Genetic Diversity in Taro (*Colocasia esculenta* Schott, Araceae) in China: An Ethnobotanical and Genetic Approach[1]

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Xu Jianchu, Yang Yongping, Pu Yingdong *(Kunming Institute of Botany—CAS, Heilongtan, Kunming, Yunnan, China),* **W. George Ayad, and Pablo B. Eyzaguirre** *(International Plant Genetic Resources Institute, Via delle Sette Chiese 142, 00145 Rome, Italy). Economic Botany 55(1):14–31, 2001. Taro,* Colocasia esculenta *(Araceae), is a widely distributed and important food crop in the humid tropics and subtropics. Relatively neglected by science, much knowledge of genetic diversity in taro is with farmers. Taro genetic resources managed by five ethnic communities and Han farming villages in diverse ecosystems were sampled and characterized in Yunnan Province, southwest China. This study documented a new type of flowering taro selected by farmers which is widely and intensively cultivated for its edible flower. Samples representing 20 traditional cultivars were grouped into five major morphotypes according to ethnobotanical, agro-morphological, and preliminary genetic characterization. Folk taxonomy and uses tended to confirm the five morphotypes recognized by peoples of Yunnan for their distinctive properties and uses. These major taro morphotypes are key units for assessing how patterns of use maintain genetic diversity and to monitor potential genetic erosion. The morphotype groups also suggest possible evolutionary relationships in cultivated taros.*

Key Words: taro; *Colocasia esculenta*; China; genetic diversity.

Taro, *Colocasia esculenta* (Araceae), is a widely distributed food crop and is locally important in many parts of the humid tropics and subtropics. It can fit well into tree crop and agroforestry systems, and some taro types are particularly well adapted to difficult land and soil conditions such as swamps. Others are grown under intensive cultivation as starch crops. Taro is also known as *dasheen, eddoes, malanga,* and *cocoyam* in the Caribbean and West Africa. Although the roots (corms and cormels) are the most widely used and important part of the plant, the leaves, stalks, and flowers (Fig. 1) are also eaten depending on the cultivar and the culture. In Asia and the Pacific, taro is the staple food of many Pacific Island cultures; according to production statistics, the average annual taro production in China is over 1.2 million tons (FAOSTAT 97). Because its commercial importance is largely local, the extent of taro production and distribution is often underestimated even in national statistics.

This widely consumed tropical root crop has been relatively neglected by research and conservation efforts. Taro genetic resources maintained in ex situ collections are limited and there is a dearth of information to assess how much genetic diversity exists and how much has been conserved (Lebot and Aradhya 1991). The various systems for growing and using taro are also poorly documented. More information on the distribution of genetic diversity and its uses by farmers, and within-crop gene pool is essential to conserve and maintain genetic diversity in cultivated taros.

Taro is a vegetatively propagated crop. Propagation under cultivation is through the corms and cormels, and in the wild, vegetative propagation is through stolons. Plants are monoecious, and flowering and seed setting is common in wild and naturalized taros, but almost no information is available regarding seed dispersal and germination (Matthews 1997). Under cultiva-

[1] Received 21 October 1997; accepted 4 November 1999.

Fig. 1. Flowering taro in a swidden field.

tion, flowering and seed setting is a rare occurrence. The centers of diversity for taro are northeast India, Southeast Asia, and Melanesia (Plucknett 1976). Debate and research continue on the centers of origin of this global crop, with northeast India and Melanesia possibly being separate centers of origin and domestication (Kuruvilla and Singh 1981; Coates, Yen, and Caffey 1988; Matthews 1995). The taxonomy of taro is still uncertain, although there is growing evidence for grouping cultivated taro into at most two species (Hay 1996; Matthews pers. comm.).

Yunnan Province in southwest China is an important region for ethnobotanical and genetic studies of taro diversity. It is at the margins of the centers of diversity in Assam and Southeast Asia. Yunnan is also a major producer of taro under a range of farming systems from tropical swidden to intensive irrigated agriculture. Historical records clearly show the importance of taro cultivation nearly 2000 years ago. *Qi-Ming-Yao Shu* a book on agricultural technology written by Jia Sixi in 600 A.C. describes taro cultivation in great detail. This long history of taro cultivation in a region with rich ethnic and ecological diversity and frequent contacts with other centers of taro diversity provides the background for our research on the human impact on the distribution and maintenance of genetic diversity in taro.

The objectives of the research were to identify and document genetic diversity in cultivated taro. At the same time, the research was designed to develop integrated approaches combining ethnobotanical methods with genetic analysis of taro at the molecular level. A holistic approach affords the best insight into how crop genetic diversity is maintained and managed by different communities in distinct socioeconomic environments and ecologies. This enables us to identify community-based approaches for conservation and use of neglected tropical root crops such as taro.

Materials and Methods

The study of taro diversity in Yunnan Province began in November 1995. Ethnobotanists from the Kunming Institute of Botany (Chinese Academy of Sciences) conducted field surveys, coarse-grid sampling, and cytological analyses. Scientists from the Institute of Flowers and Vegetables and the Biotechnology Research Center of the Chinese Academy of Agricultural Sciences in Beijing carried out molecular and biochemical analyses of genetic diversity. The second phase of the study will be completed in 1999 and will report in greater detail the results of fine-grid sampling using molecular and isozyme markers to assess the distribution of genetic diversity within and across populations that have been identified by local communities. Comparison and integration of results yields new information and insight on taro genetic diversity and variation within and across plant and human communities. A particular focus is on the morphological and use traits that are valued and conserved by local peoples and how they relate to the management and distribution of genetic diversity in the taro crop gene pool.

Description of Survey Area

The taro growing areas surveyed cover three agroecological zones in Yunnan according to mean annual temperature, rainfall, elevation, and soil type (see Table 1). They include the subtropical zone, south subtropical zone, and trop-

TABLE 1. AGROECOLOGICAL PROFILES OF AREA STUDIED IN YUNNAN, SOUTHWEST CHINA.

Agroecological zone	Study area	Altitude (m)	Mean annual temperature (°C)	Mean annual precipitation (mm)	Soil type
Subtropics	Yiliang, Jianchuan, Tonghai	1400–1800	14–16	1000	Yellow soil
South subtropics	Jiangcheng	1200–1500	18–20	2000	Yellow-red soil
Tropics	Yingjiang, Jinghong	1200–1500	20–22	1500	Red soil

ical zone. Communities selected for surveys and site samples represent a range of different farming systems: a market-oriented farming system (Yiliang, central Yunnan), a swidden farming system in transition from subsistence to a market-oriented system (Xishuangabanna, southern Yunnan), and a subsistence farming system (Jiangcheng, southeast Yunnan and Yingjiang, west Yunnan) (see Fig. 2). The Yi ethnic people and Han Chinese in Yiliang, central Yunnan practice intensive irrigated paddy production with good market access and exposure to Han Chinese culture for centuries. The ethnic groups in Xishuangbanna such as Jinuo and Hani (Akha) engage in swidden cultivation supplemented by terraced paddy (Fig. 3). The recent boom in tourism and improvement of infrastructure have significantly changed production from subsistence to cash crop systems such as fruit trees and rubber trees in Xishuangbanna during recent years. The Hani (Akha) people in Jiangcheng, southeast Yunnan, and Jingpo people in Yingjiang, west Yunnan are still practicing subsistence swidden farming. Taro can be found in a range of microenvironments such as in the swidden field, rain-fed field, irrigated paddy field, home garden, swamp, and other natural habitats.

ETHNOBOTANICAL METHODS AND FOLK TAXONOMY

Ethnobotanical survey methods included a) free listing of local names; b) participatory sorting, scoring, and ranking of traditional cultivars; and c) market surveys through key informant interview. Informants were the growers and sellers of taro with attention paid to collecting information from both men and women and old and young farmers. Botanical survey includes measurement of plant characters in the field according to taro descriptors provided by IPGRI and field sampling for roots (for RAPD and isozyme analysis) and root tips (for chromosome analysis). The ethnobotanical data provide clues for study on domestication and genetic evolution; they also provide solid indication of genetic diversity. For example, morphological variation observed in the fields and indigenous knowledge about uses, folk names, selection, and management of taro can be good indicators of taro genetic diversity.

Throughout the surveys, strict attention was paid to organizing samples according to how

Fig. 2. Location map of study sites.

they were classified and maintained by the local communities. This is crucial for further research to assess how these different patterns for managing and using locally identified types of taro have maintained genetic diversity through the establishment of distinct selective pressure on taro germ plasm. The ethnobotanical study revealed specific sociocultural and use factors that underlie these distinct selection pressures. Distinctive taro types were identified with new and important uses. The ethnobotanical survey also revealed a dynamic and active process of shaping and extending new diversity in taros. These initial findings are useful in the identification of particular ecological niches and production and use systems that contribute to the maintenance of genetic diversity in taro.

Plant Sampling Methods

Sampling was carried out at three levels to capture differences in taro according to where and how it was grown and used. The first level was to sample across distinct ethnic communities. Yunnan Province has the highest level of ethnic and cultural diversity within China. Each ethnic community has a distinctive food culture and agrarian history in which taro is important. Taro types and uses in five local ethnic groups, Hani, Jinuo, Yi, Jingpo, and Dai were surveyed in detail. Data were also collected on taro cultivars used in Han Chinese communities within the same region. The second level was to sample the different agroecological zones in which taro is grown. These ranged from low-input swidden agriculture to intensive irrigated farming for urban markets. The third level was to sample variation in taros within communities and households focusing on the microenvironments within farms where they are found.

The communities selected for surveys and site samples represent a range of different farming systems such as market-oriented farming system (Yiliang, central Yunnan), a swidden farming system in transition from subsistence to market-oriented system (Xishuangabanna, southern Yunnan) and a subsistence farming system (Jiangcheng, southeast Yunnan and Yingjiang, west Yunnan). Survey missions in 1996 covered a diverse range of sociocultural and agroecological conditions. The extensive ethnobotanical

TABLE 2. INVENTORY OF SAMPLES OF TRADITIONAL TARO VARIETIES COLLECTED IN YUNNAN PROVINCE, SOUTHWEST CHINA.

Sample #	Local name	Communities	Farming system	Status	Part of plant collected	Chromosome
001	Hongyu	Jinghong	Farmland	Cultivated	Cormel	42
003	Songho (Hani)	Jinghong	Swidden	Cultivated	Cormel	42
008	Xiangyu	Restaurant	Market	Cultivated	Corm	28
009	Yeyu	Yingjiang	Stream	Wild	Living plant	28
004	Ayopi (Hani)	Jinghong	Swidden	Cultivated	Cormel	—
005	Dao (Hani)	Jinghong	Swidden	Cultivated	Corm	—
006	Zabyong (Hani)	Jinghong	Swidden	Cultivated	Corm	42
007	Yeyu	Yingjiang	Forest	Wild	Living plant	28
101	Jiutouyu	Jiangcheng	Farmland	Cultivated	Cormel	—
102	Xiangyu	Jiangcheng	Home garden	Cultivated	Cormel	28
103	Jiangbayu	Jiangcheng	Farmland	Cultivated	Cormel	42
104	Heiyu	Jiangcheng	Farmland	Cultivated	Cormel	42
105	Tianyu	Jiangcheng	Farmland	Cultivated	Cormel	42
106	Hongyu	Jiangcheng	Farmland	Cultivated	Cormel	42
107	Shuiyu	Jiangcheng	Home garden	Cultivated	Cormel	42
108	Yeyu	Jiangcheng	Swidden	Managed	Cormel	42
109	Daheimayu	Jiangcheng	Home garden	Cultivated	Corm	—
122	Kaihuayu	Jiangchuan	Home garden	Cultivated	Living plant	42
123	Qingyu	Jiangchuan	Home garden	Cultivated	Living plant	42
124	Mayutou	Jiangchuan	Home garden	Cultivated	Living plant	42
125	Wangeng	Jiangchuan	Swamp	Managed	Living plant	28
128	Qinggan-dayutou	Yiliang	Home garden	Cultivated	Living plant	42
129	Dayutou	Yiliang	Home garden	Cultivated	Living plant	42
131	Zhongyu	Tonghai	Market	Cultivated	Corm	28
132	Qingyu	Yingjiang	Home garden	Cultivated	Corm	42
133	Yeyu	Yingjiang	Forest	Wild	Corm	28
201	Jidanyu	Tonghai	Market	Cultivated	Cormel	42
202	Baiyu	Tonghai	Market	Cultivated	Cormel	42
204	Jidanyu	Tonghai	Market	Cultivated	Cormel	42
206	Kaihuayu	Yiliang	Farmland	Cultivated	Living plant	42
207	Huanggengyu	Yiliang	Farmland	Cultivated	Living plant	42
208	Gouzhuayu	Yiliang	Farmland	Cultivated	Living plant	42

TABLE 2. CONTINUED.

Sample #	Local name	Communities	Farming system	Status	Part of plant collected	Chromosome
209	Daziyu	Yiliang	Farmland	Cultivated	Living plant	42
210	Qingyu	Yiliang	Market	Cultivated	Cormel	42
214	Zhongyu	Yiliang	Market	Cultivated	Cormel	42
216	Shuiyu	Tonghai	Orchard	Cultivated	Living plant	42
217	Lugengya-danyu	Tonghai	Orchard	Cultivated	Living plant	42
218	Ileigengya-danyu	Tonghai	Orchard	Cultivated	Living plant	42
219	Guijiaoyu	Tonghai	Farmland	Cultivated	Living plant	42
220	Hongyu	Yingjiang	Market	Cultivated	Cormel	42
223	Binglangyu	Jinghong	Home garden	Cultivated	Corm	28
002	Changbiyu	Jinghong	Swidden	Cultivated	Corm	—

Notes: – = data absent.

Fig. 3. A multi-purpose taro variety grown in upland swidden, southern Yunnan.

field survey was complemented by secondary data collection together with germ-plasm sampling. A total of 53 samples representing 20 traditional cultivars were collected from 24 sites/ farmer households in four different cultural communities in Yunnan Province (see Table 2).

The ethnobotanists and farmers identified distinct taro types and grouped the material and its associated knowledge according to the indigenous or local farmer varietal name. These samples were characterized using morphological and indigenous classification and grouped into morphotypes. The ethnobotanical surveys also documented and compared the traditional agronomic practices under which taro is grown, and their location within particular microenvironments in the farm. Detailed information was compiled comparing the uses and sociocultural preferences for the various taro samples.

In collecting samples, coarse-grid selective sampling combined with a general ethnobotanical survey method has been employed. This allows for the identification of the major patterns of distribution of genetic variation in taro within

TABLE 3. USES AND STATUS OF *COLOCASIA ESCULENTA* IN YUNNAN, SOUTHWEST CHINA.

Local name	Uses	Status†
Yeyu (Han)	Root for medicine Petiole and leaf for fodder	Wild
Caiyu (Han)	Petiole for vegetable	Cultivated
Wangenyu (Han & Dai)	Petiole & leaf for fodder Stolon for pickle Inflorescence for vegetable	Cultivated
Kaihuayu (Han)	Inflorescence for vegetable Leaf for fodder	Cultivated
Maoyutou (Han)	Corm and cormel for food Leaf for fodder	Wild, managed, or cultivated
Bule (Jinuo)	Corm and cormel for food Inflorescence for vegetable Leaf for fodder	Cultivated
Byongma (Hani)	Corm and cormel for food Inflorescence for vegetable Leaf for fodder	Cultivated

† Wild—varieties found in natural habitats without human intervention in their reproduction and propagation, their life-cycle can include sexual reproduction (flowering, cross-pollination and seed setting).
Managed varieties affected by partial human intervention, thus subject to a degree of farmers selection; e.g. semi-domesticated, protected and/or used. This category can also include naturalized cultivars.
Cultivated—varieties grown in human-managed habitats, propagation is entirely subject to and dependent upon farmers' selection.

and between the communities surveyed and to compare the number and types of taro cultivars grown in farmers fields. The traditional cultivars or morphotypes were distinguished in farmers' fields, based on local name, indigenous knowledge on growth, reproduction, local adaptation, and pest and disease resistance as well as organoleptic qualities, uses, and market preferences. These were combined with taxonomic analysis using key morphological traits of blade, petiole, cormel, roots, and inflorescence. Together these characters enabled us to classify samples for collecting genetic material for the analysis of intraspecific diversity. The sample size ranged from one to three propagules per plant/morphotype. The propagules collected were cormels, corms, or whole living plants. Part of this collection has been propagated in the botanical gardens of Kunming Institute of Botany and the Chinese Academy of Agricultural Sciences in Beijing for morphological observations, karyotype investigations, and preliminary RAPD and isozyme analysis.

INITIAL RESULTS

CLASSIFICATION OF CHINESE TARO BY USE CATEGORY

The survey has combined the ethnobotanical information with morphological and cytological data to group cultivated and wild taros based upon categories of use and local name (see Table 3). The indigenous name taro in the four local languages often denotes many distinct types of cultivated and wild *Colocasia esculenta.* Although the taxonomic classification used in China has distinguished five species of *Colocasia* commonly found in Yunnan, southwest China, we prefer to consider these as botanical varieties of a single species, *Colocasia esculenta* including the wild-type taros (Matthews 1997). Local and indigenous communities in Yunnan manage these various types as populations of single gene pool, moving material in and out of cultivation and selecting among various clones for distinctive characteristics based on adaptation or uses. These taro varieties are used by indigenous people for food, vegetable, fodder, medicine, and ornament.

Taro Habitats and Cultivation Practices. Although wild types of taro most likely are found in wet habitats such as swamps, waterfalls, hot springs, and river banks, cultivated taro is adapted to a range of microenvironments including swidden-fallow fields, permanent upland fields, rain-fed and irrigated paddy fields, and home gardens because of a long history of human selection and domestication. Wild-type taros can exist in natural habitats, as weeds in cultivated

TABLE 4. MICROENVIRONMENTS OF TARO CULTIVARS IN AGROECOSYSTEMS.

Cultivars	Swidden-fallow field	Rain-fed upland	Irrigated paddy	Home garden	Orchard	Swamp and spring	Stream and river bank
Inflorescence morphotype							
Kaihuayu			+	+	+		
Single-corm morphotype							
Daziyu			+	+	+		
Huanggengyu			+	+	+		
Lugengdayutou		+	+	+	+		
Shuiyu			+	+	+		
Pobule	+	+					
Byongmanizong	+	+	+				
Multicormel morphotype							
Bulena	+	+					
Bulece	+	+					
Bulene	+	+					
Byongmasongho	+	+	+				
Byongmane	+	+	+				
Byongmazabyong	+	+	+				
Byongmaayo	+	+	+	+			
Bigeana	+	+	+				
Bikuobine	+	+	+				
Achichibiu		+	+				
Byongmaayopiu		+	+				
Qingyu	+	+	+	+	+		
Zhongyu		+	+	+	+		
Multicorm morphotype							
Gouzhuayu			+	+	+		
Mianhuayu	+	+					
Mibiu			+	+	+		
Petiole morphotype							
Caiyu			+	+	+		
Stolon morphotype							
Wangenyu			+			+	+
Yingjiangyeyu						+	+

habitats, and/or under cultivation. Domesticated taro may become ruderal or wild such as in the fallow fields of swidden agroecosystems. Some of the more primitive cultivars tend to be adapted to narrow ecological niches. Some well-domesticated cultivars, i.e., *qingyu,* or green taro, can be cultivated in a wide range of microenvironments from drylands with low fertility to permanent paddies with high fertility. Farmers report that all cultivars in swidden agroecosystems exhibit flowering. This may be due to the humid tropical environment and the fact that farmers maintain them in the fallow fields for many years.

The agronomic literature describes taro as a crop that usually needs deep soil and irrigated fertile land. However, the farming communities in the survey maintain a diversity of cultivars that are adapted to a range of microenvironments, from swidden fields, rain-fed upland, and home gardens, to paddy fields and swamps (Table 4). In Yunnan tropical areas, more taro cultivation can be found in the upland than in the lowlands. In contrast, more taro is cultivated in the lowlands than upland in the subtropical and temperate areas. The distribution of taro cultivars can reach as high as 2500 m above sea level. But the most suitable environments for taro are located below 1800 meters elevation in the humid zone with 21–27°C mean daily temperature and 2500 mm rainfall per year. Taro can also can be found in marginal agricultural lands and forest areas because it is adapted to different ecological niches. When grown in marginal areas it is often grown in a home garden or intercropped in a swidden or along a stream bed.

Land Preparation. In swidden farming systems, forest land is slashed and burned early in the dry season. In the lowlands where intensive cultivation of taro takes place, farmers usually plough the land before planting. Furrowing is commonly adopted in the lowland because it is easy for irrigation and fertilizing during growing seasons. In other less intensive systems, a hoe is used to plant. The large, single-corm type and the inflorescence type are the taro cultivars most commonly grown under irrigation or in single stands that require more intensive land preparation.

Germ Plasm Selection. Swidden cultivators often select healthy taro to store in the field hut to protect it from rain so it can be used for next year's plantation. Mother taros often are sold at local market for those who do not like to store taro. Using corms for propagation and plastic film for land cover are common practices in central Yunnan to harvest the inflorescence of taro (*C. esculenta* cv. inflorescence) early to obtain a better price for this commodity. Usually the medium-sized cormels with good top budding are selected for propagation. For the single-corm and flowering types, only the top part of the corm itself is used for planting. Some farmers even cut the bottom half from cormels for food to economize. The new cutting is treated by burned residual ash for protection against diseases. For stolon types such as *wangenyu,* farmers select those individuals with rounded leaves considered less acrid as planting material.

Planting and Cropping Pattern. Taro is often planted in field margins, fertile spots, or as land markers between different plots in the swidden fields. Intercropping with corn, upland rice, and vegetables is commonly observed. In the lowlands, taro monocropping is practiced, the distance between plants for taro planting is about 50 × 50 cm or 20 × 80 cm. Taro is often intercropped with corn, beans, sugarcane, fruit trees, and vegetables in the rain-fed and irrigated upland, rice in the paddy field, or rotated with winter crops such as garlic and broad bean. The planting season starts in February and lasts as late as April.

Weeding. The warm, humid environment is good for weeds. Although taro is weed tolerant, weeding one to two times in uplands and three to four times in lowlands is widely practiced. In swidden it is less commonly done and when weeds become well established the taro is harvested and what remains in the ground reverts to naturalized status. The roots and leaves may still be used occasionally for human or animal food.

Soil Fertility Management. Swidden cultivators often plant taro in low-lying areas to catch water and soil run-off. The application of organic fertilizer is recommended before planting in the lowland. Farmers who grow for the market say that taro needs a lot of fertilizer. Fertilizer applications can take place several times, particularly during root growth. For large-corm taro, farmers use organic fertilizer only to maintain good taste quality. For inflorescence vegetable taro, farmers use both chemical and organic fertilizers to harvest more flowers.

Moisture and Water Management. Taro always prefers high soil moisture. The farmers often apply crop residuals or rice husks for land cover to increase soil moisture particularly during certain dry periods. Irrigation is suggested before monsoon (April and May) to assist sprouting and close to the end of monsoon (September and October) for corm formation. Although high soil moisture is generally required, farmers have observed significant variation among taro cultivars with respect to water needs. One taro cultivar, 'green taro,' can tolerate drought conditions and is suitable for upland cultivation. It is widely used in upland rain-fed agriculture.

Disease and Pest Control. Taro in the swidden fields is observed to have fewer diseases and pests because of small-scale cultivation and greater diversity of cultivars used. The main diseases of taro in the lowland are the fungal diseases irvinia (*Erwinia carotovora*) and phytophthora (*Phytophthora colocasiae*), especially during high temperature and high humidity. Cutworm is a common pest for taro. Aphid infestation expands rapidly during the dry season. The farmers' strategy is: a) to use a two to three year land rotation, b) to select healthy taro for propagation, c) to use different varieties, particularly disease-resistant cultivars, and d) to use chemicals. Only inflorescence vegetable taro can be planted in the same field for many years because of its disease resistance. The reasons for this disease resistance are not yet known. It could be that because intensive cultivation of this type is fairly recent so pests and diseases have not yet reached it. Alternatively the different management practices including early harvest and planting may allow it to evade the cycles of existing taro diseases. Should this new farmer variety possess genetically determined resistance to common diseases of taro, this could be significant for areas such as the South Pacific islands where entire populations of taros, the staple food, are being wiped out by diseases. Further research on the evolution of taro diversity in China may provide answers to this question.

Harvesting and Post-Harvest Storage. The inflorescences of *C. esculenta* cv. inflorescence can be harvested from as early as late April to the end of September. Corm and cormel taro types can be harvested from the beginning of September for early-maturing cultivars to early December for late-maturing cultivars. Taro corms and cormels are usually dried for several days and then stored in a shady and open area. Some farmers, particularly swidden cultivators, bury the taro in the fields until the following year for replanting or sale. They cut the petiole and stalk during harvesting and keep the root under the ground for the next year.

VARIATION WITHIN TRADITIONAL TARO CULTIVARS (*C. ESCULENTA*) IN CHINA

Within the domesticated species *C. esculenta,* a number of traditional cultivars readily can be found in the different cultural communities, farming systems and sites surveyed in Yunnan Province. The material collected (a total of 53 samples) has been classified into 20 traditional cultivars based mainly upon cultural communities, local name, and farming systems (see Table 2). Ten traditional cultivars that are widely recognized and represent different status and use categories have been described employing key morphological traits (see Table 5).

CLASSIFICATION OF TRADITIONAL TARO MORPHOTYPES

The ethnobotanical survey across communities and ecosystems in Yunnan revealed a common set of characters that farmers use to group traditional taro cultivars into five types. The fact that this classification was widespread and linked to the uses of taro made it a useful grouping for further diversity analyses (see Table 5). The five traditional taro morphotypes are: inflorescence morphotype, single-corm morphotype, multicormel morphotype, multicorm morphotype, petiole morphotype.

*Inflorescence Morphotype (*C. esculenta *cv. inflorescence).* Taxonomy in China has described this type as the independent species (*Colocasia tonoimo*). However, it can be classified as *C. esculenta* cv. inflorescence based both on indigenous peoples' knowledge and cytogenetic analysis. This experimental classification may be revised in light of results obtained from further morphological and genetic analysis. The inflorescence type has a high market value. Farmers prefer the purple axis type for its better taste and texture as a vegetable. The total area of cultivation of this type seems to have increased dramatically in recent years because of the high market potential, this type is exemplified by traditional cultivar *'kaihuayu'* in central Yunnan.

The discovery and documentation of this flower-type taro under intensive cultivation presents one of the novel findings of the ethnobotanical survey. Previously, the inflorescence was not considered an important character in farmer selection of taro morphotypes (Tanimoto, Tsuchiya, and Matsumoto 1983). This is due to the rarity of flowering in cultivated taro and lack of cases where flowering was the primary character selected by farmers. The Yunnan survey documented irrigated fields of taro clones selected for the propensity and uniformity in their inflorescence. In the central Yunnan area, the flowering type is the taro cultivar with highest market value and is expanding. This is a recent phenomenon which evolved entirely under conditions of farmer selection. Further research is underway to determine the origins and evolution of this new cultivar type.

*Single-Corm Morphotype (*C. esculenta *cv. cormosus).* This type usually has a huge single corm as heavy as 2 kg, with few cormels. The taste of the corm is mealy and much better than the cormels. Some cultivars within this type have fragrant corms when cooked and are greatly appreciated. It needs high temperature and is cultivated in the southeast, south, and southwest China. Many famous varieties of taro in China belong to this type. The earliest Chinese dictio-

TABLE 5. MORPHOLOGICAL VARIABILITY OF 10 TRADITIONAL CULTIVARS OF TARO IN YUNNAN PROVINCE, CHINA (MORPHOLOGICAL CHARACTER/SAMPLE NUMBER).

Character	#109	#209	#207	#208	#122	#007	#218	#217	#216	#219
Stolon formation	1	1	1	1	1	2	1	1	1	1
Number of suckers	2	2	2	3	2	1	2	2	2	2
Leaf color	5	3	3	3	3	3	3	3	3	3
Petiole junction color	2	2	2	2	4	4	2	2	2	2
A	3	10	10.5	7	6.5	8	11.5	8	12	24
B	28.5	30	26	23	19	20.5	30	22	36	55
C	9	17	13	10	12.5	11.5	13	11	26	36
D	10	12	6.5	5.5	7	6	8	6	13	19
E	16	15	27	22	23	25.5	30	24	47	77.5
Petiole color top	5	3	1	1	1	1	1	1	3	1
Petiole color mid	5	4	2	3	5	1	3	1	4	3
Petiole color base	5	5	5	4	5	3	5	3	5	3
Total petiole length	1	3	3	3	2	2	2	1	2	3
Corm size	1	2	2	1	1	1	1	1	2	1
Number of cormels	1	2	3	2	1	0	2	2	2	2
Spatial arrangement of cormels	2	2	2	1	2	2	2	2	2	2
Root external color	1	1	1	2	2	1	1	1	1	1
Chromosome number	3	3	3	3	3	2	3	3	3	3

Notes: Measurement of taro leaf size: A = length between sinus and base; B = length between sinus and apex; C = width between two retrorse lobes; D = width across sinus; E = length of retrorse lobe.
Morphological description is based on the Descriptors provided by IPGRI as follows:
Stolon formation: 1 = absent, 2 = present
Number of suckers: 1 = absent, 2 = 1–5 suckers, 3 = 6–10 suckers
Color: 1 = whiteish, 2 = yellow, 3 = green, 4 = dark green, 5 = blackish
Leaf size: A = length between sinus and base, B = length between sinus and apex, C = width between two retrorse lobes, D = width across sinus, E = length of retrorse lobe
Total petiole length: 1 = less than 50 cm, 2 = 50 to 100 cm, 3 = more than 100 cm
Corm size: 1 = less than 0.5 kg, 2 = 0.5 to 2.0 kg
Number of cormels: 0 = absent, 1 = less than 5, 2 = 5 to 10, 3 = more than 10
Spatial arrangement of cormels: 1 = clustered, 2 = dispersed
Chromosome number: 2 = diploid (2n = 2x = 28), 3 = triploid (2n = 3x = 42)

nary written in the first century B.C. "Shuo Wen" (Speaking Chinese) gives the original meaning of the Chinese character taro "Yu" is "shockingly huge." This suggests that the single-corm type of taro was widely cultivated even 2000 years ago. The yield of this type is moderate, such as that of traditional cultivars 'daziyu' and 'shuiyu' in central Yunnan.

Multicormel Morphotype (C. esculenta *cv. multicormel).* This type has many cormels. The cormel is easily separated from the attached corm. The starch texture is usually sticky (glutinous). The quality and yield of the cormels is better than the corms. The production is high but the taste is moderately good, such as that of traditional cultivar 'qingyu' in Yunnan.

*Multicorm Morphotype (*C. esculenta *cv. multicorm).* This morphotype grows into several plants on individual cormels. There is no big difference between corms and cormels. The starch texture of corms or cormels is intermediate between mealy and sticky, such as those of traditional cultivar 'gouzhuayu' in Yunnan (Fig. 4).

*Petiole Morphotype (*C. esculenta *cv. petiolatus).* The petiole of this type is used for a vegetable, and is commonly cultivated in streams, ponds, and paddy fields, such as traditional cultivar 'wengengyu' with long stolons. Corms are poorly developed and not tasty.

*Stolon or Wild Type (*C. esculenta *cv. aqualitis).* This type has a poorly developed corm, no cormels, and many long stolons (see Fig. 5). This type can be wild, managed, and cultivated by farmers for different uses. In particular, the stolon or wild type is used by indigenous people in central Yunnan for making pickles (Fig. 6). Farmers can move this type easily from the wild into cultivated habitats.

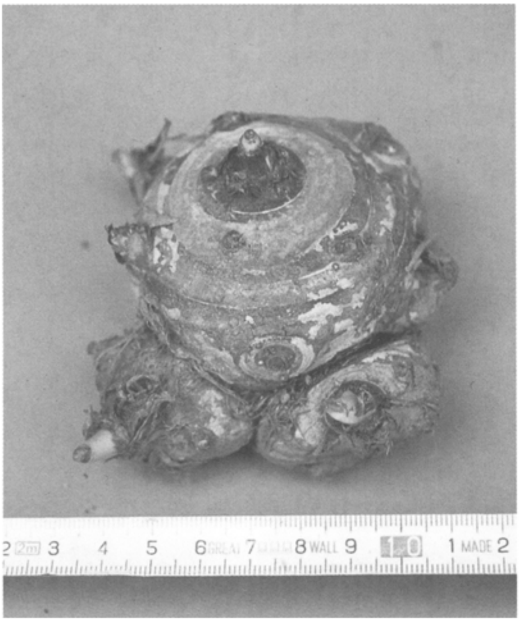

Fig. 4. *Gouzhuayu* or "Dog's paw taro," a variety preferred for the good flavor of its corms and cormels.

Fig. 5. Taro stolons from "wild type taros." These are used for the manufacture of pickles, a delicacy in southern Yunnan.

Fig. 6. Flowers of taro variety Kaihyuayu, an intensively grown high value vegetable on sale in urban markets.

Cytotypes. These were determined by the infraspecific classification of material sampled based on results of karyotype analysis and the results described in Table 6 on interrelationships between locally named morphotypes and cytotypes. The karyotype analysis of a part of the collection (13 samples) has shown that, based on different ploidy levels, the traditional cultivars of taro *Colocasia esculenta* may be grouped into two cytotypes: a diploid (2n = 28) and/or a triploid (3n = 42). For example, the wild type "yingjiangyeyu" is diploid (2n = 28) (see Table 7). The petiole-eating taro growing in the swamp, e.g., traditional cultivar 'wangenyu' with long stolons, is also diploid (2n = 28). The traditional cultivars with a big corm and few cormels are diploids and primitive (2n = 28), for example, cultivar 'xiangyu.' The other cultivars, e.g., 'huanggengyu' and 'qingyu,' are triploids (3n = 42).

Genetic Erosion in Morphotypes

The rate of germ-plasm loss varies for different morphotypes and traditional cultivars. The cultivation of inflorescence-eating taro seems to be increasing because of the high market value. The cultivation of the single-corm type also appears to be increasing because of its good taste, cooking quality, and market potential. The germ plasm of some traditional cultivars, such as "gouzhuayu," seems to be in the danger of erosion.

Discussion

Gene Flow and the Exchange of Traditional Cultivars

The swidden cultivators in Yanuo village from the Jinuo community have observed all cultivars bearing an inflorescence, particularly those perennially growing in the tropical swiddens left to fallow. The Yanuo village consisting of 82 households currently has planted a total of five different cultivar types in their home gardens and swidden fields. They stated that the neighboring villages use many other cultivars. It is a common phenomenon for farmers to exchange their varieties between different households and communities to get different cultivars for varying biophysical and socioeconomic conditions. In most cases, one farmer likes to maintain three to five cultivars in his own fields. Another farmer may use another different three to

Table 6. Agronomic and Use Characteristics of 10 Traditional Cultivars of Taro in Yunnan Province, China.

Cultivar	Fertility requirement	Water requirement	Pest resistance	Disease resistance	Yield	Edible part	Tasty	Market value	Freq. of cultivation
Kaihuayu	5	5	3	3		inflorescence	4	5	5
Qingyu	2	1	5	5	2	cormel	3	3	5
Huanggengyu	4	4	4	4	5	corm	4	2	2
Daziyu	5	4	2	3	3	corm	5	2	2
Gujiaoyu	4	4	4	5	2	corm	4	1	1
Gouzhuayu	4	4	4	5	1	cormel	5	3	3
Shuiyu	4	3	4	4	4	corm	5	4	3
Heigengyadanyu	3	2	5	5	5	cormel	3	3	5
Lugengyadanyu	2	1	5	5	3	cormel	2	1	1

Notes: 5 = very high; 4 = high; 3 = medium; 2 = low; 1 = very low.

TABLE 7. CHROMOSOME NUMBER OF 10 TRADITIONAL CULTIVARS OF TARO COLLECTED FROM YUNNAN PROVINCE, CHINA.

Local name	Morphotype	Sample no.	Chromosome no.
Ziyu	Single-corm morphotype	209	42
Zhongyu	Single-corm morphotype	131	42
Huanggenyu	Multicormel morphotype	207	42
Qingyu	Multicormel morphotype	210	42
Shuiyu	Single-corm morphotype	216	42
Heigenyadanyu	Multicormel morphotype	218	42
Gouzhuayu	Inflorescence morphotype	208	42
Wangenyu	Petiole morphotype	125	28
Xiangyu	Single-corm morphotype	102	28
Yingjiangyeyu	Wild type	007	28

Note: This table shows the co-response between chromosome and different morphotype. Ten traditional cultivars (including wild type) have been selected from each group to show the more primitive morphotype such as wild type, petiole morphotype and some single-corm.

five varieties according to their field, labor, and needs.

Once a farmer has stopped planting his or her own cultivars, some of these cultivars may disappear from the community germ-plasm portfolio. Therefore, there may be a tendency for germ-plasm erosion. This is often the result of younger farmers tending to know about and use fewer distinct varieties than their parents. Further work needs to be done to trace the patterns of taro germ-plasm exchange within ethnic communities, across ethnic communities, and ecozones. It appears that the market is increasingly important in germ-plasm selection and exchange. The effect of the market can be quite positive in maintaining and developing new taro diversity as is the case with the flowering type. It has however had a negative effect in maintaining multicorm types which have special taste and cooking attributes much appreciated in some local communities.

MORPHOLOGICAL VARIATION BASED ON NUMERICAL TAXONOMIC ANALYSIS OF MORPHOLOGICAL TRAITS AND CHROMOSOME NUMBER

The morphological characteristics of 10 traditional taro types, of different status including wild, managed, and cultivated, have been recorded and analyzed according to the following descriptors: stolon formation, number of suckers, petiole color, corm size, and spatial arrangement of cormels, root external color, and chromosome number (see Table 4). A computer-based Numerical Taxonomic System (NSTYS1.8) has been used to compare these traditional cultivars in terms of their relatedness based on morphological variation for the above traits. The analysis has shown that the wild taro *Colocasia esculenta* cv. aquatilis sample no. 007 is quite distinct from all other traditional cultivars. The inflorescence morphotype (*C. esculenta,* cv. inflorescence) was quite similar to other cultivars such as 'gouzhuayu' and 'lugengyadanyu' (samples no. 208 and 217 respectively). Two traditional cultivars 'daheimayu' and 'guojiaoyu' (samples no. 109 and 219 respectively) are distantly related to the others (Fig. 7).

GENETIC, TAXONOMIC, AND EVOLUTIONARY INFERENCES

Genetic variability within taro, *Colocasia,* may be identified, assessed, and classified at the intraspecific level of traditional cultivars and morphotypes based upon the combined findings of indigenous knowledge, including local name, status, and use category. A classification into cultivars and morphotypes has been developed to describe better the range and uses of taro diversity. For instance, the wild-type varieties of *C. esculenta* cv. aquatilis are found often under cultivation yet are distinct in morphotype and use; the corms are poorly developed and the whole plant is used as fodder and as human food. People consume it as leafy vegetable and the stolons are eaten as pickles. The flowering types that are presumed to be more prominent in wild and naturalized populations were commonly found under intensive cultivation. These are significant findings which resulted from the method.

The results of taxonomic comparisons be-

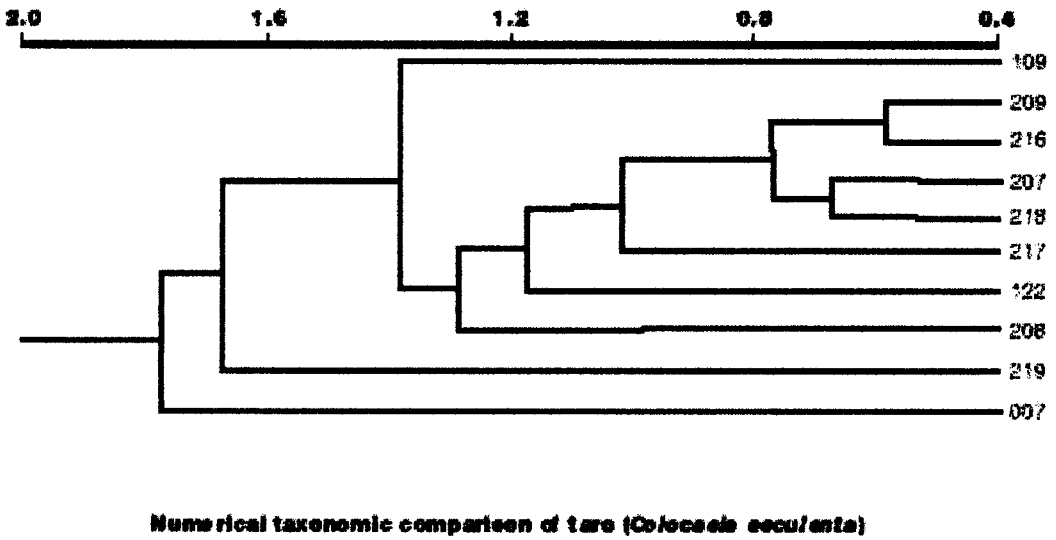

Fig. 7. Dendrogram of taxonomic relationships of 10 traditional taro cultivars in Yunnan province, China.

tween 10 traditional cultivars showed that, though not taxonomically identical, seven cultivars including the inflorescence morphotype 'kaihuayu' (*C. esculenta* cv. inflorescence, sample no. 122, 3n = 42) are found to be closely similar. In terms of site of collection, these seven cultivars represent three communities: "Yiliang xiaomajie" (4), "Tonghai" (2) and "Chengjiang" (1) and two intensive farming systems (farm land (4) and orchards (2)). Only two traditional cultivars, "Daheimayu" and "Guozhuayu" (samples no. 109 from a home garden, Mingzhishan and 219 from a farm land in Tonghai, respectively) are morphologically separated from all other cultivars (Fig. 7). These results may provide evidence of the impact of exchange of traditional cultivars between farmers and households from different communities and farming systems leading to the morphological similarity observed between these cultivars.

The wild-type taro (*C. esculenta* cv. aquatilis) ("Yeyu" sample no. 007) has been found to be quite morphologically distinct from other cultivars. The inflorescence morphotype "Kaihuayu" (sample 122) is closely related to other cultivars. Both results have been corroborated from the karyotype analysis below. In terms of chromosome number, the 20 traditional cultivars were found to be either diploid (2n = 28) or triploid (3n = 42). Of the 13 representative samples analyzed, only three were found to be diploid. These include the two traditional cultivars "Xiangyu" and "Wangenyu" (samples no. 102 and 125 from Mingzhishan and Jiangcheng communities respectively) and the wild type "Yeyu" (sample no. 007, Yingjiang community). While "Xiangyu" was collected from a home garden, cultivar "Wangenyu," the petiole eating taro with big corm and few cormels, was collected in swamp habitats typical for growth of wild taro *C. esculenta* cv. aquatilis. Each of these cultivated diploids "Xiangyu" and "Wangenyu" belong however to a different morphotype: single-corm and petiole morphotypes, respectively. In addition to the diploid "Wangenyu" (2n = 28), the petiole-eating inflorescence morphotype could also be triploid (as in cultivar "Kaihuyau"), sample 122 found in home gardens.

The cytological evidence suggests that the wild-type *C. esculenta* cv. aquatilis is isolated from traditional cultivars. Selection of the petiole morphotype has probably taken place in habitats close or similar to those preferred by wild-type taros (i.e., swamps) and have been taken from there for cultivation in home gardens. Diploid taros however are still important in cultivation in the hotter, more humid environments. There is need for further research on the evolution of morphotypes and relationships between diploid and triploid taro in China.

The origin of taro is perhaps in the tropical areas of Southeast and South Asia and the Pacific Islands. The wild-type taro is native to swamps and watercourses in humid tropical for-

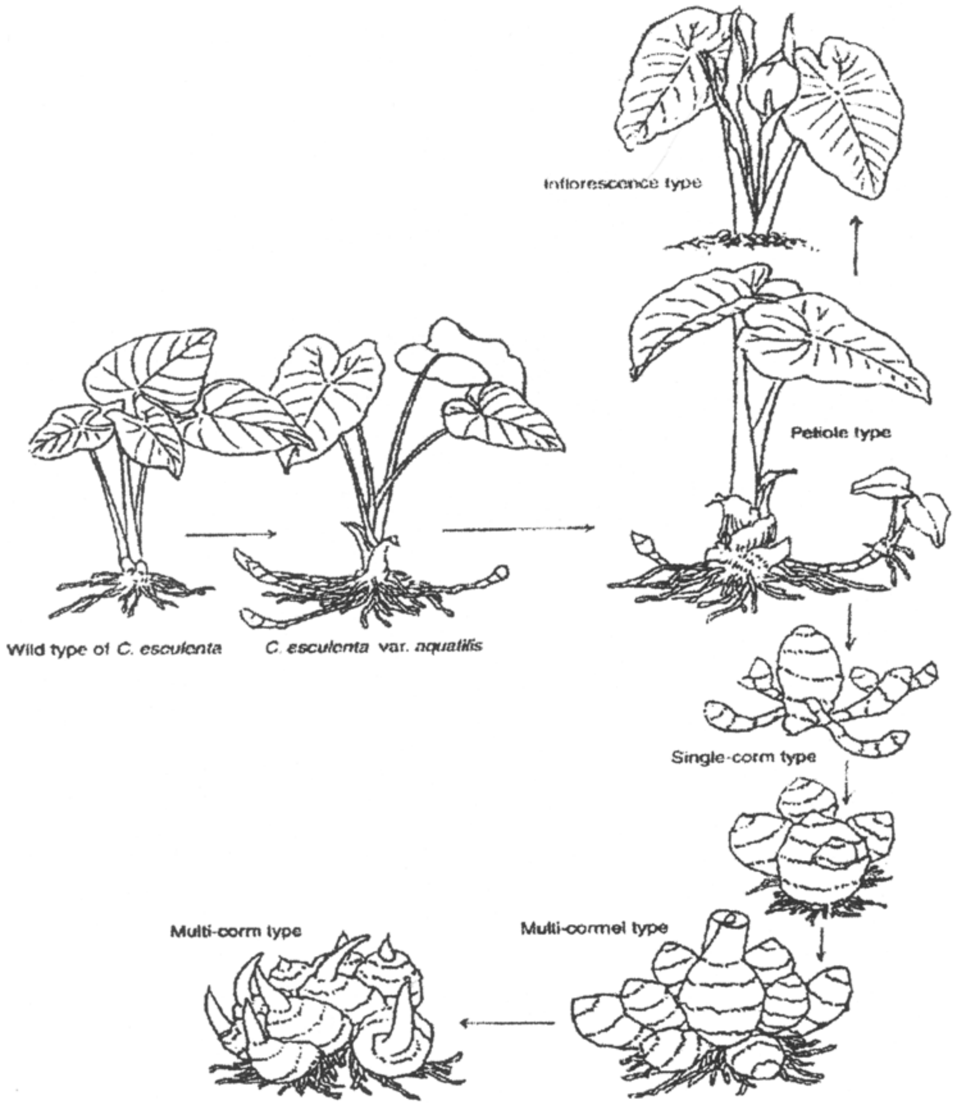

Fig. 8. Putative evaluation scheme for taro (*Colocasia esculenta*).

ests (Matthews 1997). Many cultivars have developed and easily adapted to different ecological niches, such as swamps, and irrigated and rain-fed uplands by constant human selection. As Matthews (1990) stated, it is more probable that taro first evolved as a natural species, from wild progenitors not yet identified, somewhere within the region of northeast India and mainland Southeast Asia (including southwest China). Then it evolved to *C. esculenta* cv. aquatilis, which can be found everywhere in southern Asia, Southeast Asia, the Pacific Islands, and southwest China. The wild-type taro usually has a small corm, long stolons, and a short petiole. While previously described as not edible and even poisonous, our research has documented its wide use as fodder and human food. In Yunnan, there are in fact cultivars of (*C. esculenta* cv. aquatilis) that are widely distributed. By human selection, the wild taro has gradually evolved into five main types, e.g., thick-petiole type with low acid, multi-inflorescence type, single corm type, multicormel type, and the stolon type, all of which can be found in Yunnan. We will continue to do ethnobotanical and genetic diversity research to understand the process of domestication and crop evolution in taros along the lines suggested in Fig. 8.

Conclusion

The ethnobotanical approach identified taro types with distinctive traits that are emerging and contributing new diversity to cultivated taro. This is the case with the growing use and development of taro types for their flowers as a vegetable crop. In other cases, traditional taro types with multiple corm and cormels are not finding a place in the market. Upland taros are also in danger of disappearing as changes in farming systems and land use take place in southern Yunnan with the introduction of commercial agroforestry (for example, rubber is being planted on a wide scale)

The careful recording of indigenous taro and collecting of samples for analysis in accordance with local name proved to be useful. Although different ethnic groups had different names according to local language, the major morphotypes were clearly distinguished across cultures. This supported our conclusion that there were five major categories within which intraspecific taro diversity was managed. The sampling of taro across both socio-cultural units along with agroecological units also provided more information on characters and processes for the management of genetic diversity in taro than would have otherwise been possible by focusing only on socio-cultural or ecological factors.

In general, the ethnobotanical survey found that there remains considerable interest by farmers and consumers in different types of taro and their uses. A key to the maintenance of diversity in taros thus far has been the ability to maintain and move distinct taro populations across environments and status. In particular the use of wild, managed, and intensively cultivated taros as a single complex may be the best way to maintain taro diversity within Yunnan. The case of taro in Yunnan may parallel the process in West African yams where recombination between wild and cultivated forms is an ongoing process that farmers manage (Hamon et al. 1995). Chinese farmers and ethnic communities have been effective in maintaining diversity thus far. Better documentation of the characteristics and uses of the multicorm and multicormel types can serve to maintain interest in these among farmers and consumers. Information on traditional taro cultivars is being shared with agricultural research and extension in the province to support the continued use of all major taro morphotypes in Yunnan.

The success of the combined ethnobotanical and genetic approach was to enable us to identify more readily new morphotypes than through ordinary sampling of genetic diversity according to ecogeographic factors alone. By including local uses, and the identification of characters that local people recognize and use in selection, we were able to group samples for analysis of genetic diversity more quickly (Li and Wu et al. in press). The combined approach provides a better understanding of evolution and interrelationships of wild, managed and cultivated taro. Finally, the combined analysis of taro genetic diversity with how people manage and use that diversity in their communities and fields provides an indicator of the extent to which taro genetic diversity is being maintained by farmers. In the case of a neglected crop like taro, how farmers use and manage diversity is crucial for the conservation its genetic resources.

Acknowledgments

The research grant was provided by the International Plant Genetic Resource Institute (IPGRI) in Rome. We gratefully acknowledge the assistance of Prof. Zhou Mingde and Mr. Zhang Zhongwen, East Asia Office of IPGRI in Beijing. The botanical illustration was prepared by Mr. Liu Yitao, an artist from Kunming Institute of Botany. We particularly thank the local farmers for sharing their knowledge during our field survey.

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