TARO LEAF BLIGHT MANUAL

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TARO LEAF BLIGHT MANUAL

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Abbreviations

AusAID, Australian Agency for International Development

CePaCT, Centre for Pacific Crops and Trees

CIP, International Potato Centre

fob, free on board

GA, gibberellic acid

ICCAI, International Climate Change Adaptation Initiative

INEA, International Edible Aroids Network

MAF, Ministry of Agriculture and Fisheries

PCCSP, Pacific Climate Change Science Programme

PPB Participatory Plant Breeding

TANSAO, Taro Network for Southeast Asia and Oceania

TaroGen, Taro Genetic Resources: Conservation and Utilization

TIP, Taro Improvement Programme

TLB, taro leaf blight

SPC, Secretariat of the Pacific Community

USP, University of the South Pacific

Introduction

Section 1 of this publication discusses taro leaf blight and its effect on taro cultivation in Samoa. It considers the approach used by Samoa to tackle the disease and how, through a participatory breeding programme, taro was once again returned to the fields of Samoa.

Section 2 is a more practical section and explains the steps involved in a taro breeding programme and how to establish a participatory taro breeding programme. A step by step approach is used to explain the breeding process which should enable any farmer, researcher or extension agent to breed taro.

Section 3 is brief but aims to highlight the risks of taro leaf blight (TLB) faced by other countries in the Pacific, under the projected climate conditions for the region, and to recommend strategies on which these countries should embark.

Section 1 Taro: the challenge of taro leaf blight

(a) Introduction

Taro is a clonally propagated aroid, cultivated largely in the humid tropics. Taro (*Colocasia esculenta*) has been grown on irrigated terraces in tropical Asia for 10,000 years and as such is probably the oldest crop on earth. The origin of this important crop, its domestication and spread has been much discussed (Yen and Wheeler 1968; Plucknett 1984; Matthews 1990; Lebot and Aradhya 1991; Lebot 1999; Lebot 2009). The general consensus is that taro was most likely domesticated in different locations throughout an area that stretches from India to Southern China, Melanesia and northern Australia. The spread of taro into the Pacific Islands was probably due to the settlement of the islands of Melanesia by Austronesian sailors in the period 3500 to 3000 BP although it is likely that taro was already being cultivated by the indigenous people in New Guinea (Lebot 2009). The dating of starch grains from Bourewa, southwest Viti Levu, provides evidence of taro cultivation in the period 3050 to 2500 BP in Fiji (Horrocks and Nunn 2006).

Globally, about 12 million tonnes are produced from 2 million hectares with an average yield of 6 tonnes per hectare (FAOSTAT 2010). Taro is cultivated mainly in developing countries using low input production systems. It is generally considered an easy crop to grow provided there is adequate rainfall (irrigation is rare). Its importance in smallholder production systems makes it a key food security crop in many countries. However, for some countries in the Pacific region, for example, Fiji, taro is a major export and therefore is a significant source of foreign exchange.

Almost all parts of the plant can be eaten, with the corms being most commonly consumed. The corms, which can be baked, roasted or boiled, are an excellent source of carbohydrates with the benefit of a low glycaemic index. They are high in carbohydrates and low in fat and protein, but large servings of taro corms can be a significant source of protein; taro corms can serve 'as a dietary source of carbohydrates and potassium for all ages and as a major protein source for adults who depend on taro as their staple food' (Standal 1983). The corms also provide a good range of vitamins, amino acids and minerals, with abundant levels of potassium. Leaves are also frequently consumed providing a good source of protein (higher than in the corms), minerals, and vitamins. In some countries, the flower and petiole are also used in the preparation of meals. (Matthews 2010) Relatively little information is available on their nutritional qualities, but Standal (1983) reported that the petiole contains a generous amount of potassium.

(b) Taro leaf blight: the disease and its history

Figure 1: Symptoms of taro leaf blight.

Taro leaf blight is a major disease of taro, caused by the fungus, *Phytophthora colocasiae*. The main damage can be seen on the leaf lamina but postharvest rot of the corm can occur, as well as petiole rot in susceptible varieties. The appearance of the disease has been well-described (ACIAR 2008). The first sign of the disease are water-soaked lesions, which expand to form large brown spots; infection is generally first observed on those leaves (Figure 1) where water collects. The lesions expand at night forming a 3–5 mm water-soaked margin, which dries out during the day; the following night a newer water-soaked margin forms. At night large volumes of sporangia form around the expanding margin of the lesions such that they take on a white powdery appearance. TLB lesions exude droplets of a yellow to brown liquid which dries out during the day producing dark brown, hard deposits, which is a characteristic of the disease (Singh et al. 2012). TLB is a very destructive disease, reducing the leaf area available for photosynthesis, and the number of functioning leaves. As seen in Samoa, susceptible varieties can be totally destroyed.

Usually the petiole is not infected but collapses as the leaf blade is destroyed, however, in American Samoa and Samoa, petiole infection was seen in susceptible varieties (ACIAR 2008). Corm rots can usually be observed soon after harvest and entire corms can decay in 7 to 10 days. Areas damaged at harvest are sites for the rots to occur, and infection is encouraged by wet, warm conditions (Singh et al. 2012).

Taro leaf blight was first described in 1900 by Raciborski (Ooka 1990), and is now present in Africa, Southeast Asia and the Pacific. The centre of origin for the disease is thought to be Asia (Trujillo 1967), and it was first recorded in the Philippines in 1916. It is likely that movement of the disease to Micronesia was via the Philippines as the disease was first recorded in Guam in 1918 (Weston 1918). In the Pacific the disease has been recorded in American Samoa, Federated States of Micronesia, Guam, Hawaii, Northern Mariana Islands, Palau, Papua New Guinea and Samoa (ACIAR 2008).

Phytophthora colocasiae has a limited host range, mainly infecting *Colocasia* spp. *Xanthosoma sagittifolium* is immune; *Alocasia macrorrhiza* does get infected but the impact is much less severe due to a low production of inoculum (Singh et al. 2012) TLB is easily spread over long distances through the use of infected planting material. Corms left in the field after harvest can also provide a source of inoculum in newly planted taro plots. Although mycelium usually lasts less than 5 days in the soil, encysted zoospores can survive for up to 3 months (Brooks 2011).

(c) Taro leaf blight and its impact on taro cultivation in Samoa

Taro was a major export of Samoa. In 1993, taro exports to New Zealand from Samoa were 6300 tonnes, with an fob value WST9.5 million, representing 60 per cent of exports in that year (McGregor et al. 2011). The largest volume of exports was 7800 tonnes which occurred in 1989 (Central Bank of Samoa 1999). For the 5 to 6 years after TLB, little taro was consumed in Samoa in contrast with the pre-TLB period when almost 96 per cent of agricultural households grew and consumed taro (1989 Agricultural Census). TLB meant that Samoa suffered an annual loss in foregone domestic taro consumption valued at WST11 million and a taro export market valued at WST9 million (McGregor 2011).

TLB was first detected in American Samoa in June 1993 (Brunt et al. 2001). In less than one month, TLB was diagnosed and confirmed in Samoa. The disease rapidly spread throughout both the islands of Samoa, encouraged by the planting of a highly susceptible variety, favourable weather conditions, notably high relative humidity caused by an unseasonably wet period between July and August 1993 and the movement of infected planting materials. At the time of the disease, taro cultivation in Samoa was based on one variety, taro Niue, which was preferred by overseas markets. This variety was totally susceptible to the disease, as were all other Samoan varieties.

(d) Cultural and chemical control of taro leaf blight

Cultural methods were investigated, for example, the removal of infected leaves during the early stages of disease development, but these practices proved ineffective in Samoa. The highly epidemic nature of the disease meant that significant defoliation was required, affecting the yield of the crop. In addition removing leaves on relatively large plantations was considered difficult especially when plantations were often located away from farmers' homes. Other methods are available, such as intercropping and planting during the dry season but these methods were not investigated in Samoa (Singh et al. 2012).

Successful control of TLB is possible with chemicals even in high rainfall areas. A range of fungicides, either protective or systemic have been found to provide effective control, but there is evidence that results with chemicals can be variable (Jackson et al. 1980). In Samoa, the major consideration was that the continuous use of such chemicals is neither economically sustainable nor environmentally desirable.

The failure of both cultural and chemical disease management strategies meant that taro production in Samoa came to a virtual standstill. Within 2 years from the start of the outbreak, only 200 farmers were growing taro, those with the resources to purchase fungicides. By 1994 supplies of taro on the local market were only one per cent of the supplies of the previous year. As a result imports of rice increased significantly leading to large trade imbalances (Singh et al. 2012), and possibly a decline in the nutritional status of communities.[1]

1 Polished white rice provides some energy and protein, but very few vitamins and minerals compared to taro root or leaves (SPC, 2006).

(e) Breeding for resistance to taro leaf blight

Difficulty in controlling TLB using chemical and cultural methods generated interest in finding varieties resistant to the disease. There was relative optimism with this approach as molecular studies clearly showed the existence of two distinct genepools in Asia and the Pacific, with the diversity in Southeast Asia being far greater than that found in the Pacific (Lebot and Aradhya 1991; Mace et al. 2006). There was also potential to find some resistance within the more western reaches of the Pacific as the genetic base of taro narrows from west to east, as clearly demonstrated by the susceptibility of all the Samoan varieties to TLB.

A five-year regional project 'Taro Genetic Resources: Conservation and Utilization' (TaroGen) funded by AusAID provided the resources to collect taro from around the region and to support a breeding programme in Samoa. The breeding programme in Samoa was based on a participatory approach in part to address concerns by farmers that evaluating taro through the more conventional on-station approach delayed farmer access to varieties, which was obviously a priority in those post-TLB years. The establishment and development of the participatory approach will be discussed later in this section.

The TaroGen project agreed that the most effective means of controlling TLB was polygenic or horizontal resistance. Polygenic resistance is controlled by many genes; the breeding process involves the systematic selection of resistant individuals from a population followed by a recombination of the selected individuals to form a new population. The advantage of this strategy is that minor genes are accumulated which individually would confer minimum resistance but as a group have an additive effect and provide durable resistance.

Samoa embarked on a programme to screen and evaluate exotic taro varieties from the Pacific and elsewhere. Some resistance was found initially in varieties from the Federated States of Micronesia (FSM) and the Philippines. Four varieties were multiplied and further evaluated in trials during 1996 to 1998; from these trials the Philippine variety, PSB-G2 known in Samoa as taro fili, proved to be the most satisfactory in resistance to TLB, and in dry matter content (Brunt et al. 2001; Iosefa and Rogers 1999). Introductions from Palau were later evaluated and these also showed good levels of resistance against the disease; one variety in particular found favour – P10 which became known in Samoa as Polo voli. These varieties enabled taro once again to be found in the fields in Samoa. However, they did not meet all the requirements of the farmers and consumers, and when cultivated widely, their shortcomings became apparent. For example, taro fili was relatively susceptible to TLB (especially in wetter areas), had low yields and poor storability (Hunter et al. 2007). In addition despite taro fili having the right firmness and taste if boiled, when baked in the umu, its texture was said to be too hard. Clearly a more strategic approach to developing varieties more suited to Samoan environmental and cultural requirements was needed.

The breeding programme was established in 1996 at the Alafua Campus of the University of the South Pacific (USP) under the AusAID funded Farming Systems Project. Cycle-1 combined some varieties from FSM, Samoa with PSB-G2 from the Philippines. Cycle-2 saw the start of the participatory approach under the TaroGen project. Breeding lines from Cycle-1 were crossed with varieties from Palau. Taro Niue was introduced into Cycle-3 because of its importance for domestic and export markets. However, the progeny from the selected (top) Cycle-3 clones showed few taro Niue traits, most likely because the lines with taro Niue parentage were susceptible to TLB. These susceptible lines were still included in later crosses to try and bring in the desired Niue characteristics into the resulting breeding lines. Cycle-4 consisted of crossing Cycle-3 lines. The progeny from these crosses had more or less uniform characteristics, indicating that the breeding programme had reached a genetic ceiling, and that no further progress could be achieved if only taro diversity from the Pacific region was used. Varieties from Southeast Asia were available in the Pacific at the Secretariat of the Pacific Community (SPC) regional genebank, the Centre for Pacific Crops and Trees (CePaCT). CePaCT was originally the SPC Regional Germplasm Centre, established by the TaroGen project. CePaCT was able to access these varieties through a project similar to TaroGen but more focused on Asia – the Taro Network for Southeast Asia and Oceania (TANSAO). TANSAO worked with five countries from Southeast Asia, two Pacific countries (Papua New Guinea and Vanuatu) and two countries in Europe. Through the activities of the network a core collection of 120 varieties was established (Lebot et al. 2000). The varieties were tested for viruses at CePaCT before being distributed to Samoa. These varieties were evaluated for their field performance; selections were made for inclusion in Cycle-5. This input of diversity from outside the region significantly broadened the genetic base; unlike Cycle-4, the progeny from the Cycle-5 crosses showed a huge diversity in types, as did Cycle-6 progeny (Figure 2).

Figure 2: Two Cycle-6 lines, highlighting diversity in this cycle.

The newly acquired vigour provided an opportunity to breed back taro Niue in an attempt to incorporate that variety's palatability without sacrificing disease susceptibility. Several Cycle-5 lines, which included taro Niue genes from Cycle-3 breeding, were selected for Cycle-6. These clones were pollinated, using pollen from the Niue variety to generate the first Niue back-cross generation of Cycle-6 (C-6; BC_{-1}). Top selections of elite lines from Cycle-6 were inter-crossed to generate the second Niue back-cross generation of Cycle-7 (C-7; BC_{-2}). In 2010 genotypes of Asian and Vanuatu origin were selected from the taro collection at the Vanuatu Agriculture Research and Training Centre. Some selected lines had to be eliminated as they tested positive for taro badnavirus. Because the Vanuatu varieties were all susceptible to TLB, only two varieties from Malaysia and one variety from Indonesia were finally incorporated into the breeding programme. These new varieties were brought into Samoa with the aim of broadening the genetic base of the breeding programme which at the time of this publication has advanced to the third generation of Niue back-crossing Cycle-8 population (C-8; BC_{-3}).

Table 1: Summary of the top selections from TIP over the past 15 years

Cycles	Year	No of parental combinations	No of seedlings evaluated	Top selections***
Cycle-1	1996	4	2000	10
Cycle-2	1998	5	2000	26
Cycle-3	2000	26	2000	30
Cycle-4	2002	45	5000	30
Cycle-5	2005	30	5000	42
Cycle-6	2007	33 + 9 BCF_1*	11,000	40
Cycle-7	2009	36 (17 BC_1**)	12,000	25

*BCF_1 First filial generation of the back-cross to taro Niue.
**BC_1 Second generation of the taro Niue back-cross.
*** Top selections are sent to SPC CePaCT for virus testing, distributing and conservation.

This injection of 'new blood' from Southeast Asia was a huge boost for the breeding programme. Table 2 shows that both TLB resistance and corm yield have improved with each cycle.[2]

2 This analysis was completed before Cycle-8 availability.

Table 2: Summary from preliminary trials of selected seedlings for TLB screening from each breeding cycle generation (Iosefa et al. 2012)

Characteristics/Cycle				
No of functional leaves*				
	No of seedlings	**Mean Value**	**Min**	**Max**
Cycle-3	188	3.839	2	7.4
Cycle-4	296	4.091	2	6.8
Cycle-5	156	4.378	2	8.0
Cycle-6	100	4.091	2	6.3
Cycle-7	120	4.500	3	7.0
Eating quality score**				
	No of seedlings	**Mean Value**	**Min**	**Max**
Cycle-3	188	2.789	1	4
Cycle-4	296	2.832	1	4
Cycle-5	156	2.863	1	4
Cycle-6	100	2.896	1	4
Cycle-7	120	2.800	1	4
Corm yield (kg)				
	No of seedlings	**Mean Value**	**Min**	**Max**
Cycle-3	188	0.66	0.2	1.8
Cycle-4	296	0.82	0.4	1.5
Cycle-5	156	0.72	0.3	1.6
Cycle-6	100	0.46	0.2	1.2
Cycle-7	120	0.76	0.5	1.2

*Refers to number of healthy leaves per plant.
**Eating quality score: 1 = poor; 2 = OK; 3 = good; 4 = excellent.

Figure 3: The difference in yield between breeding lines from Cycle-6 and Cycle-7.

Five promising varieties, Samoa 1, 2, 3, 4 and 5, having passed consumer acceptability tests in Samoa at the time of this publication, have been approved by the government for export. Samoa 1 and 2 were progeny from Cycle-5, Samoa 3 from Cycle-3 and Samoa 4 and 5 were from Cycle-1. Samoa 1 and 2 are the two highly favoured varieties, preferred by farmers and for export to New Zealand and the United States mainland.

The Australian Centre for International Agricultural Research under the Pacific Agribusiness Research for Development Initiative is supporting work to explore consumer acceptability in New Zealand. Samoa 1 and 2, together with three breeding lines from Cycle-6 of the breeding programme will be subjected to sensory evaluation in comparison with the taro variety exported by Fiji (Tausala ni Samoa) and currently the desired variety in New Zealand. Information from this sensory trial will assist the government and exporters to identify the best taro varieties for export.

(f) Linking to diversity

The incorporation of taro diversity from another region, with a gene pool distinct from that found in the Pacific, into the breeding programme clearly showed benefits. These varieties from Southeast Asia were virus tested and no difficulties occurred either with importing them into Samoa and or releasing them into the field for multiplication and evaluation. These initiatives were all outcomes of networks which established links between countries and researchers, all of which benefited farmers. Taro is a crop that does not fall under the mandate of any of the centres within the Consultative Group on International Agricultural Research system, unlike sweet potato, for example, which is covered by the International Potato Centre (CIP) in Peru. This lack of a centre to cater for taro means that the crop suffers from a deficit of research, and therefore a lack of data on genetic diversity, pests and disease diagnostics and so on. TaroGen enabled collections to be established, characterized and then sustainably conserved through the identification of a core collection which represented the diversity in the region (Mace et al. 2010; Taylor et al. 2010). The establishment of a regional genebank within the SPC provided the location for the safe storage of that core collection and, importantly, a distribution hub supported by the capacity to conduct virus testing. Virus testing diagnostics were improved through support from Australian Centre for International Agricultural Research ACIAR during the time of the TaroGen project. The TANSAO project was very similar to TaroGen, enabling the core collection from the Southeast Asia region to be established and for more information on taro diversity to be generated.

As Figure 4 shows, these links have been maintained through TIP's continuing collaboration with SPC CePaCT. TIP has links with SPC CePaCT so that the programme always has access to virus tested diversity. At the same time, that linkage provides a mechanism which enables selections from the TIP to be shared with other farmers in the Pacific. The top selections from each cycle of the breeding programme are tissue cultured in the USP laboratory, and then sent to SPC CePaCT where they are virus tested, ready for distribution to farmers in the other 21 member countries of SPC. Furthermore, the Pacific region agreed in 2009, that the Annex 1 collections held for the region in CePaCT could be placed in the Multilateral System of the International Treaty on Plant Genetic Resources for Food and Agriculture. In this way these improved TLB-resistant lines are also available globally. A more recent network, the International Edible Aroids Network (INEA) has supported further sharing of this important material. INEA is a 5-year project (launched in April 2011) funded by the European Union, the aim of which is to use edible aroids, primarily taro (*Colocasia esculenta*) and cocoyam (*Xanthosoma sagittifolium*) as a model to improve clonally propagated tropical crops. Fifteen countries are involved in the project covering Africa, Asia, Central America and the Pacific. All countries have received 50 varieties each from SPC CePaCT. Different countries have received different genotypes but a set of improved hybrids and selected elite cultivars (including varieties from TIP in Samoa) were sent to all 15 partners. The aim was to distribute as much allelic diversity as possible to ensure that partners would broaden their germplasm genetic bases with the introduction of these varieties, and at the same time introduce TLB tolerance/resistance and good quality (taste) so that these major traits could be used and recombined with local varieties in future breeding programmes. Country partners are now propagating these genotypes, so that the introduced genotypes can be evaluated and compared with the local ones. After evaluation, 30 genotypes, corresponding to a combination of elite local and introduced genotypes will be selected and propagated for distribution to farmers. Breeding programmes in all participating countries will conduct targeted crosses between selected elite cultivars. Breeding strategies will be developed suited to each country's needs and constraints, and through links with several European Institutes, modern biotechnologies will be used to facilitate the work. Selections from the breeding programmes in all the 15 countries will be sent to CePaCT for sharing with the farmers of the Pacific and other countries worldwide.

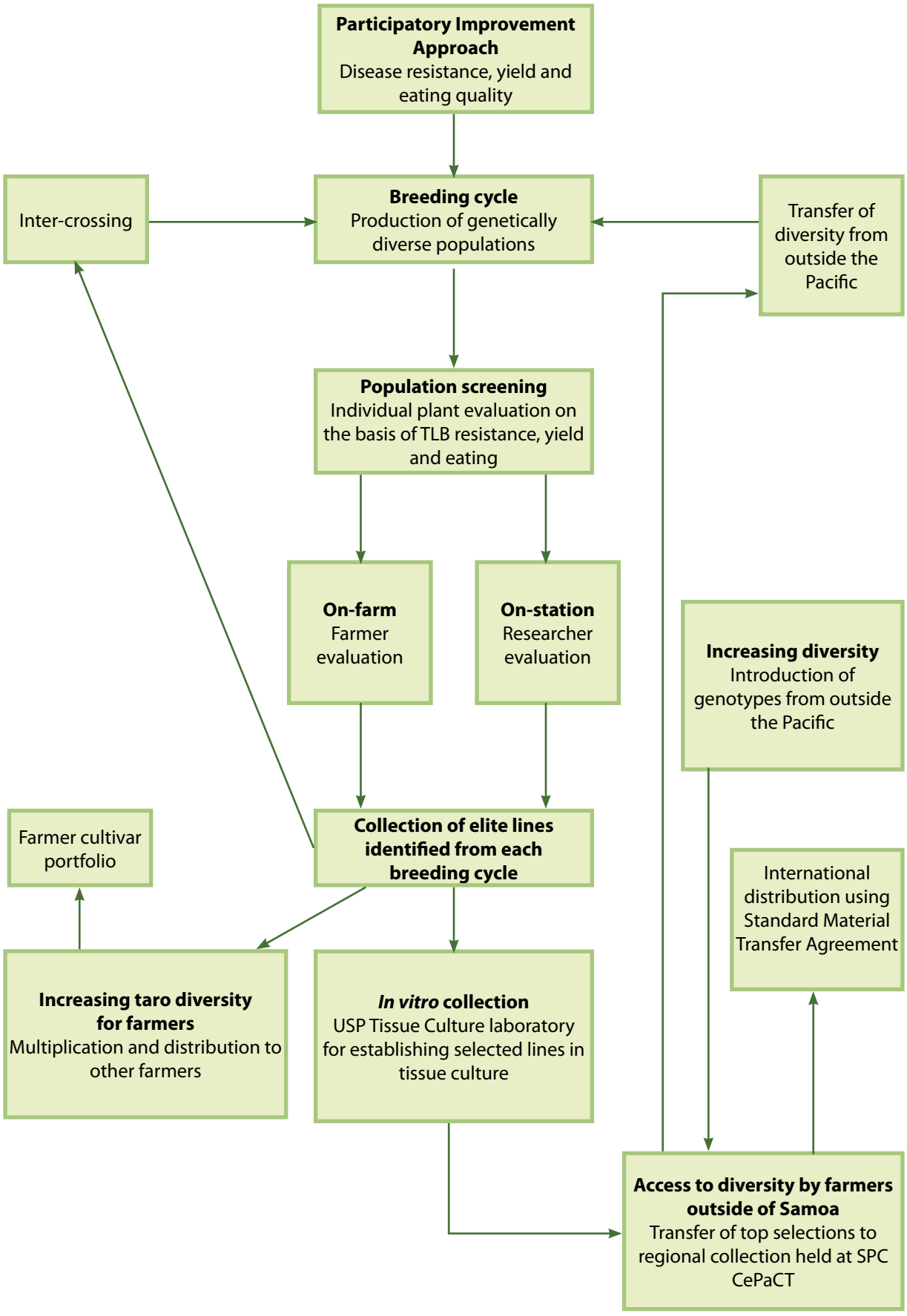

Figure 4: Taro Improvement Programme participatory approach illustrating links to informal plant genetic resources system and informal farmer network.

(g) Taro Improvement Programme (TIP) participatory approach

TIP commenced in 1999. Farmer focus groups were established to discuss how the programme could be managed. TIP also brought together scientists from USP and the Ministry of Agriculture and Fisheries, Crops Research and Extension. Membership was open to all farmers from the two islands of Upolu and Savai'i who agreed to compare taro varieties using the participatory approach. TIP farmers also agree to take part in monthly meetings, focus group discussions and regular farm visits to evaluate taro performance. Good geographical coverage of the island was a priority when establishing TIP, which exists to this day. TIP is male-dominated, reflecting the gender balance in taro cultivation in Samoa. Over TIP's 13 years of existence, more than 100 farmers have been involved and several thousand taro plants have been evaluated on their farms.

TIP is led by a researcher and breeder, Mr Tolo Iosefa, and the success of the breeding programme including the products (breeding lines) and the participatory approach is testament to his efforts and commitment. The first farmer-managed trials were planted in July 1999 using Cycle-2 varieties. TIP, using a classic plant breeding approach, took more than another decade to achieve substantive results, but throughout that time, the farmer members of TIP continue to be enthusiastic about the approach and the results, as shown by their regular attendance at monthly meetings at their own expense. An interesting and encouraging feature of TIP farmers is their relative youth; 65% of TIP members are under the 40 years of age. The interest and enthusiasm of TIP farmers in new varieties is exciting to watch; a field trip with farmers to different farms shows this very clearly, and reveals a high level of technical knowledge about the different varieties and consequently an ability to distinguish varieties, despite a similar outward appearance.

Participatory Plant Breeding (PPB) Approach:

The PPB approach makes taro improvement more relevant to user's needs compared with conventional breeding.

PPB involves farmers, extension agents and researchers and extension in criteria selection and priority setting. It therefore strengthens the link between these different stakeholders

Farmers involved in PPB provide different environments for evaluating new lines; they can select which line is best for their conditions as well as generating more information about the new lines.

PPB helps to increase the diversity of taro grown by farmers reducing the risk of similar disease outbreaks in the future.

PPB provides the basis to learn more about what the farmers want from improved taro varieties.

PPB makes more effective use of limited time and resources of researchers and extension staff PPB helps to speed up the process from selection to dissemination of acceptable, improved varieties.

Section 2: Participatory taro breeding

(a) Establishing and developing a participatory approach

Hunter et al. (2007) has described the methodology on which TIP was based. Basically, crop-focused Participatory Rural Appraisals were conducted with farmer groups to learn more about taro production problems, perceptions of taro varieties and what criteria were considered important when selecting a variety. Appraisal techniques used included focus group discussions, farm visits, farmer interviews and ranking exercises (Table 3 shows a summary of ranking of exotic varieties by the farmers).

The breeding and initial population screening is carried out by the breeder (Mr Iosefa) at USP, Alafua. Individual plants are evaluated for TLB resistance, yield and eating quality. Farmers visit demonstration sites at the USP campus to observe the breeding lines and to discuss their attributes and performance. Farmers can select those lines which will perform best in a specific location. Originally in the years when TIP was being established, farmers were asked to select up to eight varieties with 10 planting suckers per variety. The field design used by the farmer is a simple non-replicated layout, using single rows of each variety with farmer traditional spacing. The importance of labelling, plot maintenance, a trial layout plan and no use of fungicides is emphasized. Ongoing management of the trial plots is based on normal farmer practice and is the responsibility of the farmers. More recently (since Cycle-4) because of the large volume of seedlings produced from the breeding block (as many as 8000), TIP agreed that the farmers could take seedlings from the remaining stock after on-station planting. Interestingly the top five varieties approved and recommended by MAF (Samoa 1, 2, 3, 4 and 5) were all selected by farmers.

Monthly TIP meetings held at USP have been the main forums for focus group discussions. During these meetings the importance of collecting data is always reinforced, as well as the requirement to feed back information to the group. The criteria used by the farmers to evaluate the varieties include vigour, yield, TLB resistance, suckering ability and palatability; the latter is scored using a ranking system based on 1 to 4 (unacceptable to outstanding). Farmers are also expected to notify researchers when varieties are mature, so that accurate yield data can be collected. All corms and planting material remain the property of farmers. At monthly meetings, tasting is often included in the agenda so that all the farmers can comment on new varieties.

Table 3: Summary of farmer ranking of earlier exotic taro cultivars*

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	1.6
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

* Source: 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.

(b) Selection of parent materials for the breeding programme

Selection of parental lines has to be planned in advance. A successful breeding programme depends largely on the selection of parental genotypes; the success of the breeding programme in Samoa was largely due to the availability of good genetic material from different sources. Parental material should be selected from a wide range of varieties (both local and exotic), which have been evaluated for important agronomic characteristics such as pest/disease resistance, high yield, and good eating quality. Other considerations should be that they adapt well under diverse agro-climatic zones where disease pressure, such as TLB, could vary and acceptability by farmers and consumers.

(c) Promoting taro flowering

Some taro varieties flower naturally but generally Pacific taro has to be encouraged! Promoting taro flowering can be achieved by spraying the leaves with a solution of gibberellic acid (GA) dissolved in water. The optimum concentration of GA to use is 500 ppm per single application (Wilson 1990). In Samoa, ProGibb Plus 2X has been used to provide GA; this commercial formulation comprises a soluble powder that can be used at a rate of 2.5 gm/L to provide 500 ppm GA. As taro leaves are waxy, GA is always used with a surfactant, known as Agral LN, at a rate of 2.5 mL/L.

If your GA is not ProGibb Plus 2X you will need 0.56 g/L (it has a molecular weight of 346.37 gms) to provide a 500 ppm solution. Because of its limited solubility, you will have to dissolve it first in alcohol or acetone.

According to Wilson (1990) GA should be applied to taro plants when they are fully grown and have produced around three to five healthy leaves per plant. However, the presence of TLB in Samoa affects the number of healthy leaves available for spraying. To avoid early TLB infection on the varieties/plants selected for the breeding programme, these should be planted under a 50 per cent shade nursery as pot plants. Frequent watering and fertilizer applications are essential to promote good plant growth and, if necessary, insecticide application. A breeding block should also be located some distance from any taro plot to avoid early TLB infection. In Samoa, only plants with 5 or 6 healthy leaves per plant, which have been disease-free for the first 3-5 months, are sprayed with GA.

What volume of GA 500 ppm solution do you need?
If you are using a small hand-pumped sprayer then 30 mL/plant is sufficient; if using a compressed air sprayer then 50 mL per plant will be required.

When is the best time to spray? The early hours of the morning are the optimum time for spraying (Wilson 1990). Spraying should be carried out on a sunny day, and not in the rain. Both sides of the leaves, petiole and any newly emerged leaf must be sprayed. A small (5 L) hand pump sprayer is recommended as it is easy to carry through the taro plot.

When will the flowers appear? From the time of the first application of GA to the time of the appearance of the first inflorescence should take about 80 days in early flowering varieties and up to 125 days in late flowering varieties. Simultaneous flowering of parents with different flowering times can be achieved by either staggering dates of planting or dates of GA application.

The first sign of flowering is the splitting of the main stem into two; one part continues to produce leaves while the other part starts to produce a floral bract or flag leaf before an inflorescence or true flower starts to emerge a few days later. In most cases incomplete flowers will appear before any complete or true inflorescences. Some varieties produce only one flower while others will produce six or more. Generally flowers will appear singly at a rate of one every 7 or 10 days; sometimes the number of inflorescences per plant is a reflection of the vigour of that variety. Apart from inducing flowers GA also stimulates sucker and stolon production.

GA-induced deformities:
Some GA-induced deformities will appear before the normal inflorescence. These deformities include incomplete inflorescences that contain spathes but no spadices and patches of floral colour and texture on the leaves.

(d) The taro flower

Small flowers are found in inflorescences which consist of a spadix fully contained within the spathe. The male and female flowers are in different places on the inflorescence. The male flowers (staminate) are found at the top of the inflorescence and the female flowers (Figure 5) (pistillate) are located at the bottom of the inflorescence; they are separated by a constricted band of sterile flowers. The female flowers are completely enclosed within the spathe, which restricts the entry of any insects, pollen or foreign particles from outside.

Figure 5: Taro flower.

The colour of the spathe varies and depends on the colour of the petiole. Usually varieties with green or yellow coloured petioles always produce inflorescences with spathes that are yellow at the top (male flower) and stigmas that are green. In the darker coloured varieties, the spathe ranges in colour from yellow through to dark purple, with purple stigmas.

A sterile tip can be found at the top of the male flower. Sterile flowers can also be found scattered among the fertile female flowers. Colour can distinguish the two types with fertile female flowers always being green or purple, and sterile flowers always white and larger in size. In some varieties, the sterile flowers can also appear purple, but this is very rare. The more sterile flowers that are found within the female flower, the fewer the seeds that will be produced.

(e) Pollination and fertilization

When the female flowers are the most receptive, they release a strong sweet aroma in the early hours of the morning. This sweet smell attracts pollinating insects. At the same time as this aroma is released, a crack or opening appears in the spathe just above the area of the sterile band that separate the male and female flowers (Figure 6). The following day, the male flowers on the same inflorescence produce pollen. Female flowers or stigmas are usually receptive 7 to 9 days after the inflorescence has emerged from the petiole sheath. Pollen is shed 8 to 10 days after the inflorescence has emerged or one day after the female has become receptive.

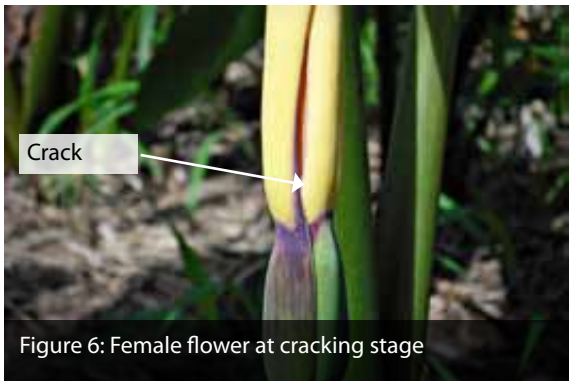

Figure 6: Female flower at cracking stage

(f) Hand Pollination

Cross pollination by hand is the only method by which crossing between two different taro varieties can be controlled. Before pollination, flowers of varieties selected to be mother plants have their male parts removed, a process known as emasculation. This process is always carried out at the time when the inflorescence is producing the strong aroma, when the male flowers are premature or when pollen is not being produced. Removing the male flowers prevents self-pollination.

Six important steps must be followed, to control pollination in taro:

Step 1: Preventing insect pollination
Step 1 is not required if female flowers are available for pollination, at the same time as the pollen is available from male flowers of the desired parent. If there are no female flowers to hand then the male flowers can be bagged for use the next day. However the procedure used by TIP breeder, Tolo Iosefa, is to remove the whole inflorescence and keep it in water until the next day. If seeds are being generated for a genetic study, all possibilities of insect pollination must be avoided. Therefore inflorescences should be bagged before and after hand pollination.

Step 2: Emasculation

Emasculating means the removal of the male part of the spadix before the pollen is shed, and must be carried out on all plants that will be used as the female parent. Emasculating is carried out at the same time as pollination. For both procedures, a knife with a small sharp blade will be required. Cut off the male portion of the spadix by cutting through the sterile flower band that separates the male flowers from the female flowers (Figure 7). You do not have to remove the spathe to find this sterile flower band – just look for the constricted area where the green basal tube of the spathe joins the yellow top of the spathe. This procedure has to be carried out on all inflorescences that will be used as the female parent.

Figure 7: Removal of male flower from female part that is ready for pollination.

Step 3: Pollination

Between 7 am and 12 noon is the best time to carry out pollination. On days that are cool, cloudy or wet, you might have to start the process later to coincide with the shedding of the pollen. On a male parent plant find an inflorescence that has pollen, remove it and carry to the female parent plant; care must be taken not to shake off any pollen. You can remove the inflorescence with pollen from the day before and keep it overnight in water. It is easier to remove the whole inflorescence rather than just the male flower. On the female parent plant, find an inflorescence that is at the 'crack' stage with an aroma, and remove the male part (emasculation).

Figure 8: Taro pollination – pollen applied by rubbing the male flower over the female flower.

The next step is to carefully cut away the spathe surrounding the female portion of the spadix, taking care not to damage the peduncle (the very base/stem of the inflorescence). Next cut off the spathe covering the male flower you have carried over to the female parent plant, and carefully remove this spathe. Gently rub the male flower and its pollen over the female flowers (Figure 8). Apply the pollen as evenly as possible to cover all the fertile female flowers, as a fruit with only a few berries (berries contain the seeds) will not develop. Remember to check inside the spathe section that surrounded the male spadix as often it carries pollen that can be used to dust the female flowers

Step 4: Bagging

After the pollination has been carried out, carefully cover the female inflorescence with a pollinating bag, which can be made of paper (Figure 9). This step prevents insect pollination and also the chance of rain washing off the pollen you have applied. In addition, the presence of the bag also helps to maintain the high humidity around the female flowers, which will increase the percentage of successful pollination. Another very useful tip, developed by TIP in Samoa is to pull back the spathe tissue to cover the female flower and then cover with the pollinating bag. The bag should remain in place for 2 to 3 days.

Figure 9: Paper bag to protect the female flower.

Step 5: Labelling

Labels with the date and the names or numbers of the parents should be attached to the peduncle of every pollinated plant (Figure 10). Easy to attach, long-lasting and weather resistant aluminium or plastic labels are recommended. An easy way to generate aluminium labels is to use the inside of drink cans. These can be easily cut up into label size; it is a very effective method of recycling. If for some reason labels are not available, then the information can be written on the peduncles of the pollinated flowers and labels attached later. The breeder's name in initials should also be on the label so that the breeder who carried out the pollination can be identified (see box below).

Figure 10: Labels.

By convention breeders write the female parent first when labelling a cross:
For example: Clone # C6-095B x Clone # C6-BCF1-064
12/09/08

TO

Step 6: Fruit bagging
Three days after pollination, the female flowers are no longer receptive, and the pollinating bag can be removed. The bag should not be left on for longer than 5 days because it keeps the developing fruit both too hot and too damp. In Samoa, because the developing fruits can be eaten by armyworms (one year almost 40 per cent of the fruits were lost due to armyworms), once the pollinating paper bag is removed, a fruit protection bag made from plastic fly screen should be attached. The fruit bag can be removed after about 2 weeks when the berries are fully grown; this will make it easier to check the fruit daily until the berries are ripe and ready for harvest.

(g) Harvesting the seeds

(i) Taro fruit
Taro fruit is a cluster of berries packed densely together to form a fruit head. The colour of the berries depends on the colour of the original variety. If the variety was green to yellow in colour then the berries will also be green, but a purple/dark coloured variety will produce purple berries.

In Samoa it takes 32 to 45 days after pollination (average of 39 days) before the fruit is ready for harvesting. Ripe fruit heads become soft. Dark green fruits turn a lighter green or yellow colour, whereas purple fruits remain the same colour. Some berries will ripen orange. It is important to check your pollinations every day. Heavy rain can wash all the seeds from soft berries onto the ground. The ripe fruit should not be allowed to become dry, because it is very difficult to wash the seeds out of the dry, hard berries.

Your pollination has not been successful if the peduncle becomes soft and falls over within 2 weeks.

Matured or ripe fruit heads must be harvested immediately, and taken to the lab for seed extraction. Care must be taken not to lose the label during harvesting and seed extraction. The method described previously of writing all the required information on the peduncle of the pollinated flower using a ball point pen can be used along with labels, if there is any concern that a label will be lost, as the labelling on the peduncle will remain intact until the harvest.

Figure 11: Matured taro fruit.

(ii) True taro seeds

The number of seeds produced per berry depends on the size of the fruit and the vigour of the plant. Taro seeds are very small, generally oval in shape, and with longitudinal ridges. Sometimes, however the seeds can be elongated or elliptical in shape. Ivancic and Lebot (2000) measured the sizes of taro seeds and estimated that average seed length was 1.4 mm (ranging from 0.7 mm to 1.7 mm) and average diameter was 0.569 mm (ranging from 0.4 mm to 0.75 mm). They also found that a big fruit (approximately 8.1 cm long with a diameter of 4.2 cm) contained 22,133 seeds. An average sized fruit (approximately 3 cm long) contained 1000 seeds or more whereas a small fruit contained 50 to 100 seeds.

(iii) Seed extraction in the lab

Figure 12: Fruit head cleaning, using a solution of 10% Clorox.

Figure 13: Fruit head is crushed to extract seeds.

Figure 14: Seeds are thoroughly washed to remove debris.

Figure 15: Seeds are extracted on a clean dry paper to dry.

1. Prepare a solution of 10% Clorox (domestic bleach).
2. Dip harvested fruit heads in the Clorox solution for at least 5 minutes.
3. Remove ripe taro fruit heads from the Clorox solution and wash using tap water.
4. Remove or detach the fruit head from the peduncle and remove the berries from the fruit.
5. Place the berries in a fine sieve (seeds must not be able to fall through) and crush them gently to extract the seeds.
6. Thoroughly wash the seeds with running water to remove seeds from debris; heavy viable seeds will sink to the bottom, pulp and lighter seeds (generally non-viable) will float to the top.
7. These steps can be repeated several times to ensure that the seeds are clean.
8. Extract seeds onto clean dry paper to dry (filter paper in petri dish).
9. Put dry seeds in a clean, labelled envelope and store in a cool, dry place.

Washing the harvested fruits in 10% Clorox is essential to remove micro-organisms such as fungal spores. This step will help to prevent taro seeds from any damping off problems during germination and when developing as young seedlings in the screenhouse.

(h) Record keeping

Record keeping is an important part of any breeding programme. During population breeding, it is very important that all crossings from each cycle are recorded, and also the varieties you have used as the pollen donor or mother plant. If a programme has been in existence for many years, you are likely to want to trace back the geneology of a line so that you can back-cross for a certain characteristic to re-introduce into your programme.

In TIP, many varieties are cross-pollinated to create horizontal resistance against TLB. Through mass recurrent, selection lines are identified from each population and then recombined to create a new, improved population, that is, a different cycle. With accurate record keeping, we can select lines for re-introducing at any stage of the breeding programme. For example, TIP decided that the variety Niue should be introduced back into the breeding programme because it was such a desired variety both for domestic consumption and the export market. The records enabled TIP to trace back some of the breeding lines from the crosses with Niue in Cycle 3.

The importance and usefulness of keeping records cannot be stressed strongly enough, which is why individual crosses are labelled. When seeds were harvested from a breeding block, each individual cross is assigned a cycle number; this number appears on the label along with the information on the parents. The female parent always comes first, then the male parent, followed by the date of pollination.

Cycle #	Parents	Poll Date
C-7	C6-095Bx C6-BCF1-064	11/09/08
C-7	C6-063x C6-BCF1-LM-L-003	18/09/08

Figure 16: Record keeping.

All individual seedlings selected from the population are assigned a cycle number which represents that selection or breeding line, and identifies the population it comes from. For example as shown in Figure 16, C6-095B is a Cycle-6 progeny, and a selection from the on-station researcher-managed preliminary trial. These cycle numbers or codes are permanent and do not change from year to year. C6-BCF1-064 is a cycle 6 progeny from a Niue first generation back-cross (BCF1). Figure 16 also shows how breeding lines selected by farmers from their on-farm evaluation plots are recorded. For example, in C6-BCF1-LM-L-003, LM represents the location (Leulumoega), L represents the farmer and the code is 003.

To keep records clear, simple and short, parental numbers are kept in separate files for the breeder's reference.

(i) Planting and growing the seeds

Seeds should be sown 1 or 2 days after cleaning. They can be stored inside a tin or glass jar with a close-fitting lid. A layer of the desiccant, silica gel, can be placed at the bottom of the container. Once the colour changes from blue to pink then the desiccant needs changing or drying.

Taro seeds are very small and grow very slowly, therefore special care is required for seed sowing and seedling management. A method was developed at the USP Alafua Campus to ensure good germination and healthy seedlings free of damping off diseases. Although the method is a little costly, it results in healthy, strong seedlings. Seeds generally germinate after 4 or 5 days. The germination rate ranges from 80 per cent to 90 per cent under normal room temperature, with lights on continuously in the room.

Figure 17: Sterilized potting mix for seeds planting.

Figure 18: Seed trays under the artificial light.

Figure 19: Seed germination, close up view of taro seeds under the microscope 10x.

Planting seeds inside a closed, clean room

Prepare a clean room to be set up as a seed germination lab. The temperature should be 25°C to 28°C. Extra lights should be installed to boost germination.

Use clean plastic containers or aluminium plates as seed trays; these should be dipped in a 10% Clorox solution before use.

Prepare potting mix for seed germination; overseas sterilized organic potting mix is used at Alafua when available.

Alternatively, potting mix sterilized with boiling water can be used, but allow it to cool for 6 hours before sowing seeds.

Scatter the seeds onto the surface of the potting mix; do not cover the seeds.

Place seeds under the lights; ensure that the lights are turned on permanently. This will give good seed germination.

Daily watering of seed trays is a must to keep the soil moist and provide enough water for germination.

Turn on fans at slow speed to prevent the lights making the temperature in the room too hot.

(j) Seedling management

Seedlings are very slow growing especially in the early stages after germination. Growth is helped if the seedlings can spend 2 to 3 weeks under the lights before being transferred to the insect-proof screenhouse. Frequent watering using distilled water is crucial at this stage. Water should be added so that the soil remains moist; if the soil is too wet, this will encourage damping off problems.

Seedlings are ready for transplanting at 3 to 4 weeks. At this stage the seedlings are strong enough to be planted individually into small polythene bags inside the screenhouse (see Figures 22 and 23).

These transplanted seedlings will need at least 2 to 3 weeks inside the screenhouse before they can be moved to the shade nursery (see Figure 24). Tap water can be used at this stage as the seedlings are sufficiently strong

Seedlings will spend 3 to 4 weeks in the 50 per cent shade nursery for hardening and bulking up before being ready for distribution for field planting (see Figure 25). Seedlings are ready for field planting when they are 10 to 15 cm high, and have three to five leaves. Seedlings can be planted at the spacing commonly used by farmers. Raising seedlings takes 3 to 4 months from germination to field transplanting in the optimal growing conditions at the USP Alafua Campus.

Figure 20: Seedlings transferred to the screenhouse after 3 weeks under artificial light.

Figure 21: Transplanting seedlings into seed tray.

Figure 22: Seedling transplant into polythene bags.

Figure 23: Seedlings in polythene bags.

Figure 24: Seedlings ready to move from screenhouse to 50% shade.

Figure 25: Seedlings in shade nursery ready for distribution.

(k) Selection process

Two common methods of evaluation were used in the taro breeding programme in Samoa: recurrent selection and back-cross breeding.

- Recurrent selection

Recurrent selection is a long-term continuous process; during each breeding cycle parent lines are selected and cross-pollinated so that the resulting seedling population is improved. A new cycle of breeding (a new Crossing Block) is started every year. A recurrent selection breeding programme has three steps:

1. create a base population by selecting parent varieties or breeding lines and inter-crossing them in as many combinations as possible.

2. grow, evaluate and select the seedling-derived lines grown from the seeds produced in the first step as described above. Inter-cross these selected lines in as many combinations as possible.

3. include the new germplasm (lines you have selected to be parents) in the Crossing Block when available (known as introgression).

The first population breeding programme for horizontal resistance against TLB was carried out in 1996, where local and introduced varieties (Pwetepwet and Toantal from FSM, and PSB-G2 from the Philippines) were used as parents to create the original or base population. The original population was evaluated and screened by the Ministry of Agriculture and Fisheries (MAF) Research Division. They selected 30 seedlings as promising lines for farmers' use and for further crossing. These selections were known as Cycle-1, and MAF named these top selections as the Nuu varieties.

Eight lines from Cycle-1 were selected for the development of the Cycle-2 population, and for the first time, varieties from Palau were introduced and crossed with the Cycle-1 selections and several local varieties in an aim to widen the genetic base and accumulate resistance against TLB. Top selections from Cycle-2 were inter-crossed producing Cycle-3 breeding lines, and the same process continued until Cycle-4.

From Tolo Iosefa:
'What I observed in the evaluation of cycle-4 was the uniformity of the population in plant height, petiole colour, shape of leaves, levels of TLB disease infection per leaf as well as yield. I made a decision to see if I could import totally different materials in an effort to widen the genetic base of taro.'

Varieties from Southeast Asia collected during the TANSAO project were imported from SPC, and successfully inter-crossed with Cycle-4 to create Cycle-5. This introgression of TANSAO germplasm into the breeding programme widened the genetic base resulting in significant variation in morpho-agronomic characteristics; Cycle-5 plants were superior, compared with plants produced during previous cycles. The variety Niue was reintroduced and back-crossed with several promising lines from Cycle-5, the aim being to create genotypes that produced the Niue type characteristics of palatability, aroma and pink coloured corm. This reintroduction of the variety Niue meant that this variety was introduced twice into the programme, because of the Niue parentage of some of the Cycle-5 lines (from Cycle-3 breeding).

Top selections from each population except for Cycle-1 were transferred to SPC CePaCT for conservation and, importantly, virus testing and further distribution.

- Back-crossing

The introduction of taro Niue was made in response to the farmers who were keen to try and 'develop' a variety as close to Niue as possible because of its eating quality, which made it also the market preferred variety.

Several promising lines from Cycle-5, which included Niue in their geneology, were used as recurrent parents inter-crossing with the variety Niue. Because of Niue's susceptibility to TLB, it was only used as the pollen donor to develop the first generation of 'Niue Back-crossing'. Very few progenies from the first filial generation of Niue BCF_1 were selected to advance the introgression to BC_{-1}. Progenies were selected based on eating quality, to resemble Niue taro taste as much as possible.

From Tolo Iosefa:
'I find it very difficult to nurse fruit heads from the variety Niue as their fruits collapse prematurely when the mother plant is weakened by TLB.'

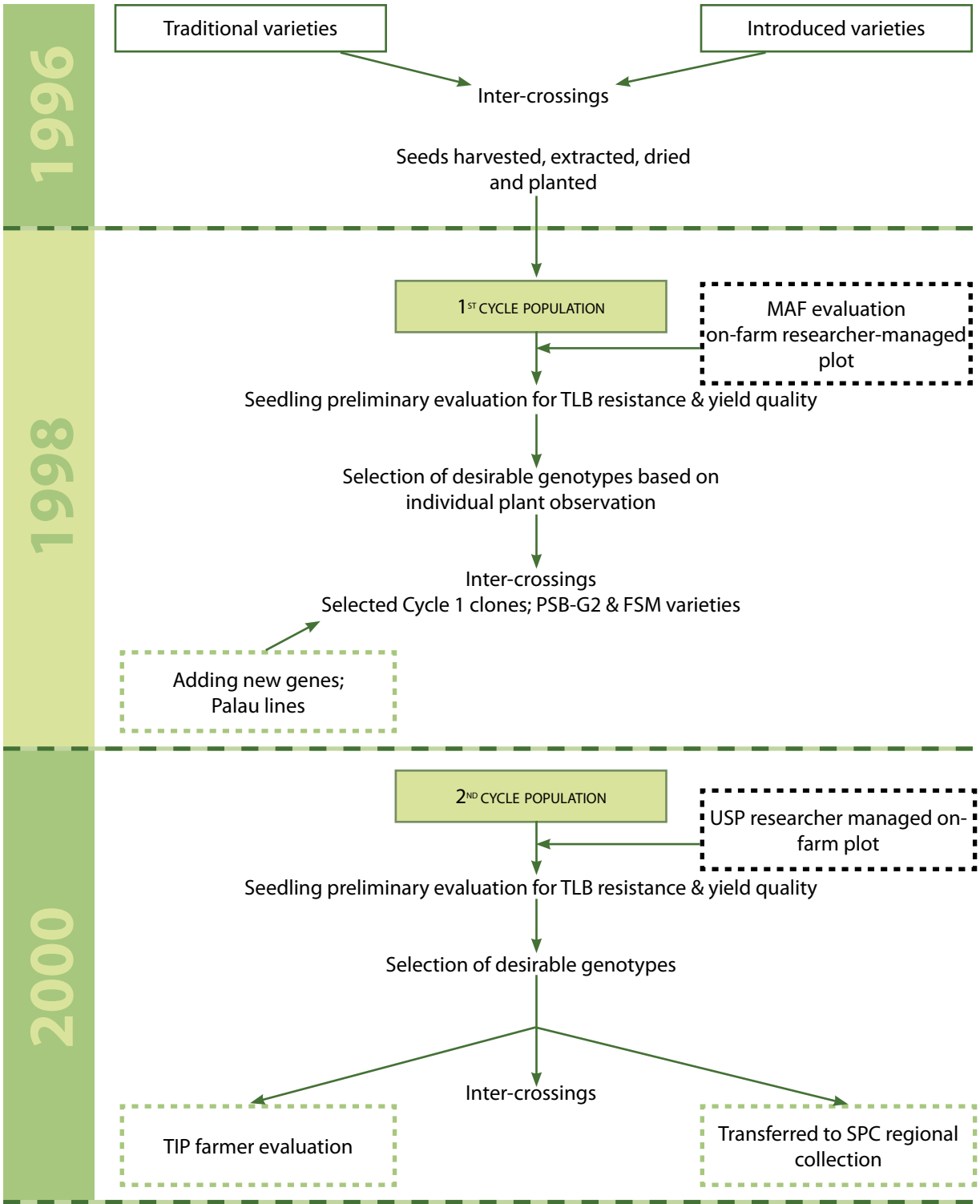

Figure 26: Systematic diagram of the Samoa taro breeding programme based on the combined recurrent selection process and modified back-crossing with a cultivated genotype for a marketable eating quality.

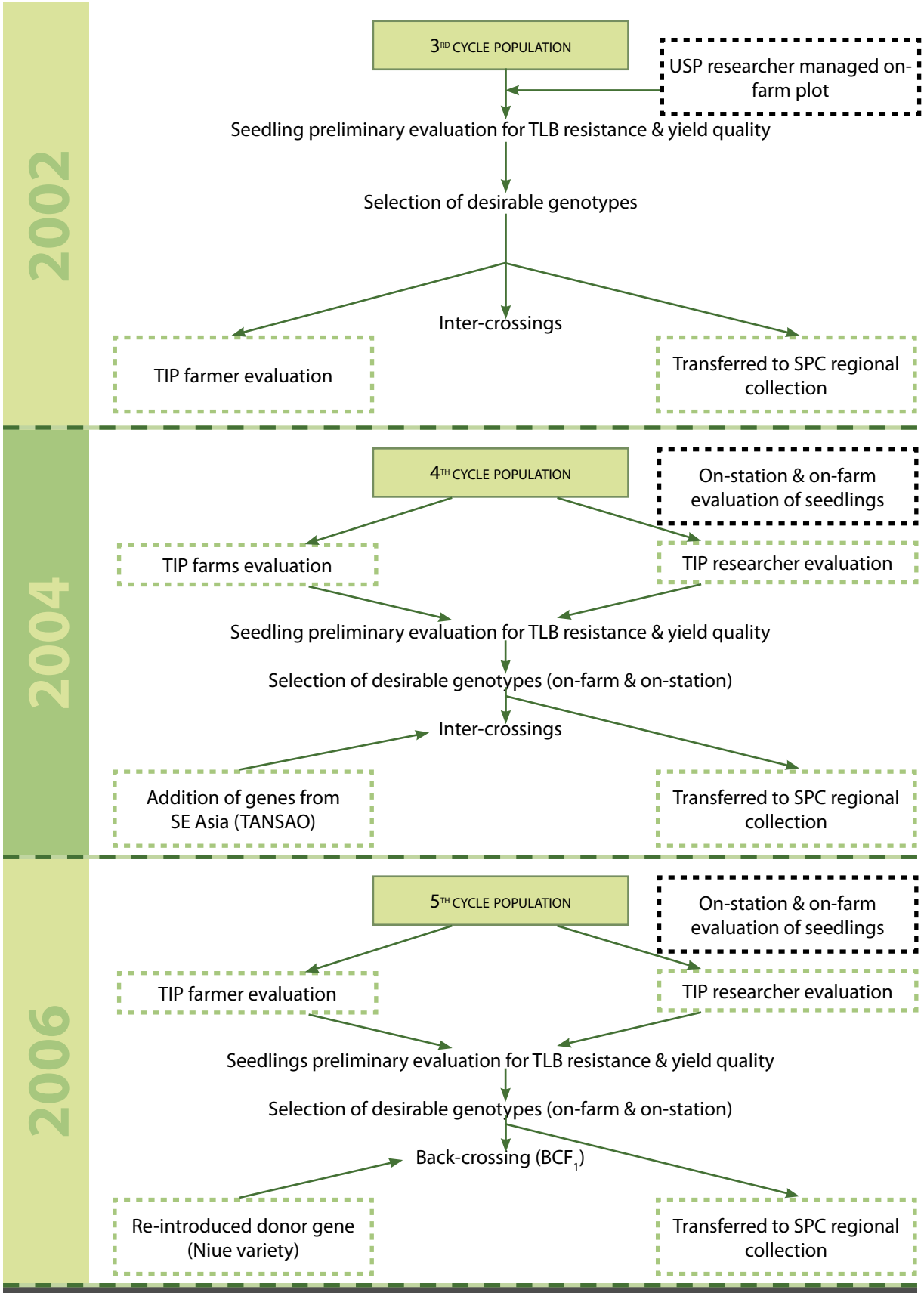

Figure 26: continued

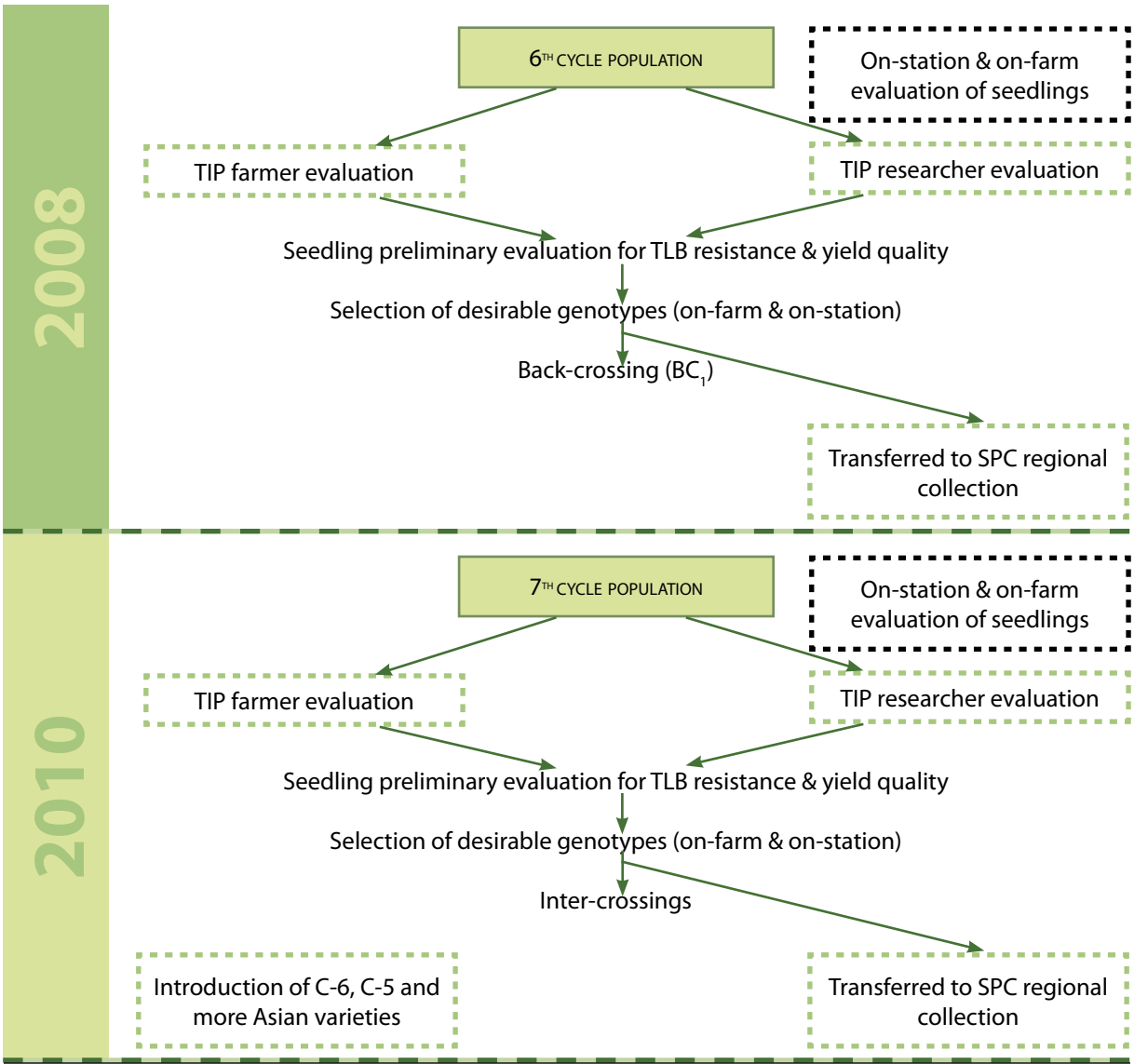

Figure 26: continued

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.

For farmer evaluation, the terms and conditions of the process were always described at TIP monthly meetings before seedlings were distributed. Farmers were asked to manage their own plots with minimal supervision from researchers. The design of the trial was a simple layout using single or more rows of seedlings from each cross, with a row of the local variety, P10 planted as guard rows separating one cross from another using traditional spacing. Ongoing management of trial plots is the farmers' responsibility, and is based on the farmer's normal practices. Farmers were advised to establish plots in an area where taro was already growing to ensure exposure of the seedlings being evaluated to TLB (Figure 27).

It is crucial that a good layout plan is drawn, that the plants in the evaluation plot are well-labelled and that the plot is well-maintained.

Figure 27: On-farm evaluation of breeding lines.

The TIP coordinator and advisory officers from the MAF visited farmers and their plots to monitor the progress of the on-farm evaluation, and worked with the farmers to help identify the lines they preferred and that worked well in their environment (Figure 28). The on-farm research and evaluation was crucial to determine whether lines performed well across all locations and environments, and to identify those best suited to specific environments.

Figure 28: A visit to a farmers' plot to assess the breeding lines.

Specific criteria were identified by TIP members for the selection process:

- good eating quality
- TLB resistance
- high yield
- tender leaves for luau (palusami)
- long shelf life
- vigorous growth

Figure 29: Farmers meet every month.

TIP farmers met every month at the USP Alafua Campus. These monthly meetings were a vital component of the success of TIP, bringing farmers together and allowing problems and challenges to be shared. Regular sharing ensured that the farmers knew their participation was vital to the breeding programme (Figure 29).

TIP farmers' club monthly meetings

Figure 30: Understanding how new varieties are imported into Samoa.

Figure 31: Discussing the new batch of seedlings from a breeding cycle.

USP Alafua Campus (Samoa) is the main venue for TIP farmers' club meetings.

Farmers and advisory staff from MAF who are involved in evaluating taro from the breeding programme meet every month to discuss the programme. Initially the focus was on solving TLB but as the resistant varieties became available from the programme, discussions considered varietal improvement and other taro cultivation and market development constraints.

Farmers are always briefed on the progress being made by the breeding programme, and the terms and conditions of the evaluation process.

The agreement on sharing of the farmers' selections and the genepool collection at USP is reinforced.

Farmers have the opportunity to visit the on-station, researcher-managed plot at USP.

Farmers taste the taro from the harvested lines of the on-station preliminary trials.

Farmers can visit each other's farms, so that they can observe different plots for comparison.

(l) Constraints

- **Selection of farmers to participate**
  It is important to maintain the enthusiasm often shown by farmers at the start of such an initiative as TIP, which often fades after planting material is given out. Project staff must make regular visits to the farmers to encourage them to continue their involvement.

- **Site selection**
  Access to the evaluation farms/sites has to be considered. The plots must be relatively easily accessed on reasonable roads. This will help in encouraging farmers to visit each other's farms.

- **Management of plots**
  Several plots were poorly managed, overgrown by weeds, resulting in poor growth. They were often located some distance from the main taro plantation which possibly accounted for their poor maintenance. Once poor management is observed it should be discussed with the farmer and generally that will solve the problem. This challenge is also one that is addressed by regular visits.

- **Monitoring**
  Monitoring can be very difficult to maintain regularly, which highlights the importance of farmer and site selection.

- **Availability of planting materials**
  Some recommended lines produce very few suckers or none at all, therefore it is difficult to provide sufficient numbers to distribute and for the farmers to evaluate. Links to a tissue culture laboratory can help.

- **Supply of quality taro to the market**
  The volume of planting material (seedlings) generated by this approach and the participatory nature of the breeding programme means that there is a wide range in the quality of taro being grown. As a result, taro of lesser quality can find its way to the market. Working with the farmers to establish some criteria of quality could be useful but if farmers are trying to generate an income to feed their family then it is likely that these criteria at times will be forgotten.

(m) Trouble-shooting

The following section highlights problems that can occur. Where solutions are known, these are recommended.

1. *Flower production:*

- Different varieties produce flowers at different length of times; some produce flowers early (2 to 3 months after planting) whereas others produce flowers late (4 to 5 months). If the flowering time of a variety is known, staggering the planting time can help to achieve synchronised flowering periods.
- Some cultivars or clones produce flowers but they are sterile. Sometimes this is because the male flower has no pollen, although some fruits can also produce seeds which do not germinate.

2. *Poor germination from seeds:*

- Small sized berries produce only small amount of very tiny seeds with poor germination rate, therefore small sized berries should be avoided.
- Taro seeds are very tiny and lose viability at room temperature; when storage at room temperature exceeds 4 weeks, seed germination is zero. However at Vanuatu Agriculture Research and Training Centre, seeds were kept in a freezer for months and after storage they germinated.
- Some taro seeds need artificial light for good germination rate.

3. *Seedling problems:*

- Taro seedlings are very vulnerable or easily affected by damping off disease.
- Inadequate care and attention is another problem: nursing seedlings is time consuming.
- Seedlings require a sterile environment, medium, water and good aeration to ensure good growth from germinating seeds.

NB: Taro breeding from pollination to seedling stage to plant distribution is a lengthy process (Figure 26), taking almost 2 years of focused work. Care and attention is needed at every stage from harvesting the seeds, through to identifying and selecting any lines of potential use. What is urgently needed is a rapid screening method for use in the early stage of seedling development, which would effectively identify the 'best' lines according to the required criteria.

Section 3: Climate change and taro leaf blight

(a) The potential for TLB to spread

Particular temperatures and regular periods of leaf wetness promote TLB epidemics by favouring pathogen dispersal, infection, and disease development (Thankappan 1985). A minimum night-time temperature of 21°C and a relative humidity of 100 per cent have been shown to provide the optimum conditions for TLB; when the relative humidity was less than 90 per cent, sporulation did not occur, and zoospores rapidly lost their viability (Putter 1965). In Papua New Guinea, research showed that temperature and relative humidity together explained 72.57 per cent of the variation in sporulation, with all these associations being highly significant (Putter 1976). It would seem therefore that the impact of night temperature on relative humidity is an important factor in the rapid spread of the disease.

Vulnerability of the genotypes being cultivated in a country is obviously extremely important. The susceptibility of the variety Niue to TLB in Samoa and the quick destruction of the crop demonstrated what happens when a disease like TLB combines with varietal susceptibility. Countries in the Pacific that continue to grow taro despite TLB being present equally demonstrate how the disease can be managed by varietal resistance. TLB is present in Palau but farmers do not regard it as a major problem because resistant varieties are available. The recultivation of taro in Samoa is the result of the introduction of resistant varieties. But what about the countries where taro is an important crop but TLB is not present? How vulnerable is taro cultivation in those countries to TLB? Fiji would have to be one of the countries in the Pacific where taro plays a vital role not only for food and nutritional security but also for income generation as a result of the very significant taro export market. Over the last few years Fiji has exported around 10,000 tonnes (fob value AUD 9-10 million), with about 65 per cent going to New Zealand and the balance to Australia and the USA (McGregor et al., 2011) Tausala ni Samoa is the favoured variety for export and, according to the studies carried out during the TaroGen project, it is genetically similar to the variety Niue from Samoa, which suggests that it would be susceptible to TLB.

In Polynesian countries, such as Cook Islands and Tonga, taro is a very important crop for food and nutritional security. Tonga has a small export market; in 2008, 572 tonnes of taro (*C. esculenta*) were exported (McGregor 2011). In Cook Islands, fresh taro supply to the markets of Rarotonga is estimated at about 120 tonnes with a value of NZD$0.25 million. This does not include taro consumed in the homes; the price of fresh taro on the local market ranges between NZD$2.80 and $4.00 per kg. The people of Cook Islands are closely connected to taro, more for its social and cultural significance than economic reasons (Wigmore, pers. comm 2013).

In a study comparing isoenzymes, 193 cultivated taro varieties from Polynesia gave the same isozyme fingerprint for six enzymes; variation for one enzyme was found in only three varieties from French Polynesia (Lebot and Aradhya 1991). The study clearly showed that the cultivated taro in Cook Islands, Easter Island, Hawaii, New Zealand, Niue, Samoa and Tonga exhibit an extremely narrow genetic diversity. Greatest variation was found in taro from Indonesia, more so than in taro from Papua New Guinea, Solomon Islands and New Caledonia. Variation in Vanuatu taro was also low. Similarly, studies using genetic markers such as Random Amplified Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP) and Simple Sequence Repeat (SSR) markers confirmed that little genetic variation exists in Polynesian taros, in contrast to those from Asia and Melanesia. A molecular study of taro genetic diversity using RAPDs confirmed that although varieties in the Pacific region exhibit remarkable morphological variation, the genetic base appears to be very narrow (Irwin et al. 1998; Mace et al. 2006). This limited genetic base is very likely to leave the crop vulnerable to pests and disease attack.

The impact that TLB has had on the majority of the countries where it is now present clearly demonstrates the risk the disease poses to food and nutritional security and income generation. The disease was first recorded in Hawaii in 1920 (Brunt et al. 2001). More than 350 varieties were known in Hawaii prior to the arrival of the disease, but less than 40 are known today (Trujillo 1996). On Pohnpei, in FSM, TLB has been responsible for the serious decline in taro as a food crop (Raynor and Silbanus 1993). Basically when TLB is present in a country, that country has to grow other staple food crops unless resistant varieties are available. The disease has been identified as a major contributing factor in the overall decline of taro as a food staple in Papua New Guinea. The major food crop grown in Papua New Guinea is now sweet potato; prior to the introduction of sweet potato as a result of TLB's impact on taro, an estimated half of the food energy from staple foods in Papua New Guinea came from taro (Bourke and Harwood 2009). Similarly in Bougainville sweet potato is now the most prominent food crop, as a result of the impact TLB had on taro cultivation. And the story of TLB in Samoa has been described in this publication.

The potential for TLB to severely affect taro production is not just a challenge for the Pacific. In 2010 TLB spread to Cameroon, West Africa, where harvest losses of up to 90 per cent were recorded. Taro or cocoyam as it is known in Cameroon is second only to maize as the most widely eaten foodstuff in the affected areas. It is the basis of *achu*, a traditional dish among some tribes of the North West region, now widely consumed throughout Cameroon (Guarino 2010). The disease has now spread to Ghana and Nigeria (Bandyopadhyay et al. 2011; Omane et al. 2012). The Caribbean region has not escaped; in 2004 the introduction of TLB led to the decimation of the taro crop in the Dominican Republic, Cuba and Puerto Rico (Rao et al. 2010).

(b) Climate and TLB

Does climate change have implications for countries that do not have the disease; do the climate projections mean that these countries are more at risk? The Pacific Climate Change Science Programme (PCCSP) (Australian Bureau of Meteorology and CSIRO, 2011), built on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007, addressed the information gaps and research priorities identified by IPCC. The PCCSP provides projections for temperature, rainfall, extreme events, sea surface temperature, ocean acidification and sea level rise for three future 20-year periods (2035, 2055 and 2090), and for three different scenarios of greenhouse gas and aerosol emissions: B1 (low), A1B (medium) and A2 (high). The PCCSP region covered East Timor and 14 Pacific Island countries (Cook Islands, FSM, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu). Considering the importance of temperature and rainfall for the spread of TLB it is useful to look at the PCCSP projections for these variables. The projected temperature for the region is about 70 per cent as large as the global average warming for all emission scenarios. The projected regional warming is around 0.5°–1.0°C by 2030. Large increases in the incidence of heatwaves, extremely hot days and warm nights are also projected. For rainfall the increases are projected to be most significant near the South Pacific Convergence Zone, affecting the Cook Islands, Fiji, Nauru, Niue, Samoa, the Solomon Islands, Tonga, Tuvalu, Vanuatu and Kiribati, and also the Intertropical Convergence Zone, affecting FSM, Kiribati, Marshall Islands, Nauru, Palau and Papua New Guinea. A widespread increase in the number of heavy rain days (20–50 mm) is projected.

These projections have implications for those countries that do not have the disease. Current climate conditions in those countries do not favour the spread of the disease, but increasing temperature and rainfall will provide the conditions that favour TLB. In Papua New Guinea the lower temperature in the highlands enables farmers to grow taro without any problems with TLB, although increasing temperatures in that area could support the spread of TLB from the lowland areas.

(c) Making the most of lessons learnt

What action should countries take that are at risk from TLB? Samoa has demonstrated the importance of crop diversity and, as stated previously, those countries that are still growing taro despite TLB being present in their countries, are only doing so because of resistant varieties. Through SPC CePaCT, TLB resistant lines and varieties for the Samoa programme can be accessed by countries and evaluated. Perhaps the taste and texture is not ideal for those countries but they would provide some form of buffer should TLB arrive on the door-step. Countries can embark on breeding programmes using the material imported from Samoa but crossing with their local varieties; such a programme is being supported for Cook Islands, Fiji and Tonga by the AusAID International Climate Change Adaptation Initiative. Some of the varieties imported from Asia and currently held at SPC CePaCT have resistance to TLB; countries at risk should evaluate these varieties for yield, taste and texture. Countries can also ensure that there is diversity in their farmers' fields, and that if export markets are developed, some consideration is given to the preferred market variety and its susceptibility to potential pests and diseases; this is not just relevant for taro.

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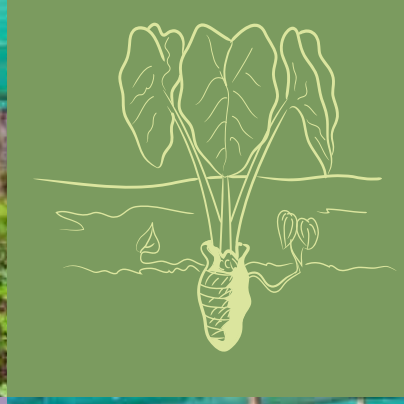





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