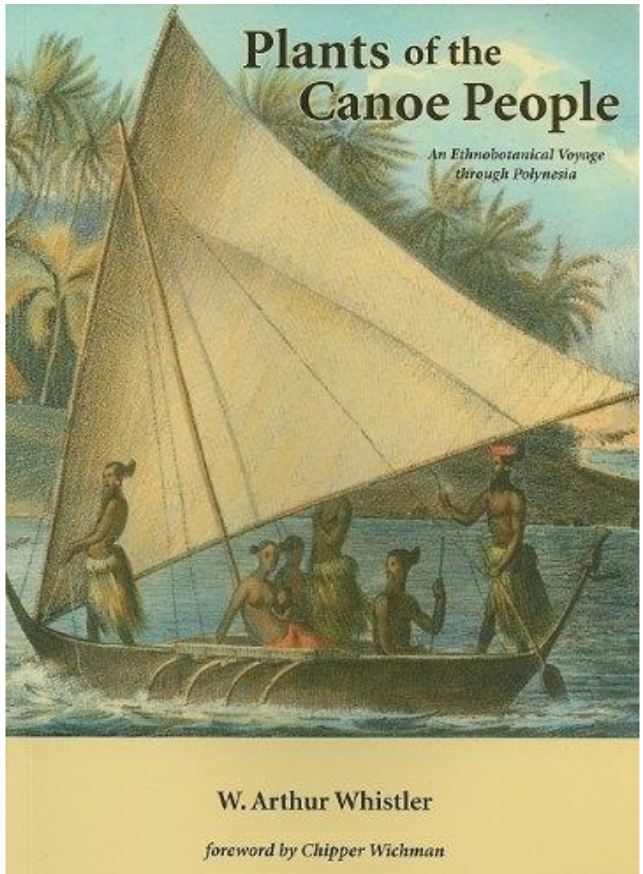

Figure 2. *Plants of the Canoe People: An Ethnobotanical Voyage Through Polynesia* by W. Arthur Whistler (book cover image)

Figure 3. Hawaiian artist: Maggie T's depiction of Haloa-naka

Figure 4. Mr. Moafanua Tolo Iosefa at the beach | Nadi, Fiji while at PS4L Validation Workshop 2018. Photo by Sefra Alexandra

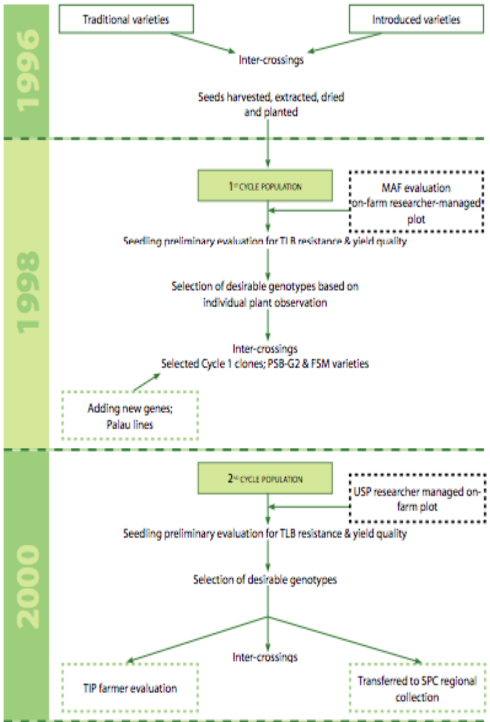

Figure 26: Systematic diagram of the Samoa taro breeding programme based on the combined recurrent selection process and modified back-crossing with a cultivated genotype for a marketable eating quality.

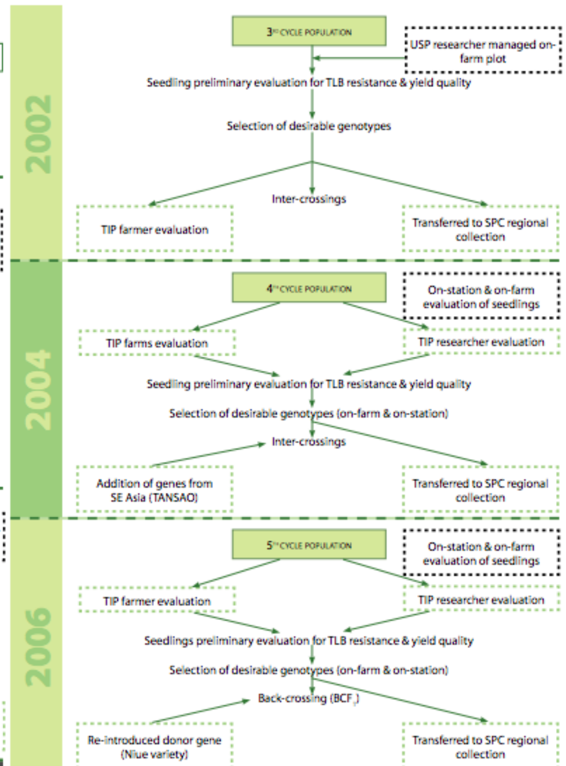

Figure 26: continued

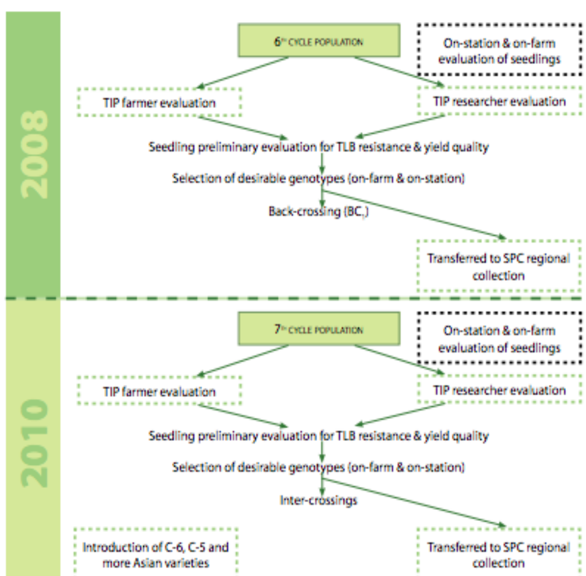

Figure 26: continued

The diagram (Figure 26) shows how the selections were made and the breeding lines were evaluated. Selections of desirable lines were made both on-farm and on-station. A combination of these selections was sent to SPC CePaCT to be included in the taro collection held by CePaCT and to be virus tested so that they were available for distribution.

Figure 5. Systematic diagram: The Samoa TLB resistant breeding cycle program led by Tolo Iosefa | SPC's Taro Leaf Blight Manual p. 26-28

Figure 6. Dr. Michel Ghanem, Programme Leader of Genetic Resources SPC and the legendary breeder Dr. Vincent Lebot, Researcher at the Ministry of Ag. Vanuatu and CIRAD in Port Vila ... on expedition| Photo taken by Sefra Alexandra

Below is a map that shows the flight path the brave plantlets, safeguarded by CePaCT, have flown to help prepare or respond to genetic resource needs far beyond the Pacific region.

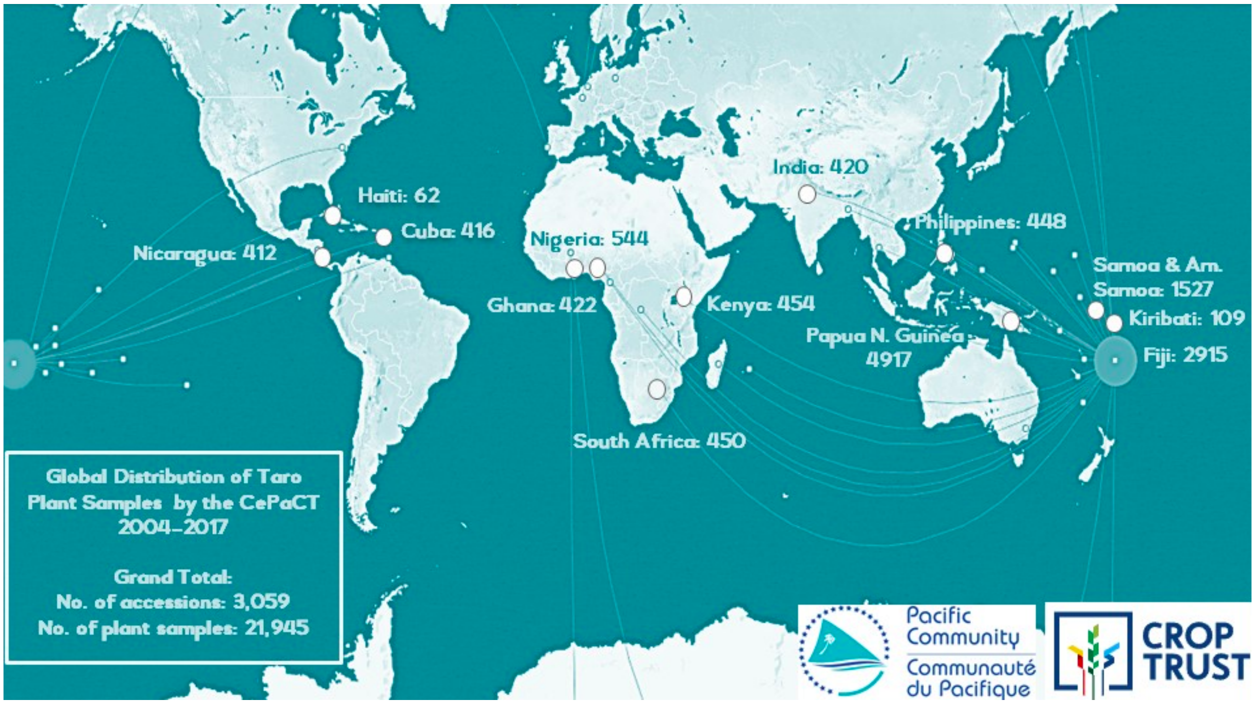

Figure 7. Global distribution of taro plant samples by the CePaCT. This map illustrates the number of taro germplasm accessions distributed Globally from the CePaCT collection. This image highlights the global demand for this vitally safeguarded germplasm. This map was adapted from the Crop Trust website by the Authors.

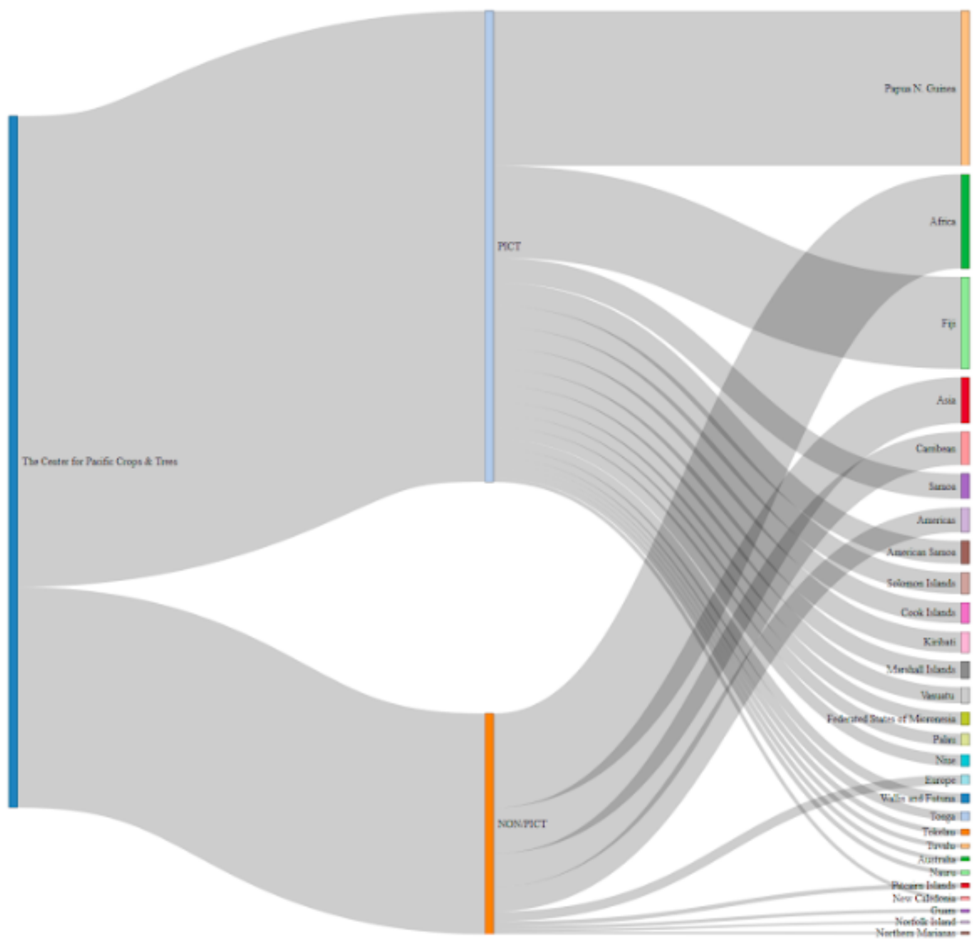

Figure 8. Sanky diagram displaying the relative proportion of the number of accessions distributed by CePaCT both within the Pacific region as well as globally. Generated by Albert Fiu: Document & Database Technician, SP

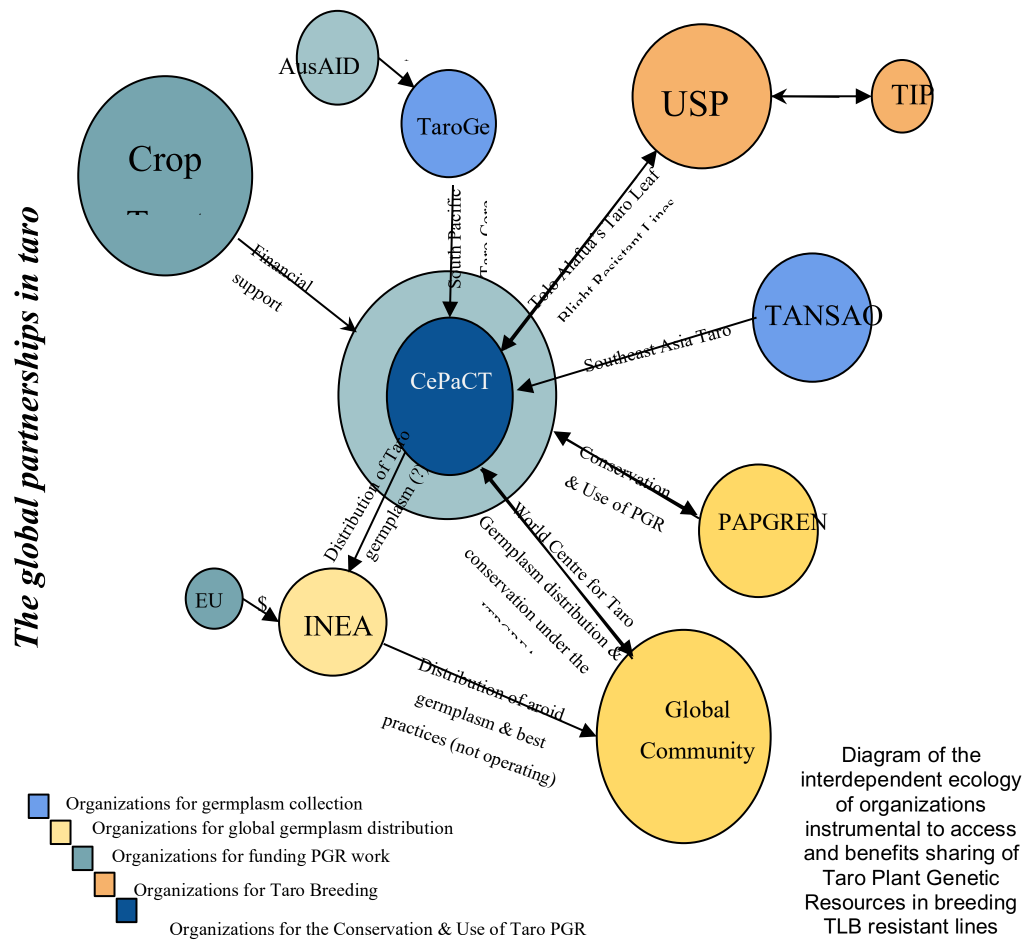

Figure 9. The global partnerships in taro conservation for breeding TLB resistant lines. Source: Authors