

Conservation and Sustainable Use of Tropical Fruit Species Diversity: Bioversity's Efforts in Asia, the Pacific and Oceania

Bhag Mal^{1*}, V Ramanatha Rao², RK Arora¹, Percy E Sajise² and BR Sthapit¹

¹ Bioversity Office for South Asia, New Delhi-110 012

² Bioversity International, Maccaresse (Rome), Italy

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Asia, the Pacific and Oceania region is very rich in genetic diversity of tropical fruits. Although, fruits have always been important agricultural species, it is only in recent years that there is an increasing awareness of the potential of native tropical fruit species as good sources of dietary vitamins, minerals and energy. They also play a very significant role for the wellbeing of the people through enhancing household income, employment generation particularly for women, and environmental protection. At the same time, their genetic diversity and even the species diversity is threatened due to various human interventions and concerted efforts are required to take corrective measures. Bioversity International, in collaboration with national partners, implemented in recent past several programmes for effective conservation and sustainable use of genetic resources of tropical fruits in the region and is continuing to do so. This paper describes the results of studies on various aspects of tropical fruit genetic diversity and species diversity as well as their sustainable use in major fruit growing countries in Asia, the Pacific and Oceania in the last decade and half. The studies included exploration and collecting, characterization and evaluation, identification of promising/elite lines, documentation, conservation, training and capacity building, socio-economic analysis, information dissemination, collaboration and networking, impacts and sustainability of efforts. The paper also touches on the current efforts and future thrusts for tropical fruit species genetic resources conservation, management and sustainable use.

Key Words: Characterization, Conservation, Documentation, Genetic resources, Species diversity, Sustainable use, Tropical fruits

Introduction

Mostly neglected in the past, tropical fruits have received high priority among the horticultural crops for agricultural development and over the last decade Asia recorded a 66% increase in fruit production, the highest in the world. The region of South, Southeast and East Asia is important in this respect and four countries, namely, India, Indonesia, Thailand and China account for 50% of the total global fruit production. Also in this region, tropical fruits account for 30-59% of total farm income especially for small holders and marginal farmers (TFNet, 2004), thus, contributing to better livelihood of the rural people largely the farming community. It is well established that the tropical fruits contribute significantly towards improved human nutrition and health. These are rich sources of vitamins and minerals and possess high dietary energy (Pareek *et al.*, 1998; Hoe and Siong, 1999; Reddy *et al.*, 2010). Native tropical fruit species are very important for the economic welfare of small farmers in Asia. Most of these species have multi-purpose use for food, shelter, timber, fuel, medicine

and other uses (Bhag Mal and Ramanatha Rao, 2003; Hodel and Gessler, 1999). Thus, in view of their diverse uses, tropical fruits contribute considerably to food and nutritional security, income generation, poverty reduction and ecosystem and environmental sustainability. The rapid agricultural development and industrialization, changing land use patterns, large scale deforestation, accompanied by other social and cultural pressures have resulted in large scale degradation of natural habitats *vis-à-vis* loss of native diversity. Hence, this diversity needs to be conserved by adopting diverse conservation and management techniques and approaches so as to utilize tropical fruit species diversity effectively.

Recognizing the increasing importance and the need of conservation and utilization of tropical fruit tree species (TFT) diversity, Bioversity International (Bioversity in short; formerly IPGRI) initiated research on conservation and use of TFT species in Asia in 1993 in collaboration with national partners which was subsequently followed by large regional projects funded by several donor agencies that strengthened

Author for Correspondence: E-mail: b.mal@cgiar.org

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Bioversity's work on TFT genetic resources management. Bioversity played a significant role towards TFT genetic resource management and use, in changing the perspective about tropical fruits' contribution to economy in general and specifically, in strengthening the national research programmes on TFT (Arora, 1995; Arora and Ramanatha Rao, 1995; Arora and Ramanatha Rao, 1998; Ramanatha Rao and Arora, 1999; Ramanatha Rao and Bhag Mal, 2002; Bhag Mal and Ramanatha Rao, 2003; IPGRI 2003a, b; Bhag Mal *et al.*, 2004; Ramanatha Rao *et al.*, 2005; Bhag Mal *et al.*, 2007).

Fruit Diversity in Asia

Asia is characterized by rich fruit diversity and about 500 species are distributed in its diverse ecosystems. Thus, a wide range of natural diversity occurs, well adapted to sub-humid, humid tropical and semi-arid conditions. In addition to the native fruit species that have been domesticated and diversified in this region, a large number of species of tropical American origin introduced in the distant past have developed agro-ecological niches and are well acclimatized (Verheij and Coronel, 1991; Arora and Ramanatha Rao, 1995). Over 70 cultivated species of major and minor fruits are presently grown in the region, along with some of the promising exotic tropical fruits (Arora and Ramanatha Rao, 1995). However, only about 20 species are better known under cultivation and these include banana, citrus, mango, pineapple, papaya, durian, rambutan, jackfruit, litchi, longan, tamarind, chempedak, carambola, langsat, guava, sour sop, custard apple, salak, passion fruit and jujube (Verheij and Coronel, 1991; Singh, 1993; Arora and Ramanatha Rao, 1995), the predominant fruits being banana, pineapple, citrus, mango and papaya.

In the humid tropics which hold very rich species diversity, TFT are a major component of multi-crop farming systems including home gardens. Some of these species have been well adapted to marginal lands, and in agroforestry and farm-forestry systems (Verheij and Coronel, 1991).

An example of rich fruit diversity in Asia is the genus *Mangifera* which comprises 58 species (Kostermans and Bompard, 1993) and is naturally distributed in south, southeast and east Asia. The Malay Peninsula, the Indonesian Archipelago, Thailand, Indo-China and the Philippines are the seats of diversity for *Mangifera*

species (Mukherji, 1985; Bompard, 1988; Kostermans and Bompard, 1993). About 26 species have edible fruits, either eaten as fresh fruits or used to prepare jams, jellies or preserves, the most important of which is mango (*Mangifera indica*).

The other important species, which produce edible fruits, are *M. caesia* Jack, *M. foetida* Lour, *M. kemanga* Bl., *M. laurina* Bl., *M. odorata* Griff. Lour. (Bompard 1992; Tanaka, 1976), *M. pajang* Kostermans (Bompard, 1992) and *M. sylvatica* Roxb. (Tanaka, 1976) which, with the exception of the later, are mostly distributed in Malaysia and Indonesia. Besides mango, the other *Mangifera* species reported from India include *M. andmanica*, *M. khasiana* and *M. sylvatica* and *M. camptosperma* (Mukherji, 1985). A large array of cultivated and wild types occur in India. Seedling races derived from monoembryonic mango stones are the most important components of diversity available in India. Almost all commercial cultivars of mango have arisen as a result of seedling selection. Although, most other countries in APO have 2-10 commercial cultivated mango varieties, India has around 1000 distinct varieties and about 30 of them are commercially grown.

Another good example is of *Citrus*. The genus *Citrus* occurs naturally from North-eastern India and Southern China to Northern Australia and New Caledonia. The cultivated species are native to the tropical and subtropical regions of Southeast Asia. The taxonomy of *Citrus* is not precisely established. Most researchers utilize the Swingle system (Swingle, 1943) which recognizes 16 species, or one of its modifications which recognizes 17 species (Bhattacharya and Dutta, 1956; Stone, 1994), 36 species (Hodgson, 1967), or 31 species (Singh and Nath, 1969). The recent taxonomy of Mabberly (1997, 1998) is essentially a modification of the Swingle system, with several genera being reabsorbed into *Citrus*. In contrast, the Tanaka taxonomy recognizes up to 162 species (Tanaka, 1977). This lack of agreement reflects differences of opinion as to what degree of difference justifies species status and whether or not supposed hybrids among naturally occurring forms should be assigned species status. There is no definitive work on *Citrus* taxonomy, and many workers use a sort of ad hoc system somewhat intermediate between the two systems. It is probable that natural hybridization took place between species and varieties resulting in an array

of complex hybrids. The commonly grown citrus fruits belong to three genera, *Citrus*, *Fortunella* and *Poncirus*. All these genera are closely related, have intergeneric fertility and readily hybridize resulting in the development of several unusual plant forms with different names. There is a great amount of variation among *Citrus* species and cultivars as a result of frequent bud mutation, interspecific and intergeneric hybridization, apomixis and long history of cultivation (Shahsavari *et al.*, 2007). The existence of intergeneric hybrids is common among these three genera (Nito, 2003). Some examples are Tangor (mandarin×sweet orange), Tangelo (mandarin×grapefruit), Lemonlime (lemon×lime), Citrange (sweet orange×*Poncirus trifoliata*), Citromelo (grapefruit×*Poncirus trifoliata*), Limquat (lime×*Fortunella* spp.), Citrangequat (*Fortunella margarita*×Rusk citrange), and Calamansi/Calamondin (mandarin×*Fortunella* spp.), etc. There are five citrus groups that are commercially important and these include sweet orange, mandarin (including Satsuma), grapefruit, lemon and lime and numerous varieties and cultivars exist. Kumquat (*Fortunella* spp.) is grown to a limited extent for fresh fruit and processing. Pummelos are of economic importance in many areas within Southeast Asia and China.

Rambutan (*Nephilium lappaceum*) is the most important species in the genus *Nephilium*. Three different forms of rambutan (var. *lappaceum*, var. *pallen* and var. *xanthioides*) are recognized based on leaflet characteristics. Rambutan occurs from southern China through Indo-China region, Malaysia, Indonesia and the Philippines. All cultivars of rambutan have been produced by cloning superior trees found in natural habitats. Jackfruit (*Artocarpus heterophyllus*) is a major fruit in south and Southeast Asia. It is usually classified in two major types based on the quality of its edible pulp. Many cultivars exist within both of these types and all the currently used cultivars are direct selections of desirable trees found in natural habitats. Similarly, durian (*Durio zibethinus*) and litchi (*Litchi chinensis*) are also important priority fruits in South and Southeast Asia and considerable diversity occur in these fruit species.

Need for Intensified Work on Priority Fruit Tree Species

As noted earlier, the number of TFT species in the region is too large and it would not be possible for any organization to focus on so many species. The

information synthesis carried out in 1993 revealed a strong need to identify a few major and minor (but still commercially important) fruit species for conducting detailed research. Based on the collaborative efforts between Bioversity-APO and International Centre for Underutilized Crops (ICUC), a survey was conducted in 15 countries in South Asia (Bangladesh, Bhutan, India, Pakistan, Nepal and Sri Lanka), Southeast Asia (Brunei, Indonesia, Malaysia, Myanmar, Papua New Guinea (PNG), the Philippines, Thailand and Vietnam) and East Asia (China) and a number of priority species were identified. Subsequently in the 'Expert Consultation on Tropical Fruits' held at the Malaysian Agricultural Research and Development Institute (MARDI), Kuala Lumpur, Malaysia in 1994, six priority species (species of major importance-mango, citrus and rambutan; and of minor importance-durian, jackfruit and litchi) and a few others, namely, carambola, mangosteen and longan were identified for intensified work at regional level and individual country level (Arora and Ramanatha Rao, 1995).

The research and development activities with emphasis on genetic resources conservation and use of these priority species were initiated by Bioversity International in Asia, the Pacific and Oceania. The rationale warranting intensified work included nutritional importance, diversified uses, economic/higher monetary return, better employment, suitability to diverse agrohorticultural and fruit based cropping systems, and agroecological considerations. Conservation efforts for fruit crops at the national and international levels had also been very limited (Bhag Mal *et al.*, 2004) and hence deserved utmost consideration.

Major Programmes/Activities

The regional collaborative research and development work focused on priority TFT species identified through regional survey and validated through an expert consultation. The major programmes/activities undertaken by Bioversity through several projects in collaboration with national programmes covered several important aspects of conservation and use of tropical fruit species. In order to implement various activities, the human resource and capacity building and networking approaches were adopted to enhance efficiency of collaboration and sustainability of efforts. The major activities included: i) information synthesis on the extent and distribution of genetic diversity, ii) identification of priority gene pools of major and minor

fruit tree species of national and regional importance, iii) studies on the status of existing collections of TFT species, iv) characterization, evaluation, documentation, maintenance, conservation and utilization of priority fruit species, v) supporting research on developing *ex situ* and *in situ* conservation methods and their adoption in national programmes, vi) genetic diversity studies to assess the status of diversity, genetic threat and promoting *in situ* conservation, vii) studies on socio-economic, indigenous knowledge and sustainable livelihood aspects, viii) human resource and capacity building, consultation meetings and workshops, and ix) promoting national, regional and international collaboration to facilitate networking and dissemination of information.

Salient Achievements

Bioversity has taken several initiatives aimed at conservation and use of native TFT species diversity in Asia, the Pacific and Oceania (APO) region. In 1990s, the activities were mostly supported from Bioversity's core budget. However, the work gained momentum from January 2000 onwards with the initiation of Asian Development Bank (ADB) funded project on 'Conservation and Use of Native Tropical Fruit Species Biodiversity in Asia' which was implemented in ten Asian countries, namely, Bangladesh, China, India, Indonesia, Malaysia, Nepal, the Philippines, Sri Lanka, Thailand and Vietnam. Subsequently, the work on cryopreservation of citrus was undertaken in collaboration with Universiti Kebangsaan Malaysia (UKM) and Universiti Putra Malaysia (UPM) in Malaysia. To promote the work on *in vitro* conservation and cryopreservation, a three year project on 'Development of Advanced Technologies for Germplasm Conservation of Tropical Fruit Species' funded by the Australian Centre for International Agricultural Research (ACIAR) was implemented in five countries, namely, Australia, Malaysia, the Philippines, Thailand and Vietnam (IPGRI 2003b). During 2004-05, a project proposal on "Conservation and Sustainable Use of Cultivated and Wild Tropical Fruit Diversity: Promoting Sustainable Livelihood, Food Security and Ecosystem Services" was developed under PDF-B Phase and submitted to UNEP/GEF for funding. This five year project was approved and its implementation started in January, 2009.

The successful implementation of Bioversity's programmes on TFT species in the region resulted in

significant achievements. The ADB funded project on six priority TFT species was successfully implemented and its objectives were fully achieved as is evident from country reports for Bangladesh, China, India, Indonesia, Malaysia, Nepal, the Philippines, Sri Lanka, Thailand and Vietnam (Budathoki 2003; Dela Cruz 2003; Hue 2003; Idris 2003; Kalloo 2003; Shantha Peiris 2003; Purnomo, 2003; Somsri 2003a; Uddin 2003; Zushang 2003). Significant outputs were delivered in securing valuable fruit crop germplasm in ten countries through collecting and conserving threatened diversity of priority fruit species, identifying gaps in collections as well as areas for future collecting, documenting information to promote access and sharing of germplasm, characterizing accessions and identifying elite lines for direct use by farmers or use in breeding programmes. In addition, socio-economic surveys for identifying constraints and opportunities in promoting potential development of fruit crops at the local and national levels were undertaken. The ACIAR funded project had also been very successful in developing and standardizing the techniques for *in vitro* conservation and cryopreservation of different fruit species which greatly helped in developing suitable strategies/plans for conservation of TFT genetic resources. These projects/programmes have been able to put fruit crops on a higher development agenda of the national governments and assisted the national agricultural research systems (NARS) in TFT germplasm collecting, characterization and evaluation, conservation, human resource development and capacity building and also in strengthening collaboration among the partners.

The country-wise and crop-wise details of accessions collected, characterized, documented, conserved and the elite lines selected are summarized in Table 1 and Table 2, respectively.

The collaborating countries have been able to collect the threatened and rare diversity of identified priority TFT species including their wild relatives and related species and identify gaps for future collecting missions. The diversity collected has been saved from loss and is safely conserved in genebanks for current and future use. Several elite lines and useful germplasm with specific desirable traits were identified and are now available for use in breeding programmes aimed at developing better varieties or for direct use by farmers.

Table 1. Country-wise details of accessions collected, characterized, documented, conserved and elite lines identified in six priority fruit tree species

Country	Existing accessions documented	Accessions databased in CD-ROM	New accessions collected	Accessions characterized	Accessions added to field genebanks	Elite lines identified
Bangladesh	857	159	206	196	199	26
China	833	833	129	326	129	28
India	404	552*	316	513*	316	30
Indonesia	110	47	127	107	52	17
Malaysia	165	108	100	140	45	6
Nepal	265	134	96	265	72	44
Philippines	419	519*	419	299	232	9
Sri Lanka	271	185	271	185	120	18
Thailand	982	982	279	799	279	3
Vietnam	661	548	241	529	241	9
Total	4967	4067	2184	3359	1685	190

*Includes additional accessions

Table 2. Crop-wise details of accessions collected, characterized, documented, conserved and elite lines identified in 10 countries in South and Southeast Asia

Country	Existing accessions documented	Accessions databased in CD-ROM	New accessions collected	Accessions characterized	Accessions added to field genebanks	Elite lines identified
Mango	2368	1665	1003	1804	734	93
Citrus	1453	1775*	555	983	511	51
Rambutan	316	265	288	285	195	17
Jackfruit	522	131	180	152	126	20
Litchi	185	143	60	40	60	1
Mangosteen	123	88	98	95	59	8
Total	4967	4067	2184	3359	1685	190

*Includes additional accessions

Locating and Collecting Diversity

Ecogeographic Studies and Distribution of Genetic Diversity

The ecogeographic studies were carried out with focus on surveys based on the ecological and climatic parameters of major distribution areas of TFT species in different countries. These studies provided better understanding of the distribution patterns, and agroecosystems of TFT species. Twenty eight ecogeographic surveys were conducted. By mapping the collected accessions, it was possible to map the areas with high diversity of TFT, predict their possible distribution in other similar agroclimatic areas and identify gaps in existing collections. The countries were able to produce the distribution maps for their respective TFT collections with the geographic information system (GIS) tools such as DIVA-GIS and FloraMap. One such good example was for *Citrus* in India (Singh and Singh, 2003). The 42 diversity maps were produced for six crops, namely, citrus, jackfruit, litchi, mango, mangosteen and rambutan showing overlapping distribution of several species. These distribution maps, which represent a first major attempt by national programmes to use GIS technologies for germplasm management, were

very useful in identifying diversity-rich areas for further collecting and *in situ* conservation and also predicting new areas with similar climatic conditions for cultivation of these TFT (IPGRI, 2003a).

Exploration and Germplasm Collecting

Germplasm collecting was done in the areas identified for further exploration through ecogeographic studies. A total of 2,184 accessions of six target TFT species were collected. This included 1,003 accessions of mango, 555 of citrus, 288 of rambutan, 180 of jackfruit, 60 of litchi, and 98 of mangosteen (IPGRI, 2003a). Thus, the collecting strategies based on sound scientific basis were developed and suggested to the national partners for making further collections for different species.

Evaluation and Utilization of Diversity

Germplasm Characterization

In a fairly large scale effort on characterization, a total of 3,359 accessions of target fruit species, namely, mango, citrus, rambutan, jackfruit, litchi and mangosteen held in the field genebanks in different countries were characterized (IPGRI, 2003a). These included 1,804 accessions of mango in 9 countries,

983 of citrus in 6 countries, 285 of rambutan in 3 countries, 152 of jackfruit in 2 countries, 40 of litchi in 2 countries and 95 of mangosteen in 2 countries. These extensive characterization and evaluation studies helped to identify elite germplasm lines that could be used in crop specific breeding programmes or directly for cultivation by farmers.

Identification of Elite Lines with Specific Desirable Traits

Based on specific desirable attributes, 190 elite lines/promising accessions were identified for further evaluation and use by the breeders in the breeding programmes or directly by the farmers for commercial cultivation. These included 93 promising lines in mango, 51 in citrus, 17 in rambutan, 20 in jackfruit, 8 in mangosteen and 1 in litchi.

Elite lines or promising accessions identified (IPGRI, 2003a) based on the evaluation studies in different participating countries included: i) Bangladesh: 4 mango elite lines possessing year-round bearing, 9 with off-season bearing and one possessing sweetness at green stage; ii) China: 8 citrus elite lines including seedless types for fresh fruits market and processing industry; 2 superior rootstocks of pummelo with vigorous growth habit, large fruit size and better fruit quality; 4 mango elite lines with dwarf growth habit, disease resistance, early bearing and large fruit size along with better quality; iii) India: 4 mango elite lines for high yield, 3 for short height, 5 for high total soluble solids (TSS), 8 for red peel with good consumer appeal, 8 for high pulp recovery, 5 for large fruits, 5 for regular bearing, 4 for early maturity, 3 for high tolerance to shoot borer and 2 hybrids for export possessing medium size fruits with high TSS, high acidity and high pulp recovery; In Rangpur lime, 4 elite lines, one each for large fruit size, thinnest peel, less seedy fruits and very high TSS; In rough lemon, 4 for low seed number and one for large fruits; In trifoliate orange, one for thin peel and one for high TSS; In litchi, 3 elite lines, one each for high fruit weight, low peel percentage and high sugar percentage; iv) Indonesia: 2 elite lines of rambutan for large fruit size, flesh quality and ease of rind opening; 2 of mangosteen for dark purple rind; v) Malaysia: 3 elite lines of pulasan (*Nephilium ramboutan-ake*) and 3 of kuini (*Mangifera odorata*) possessing desirable traits; vi) Nepal: 2 seedless varieties of mandarin, one of sweet orange and one of mango for earliness

and very high TSS; vii) Philippines: 2 elite lines of mango for large fruit with small stone, 3 of citrus and 3 of mangosteen for large fruit size, high TSS and regular bearing; viii) Sri Lanka: 2 elite lines of mango, one edible at green stage and the other for pickle, and 2 of jackfruit for good fruit quality and attractiveness; ix) Thailand: 2 elite lines of mango for high fruit weight, firm and thick pulp texture, sweet, yellow peel, small stone and longer shelf life; one of rambutan with firm aril texture, thick aril, normal skin thickness, orange red skin, high TSS, high fruit weight, long shelf life and rind and hair colour not fading even after 30 days after maturity on the tree; x) Vietnam: two best rootstocks of trifoliate orange (*Poncirus trifoliata*) and one of litchi.

Some of the promising elite lines identified were multiplied and given to the farmers for cultivation in China, Nepal, Sri Lanka and Vietnam, thus demonstrating direct application of the findings in the field. In China, one elite line of mango and one of citrus were included in the recommendation package for farmers and mass propagated for distribution to fruit growers. A total of 1,20,000 plants and 8,00,000 buds of 8 elite citrus types, and 4 of mango were multiplied and distributed to farmers. Also, the early and late Ponkan, seedless Ponkan, early and late Navel orange are becoming popular. Mango Carabao, the high quality type currently released was planted on 9000 ha covering nearly one third of mango acreage in Hainan province. In Nepal, 40,000 seedlings of citrus and 3,000 seedlings of mango produced by the government and private nurseries were distributed to men and women farmers. In Vietnam, 4000 grafted seedlings of mango, citrus and litchi were produced through two community nurseries and distributed to 87 farmer households. In Sri Lanka, high quality varieties of mango and jackfruit for a range of uses (fresh, processing, vegetable uses) were identified. These were mass propagated and supplied to farmers for cultivation and enhancement of fruit production. These efforts will not only ensure good quality planting material to farmers but will also contribute to the improvement of quality of fresh and processed products made out of these crops in the future. Similar efforts are underway in other collaborating countries.

In all partner countries, the information on the elite materials was shared with the agricultural departments of the provincial governments for further dissemination to farmers and other growers for their wider use.

Promoting Diversity in Orchards and Home Gardens

In order to promote the use of diversity in the orchards and home gardens, as part of conservation through use, assessment of diversity of different crops was considered important. In Nepal, assessment of diversity of citrus and mango was carried out with the active participation of grower groups and individual orchardists and home gardeners. These groups provided detailed information of the fruit quality, maturity, tree morphology, tree canopy, tolerance to diseases, pests and abiotic stress conditions with respect to the genotypes they had in their villages and neighbouring areas. This fruit growers' evaluation was based on their long experience of cultivation, fruit consumption and fruit selling, which proved to be very useful in identifying the diversity to be collected (Budathoki, 2003). Similar assessment of diversity with communities and home gardens was done in Sri Lanka (Shantha Peiris, 2003), Bangladesh (Uddin, 2003) and Vietnam (Hue, 2003). The women growers predominantly contributed to growers' evaluation. Through their help, it was possible to identify the high diversity areas of citrus and mango, high diversity orchards, home gardens and also the location of orchards and home gardens as well as the owners having very popular elite lines in the villages.

Inclusion of a large number of cultivars and species in the semi-commercial and commercial orchards is a recent practice and was further encouraged and enhanced. This was done in view of consumer preferences and market choices and to reduce the risks from natural biotic and abiotic stress conditions. The cultivars used by the growers on commercial and semi-commercial scales were mostly improved varieties and a very few local landraces were grown. In contrast, indigenous and unique types of fruit germplasm were found in the home gardens which could be further capitalized in the market. The elite lines identified in different fruit species were distributed to semi-commercial orchards and home gardens to promote diversity deployment and enhanced production.

Using Indigenous Knowledge to Improve Productivity

Documenting indigenous knowledge (IK) is extremely important as it gives very useful information on growers' preferences and uses, indigenous production

methods and on the role of growers in conservation and use, which could be used in developing appropriate research and development strategies on target fruit tree species. Some examples of IK gathered are briefly presented below:

In Nepal, IK was documented for citrus, which included varied types of information (Budathoki, 2003) such as: i) *in situ* manuring by keeping animals in the orchards, ii) use of temporary 'mobile' toilets near the trees for manuring, iii) planting of whole fruits in the field after removing the peel, iv) smoking of trees in the evenings and nights to repel the insect pests, and v) spraying small seedlings with slurry of fresh cow dung and urine to repel animals. Such information could be very useful in increasing fruit production and thereby enhancing farmers' income and can be validated by formal and more controlled research.

In Sri Lanka, IK on mango and jackfruit documented with the help of different communities (Maharouf, 2003a, b) indicated the existence of varieties that were used for a long time in specific food items and treatment of various diseases. IK on mango was gathered by interviewing the priests, village leaders, Ayurvedic doctors and the ethnic communities, namely, Singhalese and Tamils. Information pertaining to the use of mango and its plant parts in food, medicine and in festivities, weddings and other rituals was gathered. Jackfruit in Sri Lanka is also known as '*Bath Gasa*' reflecting its prime value as a food which is similar to that of the staple food rice known as *Bath* in Sinhala.

In Malaysia, decoction of roots of pulasan has been reported to be used as vermifuge for fever; and the roots are boiled and used for bathing patients inflicted with fever (Idris, 2003). The dried seed kernels with faintly sweet smell oil are suitable for use in food. In the Philippines, decoction of dried mangosteen rind is used to cure stomach-ache (Dela Cruz, 2003).

In Vietnam, litchi has been reported to have medicinal value. It is traditionally used to treat stomach-ache and the pain in small intestine. The traditional uses included the use of litchi flesh to prevent tiredness and to treat bronchocele or growth on the neck, fruit skin to treat diarrhoea and leaves to treat animal bites. Litchi tree productivity was enhanced with the use of poultry manure. The other

traditional practices included the cutting of trunk vertically in the middle to induce branching and slicing of trunk for inducing fruiting (Hue, 2003).

Conservation of Tropical Fruit Tree Genetic Resources

In situ Conservation

Under the ADB funded project on tropical fruits, Bioversity promoted the concept of on-farm conservation of fruit genetic resources (Nares *et al.*, 2001). *In situ* conservation activities were initiated in a few countries, namely, Bangladesh, India, Nepal, the Philippines, Sri Lanka and Vietnam and suitable *in situ* conservation sites were identified (IPGRI 2003a). These included: i) Ipilan-Alitao for mangosteen in the Philippines, ii) Ramnagar Mirchaiya for mango, and Karki Gaon and Banskarka village for *Citrus* spp. in Nepal, iii) Gazipur for jackfruit, Chapai Nawabganj for mango and Maulibazar for citrus in Bangladesh, iv) Garo Hills for citrus, Paiyur in Tamil Nadu and Lucknow in Uttar Pradesh for mango in India, v) Bac son district, Lang son province for mandarin; Phuc Trach commune, Huong Khe district, Ha Tinh province for pummelo; Thanh son commune, Thanh Ha district, Hai duong province for litchi; and Chiengpan commune, Yenchau district, Son la province for mango in Vietnam, and vi) several home gardens for jackfruit and mango in Sri Lanka and semi-domesticated, natural diversity sites for litchi in Southern China. These constituted the first efforts on *in situ* conservation of TFT genetic resource in APO region. These efforts also highlighted the issues arising out of on-farm/*in situ* conservation of group of species such as perennial tree species as opposed to annual crops on which fairly large amount of data could be found in the literature.

The principles of on-farm/*in situ* conservation recognize that such efforts will be successful and sustainable only through the active participation of communities who depend and enjoy the fruits of the available resources. Hence, efforts were made to encourage the farmers and communities to participate in the conservation of TFT genetic resource. In Nepal, farmer group meetings were organized with the help of Agriculture Development Department and awareness was created about the value of their fruit germplasm materials in terms of income generation, socioeconomic aspects and conservation for future use. Fruit diversity fairs, fruit shows and fruit festivals were organized

in Nepal, Bangladesh, Vietnam, Thailand and the Philippines during socioeconomic surveys and germplasm collecting missions. Close interaction with farmers and communities also motivated them to participate in the germplasm conservation efforts. What was important was that, although several farmers were carrying out *in situ* conservation (as they continue to grow traditional varieties over generations and practice some level of selection while planting new orchards or home gardens) in an unconscious manner, they became more aware of the value of what they have been doing. Farmer organization leaders, village leaders, monks in village temples, women and youth organizations helped in organizing the socioeconomic activities in the villages and provided valuable information during the socio-economic surveys. In Bangladesh, fruit tree plantation fortnight was organized in which mango growers were trained in propagation techniques and production practices. In India, a biodiversity workshop was organized in Karnataka State to create awareness amongst the people to participate in conservation of mango diversity and Snehakunj, an NGO, helped in collecting germplasm through the help of communities. A national exhibition was organized in Indonesia to create awareness among the communities for conservation and use of TFT species. In Vietnam, under the project in collaboration with Centro Internazionale Crocevia (CIC), two community nurseries for propagation of TFT species were established in Phuson, Ninh binh and Chiengpan, Sonla. The grafted seedlings of elite varieties of litchi, mango and pummelo were produced with the participation of local farmers. Two training programmes on grafting and pruning for mango and citrus were organized for these communities. As a result, a community nursery run by farmers produced materials and distributed these to other communities (IPGRI, 2003a). It is evident, from the experiences in the project, that interest of farmers to conserve fruit genetic diversity will effectively take place if they find greater use of these materials.

These efforts also indicated that different approaches (including agroforestry systems approach and community biodiversity management (CBM) approach) are required to make *in situ*/on-farm conservation sustainable and beneficial to TFT growers. The results of ADB project helped in planning and developing larger actions under UNEP/GEF project already commenced from January, 2009.

Ex situ Conservation

The national programmes in the collaborating countries are maintaining germplasm of the target species in the field genebanks at different locations in the respective countries. Fifty two field genebanks were identified/established for different crops, viz., mango (21), citrus (13), rambutan (8), jackfruit (4), litchi (4) and mangosteen (2). These field genebanks were enriched with more accessions collected during the ADB project, thus enriching the accessible genetic diversity. This included mango (734 accessions), citrus (511), rambutan (195), jackfruit (126), litchi (60) and mangosteen (59). Out of a total of 2,184 accessions collected, 1,685 accessions of six target crops were added to field genebanks in different countries (Table 1). The remaining collections were planted in the nursery for subsequent transfer to field genebanks at appropriate growth stage.

Ex situ conservation of TFT genetic resource is an expensive and labour intensive programme requiring considerable land resources. Hence, any effort in developing and managing fruit tree genebank should be based on sound strategy. To promote improved establishment and management of field genebanks, the guidelines for field genebank management developed by Bioversity may be used (Saad and Ramanatha Rao, 2001).

Development of Advanced Technologies for Conservation

Since seed conservation is not an option for most of the TFT species, Bioversity assisted the national programmes in developing advanced techniques for conserving TFT germplasm in different countries. Studies on *in vitro* conservation of citrus conducted at the Citrus Research Institute, Chongqing, China during 1993-96 resulted in *in vitro* storage of 60 accessions of citrus and further development of protocols for citrus under slow growth conditions. Cryopreservation studies in mango conducted in 1995-96 in collaboration with the School of Life Sciences, Zhongshan University, Guangzhou, China confirmed recalcitrant nature of mango seeds although no workable protocols for *in vitro* conservation could be established (Bhag Mal and Ramanatha Rao, 2003; Bhag Mal *et al.*, 2004). Cryopreservation studies in different fruit species (Chaudhury *et al.*, 2000a; Sudarmonowati, 2000) revealed varying degrees of success with different techniques and types of material used (Table 3).

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Table 3. Success of cryopreservation using various techniques in different fruit species

Species	Technique	Type of material	Survival (%)
<i>Litchi chinensis</i>	Vitrification	Embryonic axes	50
	Air desiccation	Embryonic axes	22-35
<i>Euphoria longan</i>	Vitrification	Embryonic callus	30
		Anthers	15
<i>Nephelium lappaceum</i>	Two step freezing	Shoot tips	10
<i>Citrus sinensis</i>	Encapsulation-Vitrification dehydration	Shoot tips	25
		Embryonic axes	62.5

Bioversity, with funding from the Department for International Development (DFID), UK collaborated with NBPGR, New Delhi, India on the development of cryopreservation techniques for long-term conservation of some fruit tree species. For the first time, in litchi (*Litchi chinensis* Sonn.), embryonic axes from seeds harvested 60-80 days after anthesis survived liquid nitrogen exposure (Chaudhury *et al.*, 2000b, 2001; Bhag Mal and Ramanatha Rao, 2003). Successful cryopreservation was noted in jackfruit (*Artocarpus heterophyllus* Lamk.) with 25-30 per cent survival of cryopreserved axes from partially mature and fully mature seeds (Chandel *et al.*, 1995). There was an improvement in recovery percentage of cryopreserved axes in jackfruit and litchi as compared to air desiccation.

The studies carried out in collaboration with Universiti Kebangsaan Malaysia (UKM) and Universiti Putra Malaysia (UPM), Malaysia with support from the Rural Development Administration (RDA), Republic of Korea revealed that seed survival decreased below 16 per cent seed moisture content (MC) in *Citrus aurantifolia* (Cho *et al.*, 2002) and that seeds cryopreserved without testa survived better than those with seeds at about 7 per cent seed MC. Protocol for cryopreservation of zygotic embryonic axes of *C. madurensis* were developed (Cho *et al.*, 2001).

Bioversity's work on *in vitro* conservation and cryopreservation was further strengthened through a project supported by Australian Centre for International Agricultural Research (ACIAR), which resulted in development of conservation techniques for target TFT species (IPGRI, 2003b; Drew *et al.*, 2006). In papaya, protocols for vitrification-based shoot tip cryopreservation were refined and applied successfully to a range of papaya genotypes and *Vasconcellea pubescens* (a wild relative). Papaya seeds could be

stored up to 12 months at a range of moisture content and a range of temperature including cryostorage. Protocols for slow-growth of papaya *in vitro* were developed.

It was observed that seeds of *Citrus australasica* could tolerate desiccation and ultra low temperatures indicating possibilities for seed storage along with seed of *C. inodora* and *C. garrawayi*. A micropropagation protocol was established for three Australian native *Citrus* species (*C. australasica*, *C. inodora* and *C. garrawayi*) suitable for mass multiplication and medium-term storage. Protocols for adventitious root formation and regeneration of shoot for *C. hystrix* were developed. Regeneration *via* somatic (nucellar) embryogenesis was developed for calamansi (*Citrofortunella macrocarpa*) and mandarin (*C. reticulata*). For pummelo (*C. grandis*), callus was induced from juice vesicles and albedo tissues but somatic embryogenesis and shoot regeneration was observed only in callus from albedo. Regeneration system *via* somatic embryogenesis was developed for lime using undeveloped ovules (immature seeds) (IPGRI, 2003b).

Studies also indicated the feasibility of low temperature storage of desiccated seed of calamansi, mandarin, pummelo, native lime, limon and kubot for a short-term (Philippine native *Citrus* sp.). Cryopreservation of embryogenic callus using encapsulation dehydration technique was feasible for *C. reticulata* and *C. sinensis*. For *C. hystrix*, vitrification method was modified to obtain acceptable level of survival (IPGRI, 2003b). In mango, even though 70 per cent recovery of somatic embryos was observed, a major problem was the repeatability of these results and thus more research is required to optimize the protocol.

A micropropagation system was developed in *Davidsonia* spp., an underutilized native fruit of Australia, through the production of microcuttings *in vitro*. Media for litchi and longan micropropagation were also developed. In persimmon, a suitable medium was identified for embryo culture and nodal cutting. The results of cryopreservation studies concluded that vitrification was not suitable for persimmon shoot tips (IPGRI, 2003b). Protocols for adventitious root formation and regeneration of shoot in *Nephelium* spp. were developed. Slow growth technique had shown the potential for short to medium-term storage of germplasm.

Cryopreservation is a well established method for long-term conservation of recalcitrant plant species

that include most of the TFT species. These examples showed that the work done by Bioversity and national partners in the APO region successfully demonstrated a considerable progress towards the cryopreservation of a few fruit species. However, it must be realized that a lot of research still needs to be done to refine and standardize the existing cryopreservation protocols so that these could be effectively used for conservation for TFT genetic resources.

Need for Complementary Conservation Strategy

It is now well recognized that no single approach can take care of conserving the maximum genetic diversity that is normally the goal of conservation efforts. The concept of application of the most appropriate conservation technique to appropriate portion of a gene pool has been referred to as complementary conservation strategy (CCS) or integrated conservation strategy. Such a strategy would employ different conservation options for different types of material in a gene pool under conservation— *in situ* and *ex situ* conservation, *in vitro* conservation, cryopreservation, etc. To assess this need and its implementation in wider context, the status of germplasm conservation of target fruit species in the region was reviewed (Drew and Ashmore, 2003). Various conservation options such as *in situ* conservation in nature reserves and on-farm/home gardens and *ex situ* methods such as field genebanks, seed genebanks, *in vitro* genebanks, cryobanks and pollen genebanks and their advantages and disadvantages were considered in order to crystallize ideas to develop appropriate complementary conservation strategies. A number of important issues that should be considered while developing complementary conservation strategies for topical fruit genetic resources include: i) biological factors, ii) methodologies available, iii) conservation objectives, iv) socioeconomic issues, and v) organizational issues (Brodbeck *et al.*, 1999; Ramanatha Rao and Arora, 1999; Ramanatha Rao and Bhag Mal, 2002; Drew and Ashmore, 2003).

The framework for developing a CCS for TFT requires concrete and appropriate actions to be taken at different stages, namely, i) networking of stakeholders at national, regional or international level, ii) defining the objectives and sub-objectives in accordance with 'Global Strategy for Plant Conservation' and determination of species of major importance for each of the participating countries, iii) analysis of feasibility of each option for each objective or sub-objective in terms of infrastructure needs, costs and

risks involved, iv) decision on conservation options for each objective or sub-objective relevant to each species of major importance, v) setting up enabling environment – policy and legal issues and funding source, vi) elaboration of strategic action plan by stakeholders, and vii) effective implementation of the action plan/process (Drew and Ashmore, 2003; IPGRI, 2003a).

Knowledge Documentation

Country Status Reports

Based on the recommendations of the Expert Consultation on TFT Species in Asia, the information was gathered and six priority species were identified for intensified work in national and regional context (Haq, 1994; Arora and Ramanatha Rao, 1995). During 1995-1998, Bioversity-APO brought out 23 country status reports on genetic resources of the six priority fruit species, namely, mango, citrus, rambutan, litchi, jackfruit and durian in collaboration with the key national programmes (Arora *et al.*, 1996a, b; IPGRI, 2003a; Bhag Mal *et al.*, 2004). Subsequently, status reports on minor fruits of Southeast and South Asian region, namely, litchi, kuini, pulasan, mangosteen and *aonla* (Indian gooseberry) were developed (Ghosh and Mitra, 2000; Dela Cruz, 2001; Idris and Mat Lin, 2002a,b; Pathak, 2003). These reports contain valuable information on distribution; extent of genetic diversity of cultivated and wild genepools; the status of germplasm collection, characterization, evaluation, documentation, conservation, improvement and utilization; diseases and pests; and production, processing and marketing aspects (Table 4).

Based on country status reports, the regional synthesis reports were developed for the two most important crops in the region, namely, mango (Sant Ram and Rajan, 2003) and citrus (Nito, 2003) containing consolidated information on various aspects ranging from origin and distribution through genetic resources to future prospects. In addition, the information on distribution of species of underutilized fruits and nuts was synthesized in order to provide a wider awareness. Inventory of Underutilized Edible Fruits and Nuts (Pareek *et al.*, 1998) and a monograph on durian (Brown, 1997) were also published.

Data Documentation

Documentation of information on existing collections was mostly carried out under the ADB funded TFT

Table 4. Country/regional status reports of priority fruit species

Fruit species	Botanical name	Country/regional report
Mango	<i>Mangifera indica</i>	Bangladesh, China, India, Indonesia, the Philippines, Sri Lanka, Thailand
Citrus	<i>Citrus</i> spp.	India, China, Nepal, Japan, Sri Lanka
Rambutan	<i>Nephelium lappaceum</i>	Indonesia, Malaysia, Thailand
Durian	<i>Durio zibethinus</i>	Indonesia, Malaysia, Thailand
Jackfruit	<i>Artocarpus heterophyllus</i>	Bangladesh, India, Sri Lanka
Litchi	<i>Litchi chinensis</i>	China, India, Thailand and Myanmar
Kuini	<i>Mangifera odorata</i>	Southeast Asia
Pulasan	<i>Nephelium ramboutan-ake</i>	Southeast Asia
Mangosteen	<i>Garcinia mangostana</i>	Southeast Asia
Indian gooseberry (<i>Aonla</i>)	<i>Emblica officinalis</i>	South and Southeast Asia

project. The information on extant collections gathered and synthesized by all participating countries was shared among partners. The amount of information available for different countries varied greatly, which indicated the gaps that existed. The data were standardized according to descriptors published by Bioversity for different fruit crops as well as those developed by relevant national programmes (IPGRI, 2003a). The passport and characterization data were compiled on the existing 4,967 accessions which included 2,368 accessions of mango, 1,453 of citrus, 316 of rambutan, 522 of jackfruit, 185 of litchi, and 123 of mangosteen (Table 5). Bioversity assisted national partners in setting up databases, providing guidelines and descriptors, imparting training to documentation staff, making available the tools and software and worked closely with national staff in developing appropriate documentation systems in different countries. A CD-ROM containing databases from 10 countries was produced and made available to all partners. This database contains the passport and characterization data on 4067 accessions (Table 5) of six TFT crops viz., mango (1,665), citrus (1,775), rambutan (265), jackfruit (131), litchi (143), and mangosteen (88). This laid the foundation for the use of computerized information documentation for fruit tree genetic resources in most of the countries.

New Descriptor Lists Published

To facilitate the systematic characterization and evaluation of TFT genetic resources, new descriptor lists were developed, published and widely distributed

Table 5. Existing accessions documented for passport and characterization data and accessions in databases compiled in CD-ROM for sharing

Countries	Fruit crops						Total
	Mango	Citrus	Rambutan	Jackfruit	Litchi	Mangosteen	
Bangladesh	321	96(89)	-	440(70)	-	-	857(159)
China	80(82)	653(651)	-	-	100(100)	-	833(833)
India	404(151)	-(384)	-	-	-(17)	-	404(552)
Indonesia	-	-	48(21)	-	-	62(26)	110(47)
Malaysia	99(66)	-	66(42)	-	-	-	165(108)
Nepal	130(87)	135(47)	-	-	-	-	265(134)
Philippines	265(356)	93(101)	-	-	-	61(62)	419(519)
Sri Lanka	189(124)	-	-	82(61)	-	-	271(185)
Thailand	780(780)	-	202(202)	-	-	-	982(982)
Vietnam	100(19)	476(503)	-	-	85(26)	-	661(548)
Total	2368(1665)	1453(1775)	316(265)	522(131)	185(143)	123(88)	4967(4067)

Figures in parentheses indicate the accessions in databases in CD-ROM for sharing

to the partners for crops on which no descriptors were available, such as jackfruit, litchi, rambutan, and mangosteen and the descriptors for citrus and mango were revised (IPGRI, 1999, 2000, 2002, 2003c, 2003d, 2006)

Germplasm Catalogues Developed

The participating countries identified and catalogued important varieties of relevant fruit species and these catalogues contained information on passport and characterization. For example, India produced two catalogues on mango with information on 404 accessions and the Philippines prepared a catalogue of 265 accessions of mango, 93 accessions of citrus and 61 accessions of mangosteen. The catalogues were produced in hardcopy and/or electronic versions and were made available to the partners (IPGRI, 2003a; IPB 2003a, b; Rajan, 2003; Rajan *et al.*, 2002; Dinesh and Vasugi, 2002; Somsri, 2003b, c).

Information Dissemination

Information dissemination is extremely important for their use by diverse stakeholders. The outputs and achievements made under different programmes were disseminated through research papers in scientific journals, country status reports, crop descriptors, germplasm catalogues, inventories, monographs, books and proceedings of the meetings relating to TFT species. These have also been placed on website <http://tftgrn.net/> of TFT Genetic Resources Network (TFTGRN). A CD-ROM was developed by Bioversity which contained available databases of fruit tree genetic resources from 10 countries and was made available to all the partners. All these status reports and publications were widely distributed to the national programmes and other partners in the region

which assisted in promoting research and development programmes, facilitating the exchange of materials and also in developing complementary conservation strategies providing an overall regional perspective for South and Southeast Asia and hence proved to be extremely useful.

Training and Capacity Building

Skill Enhancement/Human Resource Development

The highest priority was accorded to human resource development to improve effective conservation and sustainable utilization of TFT genetic resources in Asia and Bioversity was instrumental in imparting training to 382 personnel including researchers, technicians, and farmers on various aspects of TFT genetic resources (Arora and Ramanatha Rao, 1998; Stapleton, 2002; IPGRI, 2003a). Training opportunities were provided in various aspects of plant genetic resources including characterization, evaluation, conservation and utilization, and several related topics such as molecular marker studies, *in vitro* conservation and cryopreservation techniques, ecogeographic surveys and use of GIS tools, socioeconomic studies, data documentation and information management, grafting methods, pruning and nursery management and scientific writing and proposal development. Emphasis was also placed on in-country training courses so that a fairly large number of genebank staff could be trained in one go, which would not have been possible in regional training programmes due to costs involved. Fruit festivals were organized to enhance farmers about the variability present and the characteristics of the varieties grown by them and value of conservation efforts that they might be doing depending on availability of funds. The study visits and technical sessions back to back

with the annual project meetings were organized to promote close interaction of various partners involved. Some of the more advanced courses organized were used to turn the contents into 'reference book', for example, the proceedings of regional training course on 'In vitro Conservation and Cryopreservation of Tropical Fruit Genetic Resources' organized at NBPGR, New Delhi, India, were published which serves as a good manual for the scientists and technicians engaged in this field (Chaudhury *et al.*, 2003).

Bioversity's efforts also gave rise to the concept to 'Centres of Excellence (CoE) for regional/international training on various aspects of plant genetic resources. The National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India is now recognized globally as a CoE for training in *in vitro* conservation and cryopreservation, while Huazhong Agricultural University (HAU), Wuhan, China for training in molecular characterization and Institute of Plant Breeding and the University of Philippines, Los Baños (UPLB), the Philippines for data documentation. These CoEs are continuing to play a significant role in improving the capacity for plant genetic resources education and training in the region.

Strengthening laboratories and infrastructure support under various projects during the past one and a half decade, several laboratories in over 15 collaborating countries were strengthened by providing equipments such as global positioning system (GPS), laboratory equipments, software for geographic information system (GIS), STAT packages, important publications and electronic descriptor software to facilitate their work on ecogeographic studies, mapping, diversity analysis and database development. This kind of support significantly improved the capacity of the national programmes to undertake systematic collecting and evaluation of the collected germplasm and deliver better research outputs. Twenty one field genebanks in ten countries were assisted through scientific/technical advice and funding to ensure continued maintenance of the collected materials. Technical consultancy services were provided from the developed laboratories to developing national programmes in the region, such as using expertise of NBPGR, India for developing tissue culture facilities in Nepal Agricultural Research Council (NARC), Kathmandu, Nepal and the scientific advice in establishing National Biodiversity Centre in Bhutan.

Socio-economic Studies

Socio-economic studies were conducted on several fruit species so as to understand grower and consumer preferences *vis-à-vis* production and marketing constraints. For this, participatory research appraisals (PRA) and rapid market appraisals (RMA) were carried out. Analytical methods used in the study included simple tabular analysis and percentages to more complex one such as calculating internal rate of return (IRR). During the proposal development phase of UNEP/GEF Project, Bioversity carried out market research to better understand the role of markets in the maintenance of TFT diversity on-farm. A few case studies on integrating biodiversity conservation and livelihood improvement were undertaken by Bioversity to study the role of markets of mango and kokum (*Garcinia indica*) in India and to identify good practices for on-farm biodiversity management in Indonesia and Thailand. The focus of these studies was on linking farmers to markets *vis-à-vis* improving their livelihoods through better income generation. The studies revealed the usefulness of maintaining a mix of varieties of mango as a strategy to ensure better distribution of income due to differential ripening period and mitigating the risk of low production of some varieties (Sudha and Kruijssen, 2007). Secondly, rich genetic diversity provides major potential for income enhancement. Maintaining particular underutilized fruits may provide a market niche and ensure income for a group of farmers as observed in a case study in Thailand (Kruijssen and Somsri, 2006). It was also observed in India where many fruit trees species with several different uses are available, that some varieties may be more suitable for a certain use than others and farmers take advantage of this (Sudha and Kruijssen, 2007). Similar observations were made in studies on pummelo in Indonesia where the thickness of spongy white skin under the rind of the fruit was considered advantageous. The differences in soil composition and water availability also resulted in differences in the distribution of pummelo varieties between the sub-districts (Kruijssen and Hardiyanto, 2007). Understanding this G X E interaction is the key to develop intervention on value chain of local produces. The studies indicated that the socio-economic characteristics of the farm households utilizing tropical fruits and the market forces play an important role in their decision making for on-farm conservation and

the sustainable livelihoods. These results were used in designing the full scale proposal that includes studies on marketing and value adding activities that is currently being implemented by Bioversity.

The salient findings of the socioeconomic studies and the policy perspectives (Chengappa, 2003; IPGRI, 2003a; Kruijssen and Somsri, 2006; Kruijssen and Hardiyanto, 2007; Sudha and Kruijssen, 2007) included: i) Low investment and high return makes the target TFT ideal intercrops especially in the home gardens, ii) Commercial orchards growing native TFTs have relatively less maintenance cost, iii) Analysis of marketing constraints such as location, transportation, perishability of produce, distribution and supply revealed the need for establishing farmers' cooperatives and common facilities so as to provide a viable alternative to the farmers to realize greater share of the sale price. Appropriate institutional support will help in this regard, iv) Value addition was considered more important for the minor fruits. The use of diversity for product development and appropriate linkages between processing units and growers will result in improving supply of such products to consumers and generating more income for the rural sector, v) Establishment of processing centres in high production areas is vital in addressing the economic viability of this sector through improved utilization, product diversification of fruit genetic resources, vi) Documentation and dissemination of knowledge on nutritive and medicinal values of native tropical fruits helps to improve the level of consumption creating the demand minor fruits, vii) Training and awareness programmes to disseminate technology and knowledge on consumption patterns, post-harvest management and processing are essential to enhance utilization and conservation of diversity of these fruit crops, vii) There is the vast scope for expansion of area under native tropical fruits with good varieties and exploiting the untapped potential diversity to meet the domestic and international demand both for fresh and processed fruits, vii) Studies clearly indicated the narrow genetic base, limited number of varieties in commercial cultivation, lack of classification and indexing of local varieties, and the need to conserve the rare types possessing desirable characters are the important issues of concern and need immediate attention.

Some of these socio-economic and market related aspects will be studied under the UNEP/GEF project

that is being implemented in four countries in the region.

Collaboration and Linkages

Bioversity believes that successful conservation and use of plant genetic resources is possible only through multidisciplinary and multisectoral collaboration. In addition, as plant genetic resources are not bound by country boundaries, gene pools can only be conserved through collaboration between countries in which such genetic resource are distributed. Hence, the varied activities carried out on TFTs genetic resource as described so far were possible through Bioversity's links with a number of national, regional and international organizations. Some of these collaborative activities are briefly mentioned below:

Exchange of Information and Germplasm

Sharing of germplasm and information on them has become fairly difficult since the Convention on Biological Diversity (CBD) came into existence in 1992. However, under activities supported by Bioversity, national partners agreed to share information on fruit genetic resource and in some cases even germplasm, albeit on a limited scale. Data sharing was achieved through i) developing a central data base, ii) publishing catalogues of fruit crop varieties, and iii) placing information on tropical fruit tree website. Bangladesh shared the passport and characterization data on mango, citrus and jackfruit germplasm and elite materials with the partners in other countries. Database on citrus, mango and litchi developed in China is available for to researchers interested in exchange of materials. Malaysia exchanged information on characterization of the underutilized fruit species, pulasan and kuini, with the partner countries.

The lists of material in mango and citrus that can be exchanged from Nepal for research purpose under the material transfer agreement (MTA) were developed. The Philippines exchanged passport and characterization information of priority fruit species with several countries in the region. Accession information and databases developed in Sri Lanka were shared with the other countries. Germplasm of mango (3 cultivars) and lemon (one cultivar) were received by Sri Lanka from India under the MTA between the two countries. Thailand shared accession information, catalogue and databases with partners. The information on exchangeable varieties of litchi,

mango and citrus was made available by Vietnam to other countries in the region. Also, the seminars and workshops organized in Indonesia in collaboration with the International Tropical Fruits Network (TFNet) programme facilitated exchange of information with partners.

Collaboration with Regional and International Organizations

Bioversity's programme on tropical fruit species over the past two decades had been very successful in establishing close collaboration among the participating countries. It also facilitated its linkages and interaction with national partners and donors and international organizations such as Food and Agriculture Organization of the United Nations (FAO), Centre de Cooperation International en Recherche Agronomique pour le Developpement (CIRAD), Asian Development Bank (ADB), Australian Centre for International Agricultural Research (ACIAR), International Centre for Underutilized Crops (ICUC), Underutilized Tropical Fruits in Asia Network (UTFANET), and the International Tropical Fruits Network (TFNet) for promoting research on plant genetic resources aspects in fruit crops. Collaboration with sub-regional networks, such as the South Asia Network on Plant Genetic Resources (SANPGR), Regional Cooperation in Southeast Asia for Plant Genetic Resources (RECSEA-PGR) and the East Asia Network on Plant Genetic Resources (EA-PGR) was established for exchange of technology and information. Collaborative links were also established between different research institutions in several countries.

Such regional and/or international collaboration proved particularly useful in capacity building of the partners. Bioversity-APO and ACIAR jointly organized Citrus Germplasm Conservation Workshop at Griffith University, Brisbane, Australia on 6-7 October 1997 which was attended by several partners. At this Workshop, further plans to promote conservation and use of citrus genetic resources were made (Broadbent *et al.*, 1999) and (Ramanatha Rao and Arora, 1999; Ramanatha Rao and Bhag Mal, 2002; and Drew and Ashmore, 2003). Collaboration with the International Centre for Underutilized Crops (ICUC) resulted in identifying priority fruit species for the Asia-Pacific region (Arora and Ramanatha Rao, 1995). Collaboration with DFID resulted in the publication of several monographs, namely, tamarind (*Tamarindus indica*) ber (*Ziziphus mauritiana*), baobab (*Adansonia*

digitata), ndjanssang (*Ricinodendron heudelotii*); safou (*Dacrylodes edulis*) and *Annona* species were published (Gunasena and Hughes, 2000; Pareek, 2001; Sidibe and Williams, 2002; Kengue, 2002; Pinto *et al.*, 2005; Tchoundjeu and Atangana, 2006). Bioversity and UTFANET supported each other in the training and meetings relating to conservation and use of tropical fruit species and signed the Memorandum of Understanding (MOU) to collaborate on various activities

Impact and Sustainability

Bioversity's work on tropical fruit tree species to date has been able to successfully promote awareness about the conservation and use of TFT genetic resources at various levels including researchers, farmers, administrators and policy makers. As a result, there is now a greater commitment by the national governments in the collaborating countries to support fruit crops research and development programmes. For example, a number of related and additional research is being promoted (e.g. *in situ* conservation – botanical gardens by Forestry Department; *ex situ* conservation by MARDI, Department of Agriculture (DOA) and NGOs (CPCP); Cryopreservation by several Universities; On-farm conservation by TFNet, MARDI and DOA; Genetic diversity research by MARDI and universities; work on pests and diseases by MARDI and socioeconomic studies by MARDI) have been funded by the Governments in Malaysia. In the Philippines, the projects on 'Conservation and Use of Tropical Fruit Species Diversity in the Philippines' and 'Introduction, Evaluation and Adoption of Improved and Superior Landraces of Banana for Food and Income Alleviation' have been funded by the Department of Agriculture-Bureau of Agricultural Research (DA-BAR). In China, the central and local governments have paid great attention to the tropical and sub-tropical fruits. Some projects, such as field genebank maintenance, wild and semi-wild germplasm exploring and collecting, variety improvement etc. on citrus, have received additional assistance and funding from Agricultural Department in 2001 and 2002. The project 'Mango Genebank and Database Establishment' was mainly funded by the Ministry of Science and Technology in 2002. In Vietnam, research on tropical fruit crops has been identified as one of the ten priority areas to be given due attention by the Government. In India, fruit crop research programme has been

financially supported under the National Agriculture Technology Project (NATP) and has been included in the National Agricultural Innovation Project (NAIP) funded by World Bank to carry forward the ongoing activities. In Thailand, as a result of the awareness generated through Bioversity supported activities, more attention is now being paid by the national government to mango and rambutan research and development, especially for plant improvement and molecular biology programmes. Thus, Bioversity's TFT programme and activities triggered the placement of fruit crops on the higher development agenda of the national governments in the collaborating countries.

The countries have been able to collect the threatened and rare diversity of identified priority TFT crops including their wild relatives and related species. The use of new tools such as DIVA-GIS and Flora Map has been found very successful in identifying the hot spots of diversity, prepare diversity distribution maps and plan the future collecting missions. The diversity collected has been saved from extinction and is safely conserved in genebanks for current and future use, which will have long-term impact on the fruit crop research and development programme in the collaborating countries.

The regeneration and micropropagation techniques for rapid propagation of disease free planting material and *in vitro* conservation/cryopreservation techniques for conservation of germplasm of different fruit species such as citrus, litchi, longan, rambutan and papaya proved very useful and these advance techniques are being used by the national programmes and are also available for use in other fruit crops in different countries.

The useful diversity comprising several elite lines and germplasm accessions with specific desirable attributes is now available for use by the researchers in the breeding programmes. The elite lines identified in different fruit species having added value for specific purposes such as suitability for crop diversification, product development and market demand had great impact and the farmers had access to these lines/cultivars which proved useful in enhancing their conservation and use. For example, Tai Ya variety of mango with red rind colour and good storage quality and Boloxiamyoer with pine apple fragrance and seedless variety Anjianwyhaou of pummelo in China; and Me Amba, Atamba and Valamba varieties of mango with

bark of root and stem used for fixing broken limbs in Sri Lanka exhibited great potential for large scale cultivation in these countries. Good examples that have created impact through the application of results in the field are propagation and direct cultivation of elite varieties of citrus in Nepal and China, litchi in Vietnam and jackfruit in Sri Lanka by farmers and private nurseries.

Dissemination and sharing of the information on community participation in conservation of fruit germplasm has motivated and sensitized the researchers and fruit growers in many countries in aspects related to on-farm conservation and making better use of available diversity. The strong human resource development programme providing training to researchers, technicians and farmers for enhancing their skills on different aspects of fruit genetic resources resulted in the availability of trained human resource in the collaborating countries for enhanced utilization and conservation of fruit genetic resources.

Bioversity projects on TFT facilitated the establishment of the Tropical Fruit Tree Genetic Resources Network (TFTGRN). The Network helped to promote regional cooperation to access and share information through its website <http://tftgrn.net/> which serves as a platform for exchange of information on the progress of work on TFT species in the collaborating countries and thus sustains collaboration between the partners in the Asia region. Information was also shared through GlobalHort Portal (www.globalhort.org) which is a horticultural platform for collaboration and knowledge management.

Expanding from *Ex situ* Conservation to *In situ* Conservation: The Current Approach

Bioversity's earlier work focused mostly on *ex situ* conservation related activities. Considering the need for increased efforts on on-farm (for cultivated) and *in situ* (for wild relatives), Bioversity in collaboration with its partners developed a short proposal under PDF- B Phase with support from the Global Environment Facility (GEF) and its execution resulted in the development of a full scale project proposal which was approved by GEF and the implementation of the project on "Conservation and Sustainable Use of Cultivated and Wild Tropical Fruit Diversity: Promoting Sustainable Livelihood, Food Security and Ecosystem Services" started in January 2009. The project is focusing on

four TFT species, namely, citrus (*Citrus* spp.), mango (*Mangifera indica*), mangosteen (*Garcinia mangostana*), rambutan (*Nephelium lappaceum*) and their wild relatives (some of which are edible). These are commercially important TFT species in the region with high diversity levels, both at intraspecific and interspecific levels. This GEF funded project is being implemented by the United Nations Environment Programme (UNEP) and executed by Bioversity International in four countries, namely, India, Indonesia, Malaysia and Thailand. These four countries were selected as these are located in the centres of diversity of these species.

This new project aims to help farmers to make use of selected TFT species to sustain their communities and by doing so to conserve the genetic diversity of TFT species and their wild relatives. The project will contribute to improvement of livelihoods and food security of target beneficiaries through conservation and use of fruit tree genetic resources. The project aims to promote conservation *in situ* and on-farm of TFT genetic resources through strengthened capacity of farmers, user groups, local communities and institutions to sustainably apply good practices and secure benefits. The major outcomes expected from this project are i) diversity of TFT genetic resources is conserved *in situ* and on-farm through improved knowledge of its value, use and sustainable management, ii) rural communities benefit by using methodologies and good practices for the management and conservation of TFT species and intra-specific diversity, and iii) stakeholders have the capacity and leadership skills to apply good practices for managing TFT diversity for sustainable livelihoods, food security and ecosystem health. The species complexes chosen for this project represent a reasonably comprehensive for providing methods and lessons to other countries and regions. Two of the genera (citrus and mango) are of worldwide importance while the other two (rambutan and mangosteen) are regionally important. These contrasts provide important learning opportunities for the project partners as they seek to improve incomes by developing markets for less commercialized tree fruit species.

Future Thrusts

In order to improve the conservation and utilization of fruit genetic resources in the APO region, an integrated approach needs to be adopted. This would improve productivity and quality as well as enhance

income from cultivation of native TFT species, and contribute towards food and nutritional security, poverty alleviation and the protection of environment in the rural sector in the region. The following important areas need greater thrust for research and development for effective and efficient conservation and use of TFT genetic resources:

- The existing gaps in the collections need to be filled by targeted collecting of rare and threatened materials using the improved techniques of DIVA-GIS and FloraMap and the collected diversity needs to be characterized.
- The utilization of diversity collected and conserved in the genebanks needs a focused attention and the elite lines/germplasm with specific desirable traits need to be used by the breeders to develop improved varieties. The TFT genebank managers should find ways and means for enhancing the use and should increase their involvement in pre-breeding so that they can sell their genetic resource to the plant breeders.
- Diversity of TFT genetic resources needs to be conserved *in situ/on-farm* through improved knowledge of its value, use and sustainable management practices by way of documentation of farmers' and users' knowledge, identification of market and non-market values, identifying populations under threat and developing key methodologies and good practices such as participatory rapid appraisal, genetic diversity mapping, developing descriptors, efficient conservation techniques, etc.
- TFT genetic resource should be used as a major tool to promote diversity for nutrition security. Sincere efforts need to be made for large scale evaluation of germplasm for their nutrient contents and nutraceutical properties and elite lines possessing better quality traits need to be promoted for wider use.
- Appropriate tools for quick estimation of genetic diversity at the field level need to be developed. Greater thrust also needs to be given for developing appropriate methodologies and good practices for the management and conservation of TFT species and intraspecific diversity. A sustainable livelihood approach for promoting TFT conservation needs to be developed.

- Greater focus needs to be placed on the use of TFT genetic resources for upgrading marginal and degraded lands and combating adversities due to climate change by selecting matching species for the changing sites. Integrated farming with perennial fruits in orchards can be potential research scope for mitigating and adapting climate change.
- Product development, processing, post-harvest handling and marketing aspects of TFT species need to be paid adequate attention for income enhancement of the farmers and the benefits to the consumers. Research and development programmes addressing these aspects need to be strengthened.
- The full value of TFT being perennial tree crops must be fully accounted for in terms of its contribution to carbon sequestration and other environmental services. Application of economic valuation methodologies can be applied for this purpose.
- There is a greater need to further promote networking and collaboration at the regional and international level and facilitate sharing of information, technologies and germplasm among the partners in order to exploit the native tropical and subtropical TFT diversity in the region. The existing Tropical Fruit Genetic Resources Network (TFTGRN) could be further strengthened to enhance conservation and use of TFT species. The list of exchangeable varieties of priority fruit tree species in different countries need to be developed and the material exchanged based on mutually agreed terms and under a material transfer agreement (MTA) for the benefit of collaborating countries.
- Bioversity has been supporting the idea of regional or sub-regional genebanks and sharing the responsibilities and benefits from such an effort. For example, Bioversity through its International Coconut Genetic Resources Network (COGENT) has established a multi-site International Coconut Genebank (ICG) consisting of a regional genebank in each of the five COGENT regions (Batugal and Oliver, 2004). Such an approach could be followed for TFT species also for the sustainability of regional efforts towards conservation and use of TFT species.

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