Conventional coconut breeding

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Introduction

Coconut genetic resources have been traditionally collected and conserved in major coconut producing countries with the objective of using these to improve the genetic make up of their existing cultivars. Selected germplasm are generally used as: a) planting material to improve the coconut productivity in the country or a region; b) test material to determine the phenotypic and genotypic characters of value and c) population base for breeding superior hybrids/varieties.

Based on their origin, these germplasm could be categorized into: traditional varieties or landraces, as exotic varieties introduced into the country, or as modern varieties or hybrids resulting from a national breeding effort. Most coconut producing countries have a mixed population of landraces and introduced hybrids/varieties. There are continuing efforts to further improve cultivars through mass selection and hybridization, and to produce synthetic varieties for economic reasons.

As breeding material, the coconut germplasm are generally grouped according to their growth habit. In addition, the differences in their mating behaviour give the breeders flexibility in designing various breeding schemes to achieve their desired coconut ideotypes. The STANTECH manual (Santos *et. al* 1995) described the following major classification of coconut:

1. **Tall palms**, sometimes referred to as var. *typica* (Nar.), are essentially cross-pollinating and therefore considered to be heterozygous. They are slow maturing and flower 6-10 years after planting, and can grow to a height of 20-30 m. They have an average economic life of 60-70 years.
2. **Dwarf palms,** sometimes referred to as var. *nana* (Griff.), are normally self-pollinating and therefore considered to be homozygous. They are believed to be mutants from Tall types with short stature, 8-10 m when 20 years old. They begin bearing about the third year sometimes at less than 1 m stem height but have a short productive life of 30-40 years.

There are also rare 'intermediate types' which do not express the phenotype normally associated with either the Talls or the Dwarfs. Natural crosses between Tall and Dwarfs occur sporadically in traditional populations. In some instances, such open-pollinated hybrids may become fixed as 'semi-Talls', which have the same mating behaviour as Dwarfs but grow faster. In the South Pacific, there is also a Niu Leka Dwarf, which has all the characteristics of a Tall type coconut, except for its short stature. These intermediate types have a good potential in broadening the genetic base of the breeding population but their parental value has yet to be fully evaluated.

This paper presents the various ways these coconut germplasm are used in conventional breeding, the general status of the breeding programmes for coconuts including their limitations and constraints, and future breeding strategies.

Population base

The coconut (*Cocos nucifera* L.) is a diploid with 32 chromosomes (2n=32) and the sole species of the genus *Cocos*. As such, current breeding work on this tree crop is limited to the intraspecific level.

The coconut palm is monoecious, i.e. its inflorescence carries both staminate (male) and pistillate (female) flowers (Frankel and Galun 1977). Generally, Talls, being protandrous, shed pollen prior to stigma receptivity. They are generally considered as allogamous. Nevertheless, selfing is possible because of the variable overlapping between the female phase of an inflorescence and the male phase of the next inflorescence. The speed of emission of inflorescences varies according to genotype and environment, with a great seasonal variation; so do the selfing rate. On the other hand, the Dwarfs are generally considered homogamous as stamens and pistils mature simultaneously thus Dwarfs can shed and receive pollen at the same time resulting in inbreeding. Apart from their short stem, most of the Dwarfs show a combination of common characteristics: preference to autogamy, sensitivity to environmental stresses, small-sized organs, precocity, and rapid emission of inflorescence. Because of the last three characteristics, the Dwarfs play an important role in hybridization programmes. However, the genetic determinant of coconut dwarfism is still unknown.

The bisexual nature of the Talls and the Dwarfs allow manipulation of pollination to secure the desired level of genetic introgression with the Talls as source of heterozygous genotypes while the Dwarfs provide the progenitors of homozygosity.

The genetic structures of coconut are yet to be fully understood, and the diversity of identified and collected coconut germplasm are yet to be fully exploited. As of 2003, the Coconut Genetic Resources Database

(CGRD) of the International Coconut Genetic Resources Network (COGENT) listed 599 Talls, 111 Dwarfs and 1 semi-Tall cultivar plus few cross- fertilizing Dwarfs (Hamelin 2003). However, a total of 1416 accessions are entered into the CGRD of which less than 5 % (<60) are actually being used as parents in national breeding programmes of the COGENT member countries as revealed by COGENT country surveys in 2001-2003. These also revealed that the more popular parental accessions for hybridization were the West African Tall (WAT), Rennell Island Tall (RIT), Vanuatu Tall (VTT), Malayan Yellow Dwarf (MYD), Malayan Red Dwarf (MRD), Malayan Green Dwarf (MGD) and Cameroon Red Dwarf (CRD). According to Bourdeix (1999), before 1993, about 400 coconut hybrids were created around the world in national research programmes; however, less than 10 of these coconut hybrids have been tested internationally under various ecological conditions. Recently, COGENT has tested 34 promising hybrids in three African (Benin, Côte d'Ivoire and Tanzania) and three LAC countries (Brazil, Mexico and Jamaica) to test their agronomic performance and their Germplasm x Environment interaction (see Batugal *et al.* in Chapter 5). The availability of characterization data (quantitative and qualitative descriptions of major traits) on most of the catalogued accessions of the CGRD, and the establishment of the International Coconut Genebank (ICG) and national genebanks (28 genebanks in 24 countries), there are now new options for breeders to incorporate more accessions into their breeding schemes.

The patterns of genetic differentiation for many of the available coconut accessions are being determined at the morphological and molecular levels (see related articles in Chapters 4 and 5). Initial results showed close relationship between some accessions which helps to avoid the use of 'duplicates' in breeding programmes. Some cultivars such as the Malayan Tall and Pakistan Tall (represented by 49 and 32 accessions, respectively) are described very often in the CGRD (Hamelin 2003). Similarly, there were 31 accession entries of East African Tall reported from Tanzania and five from India. Obviously, the same genotype may carry different accession codes/names depending on the source of origin or collecting site.

In many small coconut producing countries, breeders accessed germplasm not necessarily for breeding purposes but to select genotypes for direct release as varieties. The selection process is usually done through on-farm varietal evaluation with the traditional cultivars serving as basis of comparison or control. This provides a short cut to the long and tedious process of undertaking a hybridization programme, which in coconut usually takes 14 to 15 years, just to produce and evaluate a single generation of progenies. Nevertheless, this type of short-term selection inhibits further work towards maximizing heterosis that only a well-designed breeding programme could achieve.

Although coconut is a monotypic, the genetic variability that is present in the current collections is sufficiently broad for the breeders to undertake various breeding schemes in developing improved coconut varieties. The existing variable traits between the Tall and Dwarf populations and within the Talls provide a good opportunity to produce various recombinants that could yield the desired characters. It is only through actual germplasm use, such as in conventional breeding, that the continuing activities on collecting, maintaining and characterizing of coconut germplasm could be justified.

Conventional breeding schemes

Mass selection methods

Three options of mass selection exist, according to the choice of a reproductive system: mass selection using open pollination, selfing or intercrossing.

Mass selection using open pollination has been the mostly practised method. The main advantage of this method is its simplicity; the seednuts are collected from palms that present attractive characteristics at a time. The progenies resulting from open pollination are the basis of an improved population which will then undergo other selection cycles. In the case of coconut, the efficiency of mass selection using open pollination has been the subject of a harsh controversy (Bourdeix 1988). Divergent results were obtained, partially because of the natural reproductive system of the Tall palms. Although Talls are mainly allogamous, selfing remains possible. The rate of selfing increases with the speed of inflorescence production. Best palms on best plots produce more inflorescences so they may have a higher selfing rate than others. Their progenies will suffer from an inbreeding handicap. The speed of inflorescence emission also varies strongly between seasons. Therefore, selection results will differ according to the season within which seednuts are harvested. Although there was a positive response to the selection, the best result obtained was at most a 14.4% gain in the first generation from a selection of 5% best palms (Liyanage 1972). The severe selection required for obtaining a genetic progress limits seednut production capacity.

For the coconut palm, the effectiveness of the mass selection using selfing seems to be limited. A single generation of selfing in a Tall coconut population generally causes a decrease of fruit production of about 15 - 25 % (Bourdeix 1999). Obtaining pure lines from heterozygous Talls remains a long-term prospect which “would discourage the most ardent”

(Charles 1961). The four generations required to create 95% homozygous structures represent a period of 25 to 60 years, depending on the method of parent evaluation.

Mass selection using intercrossing has never been evaluated for coconut. The principle is to select parent palms on the basis of their phenotypic performances and to intercross them. Various crossing schemes can be followed, such as independent pairs and factorial crosses. Forty to fifty mother trees can be pollinated with the pollen of a single male parent, allowing for a stricter selection among the male parents. One could retain 10-20% of the population as mother palms and use a selection rate of less than 1% for the male parents.

The three mass selection methods can be ranked by increasing efficiency: selection using selfing, open pollination and intercrossing (Bourdeix 1999). The first two methods are of limited effectiveness. Selfing induces a yield decline without appreciably increasing production homogeneity. Open pollination leads to variable results, due to absence of control on pollen origin. Mass selection using intercrossing appears theoretically more effective, as it allows for a strict selection of pollinators while retaining a large potential of seednut production. However, there are no experimental results available that make it possible to assess the genetic progress that could be realized with this last method.

Other intra-population breeding methods

These methods based on progeny testing within a given population were occasionally applied to a few Tall varieties located in Indonesia, Sri Lanka and India. Harland (1957) introduced the concept of 'prepotent palms' as mother palms, which in spite of having indiscriminately pollinated by miscellaneous males possess sufficient dominant yield traits to pass on to their offspring. Later, Satyabalan and Mathew (1983), using modern breeding concepts, argued that 'prepotent palms' are nothing more than palms with good general combining ability. Since evaluating coconut progenies is time consuming and laborious, attention was diverted to the possibility of identifying so-called 'prepotent' palms from their progeny at seedling stage (Nampoothiri 1991). Many researches, especially from India, are studying the correlation of seedlings characters with adult palms.

Single cross hybrids

As mentioned above, the current base populations of breeding programmes for coconut generally consisted of selected Talls and Dwarfs. A parental genotype is usually selected based on its proven performance in the areas of intended use, such as nut, copra or oil production. The other parent is usually chosen because it complements the specific weakness of the first parent, such as precocity or resistance to biotic and abiotic stresses. Preferred major traits of a Tall parent are high productivity, broad adaptability and tolerance to specific pests and diseases. Dwarfs are preferred for their precocity and high rate of bunch emission (Bourdeix *et al.* 1998).

Unlike in most annual crops where selected parents are first developed into inbred lines to produce uniform progenies, most coconut breeders practised straight forward parental selection based on combining ability tests and/or on previously reported performance or traits from the source of origin. This is due to the very long-term nature of purifying the parental lines and producing a generation of progenies. The most popular scheme of improving coconut cultivars is through hybridization of parents with exceptionally good combining ability. When hybrid varieties are feasible, they make better use of heterosis than any breeding procedure yet developed (Allard 1960).

The most common types of commercial coconut hybrids are single crosses between Dwarf and Tall (D x T) and between unrelated lines of Tall populations (T x T). Single crosses are believed to provide the greatest opportunity for expression of hybrid vigour and usually have higher yields than other types of hybrids (Wright 1980).

Most breeding programmes of the COGENT member countries prefer D x T hybridization (Table 1) because of the ease of pollinating the mother palm due to its shorter stature and due to the relative precocity of the resulting hybrid. However, this requires careful emasculation of the Dwarf parent to prevent self pollination. The possibility of finding male-sterile and self-incompatible lines among the Dwarf populations has yet to be explored in coconut. The reciprocal T x D crosses were earlier done in India, Papua New Guinea and Nigeria largely to determine the general and specific combining abilities of the parental lines for specific traits (Batugal and Ramanatha Rao 1998).

Traditionally, the T x T breeding scheme is practised in most coconut producing countries through a formal breeding programme or as a result of natural outcrossing among and within the Tall populations. Using genetically distant ecotypes, the principal effect of hybridization is the increase of the frequency of heterozygous genotypes that could enhance artificial selection towards the desired traits. Open-pollinated palms from selected Tall parents with outcrossing behaviour would similarly exhibit hybrid vigour and could be naturally produced in isolated gardens with the help of wind, insects and other pollen vectors.

Comparing D x T and T x T, initial country reports showed that D x T hybrids generally outperform the inter-Tall crosses. D x T could be considered a wider cross than the inter-Tall crosses and hence, expectedly have higher genetic variances and overall population means. However, Bourdeix (1998) reported that in the long term the T x T can have a cumulative production equivalent to the yield of D x T as demonstrated in the comparison between the WAT x RIT improved hybrid and the PB121 (MYD x WAT) at the 9^{th} year of production cycle. Later, it was reported that the T x T hybrid even outyielded the PB121. Similarly, Santos (2001, unpublished) observed that after 15 years, the yield of the Philippines' local Talls, such as Tagnanan Tall and San Ramon Tall, could equal the yield of D x T hybrids and that the superiority of these hybrids appeared to be only in the first 12 years. Apparently, it would take several production cycles to fully assess the comparative advantage of the different conventional breeding schemes for coconut.

The D x D hybridization technique is not very popular among the coconut breeders. Dwarfs are reputed sensitive to environmental stresses, such as drought and low fertility soils. Nevertheless, some of the most profitable coconut plantations in the world are probably those of Green Dwarfs found in Brazil and Thailand; with high planting density (more than 200 palms per hectare), high fertilization rate and sufficient irrigation. The Thailand coconut breeding programme is now mainly focused on the improvement of the Aromatic Green Dwarf varieties. An experiment was conducted in Côte d'Ivoire in 1971 to test the three possible hybrids between MYD, MRD and Brazil Green Dwarf (BGD) and compare them with MYD as control (Le Saint and Nuce de Lamothe 1987). The hybrid MYD x MRD produced an average of 3.8 tonnes copra per hectare which was comparable to the production level of a good D x T hybrid. An important feature of D x D hybrids is their high genetic homogeneity. As the two Dwarf parents are close to pure line, their progenies are less likely to be variable in genotype than the D x T and T x D hybrids.

Some of the best D x T and T x T hybrids were improved using the individual combining ability tests method and by exploiting the genetic variability that exists within the populations of Talls. For a description of this method, it is better to use an example. The hybrid PB121 is a cross between the MYD and a selected population of WAT. Its good performance in Côte d'Ivoire has stimulated its further improvement. Forty-five WAT parent palms were selected based on phenotype and individually crossed with the same MYD population. The 45 progenies thus obtained are considered half-sib families. In only one generation of breeding, it was possible to improve the yield of the earlier PB121 hybrid from 15 to 25 percent; some of the improved F_1 progenies were also proven to be more tolerant to the *phytophthora* disease in Côte d'Ivoire (Bourdeix *et al.* 1992). This method, initially developed by CIRAD in the 1970s, was applied mainly in Côte d'Ivoire and Vanuatu on D x T and T x T hybrids using the West African, Rennell Island, Tahiti and Vanuatu populations of Talls.

Complex hybrids

In breeding coconut, promising hybrid progenies are identified, evaluated and selected for specific traits as early as in the F_1 generation. This, of course, limits a complete exploration of possible polygenic recombination of a cross. Few countries are currently testing multiple crosses to develop varieties with desirable multiple traits or simply carry on the selection process to the next steps.

Thailand is testing 3-way cross hybrids (TxT) x T and (DxT) x T. It will be interesting to compare the level of heterogeneity of these two kinds of combination. Because of segregation for dwarfness, (DxT) x T will be probably more variable than (TxT) x T, but this remains to be studied.

In Côte d'Ivoire, as early as 1976, the MYD was crossed with the hybrid WAT x RIT. This 3-way hybrid, planted in medium agronomic conditions, yielded only 77% more than the WAT control. In other better experiments, the single cross hybrids MYD x WAT and MYD x RIT yielded 97% and 129% more than the WAT control, respectively (Anonymous 1988). Nevertheless, in Côte d'Ivoire, Dwarf varieties are now systematically crossed with a tester made of selected parent palms from the hybrid, WAT x RIT. Also in Côte d'Ivoire, from 1986 to 1992, double or 4-way cross hybrids were also created: (DxT) x (DxT), (DxD) x (TxT) and (DxT) x (TxT) using selected Tall and Dwarf progenitors. However, these were not included as a part of the main classical breeding scheme. They were specially conceived anticipating the possible development of a cloning technique.

Synthetic varieties

In addition to the hybridization method of improving coconut cultivars, the Philippines is spearheading the development of synthetic varieties which are predicted to have wider adaptability and stability in performance due to the utilization of several selected parents as compared to single cross hybrids (Santos and Rivera 2002). The parental base of a synthetic variety is a composite of selected parental lines which combined well in all combinations through natural crossing. Hence, prospective parental genotypes are first tested for their combining ability or additive gene effects before they are entered into the mating pool. Accordingly, the most critical stage in the development of a synthetic variety is the selection of the parents for the composite. In corn, the expected yield of the Syn_2 increased steadily as inbred lines with higher combining ability were added, reaching a maximum at 5 or 6 parental lines, after which the expected yield decreased steadily as more lines were added (Allard 1960). To summarize, finding the optimal number of parental lines requires a trade off between the selection of best lines, which tends to reduce this number and reduction of consanguinity, which tends to increase it. In coconut, the main drawback in developing synthetic varieties is that the combined genes favouring the desired traits may only attain equilibrium after several cycles of intermating since inbreeding or purification of parental lines are generally circumvented.

An important question related to the use of synthetic varieties is that seednuts released to farmers are obtained from open pollination. Therefore, the same problem may arise as described in the mass selection process. Selfing rate varies with the speed of emission of the inflorescences, depending on genetic and environment factors, and is very sensitive to seasonal effects. As there is a strong inbreeding depression, the mean values of the seednuts may vary with seasons. This could be avoided by removing the 'unwanted' inflorescences in the seed gardens at the critical seasons. This way, the possibility of natural selfing will be eliminated and the mean value of seednuts will increase and become homogeneous.

Status of coconut improvement

Breeding goals. In general, the short-term goals of most coconut producing countries are designed to develop varieties and hybrids based on their target ideotypes. Their intermediate- and long-term goals include characterization and development of materials that have potential in future breeding programmes. Coconut breeders are understandably concerned with and more focused on short-term goals. Although the improvement of breeding populations and conservation of genetic variability are important long-term goals, the resource requirements for such undertaking are mostly beyond the capability of national coconut breeding programmes. Hence, as a complementary effort, COGENT established the International Coconut Genebank (ICG) in 1997 to pursue these long term goals. There are four regional ICGs based in: Indonesia for Southeast Asia, India for South Asia, Papua New Guinea for the South Pacific and Côte d'Ivoire for Africa and the Indian Ocean (Ramanatha Rao and Batugal 1998).

Breeding results. Despite the limitations on breeding, resource and time investments, coconut breeders have been successful in developing varieties and hybrids for environments in which they were grown. Table 1 shows the types and number of promising and/or recommended single cross hybrids in major coconut growing countries. The D x T hybrids obviously dominated the breeding output, followed by the T x T progenies. Promising T x D and D x D crosses were reported only in India and Fiji, respectively; although Côte d'Ivoire has already produced exceptionally high yielding MYD x MRD hybrid as early as 1971.

Table 1. Types of promising/recommended (single cross) hybrids in selected coconut growing countries
*(Sources: *P Batugal 2004; **P Batugal and V Ramanatha Rao 1998)*

Country *	Types and number of hybrids			
	D x T	T x T	T x D	D x D
Benin	2			
Côte d'Ivoire	6	2		
China	1			
Fiji	3			1
Ghana	2			
India	1		3	
Indonesia**	3	4		
Mexico	4			
Philippines	7	3		
Papua New Guinea	15			
Sri Lanka	1	2		
Tanzania	14	5		
Thailand	2	1		
Vanuatu	1	1		
Vietnam	3	3		
TOTAL	**65**	**21**	**3**	**1**

In terms of breeding for resistance to biotic and abiotic stress, the infusion of resistant genes is done by intercrossing stress-tolerant germplasm with adapted germplasm. Some of the known cultivars being used in breeding for major coconut disease resistance are: Vanuatu Tall for tolerance to coconut foliar decay, Pacific Tall and Malayan Dwarf for lethal yellowing disease resistance and Sri Lankan Green Dwarf for Cape St. Paul wilt tolerance. Rajagopal *et al.* (Chapter 5) reported that in general, Talls and hybrids with Tall as mother palm have higher drought tolerance compared to Dwarfs and hybrids with Dwarf as mother palm. Most drought tolerant varieties have thick leaflets and thick cuticle. In addition to anatomical feature, the behaviour of coconut varieties on drought is influenced by environmental physiological and biochemical factors.

Technology gap. Comparing the national yield average in farmers' fields and those of research stations in 15 coconut growing countries, the estimated technology gap in terms of nuts and copra yield ranged from

33 to 84% (Table 2). The significant improvement in productivity at research stations could be attributed to using hybrids/improved varieties in conjunction with proper management and cultural practices. The low productivity in farmers' fields could be due to poor cultural management/ lack of production inputs and the use of poor quality planting materials.

Table 2. Coconut productivity in farmers' field and research stations, and area planted to hybrids
(Source: P Batugal and J Oliver, 2003)

Country	Yield per Year: (A) Farmers' Fields/National Average Nuts Copra (t ha^{-1})	Yield per Year: (B) Research Station/Hybrids Nuts Copra (t ha^{-1})	Technology Gap [100-(A/B x100)]	Area grown to Hybrids (% of Prod'n area)
South Asia				
Bangladesh	21/palm	69/palm	70	nil
India	6892/ha	23 700/ha	71	14
Sri Lanka	42/palm	63/palm	33	11
Southeast Asia				
Indonesia	1.1	3.5	69	5
Malaysia	10 000/ha	23 000/ha	57	n.d.
Philippines	0.78	4-6	84	n.d.
Thailand	1.2-1.5	3.0	55	10
Vietnam	38-40/palm	55-80/palm	42	<0.1
South Pacific				
Fiji	0.3-0.5	2.0	80	<5
PNG	0.66	2.8-3.6	80	
China	1.27	3.6	65	1.5
Africa				
Ghana	20/palm	n.d.		3
Tanzania	40/palm	80/palm	50	n.d.
LAC				
Jamaica	0.8	3.7	78	n.d.
Mexico	0.65	4.0	84	1

Although hybrids generally performed better than the traditional varieties, they are currently being grown in limited areas, less than 0.1 (or even nil) to 14% of cultivated coconut farms in various countries (Table 2). The poor adoption of hybrids may be attributed to inadequate information dissemination on the availability of improved hybrids/varieties and lack and affordability of planting materials. Those who planted hybrids, mostly favoured D x T and T x D for their high yield, early bearing, good nut size and better resistance to pests and diseases (Rethinam *et al.*, Chapter 5). However, some dissatisfaction on these hybrids was expressed in terms of bunch buckling, high input requirement, vulnerability to moisture stress, and pests and diseases.

Breeding limitations and opportunities

The primary breeding procedure in coconut continues to be single-cycle selection due to its 9-10 year production cycle, excluding the breeding and evaluation phases. This is a limiting factor because selection, when done in early generations, fails to consider undesirable linkages that may occur between qualitative genes and genes for quantitatively inherited traits (Halluer 1981). It takes time for recombination to break up these allelic associations and release the latent genetic variation (Falconer and Mackay 1996). For perennial plant like coconut, molecular marker techniques would enhance the efficiency in locating diversity during collecting activities and in characterizing diversity to eliminate duplicates in the genebanks (Batugal 1999). The technique would require finding specific markers that could highly predict the progenitor's value. Individual selection could then be done even at embryo stage as long as molecular markers are manifested. In potato (Peloquin 1981; Khwaja *et al.* 1986), the use of 2n pollen as a marker eliminated the need for field testing of diploid species which may be compatibly crossed with the cultivated tetraploids. In coconut, marker-assisted selection is currently limited to partitioning the genetic distance between and among populations (see Chapter 4). An early growth marker (molecular or morphological) with strong correlation with desirable traits would translate to significant savings on time, space and cost of breeding coconut.

Another major limitation in breeding coconut is the long and expensive process of propagating the selected progenitors. The use of embryo culture may facilitate the rapid and safe propagation of breeding materials with the development of viable protocols (Batugal and Engelmann 1998; Engelmann *et al.* 2002). The ICG is promoting the use of *in vitro* cultured embryos to save on cost and facilitate the safe movement of germplasm accessions. In the past, somatic embryogenesis has been tried to increase propagation efficiency. However, the recovery rate of somatic embryos and *ex vitro* seedlings in the nursery had been very low, making it an expensive proposition. Recent findings at the EXPAND (PALM2LINK) conference in Manila (Oropeza *et al.* 2004) indicate significant progress and increased recovery rates, enhancing the potential of somatic embryogenesis for reducing the cost of propagating improved varieties and hybrids both for breeding and for replanting.

A procedural limitation in breeding coconut is the artificial or hand pollination of mother palms which requires substantial human and financial resources. Unlike the protandrous populations which can naturally be crossed in isolated gardens, production of hybrid progenies requires the tedious process of artificially emasculating and pollinating the mother palms. Identification of cultivars that exhibit sexual characteristics different from the norms due to environmental or other mutagenic conditions would allow manipulation of pollination for breeding purposes. Self-incompatible or male sterile lines to facilitate hybridization in otherwise self-pollinating plants are commonly practised in many annual crops. Thus, a careful search for male-sterile coconut palms could prove useful.

Considering the substantial number of coconut accessions conserved *in situ* and *ex situ* worldwide, the available genetic variability for breeding manipulation is tremendous but hardly used. Current breeding programmes are using very few of these available germplasm. The main problem appears to be the lack of complete characterization (morphological, physiological and molecular) of most of the conserved germplasm which would give an indication of their potential as breeding materials. Only a little over half of the accessions listed in CGRD have values for 25% to 50% of their passport and assessment descriptors. Hence, COGENT is generating more support to maximize characterization work of *ex situ* conserved germplasm.

Largely untapped are landraces or farmer varieties which are yet to be fully collected and conserved in genebanks. Landraces may generally be characterized by their high levels of heterogeneity compared to modern commercial cultivars, comparative stability across seasons, location specificity and generalized, rather than highly specific, tolerances and resistances (Hawtin *et al*. 1997). These landraces actually evolved through generations of simple mass selection by coconut farmers. Hence, farmer-participatory approach to characterizing the traditional cultivars and *ex situ* conservation of promising populations could significantly facilitate the utilization of landraces for breeding efforts. COGENT has recently developed a protocol for farmer characterization of coconut varieties to secure indigenous information on landraces.

Farmers' varietal preferences

The survey on the performance of high-yielding hybrids and varietal preferences conducted by APCC through the financial support of APCC, BUROTROP and COGENT (see Rethinam *et al.* in this chapter) indicated the following: 1) there is no universal hybrid; 2) hybrids perform better than traditional Tall varieties under good rainfall and soil conditions; 3) several farmers prefer traditional Tall varieties to hybrids because of various reasons. The reasons could include that the Tall varieties may be well adapted to their cultural and traditional practices, and perform better under low fertility and high abiotic stresses. For example, in the typhoon that hit Fiji in January 2003, only about 20% of the traditional Talls were damaged compared to about 80% of the Dwarfs and D x T hybrids. In Comoros Islands, roofs and fences made with coconut foliage of Tall varieties last longer (two times longer) than those made using D x T hybrids leaves. Many farmers wish to sow both Talls and Hybrids.

Under COGENT's current ADB-funded 'Development of sustainable coconut-based income generating technologies project', farmers have identified some varieties that have traits suitable for the production of high-value coconut products. Based on the above, breeding programmes should be designed to develop and provide either varieties or hybrids that suit specific agroecological conditions and small-scale farmers' needs. In the end, each national coconut breeding programme should be able to propose to farmers a set of well-evaluated varieties including Dwarfs, Talls, and Hybrids.

Future breeding plans

Barring any breakthroughs in genetic engineering, the conventional breeding approaches would remain to be the major methods of utilizing coconut germplasm. In view of this, COGENT is proposing a globally coordinated breeding programme for coconut to facilitate the use of available germplasm worldwide and expedite works on developing improved varieties. The breeding programme shall focus on the global/ regional needs of COGENT member countries instead of merely those of individual countries and will adopt participatory plant breeding approach to incorporate farmers' varietal preference.

Specifically, the programme initially aims to: 1) characterize conserved germplasm and farmers' varieties using morphometric and molecular techniques; 2) screen and identify ecotypes tolerant or resistant to the lethal yellowing disease and drought; 3) improve yields for specific uses and adaptation; 4) develop varieties which are suitable for the production of high-value products from husk, fibre, shell, meat, water, wood and leaves; 5) develop technical support systems for national breeding programmes (i.e. information, pollen and embryo provision, etc.); and 6) provide a platform to promote the dissemination and use of the results of the above-mentioned coconut breeding projects to achieve socioeconomic and environmental impact. Ultimately, the programme should be able to significantly increase the choice of hybrid cultivars among coconut growing countries, by maximizing the use of available genetic resources for breeding purposes, and improving the quality of the planting materials for distribution to users or farmers.

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