Chapter 5

Breeding

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1. Introduction

Cocos nucifera L. belongs to the monocotyledon family Arecaceae (Palmae) in the subfamily Cocoideae and is the only species of the genus *Cocos*. The coconut palms are diploid with 32 chromosomes (2n = 2x = 32). Although it is cultivated in most tropical and subtropical countries within 25 degrees of equator, the better yield performance has been reported within 20 degrees and some in some extended areas having warm sea currents. It is grown commercially as plantations up to about 800 m from mean sea level in tropical regions. Coconut palms are regarded as *Kalpa vriksha* in India meaning *Tree of life* considering its ability to provide all necessities of life. Different parts of the coconut palm provides nutritious food in terms of oil, milk, drink, sugar, dietary fibre and palm cabbage, several inputs for industries uses such as husk fiber, leaves, hardy shells, timber and a variety of miscellaneous products for traditional medicinal uses. Besides, abundance of coconut palms in fragile island ecosystems provides environmental services in safeguarding the ecosystem. Coconut palms are now primarily focussed for their ability to provide health food, tender coconut water, virgin coconut oil, unfermented inflorescence sap and sap sugar. Besides, the coir fibre, coir dust and wood are gaining importance in preparing several domestic and industrial products including coir products, geotextiles, potting media for soilless culture of several high value crops and furniture. Although coconut palms are used in numerous ways as detailed above, the breeding efforts were largely focussed on identification and development of high yielding types in terms of fruit yield and copra out turn under specific locations or conditions of disease affected or drought affected regions. For these conditions, the natural coconut diversity existing among different coconut populations in specific locations was used. The *ex situ* field gene banks have greatly contributed to the crop improvement works around the coconut growing countries through identification, conservation and multiplication of those types.

The perennial nature of coconut palms with a long juvenile phase, high level of inherent heterozygosity in individual palms within the cultivars and the high resources requirement in terms of land and human resources for experimentation, lack of successful reproducible vegetative propagation technologies are the major factors impeding the ongoing breeding efforts. Though the most breeding efforts of present are conventional approaches of mass selection and hybridization, attempts have also been reported on individual palm selection for targeted novel traits. The recent developments in biotechnological tools have also accelerated advancements in revealing diversity among the conserved germplasm, identification of better parental lines, molecular characterization and hybridity testing (Rajesh *et al.*, 2012). The information on varietal groups, genetic resources, current breeding objectives and approaches and achievements and future strategies of coconut breeding are enumerated hereunder.

2. Varieties

2.1. Varietal Groups

Coconut cultivars have been described by researchers using different parameters such as growth habit, pollination mechanism, characteristics of fruits etc. Among these, the major grouping is based on stature of palms and breeding behaviour, dividing the coconut populations broadly into two groups or types. They are tall and dwarf (Narayana and John, 1949). In this, the tall type is primarily described as out crossing while the dwarf type is mainly self-pollinating due to overlapping of male and female flower opening in the same inflorescence. However, there are some dwarf types with predominantly outcrossing traits and similarly there are some tall types having inter-spadix overlapping of male and female phases resulting in some amount of selfing. Hence, the breeding behaviour is sometimes subject to growing conditions and the level of out crossing depends on presence of other palms in the vicinity. Studies suggest that dwarf coconuts may have originated as a result of inbreeding among tall coconuts as they show limited self-pollination. Purseglove (1968). states that dwarfs are probably mutations of tall types.

In another system of grouping, based on the morphological traits, the cultivars are classified as var. *typica* (talls), var. *nana* (dwarfs) and var. *javanica* (intermediate) with two mutant varieties var. *androgena* (male coconut palm) and var. *spicata* (unbranched inflorescence). Based on the fruit characters and seed-germination traits, *Niu Kafa* and *Niu Vai* types of coconuts were suggested to denote wild and domesticated coconuts, respectively wherein *Niu Kafa* fruits are with more proportion of husk, lengthy fruits having small nuts with lesser cavity and *Niu Vai* fruits with more nut proportion, round or oblong shaped having bigger round nuts with large cavity.

The Makapuno type from the Philippines and similar soft endosperm types from other coconut growing areas where the endosperm is buttery soft and almost fills the nut cavity is used in delicious preparations. In India these types are called

Thairu Thengai and have been reported from Andaman Islands (Jerard *et al.*, 2013). Besides, sweet kernel type called Mohacho Narel (Samsudeen *et al.*, 2013) and sweet tender husked type called Kaithathali (Satyabalan, 1997) have also been reported from India and are being conserved. These types are known to occur in other countries, in different coconut populations. Aromatic coconut types widely exploited in Thailand are another type preferred for improvement.

Based on the results of molecular marker studies, the coconut populations have been classified into two major groups: the Pacific group with five sub-groups (Southeast Asia, Melanesia, Micronesia, Polynesia and the Pacific coast of Central and South America) and the Indo-Atlantic group. The Pacific group includes the domesticated coconut while the Indo-Atlantic group, includes Niu Kafa coconut types. No single method of classification can account for the variability observed in the coconut populations worldwide as suggested by Perera *et al.* (2009).

2.2. Features of Varietal Groups

The level of genetic diversity existing among present day coconut populations can be considered as the result of natural evolution based on adaptation to different environments and human selection for several requirements. The tall type cultivars are commonly cultivated for their higher fruit yield aiming for higher copra production, their ability to withstand adverse situations in respective coconut growing regions and longer economic life of over 80 years. The different dwarf

Table 5.1: Features of Tall and Dwarf Coconut Types

Trait	*Tall*	*Dwarf*
Stem	Sturdy with bulbous base	Mostly thin and cylindrical
Stem growth increment per year	Greater than 50 cm	Less than 50 cm
Arrangement of leaf scars on stem	Sparse with definite gap	Very close
First flowering	Late (5–9 years)	Early (3–4 years)
Mode of pollination	Predominantly cross-pollinated	Predominantly self-pollinated
Overlapping of flower phases	Gap between male and female phases, occasionally inter-spadix overlapping	Overlapping of male and female phases as intra-spadix overlapping and occasional inter-spadix overlapping
Colour of fruits and petioles	Generally mixtures of greens and browns	Either pure green, yellow, red (orange) or brown
Leaf and bunch traits	Longer leaves, broader leaflets, firm and strong attachment to stem	Shorter leaves, narrow leaflets, fragile attachment to stem
Fruit size	Very large to very small	Small to medium
Alternate bearing habit	Not common	Common
Phenotypic variation:		
Within cultivar	High	Low
Between cultivars	High	High
Root distribution	Generally more dense and plentiful	Less dense and few

cultivars are presumed to have been originated from different tall populations either through mutation (Menon and Pandalai, 1958) or by inbreeding in selected talls (Swaminathan and Nambiar, 1961) followed by human selection. Most dwarf type cultivars are preferred for their tender nuts, ornamental look, convenience of accommodating in home gardens and ease of climbing relatively lesser height for many years. Tender coconuts from dwarf cultivars are preferred over talls, as they generally exhibit high total soluble solids, low acidity, high total and reducing sugars, high potassium and tasty nut water. Some of the dwarf cultivars are also promoted as they possess resistance to phytoplasmal diseases such as lethal yellowing. Hence, the dwarf cultivars are used widely for breeding purposes. The following are the distinguishing features of tall and dwarf cultivars (Table 5.1).

2.3. Tall and Dwarf Genetic Resources

The predominant varieties grown in major coconut growing regions are either selections from the respective tall or dwarf populations of the region or hybrid progenies among the selected tall and dwarf cultivars. Both tall and dwarf selections have been used for the development of hybrids with an aim to combine the early-flowering trait of dwarfs with the hardiness and high fruit yielding character of tall parents, and also to exploit the potential hybrid vigour for desirable traits. Some of the important coconut cultivars of different coconut growing regions are listed here (Table 5.2).

Table 5.2: Important Tall and Dwarf Coconut Cultivars

Region	*Tall cultivars*	*Dwarf cultivars*
Southeast Asia	Malayan, Klapawangi, Philippines, San Ramon, Laguna, Lono, Dalig, Makapuno, Bali, Tenga, Thai, Java, Cochin China Tall	Aromatic green, Nias Yellow, Nias Green, Bali Yellow, Coco Nino, Catigan, Tacunan, Malayan (red, yellow, green), Pilipog Green Dwarf
Central and South America Atlantic	Surinam, Jamaica, Sanblas, Panama Tall	Surinam Brown, Brazilian Green, Malayan Dwarfs
Africa	East African, West African Tall	Cameroon Red, Pemba Dwarfs
Pacific Ocean Islands	Markham, New Guinea, Karkar, Rotuma, Fiji, Samoan, Rangiroa, Lifou, Solomon, Rennell, Vanuatu, Gazelle Peninsula Tall	Niu Leka, Hari Papua, Madang Brown, Vanuatu Red, Malayan (red, yellow, green) Dwarf
Indian Ocean Islands	Seychelles, Comoros, Coco Raisin, Coco Bleu, Sambava Tall	Pemba Dwarf (red, yellow, green)
South Asia	Indian West Coast, Indian East Coast, Tiptur, Andaman Giant, Andaman Ordinary, Lakshadweep Ordinary, Lakshadweep Micro, Kaithathali, Kappadam, Benaulim, Sri Lankan, Gonthembil Tall	Chowghat (orange, yellow, green), Gangabondam Green, Lakshadweep (orange, yellow, green), Andaman (yellow, green, orange), King Coconut, Sri Lankan (red, yellow, green) Dwarf

2.4. Identification of Trait Specific Accessions

The assembly of these collections at one place in *ex situ* conservation plots of CPCRI has helped in identification of some accessions for specific traits over the years which are used in the ongoing improvement programmes or could be used in future breeding programme (Niral *et al.*, 2008, 2009, 2010, 2014a; Thomas *et al.*, 2014).

The perennial nature of the collections in the field gene bank provide opportunity to use them for evaluation against emerging issues like new pest or disease outbreak, moisture stress tolerance, morphological traits, fruit component traits, ball copra production, insect/disease resistance and exhibition of novel traits. The observed response of the germplasm provides information on the presence of adaptive traits in the accessions and aids in identification of trait specific accessions. The identified trait specific accessions in India which have potential for use in breeding programmes are listed here (Table 5.3) and some are depicted (Figure 5.1).

Table 5.3: Trait-specific Accessions of Coconut Identified in India

Trait	*Accessions*
High female flower production	Spicata Tall, Laccadive Micro Tall, Ayiramkachi Tall, Champin Micro Tall, Katchal Micro Tall
Large inflorescence	Borneo Tall
Higher copra content(>300 g)	San Ramon Tall, Malayan Tall, Markham Tall, Laccadive Giant Tall
Lower copra content (<125 g)	Surinam Brown Dwarf, Chowghat Green Dwarf, Malayan Yellow Dwarf, Laccadive Micro Tall, Ayiramkachi Tall
High Oil content (>72 per cent)	Laccadive Micro Tall
Dwarf with high copra content (>200 g)	Cameroon Red Dwarf, Niu Leka Green Dwarf
High copra/oil output (>4 mt copra/ha and >2.5 mt oil/ha)	Fiji Longtongwan Tall, Adirampatnam Tall, Cochin China Tall, Java Tall, Philippines Ordinary Tall, San Ramon Tall
Ball-shaped copra production	Laccadive Micro Tall, Tiptur Tall, West Coast Tall, Ayiramkachi Tall, Java Tall
Good quality tender nut water	Chowghat Orange Dwarf, Malayan Orange Dwarf, Philippines Ordinary Tall, Malayan Green Dwarf, Gangabondam Green Dwarf, Cochin China Tall, Kulasekharam Green Tall
Drought tolerance	Andaman Giant Tall, West Coast Tall, Java Tall, Federated Malay States Tall, Laccadive Ordinary Tall, Cochin China Tall, Tiptur Tall
Root (wilt) disease resistance	Chowghat Green Dwarf, Malayan Green Dwarf,
Eriophyid mite resistance	Chowghat Orange Dwarf, Kulasekharam Green Tall, West Coast Tall-Spicata
Stem bleeding – less infection	Cochin China Tall, Gangabondam Green Dwarf, Laccadive Ordinary Tall
Aroma in coconut water and meat	Klapawangi Tall, Andhra Aromatic Dwarf
Sweet endosperm	Mohacho Narel
Sweet tender husk and mature soft husk	Kaithathali Tall
Soft endosperm	Andaman Thairu Thengai or Nei Thengai or Ghee Thengai
Pink husk (tender fruits)	Guelle Rose Tall, West Coast Pink Tall, San Ramon Pink
Horned coconut	Andaman Horned Coconut
Compact crown	Niu Leka Green Dwarf
Early flowering	Chowghat Green Dwarf, Hari Papua Orange Dwarf, Nikkore Orange Dwarf
Vigorous seedling parameters	Federated Malay States Tall, Philippines Ordinary Tall, Borneo Tall
Smallest fruits	Laccadive Mini Micro Tall

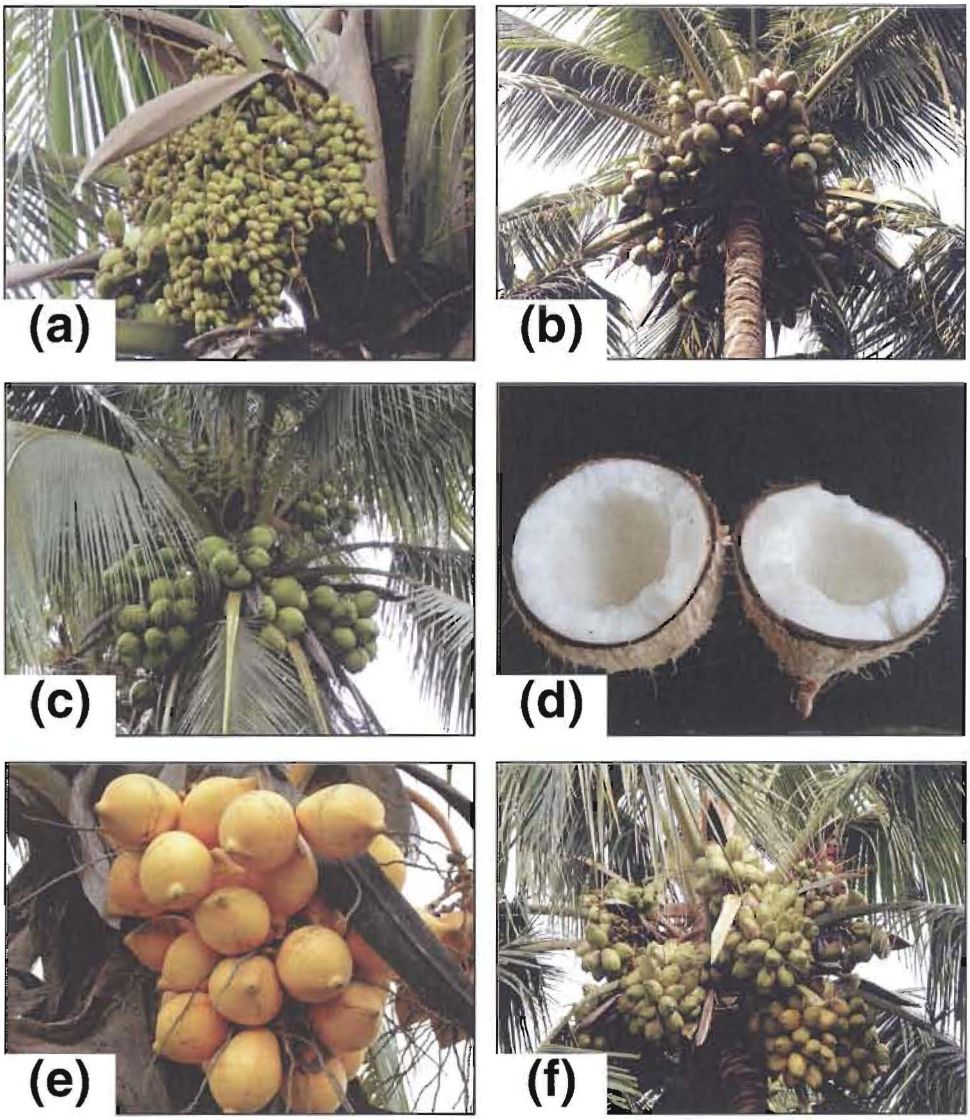

Figure 5.1: Some Trait Specific Accessions, Ayiramkachi Tall (a), Gangabondam Green Dwarf (b), Kulasekaram Green Tall (c), Andaman Thairu Thengai Tall (d), Nikkore Orange Dwarf (e) and Laccadive Micro Tall (f).

3. Breeding Objectives

As majority of coconut is cultivated and used for oil production in major growing areas, the breeding objectives are mainly focused on high fruit yield with more weight of meat/copra out turn which contributes to oil yield. However, breeding for oil quality and for oil rich in a particular fatty acid are yet to be focussed in coconut breeding which will be useful when competing with other edible oils. As the juvenile phase of widely grown tall coconut cultivars are fairly longer, over 5 to 9 years, precocity in flowering and bearing is considered as an important objective. Significant progress has been achieved in precocity by combining early flowering trait of dwarf selections with promising tall cultivars. As the product diversification is in the focus to increase the profitability of coconut cultivation, the tender fruit traits are getting importance. Though the dwarf selections are suitable for tender nut purpose, they are mostly low yielders when compared to hybrids and tall cultivars and also susceptible to adverse conditions. Hence, there is need to focus on incorporating the superior tender fruit traits of dwarf selections along with the dwarfness and early flowering traits into the hybrids involving superior tall selections.

With the advent of global warming and climate change, moisture stress have become frequent in many coconut-growing areas and several plantations have been lost in India in the past two decades, with reduction in fruit production in the surviving palms. Therefore, in the recent past, breeding for moisture stress tolerance has become an important objective. Selection of better-performing cultivars and individual genotypes in drought prone areas has been followed with the objective of selecting parents for further breeding programme or improvement of putative drought tolerant local cultivars through selection.

Emerging and invasive pests owing to climate change and other factors pose a major threat to coconut populations even though refined management practices are regularly developed to tackle major and minor coconut pests. Breeding for tolerance to coconut mite (*Aceria guerreronis*) is a current breeding goal in the coconut breeding program in India. In many coconut growing countries, the occurrence of phytopalsmal and viroid diseases of coconut such as lethal yellowing, foliar decay, cadang cadang, Weligama wilt are reported as threat to the coconut populations necessitating breeding for resistance against those diseases. In India, breeding for disease resistance has been an active objective given the situation that the root (wilt) disease drastically impacted production and productivity in the major coconut area in Kerala state and adjoining places in India.

As all coconut palms grow taller over the years, irrespective of whether they are tall or dwarf or hybrid varieties, skilled manpower is always required for harvesting and taking up other operations. Due to several social factors, the availability of skilled manpower for climbing coconut trees has become an issue in many coconut growing regions. Although mechanisation is being attempted, it is limited due to inherent difficulties. Considering the issues related to availability of skilled coconut climbers, the growers prefer to cultivate short-statured cultivars. Hence, breeding for short-statured palms is to be considered as important to sustain coconut farming.

Considering the fluctuations of prices of coconut commodities, cultivation of coconut as monocrop has become less remunerative in many parts of the coconut growing areas. Hence, coconut cultivation is promoted now as cropping systems with integration of many crops and livestock. As the differential response of coconut cultivars have been reported to management situations, it is important to develop varieties suitable for different management conditions or cropping systems.

4. Breeding Approaches

Coconut breeding is limited to use of the identified trait specific diversity for improvement or combining the targeted traits within the species. Use of traditional breeding methods in coconut is mainly limited due to the long duration taken for evaluation of yield. Although attempts have been made in the past by several researchers, obtaining a pure line from heterozygous coconut has still not been achieved because of the long vegetative phase. Hence, coconut breeding is confined to mass selection of phenotypically superior parental palms identified through a set of traits called mother palm traits, and their use in inter-varietal hybridization. Traditional methods of mother palm selection followed by seedling selection continue to be widely practiced by coconut farmers and breeders. All the ongoing breeding experiments are following a series of selections *i.e.* mother palm selection, seed selection, seedling selection and better performing varietal selection after evaluation.

4.1. Mother Palm Selection

Mother palm selection is the first step followed in any coconut improvement programme. The criteria to be followed for mother palm selection may vary with cultivar, location, nature of the garden and purpose for selection. But, among tall cultivars, palms which are consistently yielding an annual average of 80 fruits or more with a copra yield of over 20 kg/palm/year are considered for selection as mother palms. The mother palms should be having at least 25 years of age so that the average performance is known. Various studies have shown that the average number of female flowers per inflorescence, number of functional leaves exist on the crown of palm, total leaf production up to 3 years after sowing and time taken for flowering after planting are important parameters contributing to yield of fruits. Hence these traits are given priority in selection programme.

Understanding the floral biology in individual palms of the selected cultivar is necessary while choosing the palms for any breeding work. The expression of male and female phases must be considered before making the choice of mother palms for any crossing program as this would help in identifying the typical dwarf or tall palms in the population (Thomas *et al.*, 2015). The coconut inflorescence is a spadix with a branched spike having multiple branches called spikelets. The spikelets bear both male and female flowers wherein the few female flowers are located at the bottom of the spikelets and the male flowers cover the remaining portion of spikelets. The male and female flowers come to maturity at different times. Generally, the male phase is followed by the female phase where the former is the time interval between the opening of the first male flower and shedding of the last male flower in an inflorescence. The female phase is the time interval between the receptivity of the first female flower and the last female flower in an inflorescence. Depending on the cultivar and the location of palms, the male phase lasts from 18 to 25 days from the day of inflorescence opening, during which the anthers dehisce pollen. The female phase which is the receptive stage of stigma usually lasts for shorter period of about 3 to 9 days. In most tall accessions, there is clear time gap between these two phases making cross- pollination the only option for fruit set with few exceptions where inter spadix overlapping occur between successive inflorescences (Figure 5.2) on the other hand, in most dwarf accessions, these phases overlap either within an inflorescence (intra-spadix overlapping) and successive inflorescences (inter-spadix overlapping) or both types of overlapping (Figure 5.3) making the possibility of self pollination more (Nair *et al.*, 2016).

Figure 5.2: Inter Spadix Overlapping of Male and Female Phases in Talls.

Figure 5.3: Intra Spadix Overlapping of Male and Female Phases in Dwarfs.

4.2. Seed and Seedling Selection

The seed nuts are to be selected from the identified mother palms. For the production of good quality seed nuts, the fruit bunches are to be harvested at the stage where at least one nut in the bunch has started drying. The fruit bunches are to be lowered to the ground from tall palms by tying with a rope to avoid damage to the husk. The medium sized seed nuts pertaining to the cultivar are to be selected for sowing. Seed nuts with severe pest and disease infestation are to be avoided. The sowing conditions of different genotypes in an experiment are to be uniform either in poly bags or in nursery beds. The seed nuts which germinate within 6 months after sowing alone are to be retained in the nursery for comparing the seedling parameters to be followed for seedling selection. At 12 months after sowing, the seedlings are to be compared for a set of morphological traits such as early sprouting, faster growth rate, early splitting of the unexpanded leaf into leaflets, seedling vigour in terms of girth at the collar, height and number of leaves and colour of petiole which have been reported as correlated with early flowering and high yield in the adult stage. Although the benchmark for these traits may vary according to varieties, generally a seedling having 6 to 7 leaves with at least one split leaf, collar girth of over 10 to 12 cm and free from pests and diseases are regarded as better seedlings (Figure 5.4). The colour of petiole and height of seedlings are important traits that are to be looked into as per the characteristics of the parental palm selected for breeding work. In any breeding programme, seedling selection takes about 24 months from commencement of pollination. Seedling selection is to be followed among hybrid progenies also, as the selected parental palms if heterozygous are expected to give variable hybrid progenies. Hence it is better if the mother palms are selected on the

Figure 5.4: A Good Selected Coconut Seedling.

basis of progeny testing for seedling characters. Molecular markers may be useful in identifying the true to type progenies as suggested by Rajesh *et al.* (2013).

4.3. Evaluation of Cultivars and Selection

Although the earliest reported selection of coconut was for large round fruits having more of sweet uncontaminated water for the use of seafarers travelling from island to island, fruit yield with more copra out turn has become the priority when coconuts were increasingly exploited for oil purpose during later years of nineteenth and twentieth century. Presently, the selection is followed for many useful traits such as precocity in bearing, dwarfness, stress tolerance or resistance to biotic and abiotic factors and traits associated with product diversification. Considering the need for large quantity of planting material, the heterozygous nature of the species resulting in wide variation, the mass selection of mother palms for desirable characters has been widely employed. The selected material is then either used directly for cultivation or for further exploitation in breeding programmes. The germplasm and the progeny trials using the selected materials in early coconut breeding efforts in different coconut environments have generated useful information for formulating strategies for mother palm and seedling selection.

Evaluation of local cultivars along with exotic cultivars in multi-location trials has been a very successful method in coconut breeding and has resulted in the identification of better performing cultivars for a particular region and development of new varieties. In some countries, selective introductions were made to test against the specific needs such as disease tolerance and the selections from the populations are commercially exploited. In Philippines, selections were made from promising talls as well as dwarfs like Tacunan Dwarf, Catigan Dwarf, Aromatic Dwarf, Malayan Red Dwarf, Rennel Island Tall and Baybay Tall and used for multiplication for establishment of seed gardens (Gerardo and Rivera, 1998). In Indonesia, beginning from 1970, local ecotypes with high copra yield were identified *viz.*, Mapanget, Tenga, Bali, Palu, Sawarna, Riau, Igo Daku and mass selection from high yielding blocks of these tall coconut populations was adopted for production of quality planting material (Novarianto *et al.*, 1998). In Thailand, selection from Maphrao Yai or Thai Tall is the commercial grown cultivar for copra yield and a toddy type was also selected for its high sugar content in the sap (Chulapan and Anupap, 1998). In Vietnam, the cultivars *viz.*, Catigan, Sri Lanka Green Dwarf, Malayan Yellow Dwarf, West African Tall, San Ramon and Hijo Tall are reported to perform better (Vo Van Long, 1998). Selections from Fiji Tall, Rotuman Tall and Rennel Tall are recommended for cultivation in Fiji (Joeli, 1998). Considering the higher level of tolerance to Coconut Foliar Decay disease, the palms are selected from Vanuatu Tall population both for cultivation and for use in hybridization programmes, although it produces smaller sized fruits with mediocre productivity (Gerard, 1998). Hence, the selection is flexible according to the priority. In India, despite the lesser productivity, a selection from Chowghat Green Dwarf (Figure 5.5) is recommended in root (wilt) diseased tracts considering the higher level of disease resistance. In Cote d'Ivoire, West African Tall is the predominantly grown cultivar and the mother palms selected from the population are used for seed production

Figure 5.5: Chowghat Green Dwarf, with Root (Wilt) Disease Resistance.

(Bourdeix *et al.*, 1998). In Tanzania, the East African Tall and Pemba Red Dwarf are the widely grown cultivars (Mkumbo and Kullaya, 1998).

Selection and evaluation of promising coconut accessions conserved both at the Central Plantation Crops Research Institute, India and the coordinating centers under the All India Coordinated Research Project on Palms and State Agricultural Universities have resulted in the development and release of 27 high-yielding varieties of coconut (Figure 5.6–5.9), suitable for India's different agro climatic zones, through application of mass selection (Table 5.4).

4.4. Exploitation of Hybrid Vigour

The striking difference between the tall and dwarf cultivars and the potential of combining the desirable traits of precocity with high yield and sturdiness support the development of hybrids using different talls and dwarfs. The first controlled hybridization was carried out between two dwarf parents Malayan Red Dwarf and

Table 5.4: Indian Coconut Varieties Developed through Selection

Variety	*Important Traits*	*Nut Tield (ha^{-1} year^{-1})*	*Copra Yield (t ha^{-1} year^{-1})*	*Agency Released*
Chandra Kalpa	Drought tolerant, high copra oil content, suitable for neera tapping	17700	3.12	ICAR-CPCRI
Kera Chandra	High yield, dual purpose variety for copra and tender nut; suitable for soap industry	19470	3.86	ICAR-CPCRI
Kalpa Pratibha	High nut, oil yield, dual purpose variety for copra and tender nut	16107	4.12	ICAR-CPCRI
Kalpa Mitra	High nut, oil yield, drought tolerant	13973	3.68	ICAR-CPCRI
Kalpa Dhenu	High nut, oil yield, drought tolerant	14160	3.41	ICAR-CPCRI
Kalpa Haritha	Dual purpose variety for copra and tender nut; less eriophyid mite damage	20886	3.70	ICAR-CPCRI
Kalpa Shatabdi	High yield, suitable for tender nut and copra	18375	5.01	ICAR-CPCRI
Kalpatharu	Drought tolerant, ball copra, high yield, coir fibre amenable for dyeing	20709	3.64	ICAR-CPCRI AICRPP, UHS, Bagalkot, Karnataka
Pratap	High yield	20826	3.60	Dr. BSKKV, Maharashtra
Kamrupa	High yield	17877	2.90	AAU, Assam
ALR (CN) 1	High yield	22302	3.50	TNAU, Tamil Nadu
Kera Bastar	High yield	19470	3.18	ICAR-CPCRI AICRPP, IGAU, Chhatisgarh
Kalyani Coconut 1	High yield	14066	2.17	BCKV, West Bengal
Kera Keralam	High yield, drought tolerant, suitable for neera tapping; soap industry	26019	3.53	ICAR-CPCRI AICRPP, TNAU, Tamil Nadu
VPM-3	High yield, drought tolerant	14868	3.41	TNAU, Tamil Nadu
Kera Sagara	High yield	17523	3.64	KAU, Kerala
Chowghat Orange Dwarf	Tender nut purpose, orange colour fruit, coarse fibre	19824	2.78	ICAR-CPCRI
Kalparaksha	Semi-tall, high nut and oil yield in RWD prevalent areas; tender nut purpose	13260	2.85	ICAR-CPCRI
Gouthami Ganga	Tender nut purpose, green colour fruit	15930	1.54	ANGRAU, Andhra Pradesh
Kalpasree	Early flowering, green colour fruit; superior oil - rich in linoleic acid, recommended for root (wilt) diseased areas	15930	1.80	ICAR-CPCRI
Kalpa Jyothi	Tender nut purpose, yellow colour fruit	20178	2.83	ICAR-CPCRI

Contd...

Table 5.4–*Contd...*

Variety	*Important Traits*	*Nut Tield (ha⁻¹ year⁻¹)*	*Copra Yield (t ha⁻¹ year⁻¹)*	*Agency Released*
Kalpa Surya	Tender nut purpose, orange colour fruit	21771	4.00	ICAR-CPCRI
Kera Madhura	Semi-tall, dual purpose variety for copra and tender nut	21000	4.16	KAU, Kerala
CARI-C1 (Annapurna)	High copra content, tender nut purpose, green colour fruit	9100	2.23	ICAR-CIARI, Andamans
CARI-C2 (Surya)	Ornamental purpose, orange colour fruit	18725	1.31	ICAR-CIARI, Andamans
CARI-C3 (Omkar)	Ornamental purpose, yellow colour fruit	19775	1.45	ICAR-CIARI, Andamans
CARI-C4 (Chandan)	Ornamental purpose, orange colour fruit	17150	1.74	ICAR-CIARI, Andamans

Niu Leka Dwarf in Fiji by Marechal (1928). In India, the first hybridization between tall and dwarf (West Coast Tall x Chowghat Green Dwarf) was attempted in 1930, with the intention of combining the quality of copra from the tall parent and the high productivity as well as early flowering from the dwarf parent. The discovery of hybrid vigour in coconut by Patel (1937), in a cross between West Coast Tall and Chowghat Green Dwarf made in 1932 at the Nileshwar Coconut Research Station,

Figure 5.6: Chandra Kalpa, with Moisture Deficit Stress Tolerance.

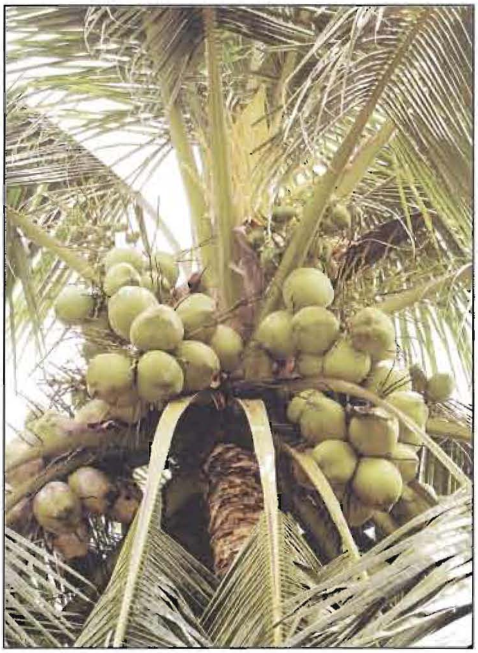

Figure 5.7: Kalpa Pratibha, Dual Purpose Copra and Tender Nut Variety.

Figure 5.8: Kalpa Haritha, with Lesser Eriophyid Mite Damage.

Figure 5.9: Kalpa Surya, a Variety for Tender Nut Purpose.

was a significant landmark in the history of coconut improvement. This important finding led to the many successful coconut breeding programs not only in India but also in the Philippines, Indonesia, Sri Lanka, Ivory Coast, Jamaica and other countries. The varieties selected after evaluation of germplasm have been utilized in the crossing programme to develop hybrid combinations and evaluated for yield and resistance/tolerance to diseases. Most of the hybrid tests that were conducted using different Dwarf x Tall, Tall x Dwarf and Tall x Tall crosses have revealed the superiority of hybrids over local tall cultivars under better management conditions. These inter-varietal hybrids are early-bearing and high-yielding in terms of copra and oil yield per palm. Bourdeix *et al.* (1998) reported significant yield difference between hybrids and the West African Tall and the best hybrids yielded twice than the local WAT at the Marc Delorme Research Station, Cote d'Ivoire. The hybrid PB121 involving MYD and WAT was identified as superior hybrid and sent for demonstration or evaluation or commercial cultivation in many countries besides grown predominantly in Cote d'Ivoire. In Sri Lanka, the multilocation trials have confirmed the superiority of the hybrids Green Dwarf x Tall and Yellow Dwarf x Tall (Jayasekera *et al.*, 1993). Yield advantage of about 30 to 70 per cent for fruit yield, copra yield and oil yield of Dwarf x Tall hybrid Kalpa Samrudhi was reported over the local tall and other tested hybrids from India (Jerard *et al.*, 2015). Besides, the hybrid PB121, the other better performing hybrids PB111 (Cameroon Red Dwarf x WAT) and PB141 (Guinean Green Dwarf x WAT) are also cultivated in Cote d'Ivoire.

In Indonesia, after the initial distribution of PB121 for cultivation, the local Nias Yellow Dwarf (GKN) was used as a female parent in hybridization and the hybrids KHINA-1 (GKN x Tenga Tall or DTA), KHINA-2 (GKN x Bali Tall or DBI) and KHINA-3 (GKN x Palu Tall or DPU) were released for commercial cultivation considering their precocity in flowering in about three years after planting (Novarianto *et al.*, 1998). Based on the evaluation for yield performance, Philippines Coconut Authority (PCA) has recommended hybrids, CAT x LAG (PCA 15-1); Malayan Red Dwarf or MRD x TAG (PCA 15-2); and MRD x BAY (PCA 15-3) for a small-scale replanting programme (Gerardo and Rivera, 1998). In Thailand, apart from PB121 or MAWA called as Sawi Hybrid No 1, two hybrids *viz.*, Chumphon Hybrid 60 (THT x WAT) and Chumphon Hybrid No 2 (MYD x HIT).have been recommended for cultivation (Chulapan and Anupap, 1998). In Vietnam, the hybrids PB121, PB141, JVA1, JVA2, Tam Quan x Hijo Tall, MYD x Ta Tall, MYD x Palu Tall, and MYD x Rennell Tall are produced for exploitation for which pollen of Palu Tall and Rennell Tall were reportedly obtained from Indonesia (Vo Van Long, 1998). The potential of growing hybrid coconuts and the better performance of MAREN hybrid (Malayan Yellow Dwarf x Rennell Tall) have been demonstrated for yield and precocity in Papua New Guinea although is reported susceptible to beetle attacks (Thompson, 1981; Brook 1985). Among the hybrids tested using MRD as female parent, the MRD x FJT was found better for precocoity and higher yield and hence has been promoted for cultivation in Fiji Islands (Joeli, 1998).

The hybrids CAMWA (Cameroon Red Dwarf x West African Tall) and MAWA(Malayan Yellow Dwarf x West African Tall) are known to be grown in Tanzania as reported by Mkumbo and Kullaya (1998). considering their precocity in bearing but subsequently they were discontinued due to reported low yields during drought and susceptibility to Lethal Disease. This highlight the importance of the location specific needs while breeding varieties. In Jamaica, from among the F_1 hybrid combinations between Malayan Dwarf with tall cultivars, Jamaica Tall and Panama Tall, the MAYPAN hybrid (Malayan Dwarf x Panama Tall) was selected and released for commercial planting considering its acceptance by farmers due to larger nut size, greater windstorm tolerance and ability to sustain the production under marginal/low input conditions (Charles 1961; Harries and Romney, 1974).

Strategies to produce superior hybrids also include selection of parents for crossing on the basis of combining ability tests. The experience in Ivory Coast in the production of the MAWA (Malayan Dwarf x West African Tall) hybrid points to the need for employing combining ability tests such as Line x Tester, diallel, for selection of parents for the crossing program for the production of superior D x T and T x T hybrids with more homogenous performance. In Cote d'Ivoire, the Rennell Island Tall (Pacific) and the West African Tall (Cote d'Ivoire and Benin) were identified as possessing good combining ability between themselves as well as with other dwarf and tall ecotypes (Bourdeix *et al.*, 1992). Similarly, in India, the Laccadive Ordinary (LCT) and Gangabondam Dwarf (GBGD) were identified as best general combiners for fruit yield (Nampoothiri *et al.*, 1999) and the hybrid LCT x GBGD was identified with good specific combining ability for copra and nut yield from a trial planted in 9 x 9 diallel mating system. The exotic materials, Malaysian Yellow Dwarf (MYD), Malaysian Red Dwarf (MRD), West African Tall (WAT), Polynesian Tall (PYT) and Rennell Tall (RIT) have been used in combining ability tests with the local germplasm in Indonesia to determine the best parental combination (Novarianto *et al.*, 1998).

Tall x Tall crosses between unrelated lines of tall varieties have been attempted to develop improved varieties with high output of good quality copra and tolerance to biotic and abiotic stresses. Individual trees of high breeding value were identified and these genotypes utilized for production of Tall x Tall hybrids. Although late-bearing, the yield potentials of Tall x Tall hybrids are good. In India, only two Tall x Tall hybrids have been released for commercial cultivation. At CPCRI, the Tall x Tall hybrid combinations are presently under evaluation for their drought-tolerant nature. Two hybrid combinations WCT x SSAT and LCT x CCNT were released for cultivation in Kerala and Tamil Nadu states, respectively for higher copra yield. In the tall x tall hybrids improvement at Cote d'Ivoire, the basic trials consisted of crossing every new accession with two complementary tall testers, the WAT and Rennell Tall. The hybrid WAT x RIT produced cumulative production equivalent to the yield of the hybrid PB121, at the ninth year and later out yielded the PB121 (Bourdeix *et al.*, 1998). Hence it was opined that Dwarf x Tall may be profitable in the initial years but improved Tall x Tall hybrids can be considered for long term income generation (IDEFOR/DPO, 1992). However, the improved Tall x Tall (CRIC 60) material was not found superior for yield over the Local Ordinary Talls (plus palm tall) across the different agroecologies in Sri Lanka (Peries, 1998). Four Tall x Tall hybrids namely: KB-1, KB-2, KB-3 and KB-4 (Balitka, 1989) were released for cultivation in Indonesia.

Although the first crossing work in coconut was reported from Dwarf x Dwarf coconut hybrid, they are still the least exploited type of hybrids. Bourdeix *et al.* (1998). opined that the more the dwarf genotype increases in a hybrid, the more precocious it is and it may be suitable for higher planting density with the the resulting reduced bulkiness. In Cote d'Ivoire, The hybrid between the Malayan Yellow and Red Dwarfs yielded 3.8 t of copra per hectare during the adult phase, at a planting density of 170 palms/ha (Le Saint *et al.*, 1987), whereas in same trial, Malayan Yellow Dwarf which was the control produced one ton of copra less than the hybrid, the yield of which is comparable to the dwarf x tall materials (IRHO-CIRAD, 1989). It was suggested (Bourdeix *et al.*, 1991) that Dwarf x Dwarf hybrids should be created for cumulating desirable genes of precocity and higher rate of bunch production. In India, 21 Dwarf x Dwarf hybrid combinations were developed and planted during 2003 for identification of superior heterotic hybrids for tender nut yield and quality (CPCRI, 2004). The evaluation revealed the dwarf x dwarf hybrids as early flowering, with positive heterosis for growth, and yield traits (CPCRI, 2014). Earliest flowering in 15 months after planting and regular bunch production was observed in the cross MYD x CGD (Figure 5.10). Besides, some dwarf x dwarf combinations such as MYD x NLGD (Niu Leka Green Dwarf) produced a compact crown, long bunches with a high number of medium-sized fruits having higher kernel and tender nut water and sturdy stems with slow vertical growth (Figure 5.11); and COD x GBGD

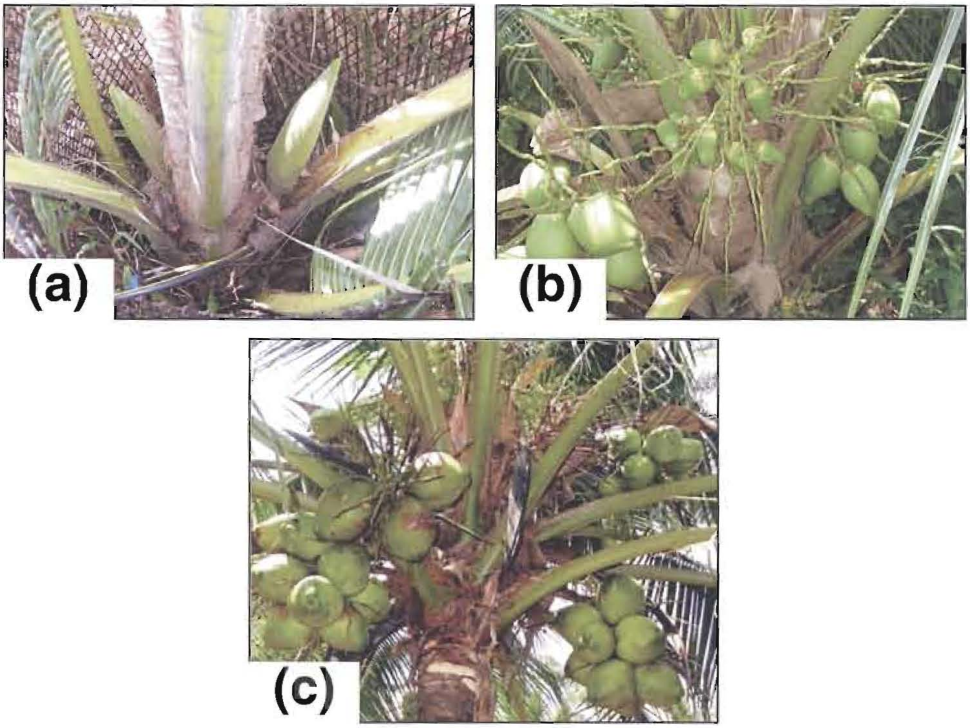

Figure 5.10: Dwarf x Dwarf Hybrid MYD x CGD Early Flowering (a, b) and Bunch Production (c).

with early flowering and high yield in terms of number of fruits; these examples highlight the potential of D x D hybrids for future exploitation.

After the initial successful attempt in development of high yielding hybrids, numerous hybrids have been produced by crossing different selected dwarf and tall cultivars originating from various geographical regions and evaluated. The crosses COD x WCT, WCT x COD, COD x LCT, COD x WAT, MYD x WCT, MYD x TPT, MYD x EAT 32, ECT x MGD, ECT x MOD, ECT x MYD, GBGD x ECT, CGD x WCT, LCT x GBGD, LCT x COD, GBGD x PHOT, GBGD x LCT are some of the most promising present day coconut hybrids in India identified for specific traits in addition to fruit and copra yield. Besides, the locally produced hybrids in Lakshadweep, such as namely Laccadive Yellow Dwarf x LCT and Laccadive Green Dwarf x LCT were found to be better for yield of fruits and copra out turn. More than 130 cross combinations involving different tall and dwarf accessions were evaluated at ICAR-CPCRI and other co-ordinating centers in different agro-climatic zones and a total of 20 superior hybrids (Figures 5.12–5.16), including 8 Dwarf x Tall hybrids and 10 Tall x Dwarf hybrids and two Tall x Tall hybrids have been released for commercial cultivation in different regions across the country (Table 5.5).

Among these combinations, high yielding Dwarf x Tall hybrid combinations have distinct advantage over Tall x Dwarf and Tall x Tall hybrids for ease of large

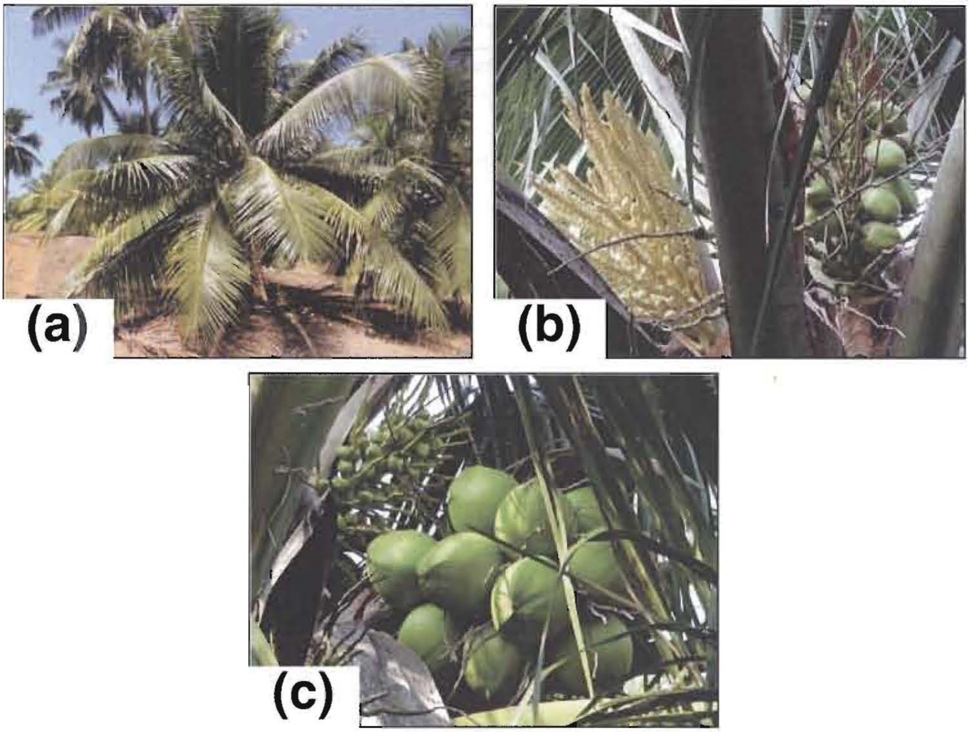

Figure 5.11: MYD x NLGD, a Promising D x D Hybrid: 13 Year Old Palm (a), Inflorescence (b) and Bunch (c).

scale hybrid seed nut production by regularly emasculating dwarf mother palms, permitting free natural crossing with the pollen of tall palms growing nearby. Three way and four way complex coconut hybrids are also reported as developed and tested in some places like India during 1960s and Cote d'Ivoire during 1970s, to evaluate the genetic variability of hybrid progenies and to select outstanding individuals for possible multiplication through somatic embryo culture technique when it is available. But these attempts are mostly discontinued probably due to the inherent difficulties in evaluation of the large number of individual combinations and the segregation for number of traits making the selection difficult.

5. Status and Achievements of Breeding for Specific Traits

5.1. Drought Tolerance

Although coconut is known to grow on its own in islands and coastal areas, adequate irrigation or well-distributed rainfall to ensure soil moisture is essential to realize potential high productivity or sustenance of palms in many plantations. The palms that are periodically exposed to inadequate rainfall or prolonged dry periods resulting in poor yield and continuous dry periods may lead to complete drying of palms (Figure 5.17). The adverse effects of drought on coconut can persist

Figure 5.12: Chandra Sankara – The Most Popular D x T Hybrid in India.

Figure 5.13. Chandra Laksha – Moisture Deficit Stress Tolerant T x D Hybrid.

Figure 5.14: Kalpa Samrudhi – A Dual Purpose Hybrid for Copra and Tender Nut.

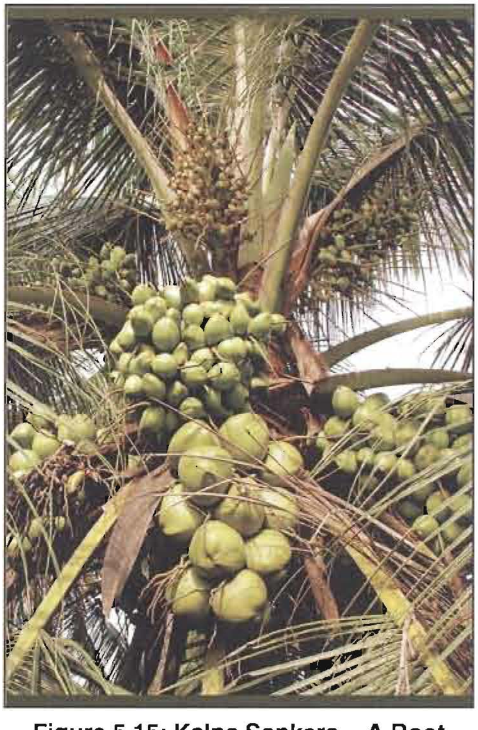

Figure 5.15: Kalpa Sankara – A Root (Wilt) Disease Tolerant Hybrid.

Table 5.5: Released Coconut Hybrids from India

Hybrid Variety	Source Population of Parents	Important Traits	Nut Yield@ (ha^{-1} $year^{-1}$)	Copra Yield@ ($t\ ha^{-1}$ $year^{-1}$)	Agency responsible for Release
Chandra Sankara	COD x WCT	High yield	20532	4.27	CPCRI
Kera Sankara	WCT x COD	High yield, drought tolerant	19116	3.78	CPCRI
Chandra Laksha	LCT x COD	High yield, drought tolerant	19293	3.76	CPCRI
Kalpa Samrudhi	MYD x WCT	Dual purpose variety, Drought tolerant, higher nutrient use efficiency	20744	4.35	CPCRI
Kalpa Sankara	CGD x WCT	Tolerant to root (wilt) disease, high yield	14868	3.20	CPCRI
Kalpa Sreshta	MYD x TPT	Dual purpose variety, High yield	29227	6.28	CPCRI
Laksha Ganga	LCT x GBGD	High yield	19116	3.73	KAU
Ananda Ganga	ADOT x GBGD	High yield	16815	3.63	KAU
Kera Ganga	WCT x GBGD	High yield	17700	3.56	KAU
Kera Sree	WCT x MYD	High yield	23364	5.05	KAU
Kera Sowbhagya	WCT x SSAT	High yield	23010	4.49	KAU
VHC-1	ECT x MGD	High yield	21240	2.87	TNAU
VHC-2	ECT x MYD	High yield	25134	3.74	TNAU
VHC-3	ECT x MOD	High yield	27612	4.47	TNAU
Godavari Ganga	ECT x GBGD	High yield	18585	2.79	ANGRAU, A. Pradesh
Konkan Bhatye Coconut Hybrid 1	GBGD x ECT	High yield	20532	3.47	Dr. BSKKV, Maharashtra
Kalpa Ganga	GBGD x FJT	High yield, suitable for ball copra production	21417	3.38	UHS, Bagalkot, Karnataka
Vasista Ganga Andhra Pradesh	GBGD x PHOT	High yield	22125	3.88	Dr.YSRHU,
Ananta Ganga Andhra Pradesh	GBGD x LCT	High yield	22656	3.84	Dr.YSRHU,
VHC 4	LCT x CCNT	High yield under rainfed conditions	19000	3.5	TNAU

even for the subsequent 2-3 years drastically affecting the health of the palms. It is increasingly reported that many coconut growing areas experience erratic rainfall pattern, prolonged drought, extreme weather conditions and higher temperature due to the effect of climate change affecting the coconut yields. In severe cases, most of the palms die and the surviving palms take a long time to recover from the shock provided not exposed by stress again. Under these circumstances,

Figure 5.16: Kalpa Sreshta – A Hybrid for Tender Nuts, Copra and Ball Copra Production.

developing drought tolerant varieties/hybrids is of great importance to increase coconut production in affected areas. Drought tolerance in coconut has been attributed to many phenotypic traits such as high root mass and fine root density

Figure 5.17: A Severely Drought Affected Coconut Garden.

(Cintra *et al.*, 1993), physiological traits such as leaf stomatal frequency, stomatal index, chlorophyll fluorescence, epicuticular wax content, activities of lipases and proteases (Rajagopal *et al.*, 1988; Repellin *et al.*, 1994). Based on screening for selected morphological and physiological traits, drought-tolerant cultivars have been identified at CPCRI, namely, WCT x WCT, LCT x COD, Federated Malay States, Java, Fiji, Laccadive Ordinary and Andaman Giant. These cultivars are currently utilized in the breeding programme along with other selected tall types. The high yielding hybrid combinations, Laccadive Ordinary Tall x Chowghat Orange Dwarf and Malayan Yellow Dwarf x West Coast Tall have been found to be drought tolerant (Rajagopal *et al.*, 2005; Kasturi Bai *et al.*, 2006) and later released as improved varieties. Screening conserved coconut germplasm and its evaluation in drought-prone areas for their performance and adaptability may take a very long time. Hence, the possibility of utilizing the available plantations in drought prone areas for identification of putative drought tolerant palms based on the phenotype and the physiological parameters has been attempted (Naresh *et al.*, 2006). Utilization of such *in situ* drought tolerant palms from drought affected areas in the breeding programme is expected to reduce the time duration required for breeding varieties. Preliminary observations revealed that the seedlings of the putative drought tolerant palms identified *in situ* from East Coast Tall population of Tamil Nadu are more vigourous and uniform for seedling traits, highlighting the potential of natural selection (Jerard *et al.*, 2013). The identified *in situ* palms are used to develop hybrids with selected dwarfs and are being evaluated along with identified tall progenies. The putative drought material exhibited better growth and establishment in the drought prone area amidst the affected palms (Figure 5.18). Since, the tall cultivars are known to be hardier than the dwarf cultivars, the selected talls are crossed to produce Tall x Tall hybrids and also Dwarf x Tall combinations for further evaluation. Preliminary results indicated significant differences among Tall x Tall hybrids for the fruit yield under moisture stress conditions and the hybrid WCT x

Figure 5.18: *In situ* Evaluation for in Drought Prone Area.

FJT appears to be better over other hybrids (CPCRI, 2015). As it is expected that the requirement for moisture deficit stress tolerant coconut materials would increase in the years to come, there is an urgent need for identification and purification of more coconut cultivars or genotypes for use in evaluation for drought tolerance combining other desirable traits such as dwarfness and precocity in bearing.

5.2. Cold Tolerance

Primarily, coconut, being a crop of tropical regions requiring good rainfall and warm weather for better yield performance with fruit set, the palms are known to be highly susceptible to low temperatures. The low temperature affects the leaf production and thereby inflorescence production. The fruit set is also affected and the unopened male and female flowers appear dried and shed prematurely (Figure 5.19). The flowering and fruit set is affected below 13°C. Mao (1986), while investigating the meteorological indices for coconut cultivation in China, enumerated that the spear leaf damage, drying of leaves and uneven or wrinkled kernel inside the nuts are symptoms due to cold injury. Although no breeding efforts have been extensively carried out, few accessions of Hainan Tall of China and Kamrup Tall of India are reported to possess cold tolerance (Mao and Lai, 1993; Chowdhury *et al.*, 2001). Besides, the coconut populations established in elevated places such as Nilgris and Coorg hilly areas of India offer scope for identifying cold tolerant

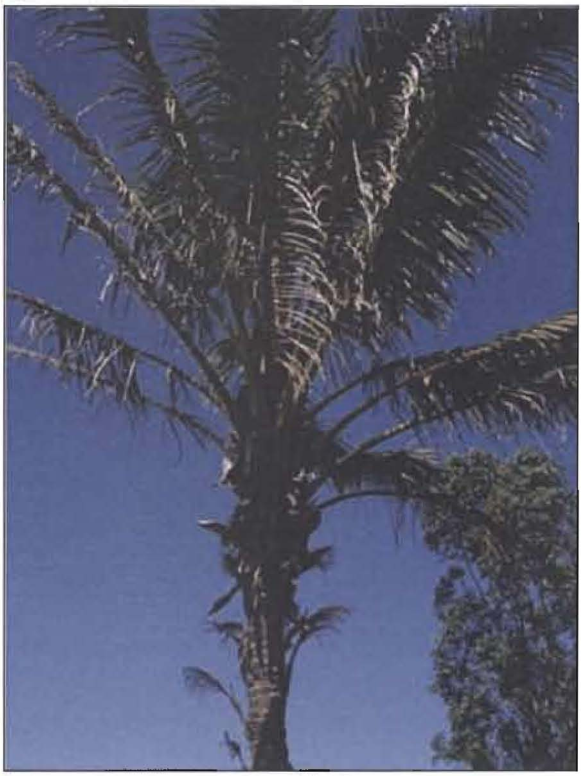

Figure 5.19: A Palm Affected by Cold Injury.

genotypes. CPCRI has identified such putative cold tolerant coconut accessions from Sub-Himalayan terai region of West Bengal (CPCRI, 2009), Karnataka (CPCRI 2009), Assam and Meghalaya (CPCRI, 2010) and Bihar (CPCRI, 2011) for conservation as well as utilization in the breeding programme. The coconut area expansion in colder plains of northern part of India necessitates identification and development of cold tolerant lines in the near future.

5.3. Disease Resistance

Coconuts are infected by a number of diseases in different growing regions including fungal and phytoplasmal diseases. Each coconut region has different priorities with regards to tackling diseases considering the potential damages. Globally, the lethal yellowing disease caused by phytoplasma is considered as the devastating one in many countries. Besides, the root (wilt) of India, Weligama leaf wilt of Sri Lanka, Foliar Decay Disease of Pacific region, Cadang cadang disease Philippines, bud rot, stem bleeding, basal stem rot of many regions are the major diseases assumed significance. In India, the important diseases of coconut are bud rot caused by *Phytophthora palmivora;* leaf rot caused by *Colletotrichum gloeosporoides, Exserohilum rostratum* and *Fusarium solani;* stem bleeding caused by *Thielaviopsis paradoxa;* basal stem rot or Thanjavur wilt caused by *Ganoderma lucidum* and *G. applanatum*. Coconut palms are also affected by root (wilt) disease caused by phytoplasma.

5.3.1. Root (Wilt) Disease

The coconut root (wilt) disease, the major disease causing huge production loss in major coconut areas in Kerala state of India, is a non-lethal, debilitating malady, caused by Phytoplasma that reduces the production potential of the palm. The symptoms of the disease are characteristic bending of the leaflets termed "flaccidity", along with foliar yellowing and marginal necrosis of leaflets followed by a progressive decline in yield. Investigations carried out at CPCRI, Regional Station, Kayamkulam on the etiology of the disease, suggested the association of phytoplasma (Solomon *et al.*, 1983). Considering the phytoplasmal etiology of the disease, development of resistant varieties is considered to be the practical solution for the management of the disease. Screening of available coconut germplasm by planting seedlings in a disease affected farm at CPCRI Regional Station, Kayamkulam was initiated in 1961. Radha (1961) reported a higher degree of resistance to both leaf rot and root (wilt) in Andaman Ordinary Tall and New Guinea Tall based on disease incidence in the field. Large-scale screening trials undertaken during 1972 at CPCRI, Kayamkulam and also in farmers' gardens revealed that all the evaluated cultivars and hybrids have contracted the disease. A comprehensive breeding program for evolving resistant/tolerant coconut varieties was implemented at CPCRI in 1988 (Nair *et al.*, 2010). The high-yielding, disease-free palms existing amidst heavily diseased palms in disease hotspots were used as the base material. Systematic evaluation trials have led to the release of three coconut varieties with resistance/tolerance to root (wilt) disease. Observations in farmers' gardens and in a screening trial involving ten varieties revealed that Chowghat Green Dwarf had the highest level of resistance (Nair *et al.*, 2004). Considering the high yield and low incidence of root (wilt) disease, the selection made from CGD was released under the name Kalpasree for cultivation in homesteads of the root (wilt) prevalent areas. Subsequently, studies carried out from a seed production plot at the Coconut Development Board Farm at Neriamangalam, planted with five dwarf varieties of coconut, namely, Malayan Green Dwarf, Malayan Yellow Dwarf, Malayan Orange Dwarf, Chowghat Green Dwarf and Chowghat Orange Dwarf in 2004 resulted in identification of another promising variety, Malayan Green Dwarf as resistant to root (wilt) disease (Nair *et al.*, 2007). The popular cultivated variety West Coast Tall (WCT) which was used as control showed 84 per cent disease incidence whereas, CGD showed maximum resistance with disease incidence of 19.9 per cent followed by MGD with 22.4 per cent. Observations on CGD x WCT progenies, planted during 1991 indicated that 70 per cent of the hybrids became infected with the disease within 18 years of planting. Even though a majority of CGD x WCT hybrids were diseased, they gave a 10 year cumulative average yield of 84 nuts/palm/year indicating that this hybrid is tolerant to root (wilt) disease (Nair *et al.*, 2006). Considering the performance of CGD x WCT in the root (wilt) disease prevalent area it was released for cultivation under the name Kalpa Sankara.

Anatomical studies in dwarf varieties revealed that lower cuticle thickness was more in MGD (10.27 µm) compared to other varieties. Younger leaves of CGD had higher values for leaf thickness (1077.65 µm), parenchyma (between the vascular bundle and epidermis) width (47.29 µm), and larger distance between the stomata to phloem tissues (88.25 µm). These morphological/structural features may be some of the factors contributing for the higher level of resistance reported in CGD and MGD (CPCRI, 2009).

5.3.2. Bud Rot Disease

The susceptibility to bud rot and nut fall caused by *Phytophthora palmivora* (Bennett *et al.*, 1985) was a major factor limiting coconut production in Indonesia and Novarianto *et al.* (1998) reported the hybrid MYD x PYT as most resistant, cultivars PYT, RLT, DJP and DBI as more resistant and the hybrid PB 121 and WAT as more susceptible to bud rot of coconut.

Generally the dwarf palms with erect leaves such as Chowghat Orange Dwarf palms are susceptible to bud rot disease as the rupturing or bending or breakage of the spindle during moderate to heavy winds facilitates the entry of pathogen to the bud. Besides, the spindles damaged by rhinoceros beetles are also prone to bud rot infection.

5.3.3. Coconut Foliar Decay Disease

The Coconut Foliar Decay disease (CFD) is reported to be prevalent in Pacific Ocean Islands such as Vanuatu. The tolerance was observed among the local talls and almost all the introduced ecotypes were susceptible except Rennell Tall which was the least susceptible exotic cultivar and its hybrid with Vanuatu Tall (VTT) was almost free of CFD (Gerard, 1998). Hence, the strategy for planting material production for Vanuatu is focussed on exploitation of CFD tolerance among the local ecotypes.

5.3.4. Lethal Disease

Lethal Disease characterized by yellowing of foliage, rapid decline of yield and death of palms has been known to cause severe economic losses to growers in many countries. Most evaluated cultivars have been found to be susceptible in many affected regions. Malayan Yellow Dwarf was reported to show high resistance to the disease (Been, 1992). Globally, breeding programme against lethal yellowing has used the Malayan Dwarfs as source of resistance to produce hybrids involving the local talls. However, there are reports that after being free from the disease in the initial years, they take up the disease at later stage. Cape St. Paul Wilt Disease (CSPWD), similar to lethal disease, poses threat to all coconut cultivars in Ghana (Joseph and Sylvester, 1998). Similar diseases are reported to occur in the Caribbean, Florida, South America, Togo, Nigeria and Cameroon (Romney, 1972). Presence of LD caused by phytoplasma has been recorded in Tanzania, Kenya and Mozambique as reported by Mkumbo and Kullaya (1998).

The hybrid, Malayan Yellow Dwarf x Panama Tall was reported as resistant to the Caribbean strain of Lethal Yellows, but was found to be susceptible to the disease in East Africa, indicating the possibility of different strains of Lethal Yellowing phytoplasma. Subsequently, the East and West African strain of Lethal Yellowing phytoplasma were proven to be different (Tymon *et al.*, 1993). The Malayan Yellow Dwarf x Panama Tall hybrid was known to exhibit high tolerance to LY disease in Jamaica. The cultivars Vanuatu tall and Sri Lankan Green Dwarf were observed to be fairly tolerant, in Ghana indicating that resistant coconut cultivars could be present in the Asian countries as reported by Joseph and Sylvester (1998).

The breeding programme in Mexico suggested by Carrillo (1993). was based on the selection of Malayan dwarf mother palms, identification of domestic Pacific tall ecotypes to develop F_1 hybrids with improved tolerance to the LY disease as reported by Jose (1998). Harries (1990) suggested the possibility of domestic populations from the Pacific coast to be an important source of resistance to LYD from the reports from different countries, it was evident that the possible resistant/ tolerant sources to LYD are very narrow, limited to Malayan dwarfs and its hybrid with Panama tall. Newer introductions of green dwarfs from Asian region could be used in future breeding efforts.

5.3.5. Other Diseases

Apart from this breeding initiative against root (wilt) disease in India, there have only been reports on identification of disease resistant or tolerant types or susceptible types against stem bleeding, bud rot and leaf spot diseases. Cochin China Tall, GBGD, Laccadive Ordinary Tall were selected as having lesser incidence of stem bleeding disease in varietal evaluation trials. Besides, a destructive coconut cadang-cadang disease caused by the Cadang-CadangViroid (CCVd) has been reported to be responsible for the death of large number of palms in Bicol region of Philippines and till date there has been no resistance sources reported.

5.4. Pest Resistance

There are many pests infesting coconut in different parts. The pests such as rhinoceros beetles or black beetles and red palm weevils are the major ones causing economic losses in almost most coconut areas. The coconut eriophyid mite prevalent in many countries has caused devastation in India when it emerged during 1998 and caused major economic losses in most cultivation areas. The breeding programme against this pest depends on the response of coconut cultivars to the infestation. Variability for eriophyid mite tolerance in coconut was reported and the traits such as fruit color, fruit shape and tepal aestivation in the flowers are reported to have association with the lower incidence of the pest. The regular arrangement of inner tepals favors less incidence of mite when compared to the irregular arranged inner tepals as the gap becomes very less under the former case (Figure 5.20) but the arrangement varies within the palm from flower to flower. Hence, a conclusive test to determine resistance is still elusive. Round and dark green fruits show better tolerance against the eriophyid mite than the elongated fruits and of other colors, as reported by Moore and Alexander (1987). The entry of mites depends on the tightness of tepals to the fruits at the early stages of fruit development. When the gap between the young developing fruit and tepal is smaller, then there was lesser incidence of mite damage. Greater tightness is achieved in round rather than elongated and angled fruits. In India, Kulasekharam Green Tall, a selection from a Kulasekharam coconut population which is a derivative of Malayan Green Dwarfs, was found to suffer less mite infestation (Niral *et al.*, 2014b) and a selection was released as a variety called Kalpa Haritha with lesser mite incidence when compared to West Coast Tall, the local cultivar. The accessions with angled and longer fruits such as Laccadive Micro were observed to show higher mite infestation levels. Among the dwarf cultivars, Chowghat Orange Dwarf (Nair, 2000) and Kenthali (Ramaraju *et al.*, 2000) were identified with less mite damage and the *spicata* mutant has shown a fair level of resistance to the mite. Tepal aestivation in female flowers, shape of the developing fruits, growth rate and pattern of fruit enlargement are some of the traits identified as contributing to a lesser mite incidence in coconut.

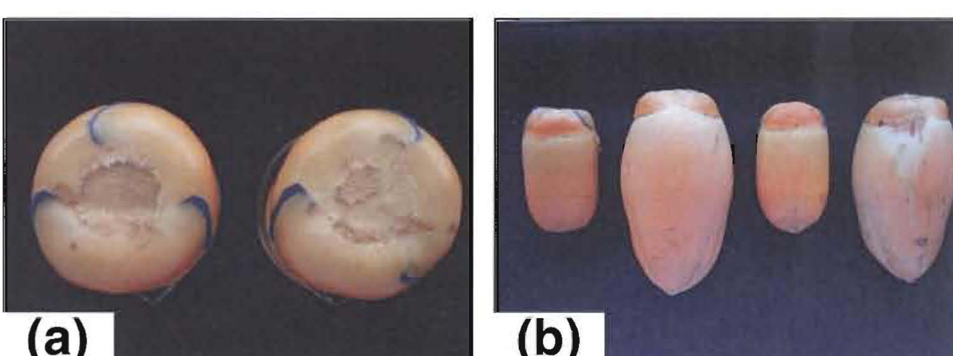

Figure 5.20: Regular and Irregular Arrangement of Inner Tepals (a) with Levels of Mite Infestation (b).

Although all the coconut cultivars are prone to damage by rhinoceros beetles, the hybrids resultant from Chowghat Orange Dwarf as pollen parent was reported to be more susceptible (Nambiar, 1988). Similarly, lesser incidence of rhinoceros beetle damage is observed in San Ramon tall in India. Sosamma *et al.* (1988). identified Java Tall, Klapawangi Tall, Kenthali Orange Dwarf and Andaman Giant Tall as more tolerant to damage by burrowing nematodes.

5.5. Novel Traits

The profitability of coconut plantations are decreasing while the major focus is on the copra and oil production due to unstable prices and difficulties experienced while competing with other oil yielding crops. Hence coconut is now increasingly promoted as a food crop with varied uses. The spontaneous mutations with desirable traits have been reported in coconut which has potential to be used in breeding programs (Arunachalam *et al.*, 2001) for improving profitability, increasing consumer preference, promote product diversification and reduce drudgery of coconut climbing. A spontaneous mutant *spicata* with many flowers on unbranched inflorescence (Arunachalam *et al.*, 2014), the Thairu Thengai mutant with soft endosperm (Jerard *et al.*, 2013a), the Kaithathali with edible husk at tender stage (Satyabalan, 1997), sweet kernel coconut (Samsudeen *et al.*, 2006) and flavoured tender and matured coconut (CPCRI, 2009), pink husked coconuts (Jerard and Niral, 2016), coconut palms with compact crown (Bourdeix, 1998), occurrence of haploid seedlings and bulbil producing palms (Jerard *et al.*, 2014) are some of the novel traits which have immense potential in coconut improvement.

5.5.1. Soft Endosperm

Soft endosperm types have been reported from almost all the major coconut growing countries (Arunachalam and Rajesh, 2008) and named differently such as *Makapuno* (Philippines), *Dikiri Pol* (Sri Lanka), *Kelapa Kopyor* (Indonesia), *Maphrao Kathy* (Thailand), *Coco Gra* (Seychelles), *Niu Garuk* (Papua New Guinea), *Pia* (Polynesia), *Dong Kathy* (Cambodia) and *Dua Sap* (Vietnam). Makapuno coconut originally reported from the Philippines is a single recessive mutation, having soft endosperm filling the cavity of fruits. This mutant has been successfully exploited through controlled pollination among makapuno bearing palms followed by culture of makapuno embryos *in vitro*. As the soft kernels provide newer opportunities for product diversification, conservation and development of pure populations of such selected types would be desirable. In Indonesia, Kopyor dwarf coconut having higher percentage of kopyor fruits per bunch (15-20) as compared to the tall kopyor types (5-10) has been reported and evaluation of Kopyor Green Dwarf, Kopyor Brown Dwarf, and Kopyor Yellow Dwarf coconut seedlings obtained from zygotic embryos through embryo culture techniques is in progress (Maskromo *et al.*, 2013). In India, soft endosperm nuts, Thairu Thengai (Figure 5.21) have been reported from Andaman and Nicobar Islands and *in situ* conservation and participatory breeding efforts have been suggested (Jerard *et al.*, 2013a) for identification, characterization and utilization of such types among indigenous populations.

Figure 5.21: Soft Endosperm Coconut.

5.5.2. Sweet Kernel and Sweet Edible Husked Types

The sweet kernel coconut (Mohacho Narel) is another important mutant form reported in India (Samsudeen *et al.*, 2013) which has a sweet endosperm with very little or no fibers, making the kernel suitable as a salad for table purpose. Development of a large population bearing sweet kernel fruits is a challenging task as the inheritance and genetics need further evaluation and progeny testing. Similar sweet kernel type named as *Ngot* (sweet) has been reported from Vietnam (Vo Van Long, 1998). An open pollinated population raised at CPCRI from Mohacho Narel palms of Maharashtra, India indicated the inheritance of the trait in few first flowered palms. Further efforts are needed to produce a pure population through *in situ* conservation and participatory approaches.

The sweet husked type called as Kaithathali coconut has been reported from Lakshadweep Islands. Though few palms are known to occur in different coconut populations, the sweet husked type is still unexploited. In these palms, the husks of very tender fruits are sweeter than the normal ones. Upon maturity, the husk becomes pale in colour and seen loosely attached with the shell making the nuts easily separable from the husk. Similar loose husked types are seen and collected from Nicobar Islands also during 2016, but the tender husks of these have not been tested for their sweetness. The occurrence, inheritance and the feasibility of possible utilization are the future needs to exploit this trait.

5.5.3. Compact Dwarf Crown

As the coconut palms increasingly pose challenges over the years in climbing for harvesting and other operations on the crown, dwarf statured palms combined with other traits of talls are required. In the natural diversity, the Niu Leka dwarf of Fiji, conserved at CPCRI has been reported to possess the traits of tall coconuts for fruit components coupled with a very short stem and compact crown. A selection

Figure 5.22: Niu Leka Dwarf – A Compact Dwarf.

made from Niu leka Dwarf (Figure 5.22) has been registered for its unique trait of dwarfness coupled with high copra content (Jerard *et al.*, 2014b). Palms similar to the Niu Leka Dwarf but for varied nut colour and bigger bole has been reported as compact dwarfs at Fiji (Vijayan, 2016, personal communication). Utilization of these kind of compact dwarfs will be an important area in future coconut breeding, development of which may not only provide ease of climbing the palm for many years but also help in accommodating more palms per unit area which will eventually increase the productivity. Besides, recent observations in Fiji have indicated the compact dwarfs as less affected by cyclonic storm when compared to commonly present Fiji tall (Unpublished) reported tolerance/resistance of Niu Leka Dwarf to Lethal disease (Merrow *et al.*, 2003) also signify the need to exploit these dwarfs. A different but extremely dwarf mutant with very compact crown having shorter leaves and narrower leaflets was also identified in India (CPCRI, 2010) from Lakshadweep coconut populations and conserved for further exploitation. Use of such compact dwarf palms and their progenies in coconut improvement would help in manipulating the plant type, eventually resulting in coconut varieties suitable for high-density planting.

5.5.4. Spicata

The *spicata* are still under-exploited types although they have been collected long ago and conserved in different coconut populations. The spicata palms exhibit unique and distinct floral characters - they produce a large number of female flowers on the unbranched spadix, with a conspicuous reduction in the number of male flowers one of the characteristic features of the unbranched type of spicata is that female flowers are attached throughout the main rachis of the inflorescence, resulting in closely set fruits compared to normal inflorescence. The spicata palms are known to occur in most of the coconut growing countries (Sugimura *et al.*, 1994). While studying the East Coast Tall Spicata, Arunachalam *et al.* (2014) reported that these types have high female flower production, short leaflets, elongated fruit shape, lesser duration of male phase, low percentage of fruit set and tolerance to eriophyid mite infestation. The spicata palms are also reported to have low sap yield and possess thin but tight husk. Observations among the progenies of spicata tall progenies revealed wide variability for the palm stature and fruit characteristics and a yellow dwarf spicata (Figure 5.23) was selected with high yield and attractive bunches from the open pollinated progenies for further exploitation (CPCRI, 2014). The spicata trait could be very useful in studying the inheritance pattern in coconut to reveal genetic information contributing to greater femaleness.

Figure 5.23: Yellow Dwarf Spicata.

5.5.5. Aromatic Coconuts

The aromatic or scented coconuts are recently becoming popular in tender nut markets especially after its exploitation by Thailand. The aroma in coconut is released when a tender coconut is cut open. The aroma can be felt when one drinks the water and the sweet flavour provides increased palatability in consumption. The aroma is somewhat similar to basmati rice in a milder way. In Thailand, it is called Nam Hom (Aromatic Green Dwarf, Figure 5.24) and in Vietnam it is called Dua (aromatic). Similar aromatic types were collected and conserved by CPCRI from a coconut enthusiast and farmer's garden in Andhra Pradesh (CPCRI, 2012). The palms are now under flowering at ICAR-CPCRI (Figure 5.25). Among the conserved accessions, Klapawangi Tall was identified to have the aroma trait and more or less similar types have been observed in Lakshadweep tall coconut populations from Minicoy also (Unpublished). Though, a large population of these types with the desirable traits is still elusive due to high heterozygosity that hinders production of true-to-type progenies, pollen of the available palms were used to produce crosses with seven dwarf cultivars and the hybrids and have been planted for evaluation (CPCRI, 2015).

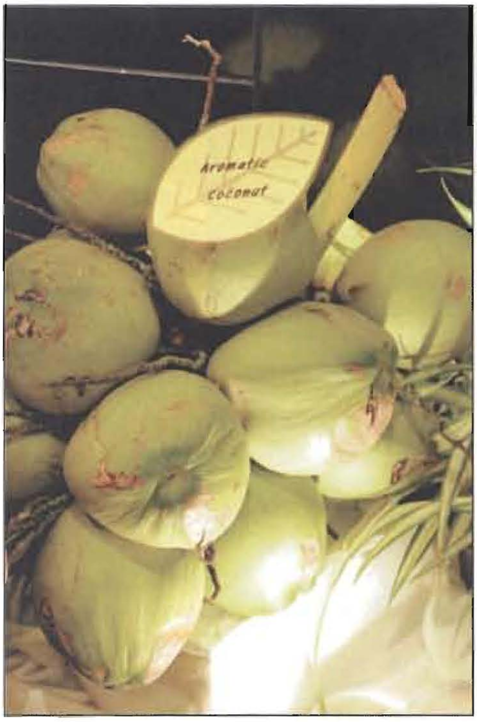

Figure 5.24: Aromatic Green Dwarf Fruits from Thailand.

Figure 5.25: Aromatic Coconut Palm in Flowering at ICAR-CPCRI.

5.5.6. Bulbil Producing Palms

Bulbil production, has been reported as a rare phenomenon in coconut in which vegetative shoots are produced in place of an inflorescence, creating possibilities of getting clonal propagules (Thomas 1961; Mohandas *et al.*, 1976; Sudasrip *et al.*, 1978). The genetic uniformity of the mother palms and their bulbil progenies was confirmed in a palm identified at CPCRI through microsatellite analysis using 10 polymorphic SSR primer pairs specific to coconut. The primary and secondary bulbil shoots were found to be capable of growing into independent plants (Figure 5.26) making it possible to use them as propagules to develop a homogeneous clonal population hitherto unavailable in coconut. These homogenous populations will have potential use in developing mapping populations and identification of markers for breeding, hitherto difficult with available heterogeneous populations (Jerard *et al.*, 2014a). Elucidating the factors of bulbil production and their artificial inducement would be helpful in streamlining the precision breeding approaches in coconut. Detailed studies on the transcriptional changes and genes controlling the morphological changes occurring during bulbil formation in coconut need to be taken up.

Figure 5.26: Rooted Bulbil Plants.

5.5.7. Haploidy

The occurrence of natural haploid seedlings among coconut seedlings in coconut have been reported by Whitehead and Chapman (1962), and presents an important opportunity for breeders to develop dihaploids, which could be useful in developing breeding lines for use in production of heterotic hybrids with high degree of homogeneity than the normal diploids. With the advent of recent advancements in molecular biology and DNA assessment techniques in coconut, there is ample scope for screening large coconut nurseries for identification of natural haploids in coconut as similar approaches have paid fruitful results in oil palm in developing successful dihaploids (Dunwell *et al.*, 2010). They have demonstrated the high-throughput screen to identify spontaneously-formed haploid (H) and doubled haploid (DH) palms. Over 1,000 H and one DH from genetically diverse material were secured and further DH/mixoploid palms were derived from H using colchicine. The outcome will help to generate 100 per cent homogeneous F_1 seed from intercrosses between DH/mixoploids once they develop female inflorescences. Similar approaches may be helpful in coconut also.

5.5.8. Pink Husked Coconut

The most commonly occurring fruit colours of tender coconut include shades of green, yellow, red or orange and brown. Generally, most tall populations produce progenies mostly with mixture of greens and browns whereas the dwarf cultivars produce palms with definite colours of green, orange or red, yellow and brown. Among these populations, some individual palms have been reported to produce an attractive pink colour near under the tepals. The Pilipog Green Dwarf from Philippines is the variety produces such palms in which the female flowers are seen with pink tinged tepals (Rivera *et al.*, 2010). The cross section of the fruits also revealed the pink colour in the husk. Although, similar pink colour has been reported from fruits of individual palms belonging different coconut populations such as yellow dwarf and East Coast Tall, West Coast Tall, recently a coconut palm bearing fruits with pink coloured mesocarp was identified from San Ramon Tall population (Jerard and Niral, 2016). In the identified type, the male and female flowers and fruits from all bunches exhibited the ring of pink colour over the surface of fruits below the tepals, slightly extending outwards (Figure 5.27). It was observed that when the tender fruits are trimmed, husk fibres also exhibit the colour ranging from intense to light pink from outer to inner side giving an attractive appearance. The pink colour also appeared on the inner surface of the young fruits of 3 to 5 months age. While the pink colour appeared on all the female flowers and also at their base of tepals, the pink colour is exhibited only in a proportion of male flowers. It was observed that the palm produces two types of male flowers having differently coloured anther filaments, one with dark pink and another with normal yellow (Figure 5.28). This observation of occurrence of two types of male flowers in the same palm with different colours is the first record which has potential use in marker assisted selection in coconut in the development of tender nut varieties with attractive pink husks. Although no morphological difference could be seen on size of male flowers and anthers, the flowers with pink filaments could be easily identified even at unopened stage as the pink tinge is present in the bottom of tepals.

Figure 5.27: Various Stages of Fruit Development in Pink Husked Coconut Type.

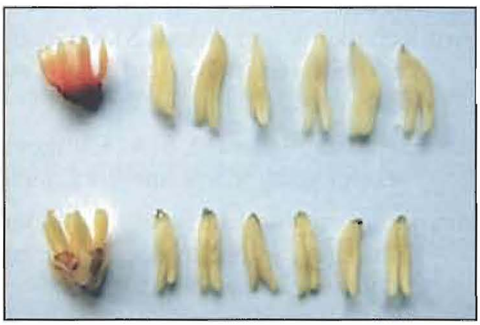

Figure 5.28: Differently Coloured Anther Filaments from Pink Husked Coconut Palm Type.

This kind of palms could be potentially used for developing a range of pink husked lines which will have better marketability when compared to the other varieties.

6. Conclusions and Prospects

Although the prominent collections of coconut diversity has been used for development of improved varieties aiming for high copra and oil yield, drought tolerance, dwarfness, precocity in flowering and bearing, there still exists possibilities for accelerating the breeding programmes for these purposes through exchange of identified germplasm among different countries on the other hand, sustaining the conserved germplasm for future use poses challenges to the hosts because of high costs of maintenance and other diminishing resources. Hence, attempts to minimise the conserved collections by eliminating duplicates would be a priority. As an alternative to this, *in situ* conservation approaches may also have to be followed on specific targeted germpalsm. Considering the need for diversifying the coconut cultivation beyond copra and oil purpose in order to increase the profitability, there is an urgent need to utilize the special types such as soft kernel types, aromatic coconut, sweet kernel coconut and pink husked types in the breeding programme. Further, the selected populations or cultivars are to be purified to the extent possible to minimise the errors in getting the desirable traits while breeding varieties and hybrids. The testing of developed varieties and hybrids in multi-location trials consumes lot of time and other resources before the technology is passed on to farmers. Hence, a simultaneous farmer participatory breeding mechanism also needs to be placed to hasten the process of evaluation. Considering the achievements made so far and the opportunities available, the strategies suggested for future breeding programs include development of varieties for yield coupled with value-added products like inflorescence sap, developing stress tolerant varieties to expand the coconut cultivation in non-traditional areas, development of inbred lines in coconut for production of vigorous hybrids, utilization of novel traits for product diversification and varieties suitable for low and marginal input regimes coupled with biotic and abiotic stress tolerance. As the base material for any breeding efforts should come from the germplasm, concerted efforts are needed for collection and exchange of diverse types among the coconut growing countries.

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