A REVIEW OF TARO (*COLOCASIA ESCULENTA* (L.) SCHOTT) GENETIC RESOURCES OF PAPUA NEW GUINEA

Okpul, T.[1], D. Singh[1,3], M.E. Wagih[2] and D. Hunter[3]

ABSTRACT

The status of taro (Colocasia esculenta (L.) Schott) genetic resources and the efforts of the National Agricultural Research Institute, together with several regional networks, in the acquisition, conservation, evaluation and utilization of the germplasm are reviewed. Wild and cultivated genotypes show enormous genetic variation suggesting Papua New Guinea is a centre of diversity. However, traditional varieties are being displaced due to biotic and abiotic factors. A representative sample of the genetic diversity of taro in Papua New Guinea has been collected and is maintained ex situ. The need to develop alternative conservation strategies for efficient management and utilization are considered.

Keywords: *Taro,* Colocasia esculenta, *genetic resources, germsplasm, genotypes, vegetable propagation*

INTRODUCTION

Taro, *Colocasia esculenta* (L.) Schott, is an edible aroid belonging to the Araceae family. It is a historical staple root crop in Papua New Guinea (PNG) and taro cultivation at Kuk in the Western Highlands Province, for example, has been dated to 9, 000 BC (Golson 1977). It has been suggested that it was the principal crop in the highlands prior to the introduction of sweet potato (*Ipomoea batatas*) 300-500 years ago (Clarke 1977; Bayliss-Smith 1982, 1985). With a long history of association with human society, taro has emerged as symbolic in traditional beliefs and rituals among many ethnic groups (Barrau 1965; Panoff 1972; Barth 1975; Morren and Hyndman 1987).

Taro is cultivated as an important staple up to an altitude of 2, 200 m (Bourke *et al.* 1998). It is grown as a minor food crop as high as 2, 740 m (Bourke 1982). It is primarily grown for its edible corm. However, leaves, inflorescences, and tender inner layers of petiole sheaths may also be used as vegetables. It is now being cultivated as a semi-commercial crop with surplus produce sold at markets. (Anonymous 2001). Annual production of taro is estimated at 170, 000 tonnes from an area of 31, 000 ha (FAO 2001).

Taro production, however, has been declining in the recent past as reported by Wagih *et al.* (1994). Taro leaf blight (TLB), caused by *Phytophthora colocasiae* Racib., taro beetles (*Papuana* spp.), the Alomae – Bobone virus complex (ABVC) and declining soil fertility all affect yield and have contributed to the declining production (Sar *et al.* 1998). Changing dietary habits and preferences for exotic foods, and the introduction of other crop species with better comparative advantages such as Chinese taro (*Xanthosoma sagittifolium)* and sweet potato have also had a negative influence on taro production (Waddell 1972; Bourke 1982; Joughin and Kalit 1986). The impact of these factors on production has unfortunately led to loss of traditional cultivars in some parts of PNG (Wagih *et al.* 1994).

This paper reviews efforts to preserve the existing taro genetic diversity by collecting and conserving farmers' varieties and evaluation and utilization of the genetic resources to improve production in PNG. Past efforts, current status and future prospects are discussed, highlighting collaboration with regional networks.

TARO DIVERSITY

Taro is believed to have originated in the Indo-Malayan region, either between Eastern India and Bangladesh (Plucknett 1983; Purseglove 1988) or in Southern China (Cable 1984). The origins of wild taros and their domesticated relatives, and the directions of dispersal remain debatable (Matthews and Terauchi 1994) *cited by* Yen 1995). Three hypotheses have been proposed for PNG taro germplasm. Firstly, it may be an eastward extension of the Indo-Malayan flora suggesting a single centre of origin in South Asia (Plucknett *et al.* 1970; Leon 1977; Yen 1982; Coates *et al.* 1988). Secondly, it may have been dispersed by early migrants and other seed vectors (Okada and Hambali 1989; Pawley and Green 1973). Thirdly, it may have

[1]National Agricultural Research Institute, WLMP-Bubia, P.O. Box 1639, Lae, Papua New Guinea.
[2]Unitech Biotechnology Centre, Papua New Guinea University of Technology, PMB, Lae, Papua New Guinea.
[3]Secretariat of the Pacific Community, Suva, Fiji.

resulted from an independent origin in PNG suggesting multiple origins of the crop (Matthews 1990, 1991; Lebot 1999), and PNG is considered as a centre of diversity (Leon 1977).

Three botanical varieties of *C. esculenta* are prevalent in PNG. Variety *aquatilis* is the commonly occurring wild type (Matthews 1991, 1987) whereas variety *esculenta* (dasheen type) and variety *antiquorum* (eddoe type) are cultivated in gardens, either in swiddens or irrigated plots. A third cultivated form expresses intermediate traits between the dasheen and eddoe types and is believed to be a hybrid (Lebot *et al.* 2000). The distribution of the cultivated forms depend on their status as a component of the cropping system practised, where taro is cultivated either as a dominant or co-dominant staple (Figure 1).

Numerous varieties exist in gardens (Panoff 1972; Rangai 1982; Morren and Hyndman 1987). The variability may be attributed to sexual recombination and perhaps somatic mutation, associated with continuous vegetative propagation and the subsequent selection by farmers based on adaptability and culinary qualities from exotic and novel varieties. Taro flowers and sets seed naturally. Protogyny and self-incompatibility systems in the inflorescence facilitate cross-fertilisation, which usually results in variable progenies (Shaw 1975; Okpul and Ivancic 1996; Johnston and Gendua 1998). Farmers have developed practices to identify, evaluate and select new varieties from natural crosses. Such practices have been observed in Pomio in West New Britain Province (Panoff 1972) and in Manus, Morobe and the Western Highlands provinces. On Manus Island after the rainy season, farmers search for seedlings of new varieties in ant nests on small trees, in bamboo patches, and in soils shifted by landslides. Similarly, in Morobe and the Western Highlands provinces, seedlings germinating in drains or ditches and alongside creeks and streams are nursed and culinary qualities assessed at maturity.

Continuous vegetative propagation has been observed to complicate colour or pigment patterns, resulting in the creation of numerous morphotypes. Exchange of such variants between communities may have resulted in new identities. A general indication of variability within the genepool can be traced from vernacular names. Novel varieties are usually named after the founder or are given names relating to culinary qualities such as texture and aroma, or even names that are analogous to human anatomy relating to the shape or pigmentation of plant parts, while introduced varieties are given the names of their place of acquisition. Clonal variants (or even unidentified but morphologically similar varieties), on the other hand, are given additional names that describe the phenotypic variation. For example, in the Morobe Province, a popular variety, Numkowec, has three variants: Numkowec-koko, Numkowec-sisip and Numkowec-yangyang, which are distinguished by their red, white and green basal ring colours, respectively.

The variability has been indicated in diversity studies based on quantitative traits (Ivancic *et al.* 1995), isozyme variations (Lebot and Aradhya 1991), variations in ribosomal and mitochondrial DNA restriction sites (Matthews 1990), Randomly Amplified Polymorphic DNA (Irwin *et al.* 1998), Amplified Fragment Length Polymorphisms (AFLP) (van Eck *et al.* 1998) and microsatellites (Mace and Godwin 2000; Godwin *et al.* In press). These studies have shown that a high level of genetic diversity exists in PNG as compared to neighbouring Pacific Islands. Nevertheless, and as exemplified by Waddell (1972), the displacement of taro is a growing concern (Wagih *et al.* 1994; Kesavan and Aburu 1982). During 1998, the present authors observed villagers in Lababia (population of >1000), Morobe Province, abandon taro cultivation in favor of sweet potato as a result of high infestation by taro beetle and epidemics of TLB. Consequently, all traditional varieties (estimated to be over 40) selected over the years under a taro-based farming system are now displaced. Such a situation raises the need to explore, collect and safeguard the existing genetic diversity for potential use.

ACQUISITION AND CONSERVATION

Collection of germplasm representing the genetic diversity is a prerequisite for its effective study, conservation and utilization for crop improvement. Past collections of cultivated and wild taros were conducted on an *ad hoc* basis by various researchers in the Department of Agriculture and Livestock (whose research functions are now under the National Agricultural Research Institute (NARI)) and the PNG University of Technology (UniTech). A total of 461 accessions were collected and maintained at the Highlands Agricultural Experiment Station (48), the Lowlands Agricultural Experiment Station (120), Laloki Research Station (135), Saramandi Research Station (28), Kuk Agricultural Research Station (10) and UniTech (120) (Aburu 1980; Jackson 1994; Levett *et al.* 1985). Amalgamation of the remnants of these collections at Bubia Agricultural Research Centre, now the Wet Lowlands Mainland Programme (WLMP) of NARI, formed the basis for the national taro germplasm collection (Arura 1985; Kambuou 1995).

Other institutions were involved on a number of occasions. The International Plant Genetic Resources Institute (IPGRI), formerly the

International Board for Plant Genetic Resources (IBPGR), funded several collection missions in the 1980s. Additional explorations resulted in the collection accruing 602 entries by 1989 (Akus *et al.* 1989) which were maintained in an *ex situ* collection at Bubia. A lot of accessions were lost before being characterized and evaluated. The losses are mainly attributed to inadequate husbandry in terms of weed control, and insect pest and disease management. Natural calamities such as floods and prolonged dry periods also had impacts on the field genebank, which was reduced to 437 accessions by 1995. Frequent staff turnover resulted in the loss of the passport data and field plans, which eventually invalidated the remaining entries and impeded efforts to re-collect (Kambuou 1998). Such errors have proved expensive and made maintenance of large *ex situ* collections unsustainable (Godden 1999).

From these experiences, the concept of a core collection and the use of complementary conservation strategies, especially *in vitro* techniques, for efficient conservation and utilization of taro germplasm were necessitated. Recently, local cultivars were re-collected throughout the country under the auspices of several regional networks: the Pacific Regional Agricultural Program (PRAP) of the Secretariat of the Pacific Community (SPC), the European Commission–funded Taro Network for Southeast Asia and Oceania (TANSAO) and the Taro Genetic Resources: Conservation and Utilization project (TaroGen) funded by the Australian Agency for International Development (AusAID). A total of 859 accessions from 16 provinces (Figure 1) have been collected, maintained *ex situ* in an augmented block design, and characterized. A core collection has been developed and a duplicate is being conserved *in vitro* in the Regional Germplasm Centre (RGC), Fiji (TaroGen 2001a).

International germplasm exchange can play an important role in broadening genetic diversity. This is an approach being emphasized by the TaroGen and TANSAO networks. The current germplasm collection also holds several exotic accessions from the Asia-Pacific region (Table 1). Recently, 134 accessions included in the TANSAO regional core collection were acquired. This set of lines is currently being maintained in tissue culture under quarar and will be virus-indexed and cleaned before ac to the field collection (Gunua *et al.* 2001).

VARIETY IDENTIFICATION AND EVALUATION

Agro-morphological characterization

Taro exhibits a wide array of agro-morphological polymorphism. Numerous variable but clonally stable traits are being used as markers for varietal identification and assessment of genetic diversity. The first descriptor list for taro, developed by IBPGR (IBPGR 1980), was used in earlier attempts to characterize the germplasm (Levett *et al.* 1985; Akus *et al.* 1989). An edited version, developed by IPGRI in collaboration with TaroGen (IPGRI 1999), is currently being used. Additionally, the TANSAO network developed a descriptor list using major agro-morphological markers for use in all of the partner countries for selection of national core samples to form a regional core collection (TANSAO 1998). A PNG core sample comprised of thirty-one varieties (Table 2) was selected based on the principal component score strategy from an initial collection of 279 accessions.

All accessions collected and maintained *ex situ* have now been characterized using the selected descriptors from the IPGRI descriptor list under TaroGen. The selected core sample from the TANSAO project has also been included. The data matrix was subjected to diversity analysis for the selection of a tentative core collection comprising the 20 per cent with the most diverse varieties. This work was conducted with assistance from IPGRI.

Molecular characterization

Lebot and Aradhya (1991) evaluated a total of 452 PNG accessions using isozyme markers. However, the information was not used to rationalize the collection due to loss of passport data and the field map. Although numerous diversity studies included PNG accessions (Matthews 1990; Irwin *et al.* 1998; Mace and Godwin 2000; Godwin *et al.* In press), the germplasm was not systematically characterized for varietal identification to rationalize the collection and to enable thorough assessment of the extent of genetic diversity.

The national core sample developed under TANSAO has been fingerprinted using AFLP at Wageningen Agricultural University and the information was used to compare genetic diversity among the accessions of the region (TANSAO, 1999, 2000). The core collection developed by TaroGen was fingerprinted at the University of Queensland using molecular markers under the ACIAR project No. CS2/94/43. Finally, 10 per cent of the whole collection comprising 83 varieties was selected to form the national core collection (Mace *et al.* 2001; TaroGen 2001a, 2001b).

Agronomic evaluation

Limited evaluation work has been conducted on yield and screening for disease resistance. Evaluations of varietal yields were, in most cases, preliminary and were sometimes inconclusive with respect to making recommendations of promising varieties for farmer adoption (Levett *et al.* 1985; Akus *et al.* 1989).

In exploiting the germplasm for disease resistance, Hicks (1967) screened for resistance against *P.*

Figure 1. **Map showing the number of accessions collected and status of taro as a staple crop in various provinces of Papua New Guinea.**

The map was produced using Mapping Agricultural Systems Project database (Bourke *et al.* 1998)

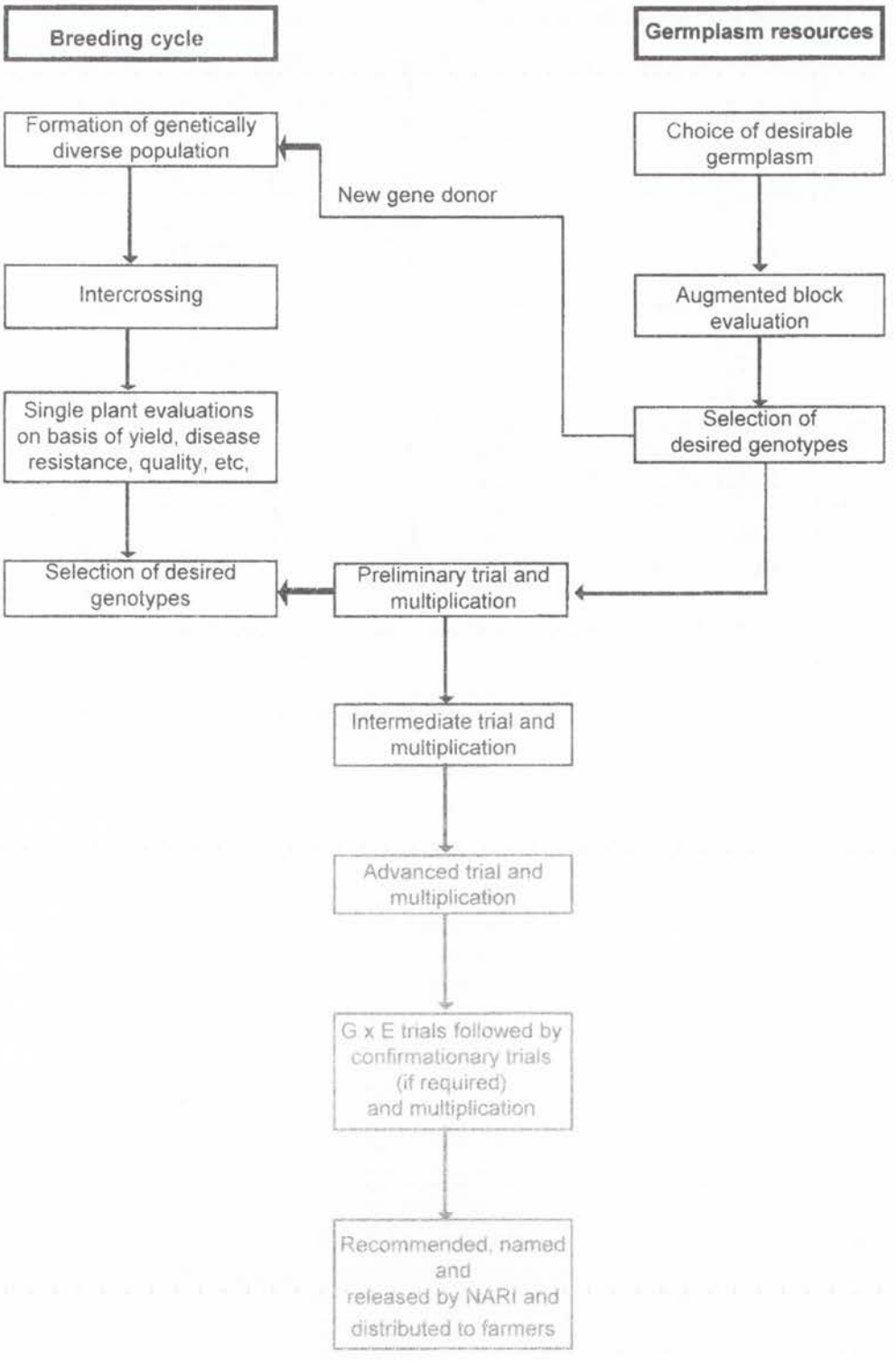

Figure 2. **Schematic representation of evaluation, development and release process for promising taro varieties**

Table 1. **Acquired exotic germplasm maintained in the National Agricultural Research Institute taro breeding working collection**

Country of origin1	Source	Acquisition date	Number of accessions	Type of sample	Current number of accessions
Cook Islands	IRETA, Samoa	1994	2	Cultivar	1
Fiji	IRETA, Samoa	1994	2	Cultivar	2
FSM	IRETA, Samoa	1994	2	Cultivar	1
Hawaii	IRETA, Samoa	1994	2	Cultivar	1
Indonesia	LIPI, Bogor	1998	10	Unknown	9
	LIPI, Bogor	2000	11	Cultivar	11
New Caledonia	IRETA, Samoa	1994	1	Cultivar	1
Niue	IRETA, Samoa	1994	2	Cultivar	1
Samoa	IRETA, Samoa	1994	2	Cultivar	1
Solomon Islands	DCRS, Solomon Islands	1993	Seeds	Semi-wide type	2
Thailand	DCRS, Solomon Islands	1993	1	Wild type	1
Vanuatu	IRETA, Samoa	1994	2	Cultivar	1

[1]FSM = Federated States of Micronesia; [2]IRETA = Institute for Research, Extension and Training in Agriculture; LIPI = Research and Development Centre for Biotechnology; DCRS = Dodo Creek Research Centre.

Table 2. **Taro cultivars forming the Papua New Guinea core sample selected for the Taro Network for Southeast Asia and Oceania regional core collection**

Assession number	Provincial Origin	Accession number	Provincial origin
BC1 643	Eastern Highlands	BC 793	Morobe
BC 646	Eastern Highlands	BC 798	Morobe
BC 656	Simbu	BC 810	Morobe
BC 661	Simbu	BC 813	Morobe
BC 674	Western Highlands	BC 818	Morobe
BC 677	Western Highlands	BC 835	Morobe
BC 680	Oro	BC 844	Morobe
BC 691	Oro	BC 846	Morobe
BC 734	West Sepik	BC 853	Morobe
BC 740	West Sepik	BC 859	Morobe
BC 749	Milne Bay	BC 874	Morobe
BC 759	Morobe	BC 885	Morobe
BC 769	Morobe	BC 887	Morobe
BC 770	Morobe	BC 894	Western
BC 773	Morobe	BC 902	Morobe
BC 786	Morobe		

[1]BC = Bubia collection number

colocasiae Racib. and noted varying levels of resistance among tested accessions. However, no further work was pursued until recently, when Kokoa and Darie (1994) screened for and identified three resistant genotypes, namely Ph-15, Ph-17, and Ph-21 as possible donors for resistance against *P. colocasiae*.

The collection is currently being systematically evaluated under the breeding program for other agronomic traits. Initial evaluations are based on the augmented block design in which performance of accessions within the collection are compared prior to formal testing and release for use (Figure 2). The selected TANSAO core sample is also being evaluated for agronomic traits and quality in formal trials (Gunua *et al.* 2001).

UTILIZATION OF CONSERVED GERMPLASM

Germplasm can be utilized directly in the form of better performing landraces or farmer varieties, or indirectly as donors of useful genes for the development of novel varieties. The germplasm has not been systematically evaluated for its direct use. Genetic improvement, on the other hand, was attempted over the years. Earlier taro breeding work was conducted at LAES. The Department of Agriculture (Anonymous 1941) reported on single plant selections that developed two high yielding varieties, 'Utility' and 'King', yielding up to 17.6 t/ha. No further improvement work was conducted until the 1980s when breeding for resistance to TLB was first attempted. A resistant Thai wild type identified as 'Bangkok' was used in crosses involving promising cultivars. This program was, in fact, an extension of Dr. G. V. H. Jackson's work in the Solomon Islands. However, no improved lines were released from LAES (Gunawardhana 1984).

Recently, three resistant genotypes, Ph-15, Ph-17 and Ph-21 from PNG, together with the genotype 'Bangkok' were used as donor parents in the base population of a modified recurrent selection procedure adopted for taro improvement at WLMP. Several cultivars (both indigenous and exotic) were used as recurrent parents in selection for yield and culinary qualities (Ivancic and Okpul 1996, 1997). The breeding work is currently in its fourth cycle (or generation). In the first cycle, selection was directed towards TLB resistance because of the strong influence of wild germplasm on yield and culinary quality (Okpul *et al.* 1997). A set of 12 lines was finally selected for intermediate trials, which resulted in the recommendation of seven lines for evaluation in national multi-location trials (Singh and Okpul 2000). These lines were evaluated in seven different sites throughout PNG (TaroGen 2000). Three lines (C2-E3, C2-E4 and C2-E8) were released as varieties under the names NT 01, NT 02 and NT 03, respectively (Okpul *et al.* 2002). The salient features of these varieties are highlighted in Table 3. Further, multi-character selection in the third cycle population has resulted in the selection of 6 lines, which are being bulked for multi-location trials. The fourth cycle population is currently being evaluated on a single plant basis and 237 superior lines have been identified.

The genebank has also provided a means for interested farmers to recover their lost varieties and many farmers have used the opportunity to diversify the number of varieties planted in their gardens. International students and researchers have also accessed the germplasm (Table 4). The regional approach to germplasm conservation being undertaken will ensure easier access by scientists and other bonafide users.

FUTURE PROSPECTS

Despite waning production, taro is still a staple of high market value in PNG. This highlights its potential as a commodity on which to base economic development in rural areas. However, taro is a difficult crop to grow because of its high requirements for soil nutrients, moisture and labour. It is also affected by numerous pests and diseases, which can have a drastic impact on yield. These factors have, cumulatively, caused farmers to lose interest in taro farming. As observed, the abandonment of taro cultivation is a serious threat to traditional varieties. In order to renew farmers' interest and prevent genetic erosion, more research needs to be conducted in developing options to circumvent production constraints. Major factors limiting production are TLB, taro beetle, declining soil fertility and ABVC together with its vectors, particularly *Tarophagus* spp. and *Aphis gossypii*. Other pests and diseases of some concern to growers include the dasheen mosaic virus, leaf defoliators (especially *Hippotion celeria* L. and *Spodoptera litura)* and the nematode *Hirschmaniella miticausa*.

Several leaf blight resistant lines have been developed and released as recommended varieties to farmers. Nevertheless, ABVC and taro beetle still remain as major constraints to production. Jackson and Gollifer (1975) have reported on varieties expressing varying levels of resistance to ABVC. The study identified varieties of the 'male types' (no relation to sexuality but generally larger plant forms) to be susceptible while the smaller 'female types' express some level of resistance. These observations need to be further investigated, although the situation is complicated by the fact that

Table 3. **Description of released taro varieties and a popular standard cultivar Numkowec***

Character	Variety			
	NT 01 (C2-E3)	**NT 02 (C2-E4)**	**NT 03 (C2-E8)**	**Numkowec (control)**
Yield	10.49 t/ha	7.68 t/ha	7.65 t/ha	5.89 t/ha
Average corm weight (g)	525 g	380 g	380 g	300 g
Yield stability	Stable	Stable	Unstable	Stable
Taro leaf blight (TLB)	Resistant	Resistant	Resistant	Susceptible
TLB diseased leaf area (%)	8.24	7.34	7.19	15.76
Taro beetle	Susceptible	Susceptible	Susceptible	Susceptible
Taro beetle damage (%)	19.70	19.04	18.74	19.53
Eating Quality	Good	Good	Good	Good
Eating Quality Score	2.64	2.59	2.54	2.52
Time to maturity (months)	6	6	6	6
Sucker production	3-4	2-3	5-6	6-8
Growth habit	Erect	Erect	Erect	Erect
Plant height	Tall	Tall	Tall	Tall
Leaf lamina	Light green	Dark green	Dark green	Dark green
Petiole colour	Light green	Purple green	Purple	Light green
Petiole junction	Purple	Purple	Purple	Purple
Flowering	Rare	Rare	Frequent	Frequent
Corm shape	Cylindrical	Elliptical	Conical	Conical
Corm skin	Smooth	Smooth	Smooth	Smooth
Flesh colour	Pink	Pink	Pink	Pink
Corm dry matter content (%)	35	41	41	38

* Source (Okpul *et al* 2002)

Table 4. **Papua New Guinea germplasm accessed by international institutions[1]**

Country	Institution[2]	Date of acquisition	Number of accessions[3]	Type of sample
Australia	ANU	1957-63, 1990-98	Unknown	Unknown
Australia	RBG	Unknown	1	Unknown
France	CIRAD	1995-1996	NA	Seed
Japan	KNAES	1986-1987	Unknown	Cultivar
Japan	OU, CU, TBG	1986-1988	9	Cultivar
Japan	NIVOT	1982, 1987	>30	Cultivar
Malaysia	SU	1989	Unknown	Unknown
Palau	PCAA	Unknown	1	Cultivar
The Netherlands	WAU	1999	40	Cultivar
United Kingdom	HRI	1986, 1994	15	Cultivar and seed
United States	UH	1994	3	Breeding line

[1]Table modified from Kambuou (1998); [2]ANU = Australian National University; CIRAD = Centre de Cooperation Internationale en Recherche Agronomique pour le Development; CU = Chiba University; HRI = Horticultural Research Institute; KAES = Kyushu Agricultural Experiment Station; NIVOT = National Research Institute of Vegetables, Ornament plants and Tea; Ou = Okayama University; PCAA = Palau Community Action Agency; RBG = Royal Botanical Gardens; SU = Selangor University; TBG = Tsukuba Botanical Gardens; UH = University of Hawaii; WAU = Wageningen Agricultural University. [3]NA = Not applicable.

several viral particles are involved whose combinations are usually manifested in varying symptoms (Rodoni *et al.* 1994).

Active search for satisfactory control measures for taro beetle has been concentrated in the last decade and is still continuing. Several biological control agents and chemicals have been identified in laboratory studies but their practical relevance is yet to be established (Thistleton *et al.* In press). Although the beetle has a wide host range, and varietal resistance does not seem to exist in taro as it attacks all varieties, it does not attack taro cultivated in flooded fields. This indicates the potential for using permanent flooding to circumvent beetle damage. Flooded or paddy culture may be an effective control measure, but it is not feasible in most areas of the ruggedly undulating terrain of PNG. Besides, cultivars in PNG are mostly adapted to rain-fed cropping systems and usually do not tolerate moisture levels above saturation point. Hence, genotypes tolerant to flooded conditions would need to be identified from the germplasm collection.

Taro breeding, as with other crop species, is strongly dependent on the availability of genetic resources. Collection and conservation of germplasm is therefore vital and a fair representation of the diversity has been collected from most provinces. A core collection of maximal diversity has been selected. In essence, the core collection was developed to ease management of the conserved genetic diversity and access to it. However, the germplasm is conserved *ex situ* where it is continuously exposed to biotic and abiotic stresses. Hence, complementary conservation strategies need to be developed to avoid the costly errors of the past. Medium to long-term storage *in vitro* should be considered. Although a duplicate of the core collection will be maintained *in vitro* in the RGC (Fiji), it is imperative to adopt such a complementary strategy nationally in PNG for ease of domestic access. Additionally, the feasibility of other options such as *in situ*, on-farm, conservation needs to be investigated.

Development of efficient screening methods and evaluation of the germplasm for varietal resistance against the main pests and diseases and for adaptability, particularly to permanent flooding, is of high priority. Long-term strategies have to be developed for pragmatic exploitation of the germplasm.

ACKNOWLEDGEMENT

The support from the Taro Genetic Resources: Conservation and Utilisation project (TaroGen), funded by AusAID; the Taro Network for Southeast Asia and Oceania (TANSAO), funded by the INCO – DC program of the European Commission; and the Secretariat of the Pacific Community, is gratefully acknowledged. The authors also wish to thank Messrs J. Maro, M. Tina, Dr. G. Wiles and the ACNARS Project for their technical assistance.

REFERENCES

ABURU, K. (1980). Germplasm at Lowlands Agricultural Experimental Station, Keravat, Papua New Guinea. *International Board on Plant Genetic Resources South East Asia Newsletter* 4(3): 6-9.

AKUS, W.L., PISEA, T., ARURA, M., OSOSO, E. and BOKOSOU, J. (1989). Taro germplasm collection and maintenance. In: *Bubia Agricultural Research Centre, Annual Report*. Department of Agriculture and Livestock, Lae, Papua New Guinea.

ANONYMOUS (1941). Department of Agriculture Annual Report. *New Guinea Agriculture Gazette*. 7(2): 76-116.

ANONYMOUS (2001). Market Prices. *Fresh Produce News*. 150: 14-29.

ARURA, M. (1985). Taro germplasm collection. In: *Bubia Agricultural Research Centre, Annual Report 1984*. Department of Agriculture and Livestock, Lae, Papua New Guinea.

BARRAU, J. (1965). L'humide et le sec. *Journal of Polynesian Society*. 74: 329-346.

BARTH, F. (1975). *Rituals and knowledge among the Baktaman of New Guinea*. Yale University Press, New Haven.

BAYLISS-SMITH, T.P. (1982). Taro (*Colocasia esculenta*) in the New Guinea highlands. In: *Proceedings of the Second Papua New Guinea Food Crops Conference, Part One*. R. M. Bourke and V. Kesavan (eds). pp. 134-147. Department of Primary Industry, Port Moresby, Papua New Guinea.

BAYLISS-SMITH, T.P. (1985). Pre-ipomoean agriculture in the New Guinea highland above 2000 metres: some experimental data on taro cultivation. In: *Prehistoric Subsistence Agriculture in the Tropics*. E. S. Farrington (ed). pp. 285-320. BAR International Series 232, Oxford, United Kingdom.

BOURKE, R.M. (1982). Root crops in Papua New Guinea. In: *Proceedings of the Second Papua*

New Guinea Food Crops Conference, Part One. R. M. Bourke and V. Kesavan (eds). pp. 51-63. Department of Primary Industry, Port Moresby, Papua New Guinea.

BOURKE, R.M., ALLEN, B.J., HOBSBAWN, P. and CONWAY, J. (1998). In: *Agricultural Systems of Papua New Guinea. Working paper No. 1*. Australian National University, Canberra, Australia.

CABLE, W.J. (1984). Spread of taro (*Colocasia* sp.) in the Pacific. In: *Edible Aroids*. S. Chandra (ed). pp. 28-31. Oxford University Press, Oxford, United Kingdom.

CLARKE, W.C. (1977). A change of subsistence staple in pre-historic Papua New Guinea. In: *Proceedings of the Third International Symposium on Tropical Root Crops*. C. L. A. Leaky (ed). pp. 159-163. International Society for Tropical Root Crops and International Institute for Tropical Agriculture, Ibadan, Nigeria.

COATES, D.J., YEN, D.E. and GAFFY, P.M. (1988). Chromosome variation in taro, *Colocasiaesculenta*: implications for origin in the Pacific. *Cytologia*. 53: 551-560.

FAO (2001). FAO Statistical (FAOSTAT) database. http://apps1.fao.org

GODDEN, D. (1999). Economic rationale for cooperation in germplasm conservation. In: *Plant Genetic Resources in the Pacific: towards regional cooperation in conservation and management. ACIAR Monograph*. 76: 59-60.

GODWIN, I.D., MACE, E.S. and NURZUHAIRAWAITY. (In press). Genotyping Pacific Island taro (*Colocasia esculenta* (L.) Schott) germplasm. *In* Plant Genotyping - the DNA Fingerprinting of Plants. R. Henry (ed). CAB International.

GOLSON, J. (1977). The making of the New Guinea Highlands. In: *The Melanesian Environment*. J. H. Winslow (ed). pp. 45-56. The Australian National University Press, Canberra, Australia.

GUNAWARDHANA, S.A. (1984). A review of taro breeding, pests and diseases. In: Food Crops Advisory Meeting (2/3rd October 1984) Report. J. George and D. Moles (eds). Bubia Agricultural Research Centre, Lae, Papua New Guinea.

GUNUA, T.G., OKPUL, T. AND SINGH, D. (2001). Activities of TANSAO in Papua New Guinea. 2000 *Annual Report*. WLMP, National Agricultural Research Institute, Lae, Papua New Guinea.

HICKS, P.G. (1967). Resistance of *Colocasia esculenta* to leaf blight caused by *Phytophthora colocasiae*. *Papua New Guinea Agriculture Journal*. 19(1): 1-4.

IBPGR (1980). Descriptors for taro (*Colocasia esculenta*). International Plant Genetic Resources Institute, Rome, Italy.

IPGRI (1999). Descriptors for taro (*Colocasia esculenta*). International Plant Genetic Resources Institute, Rome, Italy.

IRWIN, S. V., KAUFUSI, P., BANKS, K., DE LA PENA, R. and CHO, J. (1998). Molecular characterization of taro (*Colocasia esculenta*) using RAPD markers. *Euphytica*. 99: 183-189.

IVANCIC, A. and OKPUL, T. (1996). A new mutation of taro (*Colocasia esculenta*) observed at Bubia Agricultural Research Centre. *Papua New Guinea Journal of Agriculture Forestry and Fisheries*. 39(2): 6-9.

IVANCIC, A. and OKPUL, T. (1997). Importance of wild germplasm in taro (*Colocasia esculenta*) breeding. In: *Proceedings of the 1st Congress of the Genetics Society of Slovenia* (September 2-5, 1997). Pp. 83-84. Ljubljana, Slovenia.

IVANCIC, A., SIMIN, A., OSOSO, E. and OKPUL, T. (1995). Wild taro (*Colocasia esculenta* (L.) Schott) populations in Papua New Guinea. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries*. 38(1): 31-45.

JACKSON, G.V.H. (1994). Taro and Yam genetic resources in the Pacific and Asia. A report for ACIAR and IPGRI. ANUTECH Pty Ltd, Canberra, Australia.

JACKSON, G.V.H. and GOLLIFER, D.E. (1975). Disease and pest problems of taro (*Colocasia esculenta* (L.) Schott) in the British Solomon Islands. *PANS*. 21(1): 45-53.

JOHNSTON, M. and GENDUA, P. (1998). The growth performance of taro (*Colocasia esculenta*) grown from true seed. *Tropical Agriculture (Trinidad)*. 75(1): 13-17.

JOUGHIN, J. and KALIT, K. (1986). The changing cost of food in Papua New Guinea-an analysis of five urban markets. *Technical Report No. 14*. Department of Primary Industry, Port Moresby, Papua New Guinea.

KAMBOU, R.N. (1995). The current status and prospects of plant genetic resources in Papua New Guinea. *Harvest*. 18 (1 & 2): 26-70.

KAMBUOU, R.N. (1998). Status of taro collection in Papua New Guinea: Country Report. Paper presented at AusAID/SPC taro collection strategy workshop (December 7 – 11), Lae, Papua New Guinea.

KESAVAN, V. and ABURU, K. (1982). Conservation of plant genetic resources. In: *Traditional conservation in Papua New Guinea: implications for today. Monograph 16*. L. Morauta, J. Pernatta and W. Heaney (eds). pp. 379-384. Institute of Applied Social and Economic Research, Port Moresby, Papua New Guinea.

KOKOA , P. and DARIE, A. (1994). Field screening of taro (*Colocasia esculenta* (L.) Schott) for resistance to taro leaf blight (*Phytophthora colocasiae*). In: Proceedings of the Second Taro Symposium. G.V.H. Jackson and M. E. Wagih (eds). pp. 127. PNG University of Technology, Lae, Papua New Guinea.

LEBOT, V. (1999). Biomolecular evidence for plant domestication in Sahul. *Genetic Resources and Crop Evolution*. 46: 619-628.

LEBOT, V. and ARADHYA, K.M. (1991). Isozyme variation in taro *Colocasia esculenta* (L.) Schott from Asia and Oceania. *Euphytica*. 56: 55-66.

LEBOT , V., HARTATI, S., HUE, N.T., VIET, N.V., NGHIA, N.H., OKPUL, T., PARDALES, J., PRANA, M.S., THONGJIEM, M., KRIEKE, C.M., VAN ECK, H., YAP, T.C and IVANCIC, A. (2000). Genetic variation of taro (*Colocasia esculenta*) in South East Asia and Oceania. In: *2000 Annual Report. Taro Network for South East Asia and Oceania: Evaluation and breeding for rain-fed cropping systems in South East Asia and Oceania*. Pp. 98-114. CIRAD Office, Port Vila, Vanuatu.

LEON, J. (1977). Origin, evolution and early dispersal of root and tuber crops. In: *Proceedings of the 4th Symposium (1-7 August 1976) of the International Society for Tropical Root Crops*. J. Cook, R. MacIntyre and M. Graham (eds). Pp. 20-36. International Development Research Centre, Ottawa, Canada.

LEVETT, M.P., KURIKA, L. and TAKAGI, H. (1985). Germplasm collection, description and preliminary evaluation of the major root crops in Papua New Guinea. *Technical Report 85/2*. Department of Primary Industry, Port Moresby, Papua New Guinea.

MACE, E.S. and GODWIN, I.D. (2000). Using SSRs to determine genetic diversity in taro. *The Satellite*. 3(1): 4-6.

MACE, E., GODWIN, I. and MATHUR, P. (2001). Development of recommended taro core collection based on molecular characterization. In: *Taro Conservation Strategy Workshop (September 2001) Report*. pp. 19-24. AusAID/SPC Taro Genetic Resources: Conservation and Utilization. Secretariat of the Pacific Community, Noumea, New Caledonia.

MATTHEWS, P. (1987). Wild taros and the context of cultivation. *Aroideana* 10(1): 9-13.

MATTHEWS, P.J. (1990). The origins, domestication and dispersal of taro. PhD Thesis. Australian National University, Canberra, Australia.

MATTHEWS, P.J. (1991). A possible wildtype taro: *Colocasia esculenta* var. *aquatilis*. *Indo-Pacific Prehistory Association Bulletin* 11: 69-81.

MATTHEWS, P.J. and TERAUCHI, R. (1994). The genetics of agriculture: DNA variation in taro and yams. In: *Tropical Archaeobotany: Applications and New Developments*. J. G. Hather (ed). pp. 251-262. Routledge, London, United Kingdom.

MORREN, G.E.B., and HYNDMAN, D.C. (1987). The taro monoculture of Central New Guinea. *Human Ecology*. 15(3): 301-315.

OKADA, H. and HAMBALI, G.G. (1989). Chromosome behaviors in meiosis of the interspecific hybrid between *Colocasia esculenta* (L.) Schott and *C. gigantea* Hook. F. *Cytologia*. 54: 389-393.

OKPUL, T. and IVANCIC, A. (1996). Hybridization of taro (*Colocasia esculenta* (L.) Schott): floral development and stigma receptivity. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries*. 39(1): 12-18.

OKPUL, T., IVANCIC, A. and SIMIN, A. (1997). Evaluation of 35 leaf blight resistant taro lines for Bubia, Morobe Province, Papua New Guinea. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries*. 40(1&2): 13-18.

OKPUL, T., SINGH, D., WAGIH, M. WILES, G. and HUNTER, D. (2002). Improved taro varieties with resistance to taro leaf blight for Papua New Guinea farmers. *NARI Technical Bulletin Series*. No. 3.

PANOFF, F. (1972). Maenge taro and cordyline: Elements of Melanesian key. *Journal of Polynesian Society*. 81: 375-390.

PAWLEY, A.K. and GREEN, R.C. (1973). Dating the dispersal of oceanic languages. *Oceanic Linguist*. 12: 1-67.

PLUCKNETT, D.L. (1983). Taxonomy of the genus *Colocasia*. In: Taro: A Review of *Colocasia esculenta* and its Potentials. Pp. 61-66. J. K. Wang and S. Higa (eds). Hawaii University Press, Honolulu.

PLUCKNETT, D. L., DE LA PENA, R.S. and OBRERO, F. (1970). Taro (*Colocasia esculenta*). *Field Crops Abstracts*. 23: 413-426.

PURSEGLOVE J.W. (1988). *Tropical crops: Monocotyledons*. Longman Press, Essex, United Kingdom.

RANGAI, S.S. (1982). Preliminary results of a survey of taro cultivation in the Gazelle Peninsula of New Britain. In: *Proceedings of the Second Papua New Guinea Food Crops Conference, Part One*. R.M. Bourke and V. Kesavan (eds). pp. 123-133. Department of Primary Industry, Port Moresby, Papua New Guinea.

RODONI, B.C., DALE, J.L. and HARDING, R.M. (1994). Review of Alomae disease of taro. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries*. 37(2): 14-18.

SAR, S., WAYI, B.M. and GHODAKE, R.D. (1998). Review of research in Papua New Guinea for sustainable production of taro (Colocasia esculenta). *Tropical Agriculture (Trinidad)*. 75(1): 134-138.

SHAW, D.E. (1975). Illustrated notes on flowering, flowers, seeds and germination in taro (*Colocasia esculenta*). In: *Research Bulletin 13*. pp. 39-59. Department of Agriculture Stock and Fisheries, Port Moresby, Papua New Guinea.

SINGH, D. and OKPUL, T. (2000). Evaluation of 12 taro (*Colocasia esculenta* (L.) Schott) leaf blight resistant lines for yield and eating quality in Papua New Guinea. *SABRAO Journal of Breeding and Genetics*. 32(1): 39-45.

TANSAO (1998). 1998 Annual Report. Taro Network for South East Asia and Oceania: Evaluation and breeding for rain-fed cropping systems in South East Asia and Oceania, Port Vila, Vanuatu.

TANSAO (1999). 1999 Annual Report. Taro Network for South East Asia and Oceania: Evaluation and breeding for rain-fed cropping systems in South East Asia and Oceania, Port Vila, Vanuatu.

TANSAO (2000). 2000 Annual Report. Taro Network for South East Asia and Oceania: Evaluation and breeding for rain-fed cropping systems in South East Asia and Oceania, Port Vila, Vanuatu.

TAROGEN (2000). 1999/2000 Annual Report. AusAID/SPC Taro Genetic Resources: Conservation and Utilization. Secretariat of the Pacific Community, Noumea, New Caledonia.

TAROGEN (2001a). 2000/2001 Annual Report. AusAID/SPC Taro Genetic Resources: Conservation and Utilization. Secretariat of the Pacific Community, Noumea, New Caledonia.

TAROGEN (2001b). Taro Conservation Strategy Workshop (September 2001) Report. AusAID/SPC Taro Genetic Resources: Conservation and Utilization. Secretariat of the Pacific Community, Noumea, New Caledonia.

THISTLETON, B.M., MASAMDU, R., THEUNIS, W., ALOALI'I, I., TAISAU, P. and SIMBIKEN, N. (In press). A summary of studies on the taxonomy, biology and ecology of taro beetles *Papuana* spp. and *Eucopidocaulus* spp. (Coleotera: Scarabaeidae) from the South Pacific and evaluation of measures for their control. Secretariat of the Pacific Community, Noumea, New Caledonia.

VAN ECK, H.J., HAN, T. and JACOBSEN, E. (1998). Evaluation of the genetic diversity in taro (*Colocasia esculenta*) using AFLP fingerprinting. In: 1998 Annual Report, Taro Network for Southeast Asia and Oceania (TANSAO). pp. 78-82. CIRAD Office, Port Vila, Vanuatu.

WADDELL, E. (1972). The mound builders: Agriculture practices, environment and society in the Central Highlands of New Guinea. University of Washington Press, Seattle, USA.

WAGIH, M.E., SIAGURU, P. and MOUSA, N. (1994). The missing role of biotechnology in the conservation and use of floral diversity in Papua New Guinea. *Science in New Guinea.* 22(2): 51-60.

WILLS, R.B.H., LIM, J.S.K. and BAYLISS-SMITH, T. (1983). Nutrient composition of taro (*Colocasia esculenta*) cultivars from the Papua New Guinea Highlands. *Journal of Food Science and Agriculture.* 34: 1137-1142.

YEN, D.E. (1982). The history of cultivated plants. In: *Melanesia: Beyond diversity.* Volume One. R.J. May and H. Nelson (eds). Pp. 281-295. Research School of Pacific Studies, Australian National University, Canberra.

YEN, D.E. (1995). The development of Sahul agriculture with Australia as bystander. *Antiquity.* 69: 831-847.