Chapter 4

Botany, Growth and Development

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1. Introduction

The coconut palm, *Cocos nucifera* L, the most important of all cultivated palms, is essentially an oil crop but is also ranked as an important food crop. The palm not only supplies food, drink and shelter, but also provides raw materials for a number of important industries. The palm is referred to as "The Tree of Wealth" and "The Tree of Life" as it provides all the necessities of life. Coconut is considered to be an ancient species with a long history of domestication and cultivation. It is presumed that the early humans while domesticating habitats in coastal areas started domesticating the coconut palms, resulting in the absence of wild forms in the present day coconut population. The origins of this plant are the subject of controversy, with most authorities claiming it is native to South Asia, while others claim its origin is in West Coast of Central America and on the adjacent islands of the Pacific. Fossil records from New Zealand indicate that small, coconut-like plants grew there as long as 15 million years ago. Even older fossils have been uncovered in India. An origin for the whole Cocoeae tribe in western Gondwanaland seems most compatible with the present day distribution. It has been hypothesized that the tribe probably differentiated shortly before the break up of that super-continent. Members radiated and became very diverse in the Americas; some rafted on the African and Madagascar Plates, where they survive to the present day; others rafted on the Indian plate, where they are now extinct. With its ability to float the coconut became independent of plate tectonics for its dispersal. Regardless of its origin, the coconut has spread across much of the tropics, aided by sea currents and in many cases by sea-faring people. *Cocos nucifera* is hence regarded as a semi-domesticated species, with evolution of local populations having varying degrees of dependence upon humankind.

2. Taxonomic Status

Cocos nucifera, a monoecious perennial monocotyledon, is placed in Arecaceae family (formerly Palmaceae) and the sub family Cocoideae which includes a total of 27 genera and 600 species. As explained in Chapter 3, *Cocos* is categorized as a monotypic genus by Beccari (1916). The taxonomic information is listed below.

Kingdom: Plantae, Sub kingdom: Tracheobionta, Super division: Spermatophyta, Division: Magnoliophyta, Class: Liliopsida, Sub class: Arecidae, Order: Arecales, Family: Arecaceae, Genus: *Cocos* L., Species: *nucifera* L.

3. Coconut Forms and Classification

The coconut palm, though a monotypic species with no known wild/ domesticated relatives, shows diversity in forms. FAO in the 1950s initiated a questionnaire-based survey to document the different coconut types and published the responses obtained from 18 countries (Mao, 1959). In 1970 FAO published a list of descriptors of coconut under five forms on the basis of information obtained from 30 independent sources (Harries, 1970) Satyabalan (1997) has comprehensively compiled available information on known varieties/cultivars of coconut with reference to their classification.

Ever since Rumphius' *Herbarium Amboinense* (1741-53), which listed 13 varieties from the Netherlands Indies, numerous attempts have been made to document the different forms of coconut. Miquel (1855), on the basis of available reports, compiled a list of 18 varieties with Latin names and descriptions, which was used by the Dutch workers to refer coconut populations in Dutch colonies. Blume (1947) reported on the coconut varieties of Philippines with a few Latin varietal names. Narayana and John (1949), acknowledging the need for categorization as essential for proper understanding of the variations and forms of coconut, attempted the first systematic classification of the known coconut varieties (Table 4.1). They categorized coconut varieties into two groups, *viz.* Talls and Dwarfs (Figures 4.1a-b). The Talls were further differentiated into three varieties and nine forms, while the Dwarfs were differentiated into two varieties and two forms. These varieties and forms were named mostly after the countries from which they were originally obtained or where they are largely grown, or after a particular distinguishing character of the form.

This method of classification was quoted by Gangolly *et al.* (1957) in their review of literature on varieties of coconuts, which also formed the basis of the chapter on varieties by Menon and Pandalai (1958), but being cumbersome was not used for classifying the coconut varieties. Further, since the varieties from the Pacific islands, Africa or America were not included, this classification was not considered comprehensive.

Liyanage (1958) adopted the classification of Narayana and John (1949), primarly based on fruit size and appearance, to classify the varieties of Sri Lanka. He reduced the coconut varieties to three - typica, nana and aurantiaca, by removing androgena and spicata. The new variety, aurantiaca, was considered to be semi-tall, distinct from either the tall or the dwarf groups. The forms corresponded with some of those in the Indian system, but had different names. The variety typica had eight forms *viz.*, typica, kamandala, bodiri, navasi, ran thembili, gon thembili, parapol, dikri pol; variety nana had three forms *viz.*, pumila, eburnea, regia and aurantiaca had two forms namely, King Coconut/thembili, navasi thembili.

Table 4.1: Varietal Classification System Proposed by Narayana and John

Variety	*Forms*	*Important Features*
Spicata	–	Inflorescence unbranched (spikeless), with numerous female flowers and few male flowers
Typica	Ramona	Tall form, large nuts and high copra content
	Kappadam	Tall form, robust with large quantity of water in the tender nut
	Gigantea	Tall form, robust with majestic appearance, large fruits, good quantity of copra, poor yielding.
	Nova-guineana	Tall form, robust with stout trunks, massive crown with large number of long leaves and bunches, susceptible to fungal disease and attack by insect pests
	Cochin-chinensis	Tall form, robust with stout trunk, large number of leaves and bunches, thin kernel, susceptible to fungal diseases and attack by insect pests.
	Malayensis	Tall form, stout trunk, poor yield, green nuts, less copra oil content, tender nut water sweet and with a peculiar aroma, presence of pinkish colour at base of the buttons
	Siamea	Tall form, comparatively short with stout trunk, compact crown, medium-yield, green nuts, tender nut water sweet, high copra oil content
	Laccadive	Tall form, regular bearer and high yield, nuts medium sized, good quality and quantity of copra, good toddy yielders
	Pusilla	Tall form, high female flower production, high setting percentage, small size of nuts, good quality copra, very high percentage of oil, suitable for making ball copra
Nana	Nana	Dwarf form, short trunk, high yield, good copra content and the quality, suitable for tapping
	Maldiviana	Dwarf form, short thin trunk, small crown, short leaves, sweet tender water, poor copra quantity
Javanica		Intermediate between the tall and dwarf, robust palms, short trunk, prolific and early bearer
Androgena		Male tree. Inflorescence contains numerous male flowers (about 5000), does not produce female flowers and nuts

Carlos (1963) identified four botanical varieties *viz.*, typica, nana, javanica and spicata in Philippines. McPaul (1962) grouped the coconuts of Fiji under two groups, Talls and Dwarfs. Rattanapruk (1970) classified the coconuts in Thailand into three varieties based on the nut characteristics and age at fruiting.

Fremond and co-workers (1966). put forth another system of classification, on the basis of pollination characteristics. They divided the varieties into two groups, *viz.*, autogamous or self pollinating as in the case of most Dwarfs and allogamous or cross pollinating as in the Talls. However, this classification also has limitations as the Dwarfs are easily cross pollinated when surrounded by Talls and Talls are

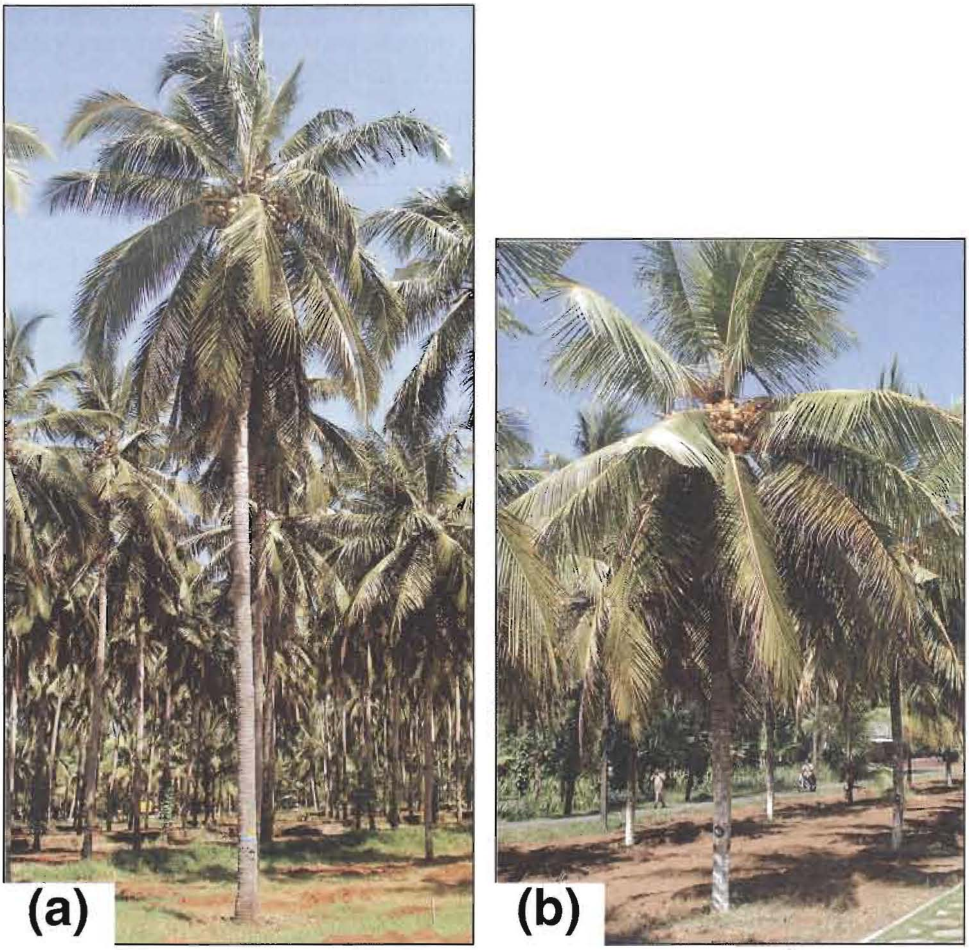

Figure 4.1a: Tall (a) and Dwarf Coconut Palm (b).

also capable of self pollination (Whitehead, 1965a; Rognon, 1976). These methods of classification, however, require the testing of local forms from different countries under controlled condition. This has a lot of practical difficulties. Therefore the widely used method of classifying coconut varieties is on the basis of their morphology and growth habit. The coconut varieties are generally classified as Tall and Dwarf, prefixed by the name of the country of origin. These two distinct groups are distinguishable based on their stature, trunk character, age of flowering/ fruiting and also the yield and nut/copra characters.

Harries (1978) put forth a method for practical identification of coconut varieties to enable comparison of varieties irrespective of their country of origin and the conditions under which they grow. He advocated use of fruit component analysis for characterizing and classifying varieties. According to Harries, the fruits of a palm being the physiological sinks are not only the most interesting but also the most uniform despite the exposure of palms to variations in the growing conditions. He

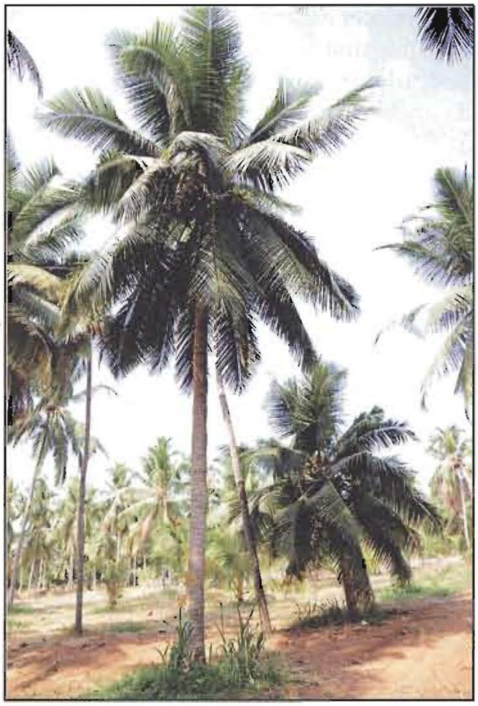

Figure 4.1b: Tall (in the foreground) and Dwarf Coconut Palm.

further reasoned that by considering the relationship between the fruit components rather than absolute values, the effects of large/small fruit size and large/small fruit number are reduced. Based on these assumptions, Harries (1978) recommended a system of classification based on contrasting the proportion of husk in the fruit with the fresh weight of the fruit. He introduced the concept of coconut variety identification based on the NiuKafa-NiuVai introgression method. According to Harries, the NiuKafa type represents the coconuts, which have evolved through natural selection in uninhabited islands and coral atolls. These coconuts are named after a variety characterized by long angular, thick-husked fruits. It has the capability of slow germination, which facilitates its survival under natural conditions. The NiuKafa type being large fruited is suited for copra production and coir processing and has therefore been introduced into inland areas for commercial cultivation. As a result the identity of its distinctive natural habitat has been lost.

The NiuVai type, on the other hand, derives its name from a variety used as a source of sweet uncontaminated water. According to Harries (1979) the coconut palm was first used by humans as a source of water. Therefore, this selection pressure led to an increase in the volume of the liquid endosperm in the immature fruit. This caused a change in the fruit characters, with these being spherical with larger nuts (cavity) and less husk. The competition for light and space resulted in these nuts developing the ability to germinate quickly and producing vigorous seedlings. Harries did not include the dwarf varieties under NiuVai and NiuKafa types as these evolved much later and can survive only under cultivation. The two ancestral types maintain their distinctive characteristics in the Central American isthumus, where these populations are geographically isolated (Richardson *et al.*, 1978). However, in Asia and Pacific, human intervention through migration and cultivation has brought these forms together and the resulting opportunity for cross-pollination has allowed the development of intermediate forms through introgression. This introgressive hybridization has resulted in the development of many of the cultivated types available today.

Harries (1981) has studied and classified a few of the present day coconut populations into NiuVai and NiuKafa types (Figure 4.2). According to him, the West African Tall and the coconuts along the Atlantic and Caribbean coast of America, such as Jamaica Tall belong to the NiuKafa type, while the Malayan Tall belongs to the NiuVai type. He considered the Tahiti Tall to be a variable population, as a result of greater introgression between NiuVai and NiuKafa types. The coconut populations in most islands in the Pacific Ocean are introgressed forms similar to the Tahiti Tall but sufficiently different to warrant distinct names. Within these introgressed types, he observed that NiuVai and NiuKafa types occur as minor variants. Harries (1981) concluded that the modern techniques such as the electrophoresis of polymorphic enzymes would show the relationship between varieties and anticipated that these studies would support the NiuKafa-NiuVai introgression theory.

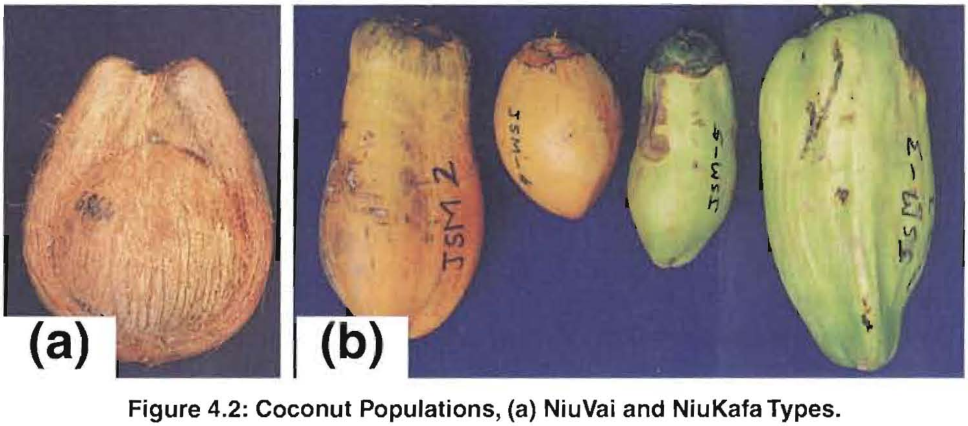

Figure 4.2: Coconut Populations, (a) NiuVai and NiuKafa Types.

Satyabalan (1997) attempted to classify the Tall and Dwarf varieties of coconut on the basis of the ratio of components from the fruit analysis data. He was able to observe five different groups in Tall coconut varieties and three groups in the three predominant Dwarf colour groups (Figure 4.3).

Talls

Group 1

Very large fruits, spherical or ovoid in shape and with thin husk. The nut inside is large, spherical, with thin meat, more water and thin shell. Copra content is more than 300 g/nut, which is less than 30 per cent of the husked nut weight. It includes

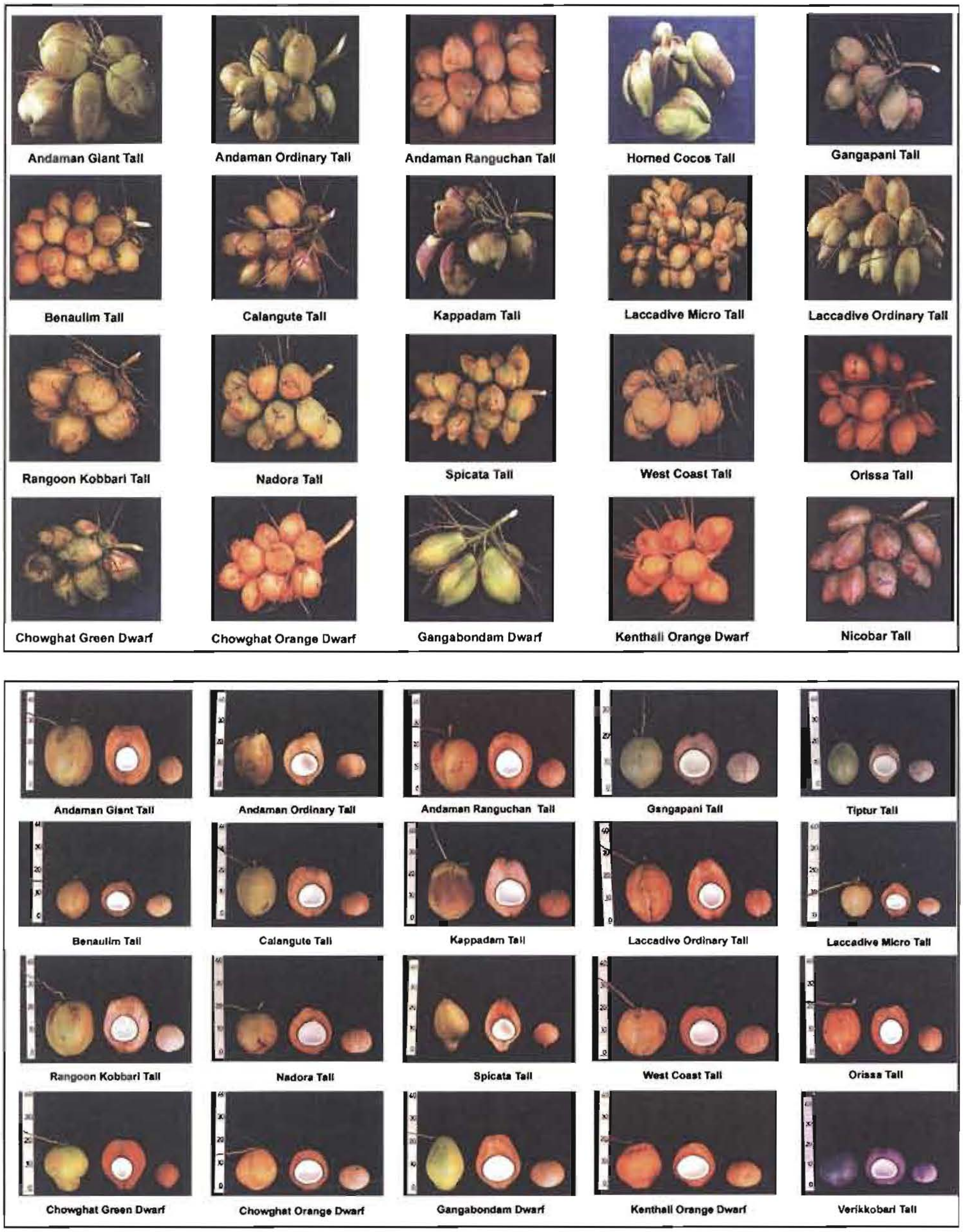

Figure 4.3: Different Groups within Talls and Dwarfs.

mainly cultivars of the South East Asian, Oceania and American regions. A few examples are, Thailand Tall, Bali Tall, San Ramon Tall, Malayan Tall from South East Asia; Rennel, Rotuma and Tahiti Tall from the Pacific (Oceania) and Panama and Equadorian Tall from America.

Group 2

Large fruits, spherical or ovoid in shape and with thin husk. The nut inside is large, spherical, with thin meat, more water and thick shell. Copra content varies from 200-300 g/nut, which is less than 30 per cent of the husked nut weight. This group also includes mainly cultivars of the South East Asian, Oceania and American regions. Some examples are, Thailand Klarng, Borneo Tall, Tenga Tall, Philippines Laguna Tall, Philippines Lono Tall from South East Asia; Solomon Tall, Fiji Tall, Natava Tall, Rangiroa Tall from the Pacific (Oceania); Surinam Tall, Pacific Tall from America and Nigerian Tall from Africa.

Group 3

Large fruits, spherical or ovoid in shape and with thin husk. The nut inside is large, spherical, with thick meat, less water and thick shell. Copra content varies from 200-300 g/nut, accounting for more than 30 per cent of the husked nut weight. This includes coconuts of all the five coconut growing regions of the world. A few examples are the Park Choke Tall of Thailand; Guam Tall, Polynesian Tall from the Pacific (Oceania); Jamaican Tall, St. Vincent Tall, Atlantic Tall from America: West African Tall, Zanzibar Tall from Africa and Ceylon Tall from Asia.

Group 4

Medium sized fruits, spherical or ovoid in shape and with thick husk. The nut inside is medium, spherical, with thick meat, less water and thick shell. Copra content is less than 200 g/nut, which is more than 30 per cent of the husked nut weight. This includes coconuts of all the five coconut growing regions of the world. Some examples are Standard Kudat Tall, Philippines Dalig Tall from South East Asia; Solomon Tall, New Hebrides Tall from the Pacific (Oceania); Blanchisseuse Tall from America; West African Tall, Mozambique Tall, Kenya Tall from Africa and Gonthembili, Laccadive Ordinary Tall, Laccadive Micro Tall, Benaulim from Asia.

Group 5

Medium sized fruits, spherical or ovoid in shape and with thick husk. The nut inside is medium, spherical, with thin meat, more water and thick shell. Copra content is less than 200 g/nut, which is less than 30 per cent of the husked nut weight. This includes coconuts of all the five coconut growing regions of the world. A few examples are the Park Choke Tall, Kongtheinyong, Klapawangi from South East Asia; Fiji Tall, Niu Ui, Solomon Tall, Kiriwana Tall, Kaveing Tall from the Pacific (Oceania); Surinam Tall from America; Seychelles Tall from Africa and East Coast Tall, West Coast Tall from Asia.

Dwarfs

In the case of the Dwarfs, Satyabalan (1997) reported three groups in all the three colour groups, *viz.* green, yellow and red/orange: Group I corresponding to small nuts with less copra content; Group II with medium to large sized fruits with medium copra and Group III with medium to large fruits with more copra content.

Green Dwarfs

Group I

Small fruits, with high percentage of shell (26-39 per cent) and copra (32-43 per cent) in the husked nuts. *e.g.* Chowghat Green Dwarf and Ayiramkachi of India; Pumilla of Sri Lanka.

Group II

Medium sized fruits with lesser percentage of copra (23 per cent) and slightly lesser shell (23-27 per cent) in the husked nuts. *e.g.* Nam Hom (Aromatic Coconut) and Nok Koom of Thailand.

Group III

Medium sized fruits with slightly higher percentage of copra (25-35 per cent) and lesser shell (20-25 per cent) in the husked nuts. *e.g.* Equatorial Green and Guinea Green of Ivory Coast; Mu-se-keo, Thailand Green Dwarf, Thungkhled and Pathiu Green Dwarf of Thailand; Malayan Green Dwarf; Gangabondam of India.

Yellow Dwarfs

Group I

Medium small fruits with high percentage of shell (20-29 per cent) and copra (24-35 per cent) in the husked nuts. *e.g.* Malayan Yellow Dwarf.

Group II

Medium sized fruits with lesser percentage of copra (21-30 per cent) and lesser shell (16-19 per cent) in the husked nuts. *e.g.* Ghana Yellow Dwarf; Malayan Yellow Dwarf.

Group III

Medium sized fruits with slightly higher percentage of copra (24-31 per cent) and slightly lesser shell (21-27 per cent) in the husked nuts. *e.g.* Malayan Yellow Dwarf; Nari-kay of Thailand.

Red/Orange Dwarfs

Group I

Medium small fruits with high percentage of shell (20-29 per cent) and copra (24-35 per cent) in the husked nuts. *e.g.* Malayan Red Dwarf; King Coconut; Mapro fire and Thalai Roi of Thailand.

Group II

Medium sized fruits with lesser percentage of copra (21-30 per cent) and lesser shell (16-19 per cent) in the husked nuts. *e.g.* Malayan Red Dwarf.

Group III

Medium sized fruits with slightly higher percentage of copra (24-31 per cent) and slightly lesser shell (21-27 per cent) in the husked nuts. *e.g.* Cameroon Red Dwarf; Malayan Red Dwarf; Chowghat Orange Dwarf; of India.

The Niu Leka Dwarf on the other hand, has a much larger fruit and produces much more copra than the normal green, yellow, orange/red dwarfs. The proportion of copra as well as the shell is much higher and is like those of palms of the tall variety.

To conclude, colour of the fruit and the fruit component data are presently the most convenient for grouping of the varieties. In most cases, the size of the fruit is genetically determined and not solely the effect of environment. However, further refinements of this technique can be undertaken for a more comprehensive and fool-proof classification system.

4. Propagation

4.1. Seed and Seed Germination

Coconut palms are commercially propagated by seeds from fruit set to seed maturity, the fruit development takes about 11 to 12 months. The matured, fruits readily germinate within 3 months on sowing, Natural regeneration also occurs widely in favourable environments if the fallen nuts are left in the field as such. Although the seed nuts are sown either vertically or horizontally keeping the broader surface of fruit facing up in commercial nurseries, the seeds can germinate mostly in all directions. In a natural fall from the palm, mostly the seeds settle on the ground as with the broader surface touching the ground soil. Whitehead (1965b) suggested speed of germination is of taxonomic significance in coconut. Generally, the seeds germinate within 2 to 5 months, depending on cultivars and management.

Earlier workers (Whitehead, 1965; Nampoothiri *et al.*, 1973; Harries, 1981) had reported that the seed nuts of dwarfs germinate early (30-95 days after sowing) while seed nuts of tall varieties germinate late (60-150 days after sowing). However, work undertaken at ICAR-CPCRI indicates that such generalizations are not true. The Malayan Dwarfs and so also the Gangabondam Green Dwarf from India show early and faster rate germination, while the Philipiness Ordinary Tall, germinates much earlier than the Chowghat Dwarfs (CGD, COD) of India (Niral *et al.*, 2006). Seed nuts of Malayan Yellow Dwarf, Gangabondam Green Dwarf and Philippines Ordinary Tall show early and faster rate germination, while seed nuts of Laccadive Micro Tall show late and slow rate of germination. Seed nuts of West Coast Tall and Laccadive Ordinary Tall, though late in germination, show a comparatively faster rate of germination than Andaman Ordinary Tall. Differential rate of germination was observed in the hybrid seed nuts and the maternal parent was found to determine the germination speed. In addition, there are some exceptional varieties with still earlier germination and also viviparous germination. Zizumbo Villarreal and Arellano Morin (1998) observed a correlation between precocity in seed germination and resistance to Lethal Yellowing disease in Mexico. The significant differences in speed and rate of germination have practical significance for coconut nursery managers and breeders and can serve as a guide in developing suitable standards for seed certification and varietal registration.

4.2. Growth and Development of Seedlings

During germination, the sprouts appear as a spear out of the nut and unfurl the lamina upon growth and development before producing few scaly leaves without lamina. The lamina of the first few leaves of seedlings is fused unlike the adult coconut palms. After producing 4 or 5 leaves with fused lamina, the subsequent leaves produce the lamina with splitting into leaflets. The length of the leaf increases from few cm in the first formed scaly leaves to upto 2 m in 6^{th} leaf stage again depending on cultivar and growing conditions. Generally, the seedlings are taken for planting at 6 or 7 leaves stage with at least one leaf showing splitting of leaflets.

5. Botanical Description

The coconut palm is a monocot. The single stem of the coconut tree, lacks bark, cambium and secondary growth features characteristic of gymnosperms and dicotyledons and hence the stem once formed never alters in thickness, except for a slight shrinkage when the stem gets old. Similarly, the root lacks a taproot and the roots once formed never grow in thickness. The palm is unbranched and does not form vegetative buds on the stem. It has a single vegetative bud at the terminal end of the stem, and if this gets killed the whole palm dies. The features of the different parts of the palm are explained below.

5.1. Root

The palm being a monocot has an adventitious root system (Figure 4.4). Roots emerge from the base of the stem (bole) and continue to be produced throughout the life of the palm. The number of roots in a tree varies with age of the palm, girth of the bole, soil fertility and management of the palm. It ranges from 1500-7000 (Sampson, 1923; Copeland, 1931; Patel, 1938) and in rare instances as many as 11,360 roots have been recorded (Menon and Pandalai, 1958). The main roots form a number of secondary roots which branch profusely forming a large absorptive surface through which the plant takes in nutrients from the soil. However, these rootlets are short-lived and are frequently replaced. The roots do not have root hairs from the main roots and rootlets, numerous pneumatophores develop and serve as breathing organs, facilitating gaseous exchange between the roots and the atmosphere. The tender growing tip of the roots is protected from injury by a root cap.

The main roots of the tree are uniform in size and long-lived. They generally, measure around 5-10 m in length and 8mm in diameter. However, occasionally, longer roots, upto 25m in length, have also been reported (Menon and Pandalai, 1958). The growing root is initially yellowish-white in colour and gradually turns light red and subsequently become reddish-brown with age. Thus in a fairly old and growing root, gradations in colour are generally visible. Coconut roots cannot indefinitely grow into water or withstand continuous water stagnation and submerged portions of the root get decayed. However, when the water table recedes, these roots produce new branch roots and/or rootlets (Sampson, 1923; Menon and Pandalai, 1958; Ohler, 1984). The roots of the coconut palm, in general can live for many years. However, the rootlets have a very short life span, as influenced by the ecological conditions in the root zone.

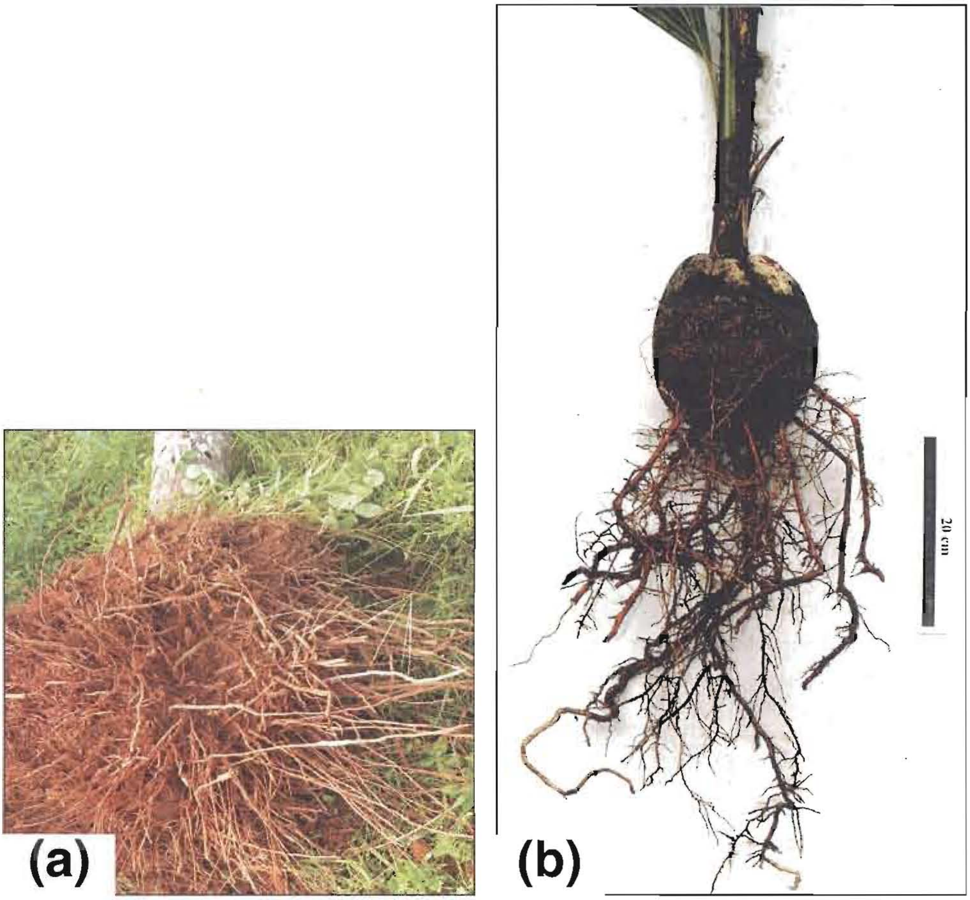

Figure 4.4: Adventitious Root System in Adult Palm (a) and seedling (b).

5.1.1. Structure of the Root

The coconut root, both the main roots as well as rootlets, has three regions, distinct in their internal structure, *viz.* the root cap, the growing root tip and the absorbing region, a little distance away from the root tip. However, the tissues in rootlets are much smaller and less defined, and carry less conducting tissues, especially xylem vessels.

The tip of the root contains the root cap (8-26 layers of dead tissue), covering the tender growing portion of the root and the meristem called calyptrogen, which is responsible for the formation of the root cap. The growing root tip, immediately behind the root cap is undifferentiated, and includes the epidermis and uniform mersitematic cells which later on differentiate into various tissues. The cells in the absorbing region of the root are differentiated, with three distinct layers, *viz.*, the outer single layered epidermis; the inner central stele and the thick cortical region in between the epidermis and the stele. The epidermis is the main absorbing tissue and the cells are much larger, multinucleate (2-4 nuclei), thin walled and short lived and wither away as soon as the hypodermis attains an impervious sclerenchymatous condition.

The central stele accounts for about one fifth the diameter of the root and comprises of conducting tissues bordered by a single layer of living cells, the pericycle. The rootlets and pneumatophores emerge from the pericycle. Immediately beneath the pericycle are 30-55 radically arranged groups of small dividing cells called the procambial strands, which differentiate into the xylem and phloem. The xylem vessels (are large) alternate with the phloem vessels (are inconspicuous). Often, two xylem vessels coalesce to form a bigger vessel and a mature root may contain about 25 large metazylem vessels. The companion cells to the vascular bundles, which are initially thin walled, later develop into thick walled sclerenchymatous bundle sheath and contribute to the tensile strength of the stele. In the centre of the stele is the narrow pith, comprising of living cells, which subsequently disintegrates as the root becomes old. In between two rows of phloem and xylem, there is a narrow ray of cells, which connects the inner ground tissue bordering the central hollow with the pericycle.

The cortical region, accounts for the major portion of the root and comprises of the hypodermis/exodermis, endodermis and mesodermis. The hypodermis lies immediately below the epidermis, and comprises of several layers of small and thin walled cells, which subsequently becomes thick walled and the epidermis looses its absorbing capacity. The hypodermis protects the central stele by its thick and pliable covering. The central mesodermis consists of large sized and loose parenchyma enclosing many air spaces and includes tannin cells as well as some empty cells of unknown function. The endodermis has a single row of small cells, whose distinct identity is maintained even in older roots. The inner wall of the endodermal cells is thick as compared to the lateral walls, while the outer wall is thin. A few thin walled passage cells exist in this layer (Menon and Pandalai, 1958).

5.2. Stem

The coconut palm has a single, straight stem, greyish in colour, topped by a crown of leaves. The stem has a single terminal bud, the death of which results in the death of the tree. The bud produces a succession of leaves and is well protected by the young unopened leaves. The stem is marked by leaf scars (Figure 4.5a). The thickness of the stem is determined by its vigour and soil conditions, in addition to varietal differences. In certain varieties, the base of the stem is swollen and is referred to as the bole (Figure 4.5b). The stem of the coconut palm becomes visible once the bole reaches the full stage of its development. In the initial years, the stem gradually becomes thick and once the maximum size is reached, there is no further appreciable change in the stem girth with age. However, the stem becomes thinner as the tree grows old and under unfavorable growth conditions.

The length of the stem is determined by the age of the palm, variety, ecological conditions and cultural factors. Dwarf varieties have shorter trunks than tall varieties. Palms under unfavourable management practices, including under

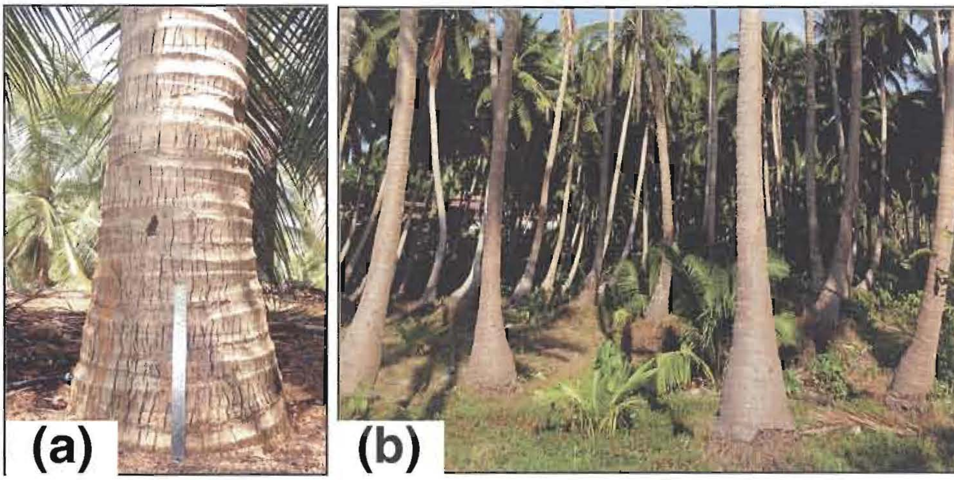

Figure 4.5: Stem: a) Leaf scars, b) Prominent bole region.

planting with excessive shade and very close planting, exhibit rapid stem elongation. In rare instances, palms with branching, due to damage to the terminal bud, is observed and upto five branches have been reported (Davis, 1969). The stem, being predominantly fibrous, combines stiffness with adequate suppleness and is tough enough to withstand considerable lateral strain, particularly when exposed to severe winds/gales, due to the presence of the numerous vascular bundles.

5.2.1. Structure of the Stem

The stem is derived from a single terminal bud, which is approximately 0.5 mm x 0.5 mm in size, visible as a small protuberance at the apex of the trunk and well protected by the leaves in various stages of development. The growing point comprises of a mass of minute cells with dense cytoplasm and large multi-nucleolate (4-10 nucleolate) nuclei. This region is 3-4 layered and has meristematic activity. Immediately below this region, in the tender stem, the cells are larger and contain numerous procambial strands along with large starch granules and sugar reserves. These procambial strands later differentiate into xylem and phloem bundles. The bundles derived from the procambial strands are closed ones and are scattered throughout the stem. The first formed bundles are comparatively short-lived but bigger than those formed subsequently from the ground meristem. The first formed protoxylem vessels are smaller than the subsequently formed metaxylem. In an young stem, 3-9 xylem vessels are observed and these form a V-shaped tissue, with the base towards the center of the stem. Small groups of xylem vessels are seen outside or above the xylem and both are enclosed within a layer of thin-walled cells that subsequently thicken with age and form the fibrous sheath. However, a few cells in certain patches of the fibrous sheath as well as the parenchyma close to the xylem and phloem are not thickened even in old stems. This is mainly confined to the apex of the bundle as a broad round tissue, and the base of the bundle is practically without the fibers. The xylem tissue, V-shaped when young, changes shapes with age. The xylem may be found in two or three groups. However, big bundles with many xylem vessels are rare. The most common type of bundle in the old stem is the one with only one big xylem vessel, a small phloem tissue above and a broad fibrous tissue lying at the outermost of the bundle. The vascular bundles towards the center are more widely spaced than towards the periphery. The number of vascular bundles in the periphery is also few or negligible; instead large numbers of small groups of fibres derived from the ground meristem are observed. Between the central part of the stem and the periphery, the vascular bundles are closely packed with few layers of intervening cells. Occasionally, the separating parenchyma is absent and therefore, two bundles coalesce into a double bundle. The size of the vascular bundles increases considerably with the age of the palm. The xylem and phloem are enclosed by cells that are initially thin walled but subsequently thicken and form the fibrous sheath.

The cortex comprises of several layers of thin walled parenchyma and a single layer of epidermis with thicker outer wall. In the parenchyma, tannin cells and air passages occur, mostly towards the periphery. Both the stem and the root lack the periderm or corky tissue seen in most plants. However, the periphery of the stem contains a peculiar storied type of cork cells, called rhytidome.

The palms do not have the power of making secondary thickening as they lack bark and cambium (the living and growing tissue between the bark and wood). However, the stem of a seedling is thin while that of an adult palm is stout. The thicker stem as the seedling grows older is the result of increased meristematic activity of the growing point resulting in the formation of more and more cells and vascular bundles, thereby forming the bole, which appears as an inverted cone once the bole is formed, the stem of almost uniform girth begins to appear. The girth of the stem remains almost the same, except for some shrinkage and tapering with age.

5.3. Leaf

The coconut palm bears a crown of leaves at the apex, comprising of the opened leaves and those surrounding the bud in various stages of development. The number of leaves in the crown varies with the variety and ecological and cultural conditions. Generally, an adult palm carries about 25-35 opened leaves on the crown. These leaves belong to four distinct sets. The first set comprises of the oldest 10-12 leaves from the axils of which bunches have been harvested. The next set comprises of the next older 10-14 leaves, supporting the fruits in various stages of development. The third set includes 10-12 opened leaves with spadices in various stages of development in their axils. The last set comprises leaves in the cabbage with the outermost ones in different stages of unfurling and the rest, which have not yet protruded.

The leaves are long, and vary from 3-6 m in length depending on the variety, age of the palm, soil fertility and vigour of the tree. The individual leaf consists of a strong petiole, extending to form a rachis with numerous leaflets (150-250) inserted on it (Figure 4.6). The leaflets on either side of the rachis are not exactly paired, with one half having about 2-10 leaflets more than the other side. The leaflets are

Figure 4.6: Leaf Morphology.

also long (60-150 cm in length), narrow, linear, tapering and lanceolate. The leaves when young retain the stipules at their bases, forming a fibrous tissue that more or less surrounds the whole stem. As the leaf becomes older, the stipules dry and fall away. In young trees, the stipules persist unbroken till the leaf dies.

The progression of leaf development from the minute bud to the enormous adult leaf takes several years on an average, the time taken from inception to final abscission of the leaf is almost five years. Different workers have explained the stages in development of the leaf (Patel, 1938; Padmanabhan, 1963), formation of leaflets (Venkatanarayana, 1957) and sequence of events involved in differentiation of leaf primordia into adult leaf (Periaswamy, 1965). The leaf primordium is differentiated almost 28-32 months prior to its emergence from the leaf sheath once the leaf emerges, its life span lasts for about 2-3 years. Under favourable conditions, the leaves of good bearing palms remain on the crown for 3-31/2 years after emergence (Patel, 1938). Generally, the life span of leaves is lesser in poor bearers than medium and heavy bearers (Patel, 1938). In addition, the season and also soil conditions affect leaf shedding. In general, heavy bearers have a higher rate of leaf production. Satyabalan (1993) observed that high yielders bear higher number of leaves on the crown indicating the longevity of the leaf as well as the drought tolerance of the palm. In regions where the seasons are more marked, there is a considerable cyclic variation in the rate of leaf opening and which appears to be more dependent on the temperature rather than the rainfall. Generally, one-year-old seedlings contain 7-9 leaves, with majority of the seedlings having eight leaves. The number of leaves on the crown increases to 30-35 during maturity and an adult tree on an average contains about 30 leaves.

The length of the leaf varies from 4 m in Dwarfs to up to 7 m in talls, depending on variety, growing condition and age of the palm. The petiole accounts for about one-fourth of the total length of the leaf, but varies with the variety. The petiole continues as the midrib of the leaf. A short and stout petiole is able to better withstand vertical pressure exerted by the developing bunch in its axil. The leaflets are borne on either side of the midrib and have differential length based on their position in the leaf. The first leaflets at the base are short, followed by a gradual increase in length of the subsequent leaflets with the maximum length being achieved at about one-third of the midrib followed by a graded decline in length towards the top of the leaf. The smallest leaflets at the tip are about 25 cm in length while the largest leaflets measure about 80-120 cm, depending on the variety. The number of leaflets in a mature palm leaf ranges from 200-500.

The leaves in a coconut palm are so arranged as to ensure maximum light availability to each leaf. They are arranged in five spirals, running either in the clockwise or anticlockwise direction, and spirality in a palm can either be right-handed (bunches hang towards the right of the petiole), or left-handed but remains the same throughout the life of the tree. Based on the phyllotaxy, the sixth leaf is positioned over the first leaf, the 11^{th} leaf over the sixth and so on. The two types of spirals are distributed almost equally in a population, with a slight preponderance of the left spiral (Davis, 1962; Louis and Chidambaram, 1976).

5.3.1. Structure of the Leaf

Patel (1938) studied the development of the leaf in coconut palms and reported that the number of leaves in the unopened cabbage is one to one and half times the opened leaves on the crown of the palm. Leaf primordium differentiation occurs 28-32 months prior to the emergence from the leaf sheath as a small indistinct protuberance on the side of the growing point. Within a month, it undergoes repeated periclinal and anticlinal cell divisions and develops into a 7-10 cell layered finger-like structure having the three layers of primary meristem, *viz.* the outer most dermatogen, the middle three cell layered periblem and inner most layer plerome. In the succeeding month, the rapidly growing protuberance assumes the shape of a hollow cone enclosing the next younger leaf and the growing point. At this stage, procambial initials, which subsequently form the vascular bundles, appear in the plerome. The developing leaf initially contains only the petiole portion and differentiation of the leaflets occurs eight months later, in approximately the seventh rudimentary leaf from the growing point. Narayana (1938) observed the formation of 18-layered rectangular mass of cells united at the margin that develops into leaflets, followed by subsequent longitudinal split in the middle of this tissue, forming the sides of the leaflets. The epidermis of the leaflets, both upper and lower, is derived from only the plerome tissue and not from the dermatogen. The inception of plications and the separation of leaflets in palm leaves is on the basis of vertical and transverse growth stresses (in the expanding and elongating lateral faces of the rachis) acting at the base of the nonplicate lamina which bears alternating lines of weaker parts between parallel rows of provascular strands whose cells elongate at right angles to the forces of vertical stress and resist them (Padmanabhan, 1984).

The procambial strands of the leaflets are formed after the xylem vessels of the first formed vascular bundles of the petiole and the main rachis have thickened. Within the leaflet, the procambial strands of the midrib are formed first, followed two months later by those of the sides. This is followed by the formation of the cross veins. In a mature leaflet, there is a strong central midrib from which slant down the two sides of the leaflet. The epidermis is observed on either side with a thick outer cuticle. The lower epidermis is thinner than the upper epidermis. Below the upper epidermis are two layers of hypoderm that serves as water storage tissue, while beneath the lower epidermis is a single broken layer of hypoderm. Below the upper hypoderm and spreading almost to the lower hypoderm is the broad palisade tissue comprising of thin walled, elongate and closely packed cells. Below the palisade tissue is a scanty spongy parenchyma. The chloroplasts are formed in the mesophyll just prior to the emergence of the leaf. Each leaflet contains about 20-25 vascular bundles running all along its length and occupying the entire thickness of the leaflet from the upper to lower hypoderm. Of these, 5-6 bundles are big while the rest are narrow. In between two large vascular bundles and just above the lower hypoderm are about three small vascular bundles made up of a few tracheids, 3-4 phloem elements and a small group of fibres. The top of the petiole contains as many as 500-1000 diminutive vascular bundles alternating with small group of fibres, which provide additional mechanical strength to the leaf. The upper epidermis is highly cutinized on the lower epidermis, numerous multicellular, dark brown, short-stalked scales containing tannin (trichomes) occur at regular intervals in small depressions. In addition, bundles of crystals of raphides are seen all over the lower epidermis. The stomata are first formed about a year prior to the emergence of the leaf and are initially confined to the margin of the leaflets away from the midrib while the vast majority of stomata are formed just about three months prior to the emergence of the leaf. The stomata are confined to the lower surface of the leaflets and are distributed all along its length in 2-4 longitudinal rows in-between every two vascular/fibre bundles. The stomata are elliptic with two guard cells containing large starch grains and a small opening. The guard cells are bordered by subsidiary cells and a small square cell at either end of the stoma joins these subsidiary cells. The stomata are fairly large with a dimension of 38 μ x 19 μ, extending to 38 μ x 40 μ along with the subsidiary cells. Normally, a leaflet contains about 170-220 stomata per mm^2. However, stomatal density is a varietal character. Dwarf varieties, in general, have higher stomatal density than talls (Satyabalan, 1993; CPCRI, 2015). The mature stomata are tetracytic, with both the polar and the lateral subsidiary cells cut off by the neighbouring protodermal cells. Each lateral subsidiary cell is the result of a longitudinal division of a trapezoid cell formed by two oblique divisions of a lateral protodermal cell. The ontogeny of stomata conforms to the perigenous type with non-intersecting oblique division (Ghose, 1979).

The midrib of the leaflet is a very strong structure with a central ring of 7-8 vascular bundles enclosed within a fibrous sheath formed by 2-3 rows of thickened cells. The outer epidermis is highly cuticularized and is continuous with that of the sides of the leaflets. Between the epidermis and the fibrous sheath are two layers of hypoderm (continuous with the upper hypoderm of the sides of the leaflet) followed by 2-3 layers of parenchyma. The attachment of each half of the leaflet to the midrib is narrow and tapering, but the place of attachment is strengthened by a group of fibres. There is also a special motor tissue bordering the inner epidermis that is continuous with the lower epidermis of the leaflet. Behind the motor tissue are a vascular bundle and a patch of sclerenchyma. In young leaflets, this motor tissue is non functional and comprises of smaller, much compressed, thin-walled elongated cells. By the time the leaflets are about to open, the motor tissue develops considerably and consists of two rows of big cells. These cells absorb water supplied by the vascular bundle behind it and become turgid, thereby causing a lateral push to be exerted along the sides of the leaflet, which gets separated from its oppressed position in the bud and remains at an angle. The bundle of fibres at the base of the attachment of the sides act as a pivot on which the side moves. However, as the epidermal folds are highly cutinized, sudden movements are checked. The outer margins of the sides of the leaflets are peculiarly folded somewhat like a hook; one margin is folded on the upper epidermis and another on the lower so that both point towards the same direction. At the bend of the fold, the epidermis is in short folds and immediately behind the fold is a motor tissue similar to the one at the base of the sides of the leaflets. The cells in the motor tissue are initially narrow, elongated and much compressed, but is developed at the time of unfolding of the tissue. When the cells become big and turgid they exert an outwards pressure and as a result the fold is straightened and the interlocked margins are released, thereby helping the leaflets to unfold. This motor tissue at the margin of the leaflets persists in some of the older leaves while in others it is lost and the epidermal folds straighten out and therefore the margin becomes a truncate structure instead of a bent one. In addition to these two motor tissues, two other motor tissues are seen at the base of the leaflet. Of these two, one is located at the angle made by the inner or upper half of the leaflet on the main rachis and helps to spread out the leaflet as a whole, while the other located on the inner side of the outer half of the leaflet at the place of attachment on the main rachis helps keep the outer half of the leaflet in position. Thus, there are four different motor tissues in the leaflet - one pair running the whole length of the midrib, one at the margins and two at the base.

The petiolar sheath is first visible as a soft wing on either side of the petiole, about a year after the leaf is differentiated. The young sheath is made up of a mass of parenchyma forming the ground tissue in which are scattered a few procambial strands. As the leaf matures, these strands develop into vascular bundles of considerable size and length with a broad mass of sclerenchyma, like those in the stem. In addition to the vascular bundles, isolated groups of fibres occur all over the sheath, especially towards the periphery. A narrow cortex is also visible in the young sheath. The old sheath consists of closely woven fibres and vascular bundles with a mass of sclerenchyma and without much of the thin-walled ground parenchyma. The importance of the mechanical tissue of the petiole sheath is evident, as at an early stage it encircles the stem and partly bears the weight of the leaf in the developing bud and as the petiole of the other young leaves enclosed in the sheath develops it is gradually torn up. The thickness of leaf sheath, fiber of weft and warp strands has relevance to adaptation, geographical affinity, mating system and taxonomic forms (Arunachalam, 2005).

5.4. Inflorescence

The coconut palm is monoecious with distinct male and female flowers borne on the same inflorescence of the same palm (Figure 4.7). The inflorescence emerges

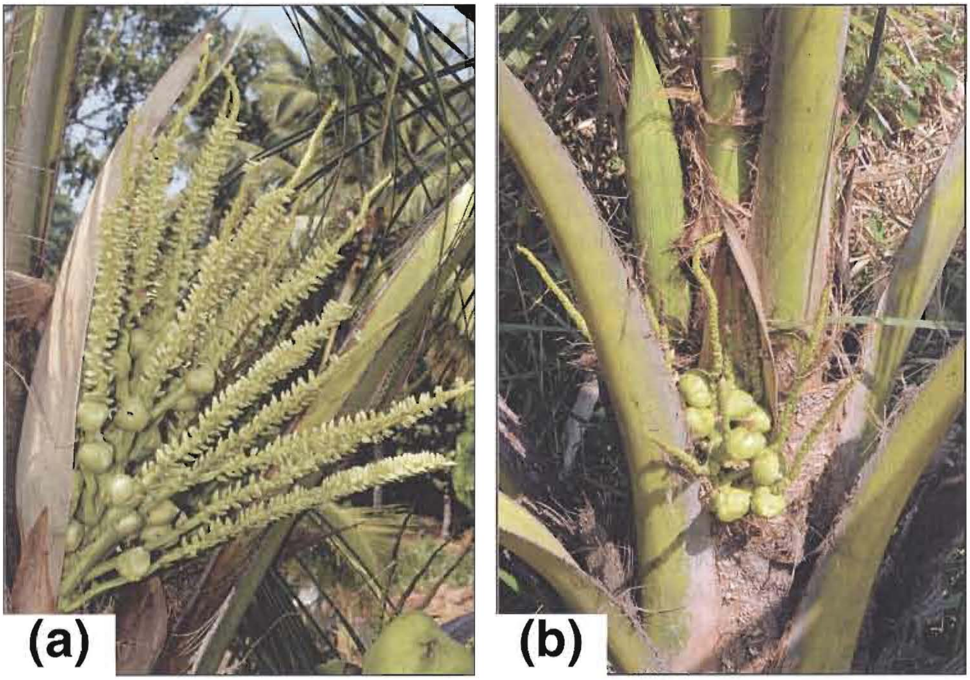

Figure 4.7: An Inflorescence with Distinct Male and Female Flowers (a) and Unopened Inflorescence in Leaf Axil (b).

from the leaf axils, and in adult palms under favourable conditions of growth, one inflorescence is produced every month from successive leaf axils. The age at initial flowering, varies with the variety as well as the growing conditions and ranges from 2-7 years after planting the seedlings in the main field. Dwarfs in general commence flowering earlier than tall varieties. The inflorescence, referred to as a 'spadix', is initially visible as an oblong flat structure enclosed by double sheath called spathe and when fully mature, becomes more cylindrical and due to the pressure exerted by the growing inflorescence the spathe ruptures along a longitudinal groove and exposes the inflorescence.

The length of the inflorescence ranges from 60-200 cm, and has about 8000-10,000 male flowers and 0-400 female flowers, depending on the variety, cultural conditions, season and age of bearing (Patel, 1938; Menon and Pandalai, 1958). The central inflorescence axis, referred to as rachis (peduncle), bears about 30-35 branches, the spikelets. The spikelets carry numerous male flowers, with few female flowers (generally 1-2, sometimes none and occasionally upto 5) borne near the base of the spikelets. Occasionally a few hermaphrodite flowers are seen alongside the female flowers in some cultivars. All the flowers are sessile/sub-sessile.

5.4.1. Structure of the Inflorescence

The flower primordium is formed about four months after the initiation of the leaf primordium and about 32 months before the opening of the spathe. The male and female flowers are differentiated about 12 months prior to the opening of the fully-grown spadix. Generally, the male flowers begin to form a month later than the females and mature a month before the stigma is receptive. The ovary is differentiated 6-7 months before the opening of the spathe. About 75 per cent of the total growth in the length of the inflorescence occurs during the period of about six months before the opening of the spathe. Soon after the opening of the spadix, the male flowers complete their life cycle while the female flowers have a longer history as it takes another 12 months for the nuts to fully ripen.

5.4.2. Development of the Inflorescence

The development of the inflorescence has been studied and described by Juliano (1926) and Patel (1938). The inflorescence arises in every leaf axil and the rudimentary inflorescence primordium is formed at almost the same time as the subtending leaf and therefore the inflorescence initials are present in the axils of the young rudimentary leaves near the growing point. The inflorescence primordia is a minute cone like protuberance about 77 μ x 107 μ found in the axil of the fourth leaf from the growing point, about 32 months prior to the opening of the spike. The whole inflorescence cluster consists of a central axis, the rachis, from which the rachillae arise in spiral succession. The rachillae at their apices bear the male flowers in the axils of tertiary bracts (floral bracts) singly in pairs and female flowers at the bases. The inflorescence initial begins as a minute protuberance at the end of two clasping bracts, one of which is situated towards the cabbage and the other between the petiole and the inflorescence initial. The first primary bract envelops the second primary bract and these later outgrow the whole floral cluster and form the outer and inner spathes enveloping the growing inflorescence. The enclosed inflorescence primordium has at its apex a ring of actively dividing cells, which shows signs of formation of the primary inner bract which later develops into a persistent inflorescence envelope. After the spathes have completely enveloped the growing point of the inflorescence, secondary bracts make their appearance as minute lateral protuberances. The lower secondary bracts tend to elongate more rapidly than those at the apex, so that their tips are nearly as long as the apex of the main rachis of the inflorescence.

The next stage in the development of the inflorescence is marked by the appearance of the primordia of the rachillae, in the axils of the secondary bracts. These primordia of the rachillae rapidly elongate vertically and lateral to the main rachis leaving behind the subtending secondary bracts. The main rachis always terminates with a single rachilla almost similar to the lateral branches. In the rachillae, tertiary or floral bracts appear and in the axil of these floral bracts there is a zone of actively dividing cells, which form the initials of the flower primordium.

5.4.3. Male Flowers

The male flowers outnumber the male flowers in a spadix, and vary depending on the length of spikelet bearing portion, number and length of spikelet in an inflorescence. The male flower comprises of three sepals, three petals and six stamens arranged in a single whorl with a rudimentary/abortive pistil in the centre (Figure 4.8) and are about 8 mm in length. Anthers are yellowish in colour and attain a

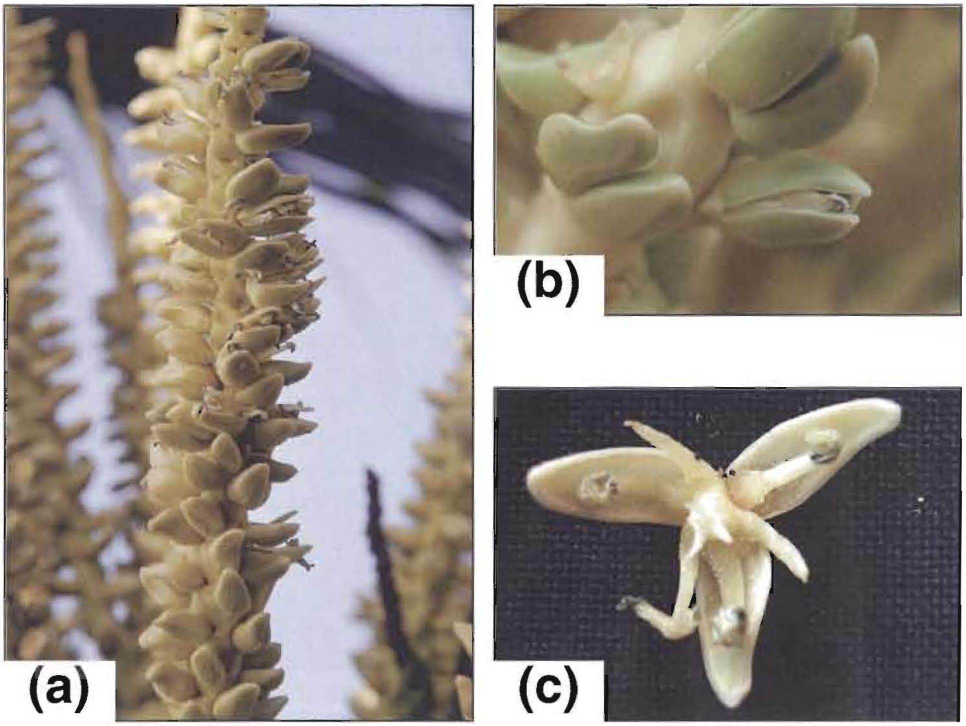

Figure 4.8: Inflorescence in Male Phase (a), Opening of Male Flower (b), Opened Male Flower (c).

bluish-green tinge on maturity. Opening of the male flowers commences from the apex of the spikelets and extends downwards and occurs throughout the day, but with maximum blooming during 8-10AM. The interval between the opening of the first male flower and the shedding of the last male flower is termed as the male phase and lasts for 18-22 days, varying with the variety, age of the palm, season and cultural conditions.

5.4.4. Female Flowers

The female flowers are comparatively few in number, as compared to the male flowers. However, the numbers of female flowers in an inflorescence varies with cultivars as well as the environment condition. Generally the first formed inflorescences in a palm have very few female flowers and in same cases no female flowers at all. Female flowers larger, with a diameter of 13-25 mm, globular in structure, bracteolate, and contain six rounded, concave, imbricate perianth (Figure 4.9) with a staminodal ring at the base and a short style with three stigmas at the centre. Ovary is tricarpellary, syncarpous with a single anatropous ovule in each carpel. However, only one ovule is fertile. Two male flowers, referred as accessory or axillary male flowers, accompany each female flower. Generally, the female flowers become receptive 3-4 weeks after the opening of the spathe (by then the male flowers in the spadix have shed their pollen and fallen off), and each female flower remains

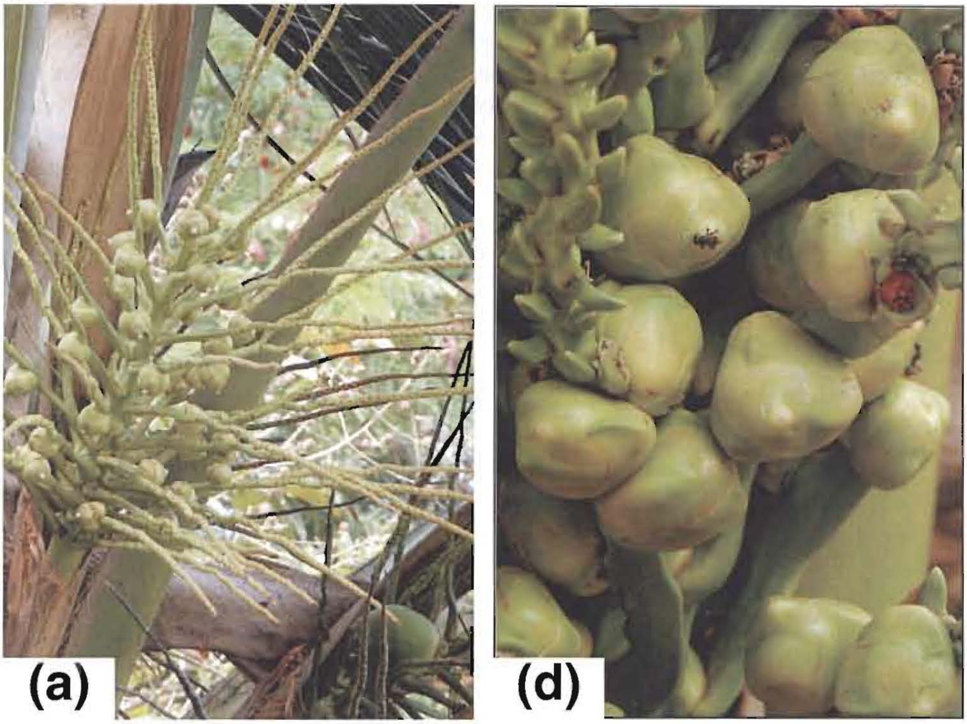

Figure 4.9: Inflorescence: a) in Female Phase and b) Female Flowers.

receptive for 1-3 days after opening. The interval between the receptivity of the first female flower and the receptivity of the last male flower is termed as the female phase and lasts for 5-7 days, depending on the variety and growing conditions.

3.4.5. Pollination

The male and female flowers being separate, transmission of the pollen from the male flower to the female flower for effecting fertilization in coconut palm is through wind or insects (Sampson, 1923; Patel, 1938; Louis and Chelladurai, 1984). Possibility of both self as well as cross pollination exists in coconut, depending on the time interval between the opening of the male flower and the receptivity of the female flowers, and varies with the variety as well as cultural and environmental conditions. In general, there is a gap of atleast 2-3 days between the end of the male phase and commencement of the female phase in an inflorescence (Ratnambal *et al.*, 1995, 1999) and hence pollination is effected through pollen from neighboring trees (cross pollination). However in majority of the Dwarf populations, self pollination is observed (Jack and Sands, 1922), due to overlapping of the female and male phases in an inflorescence (Ratnambal *et al.*, 1995, 1999). Self fertilization can also occur through overlapping of the male and female phases of successive inflorescences, during certain seasons: summer months in India (Patel, 1938), rainy season in Philippines (Copeland, 1931) and in Sri Lanka (Petch, 1913, 1931).

The pollen sacs burst and shed their pollen before the opening of the male flower or simultaneously with splitting of the perianth lobes. The fresh pollen grains are smooth and spherical in shape, and measure about 0.063 mm in length and 0.02 mm in breadth. The coconut pollen retains its viability for up to a week at room temperature. The viability period is enhanced when pollen is stored at low temperatures and/or in the desiccators. Successful pollination has been under taken at CPCRI using processed pollen stored in desiccators under refrigeration for up to 40 days. Processed pollen is regularly exchanged between CPCRI and other research institutes in India, through postal service and used for controlled pollination in selected lines.

5.5. Fruit

The fruit of the coconut palm, commonly referred to as the 'nut', is botanically a drupe. The fruit starts developing upon fertilization of the female flowers (Figure 4.10). Even though an inflorescence produces many female flowers only a few develop into mature fruits, while the rest are shed during the course of development. The coconut fruit contains an internal endosperm (kernel) with embryo embedded in it and protected externally by a thick pericarp (Figure 4.11). The pericarp has three distinct regions, the exocarp/epicarp (tough fibrous outermost layer, the colour varies from green to red to yellow to brown, depending on the variety), mesocarp (husk portion immediately beneath the epicarp) and endocarp (shell). In the tender fruit, husk is fleshy and has an astringent taste (in some varieties, husk is sweet and edible), which becomes more fibrous as the fruit matures. The thickness

Figure 4.10: Fruit Development (from fertilization to 6 months later).

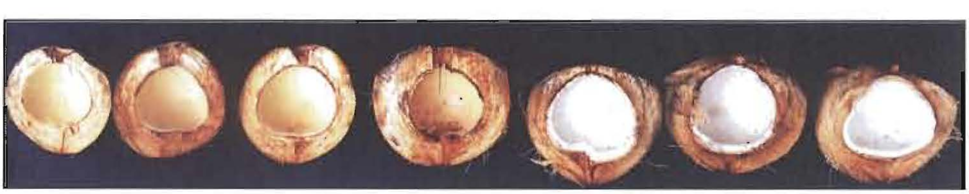

Figure 4.11: Internal Structure of Developing Fruit (11 months to 4 months from left to right).

of the mesocarp is dependent on the variety and varies from 2-15 cm. The shell, on its basal side has three pores (eyes) representing the three carpels of the ovary one of the eyes is soft while the other two are quite hard. The embryo is protected by the shell and is present beneath the soft eye. The thickness of the endosperm ranges from 0.8 to 2.0 cm, depending on the variety. In between the endocarp and the albuminous endosperm is a thin layer of testa/seed coat. The testa is brown in colour and adheres to the endosperm. In the middle of the endosperm is a cavity filled with sweet water, also referred to as the liquid endosperm. In the immature fruit, this central cavity is completely filled with water. However, the quantity of liquid endosperm reduces gradually during development and on storage for a few months after harvest once the nut water is exhausted, the fruit looses its ability to germinate (Menon and Pandalai, 1958).

The young embryonic fruits are initially yellowish in colour, but turn green, yellow or red (depending on the variety) on exposure to light on reaching complete maturity (10-12 months after fertilization), the fruits turn brown. Juliano (1926) observed that after fertilization the fruit develops with the pericarp developing more rapidly at the basal region and which appears whitish and soft till almost maturity. The endocarp is differentiated even before fertilization and appears as a soft creamy white structure. As the fruit develops, the embryo sac increases in size leaving a large vacuole at the center. The young fruits initially grow more in length than width and later, there is a greater increase in width rather than length and finally the fruits in most varieties are wider than long.

The developing nut attains its maximum size and weight around six months after development and remains so for another two months. Subsequently, there is a drastic reduction in nut weight along with a slight decrease in the size of the fruit, due to loss of water. In the final stages of ripening, there is loss of water from the liquid endosperm. Development of the solid endosperm (kernel) in the fruit begins five months after fertilization, as a thin watery lining on the shell at the basal end, away from the eyes. Subsequently, the kernel at this end thickens and subsequently then hardens. The thickness of solid endosperm reaches its maximum around the ninth month. The rate of oil deposition in the endosperm peaks at this stage and continues well after the fruits have turned brown. The fruits are ready for harvest 10-13 months after pollination, depending on the variety, with fruits of certain Dwarfs maturing in about 10 months after pollination.

6. Cytological Studies

The first detailed study on cytology of *Cocos nucifera* Linn. was by Santos (1929), followed by Janaki Ammal (1945) and Venkatasubban (1945). These workers reported the chromosome number of coconut as n=16. Subsequent studies confirmed the somatic chromosome number of 2n=32 (Figure 4.12) (Nambiar and Swaminathan, 1960; Swaminathan and Nambiar, 1961; Raveendranath and Ninan, 1973).

6.1. Karyomorphological Studies

Comparison of chromosome complements of Tall and Dwarf coconuts have indicated variations in chromosome size and presence of secondary constrictions.

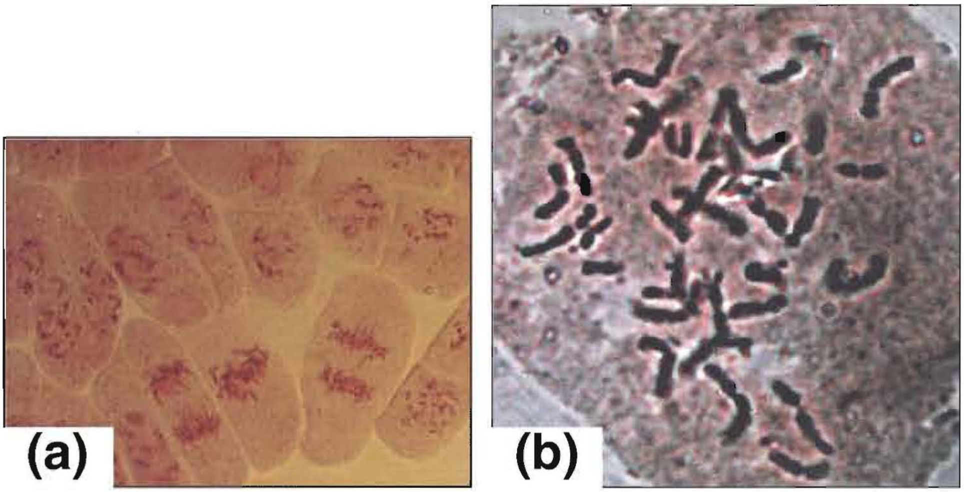

Figure 4.12: (a) Mitotic Activity in Root Tip Cand (b) Chromsomes in Somatic Cell.

Raveendranath and Ninan (1973) reported secondary constrictions on long arm of chromosome VI in Talls and long arm of chromosome III in Dwarfs. However, these differences were not consistent and additional satellites were observed on chromosome II (long arm), chromosome I (short arm), short arm of chromosome XII (Raveendranath and Ninan, 1973), long arm of chromosome XII (Thankamma Pillai *et al.*, 1983) and IX (Nambiar and Swaminathan, 1960) in Talls and in chromosome VI (long arm) in Dwarfs (Raveendranath and Ninan, 1973).

Nambiar and Swaminathan (1960) observed that in Talls as well as Dwarfs, majority of the chromosomes had submedian centromeres, with two pairs of chromosomes much longer and three pairs relatively short on the other hand, Raveendranath and Ninan (1973) observed a preponderance of chromosomes with median centromeres in both Talls as well as Dwarfs, with four submedian chromosomes in WCT, three in Dwarf Orange and only one in Dwarf Green. They also reported greater chromatin content in dwarf green than WCT, and hypothesized Dwarf Green to be the most primitive. However, evidences from morphology, breeding system and meiotic behaviour support the possible evolution of Dwarfs from Talls.

6.2. Meiotic Studies

Significant differences in meiotic behaviour of Talls and Dwarf varieties was reported by Lindquist (1960), with Dwarfs showing less stable meiosis than Talls, and more regular microporogenesis in open pollinated than inbred progenies on the other hand, Nambiar *et al.* (1970), reported differential microsporogenesis among Tall accessions. Microsporogenesis was relatively regular in both inbred and open pollinated progenies of Laccadive variety, while comparatively higher frequencies of chromosome aberration and pollen sterility was observed in inbred as well as open pollinated progenies of Cochin China and New Guinea and inbred progenies of Philippines and Andaman varieties. The lack of inbreeding depression only in Laccadive variety may either be due to differences in intensity of inbreeding and selection between these geographically distinct varieties or due to the Laccadive genotype being comparatively less sensitive to inbreeding.

Nambiar and Swaminathan (1960) observed many meiotic irregularities in Apricot from Straits Settlements and Dwarf Red forms which are derived ones from the Dwarfs, while meiosis was regular in Laccadive Ordinary. Consequently, higher pollen sterility occurred in these two Dwarf derivatives in comparison to Lacdive Ordinary. Thankamma Pillai *et al.* (1983). studied meiosis in nine cultivars and hybrids and indicated that percentage of abnormalities was highest in green and orange dwarf, while chromosome abnormalities and sterility were very low in D x T and T x D hybrids. They concluded that the higher degree of inbreeding in Dwarfs may be the reason for higher chromosome aberrations and sterility in them. Cytological studies on Spicata variety (Ninan *et al.*, 1960; Ninan and Satyabalan, 1963; Ninan and Nambiar, 1974) showed that meiosis was irregular with inversions, translocations and many other abnormalities. Spicata palms, being predominant outbreeders, are believed to have arisen from Talls through mutation.

Nambiar and Prasannakumari (1964). studied the effect of root (wilt) disease on microsporogenesis in coconut and observed low frequency of cytological aberrations, high pollen fertility and seed set. Thankamma Pillai and Vijayakumar (1972). studied the course of microsporogenesis in the progeny of a self pollinated New Guinea palm which produced defective nuts and observed aberrant meiosis. The sterility in this palm was attributed to inbreeding. Raveendranath *et al.* (1975) found no appreciable karyological differences between the Tall and abnormal coconut palm producing bulbils in the place of inflorescences and opined that cryptic structural changes or genetic mutations might be responsible for the appearance of this type of coconut palm.

6.3. Cytological Studies on Endosperm and Embryo

Dutt (1953). and Abraham and Thomas (1962) reported free nuclear divisions in coconut water (liquid endosperm). But, this was disputed by Mondal *et al.* (1970) based on the biochemical analysis of coconut water. Abraham and Mathew (1963) and Abraham *et al.* (1966)., based on their studies of 6 month old nuts, observed that size of nuclei varied considerably in the developing endosperm. They found that the tissues adjacent to the endothelium were normally triploid (3X = 48), less frequently hexaploid (6X = 96) and still less frequently dodecaploid (12X = 192) and proposed that higher ploidy levels arise by C-mitosis. They also recorded an inverse relationship between ploidy and percentage oil content, with the inner part of the endosperm having the highest ploidy level and lowest oil content (Abraham, 1963; Abraham *et al.*, 1965). In the Tall variety, the percentage oil content in the outer, middle and inner layers of endosperm was 75.7, 54.1 and 41.4, respectively. Abraham *et al.* (1965) recorded higher ploidy levels (48X and above) in buttery endosperm (Philippines Makapuno coconuts) which they felt arose through amitosis and nuclear fusion.

Unlike the endosperm, the young coconut embryos are diploids and divide by normal mitosis. Raveendranath and Ninan (1973) studied karyomorphological features of somatic chromosomes from six month old embryos and observed an essential uniformity in relative chromosome length from root tip (Nambiar and Swaminathan, 1960) and embryo cells of WCT palms. Ninan and Raveendranath (1965) reported occurrence of a haploid embryo in a WCT palm.

7. Abnormalities in Coconut

In addition to the varieties and forms of coconut discussed earlier, a number of abnormalities have been reported by different workers. Davis has observed and reported most of the abnormalities in coconut palms while Menon and Pandalai (1958, 1960) have compiled these in their Coconut Monograph. Subsequent workers have also reported similar as well new abnormalities in natural coconut populations. These abnormalities are freaks of nature and not distinct varieties; from the botanical point of view although some of them are utilized commercially.

7.1. Polyembrony

This is a phenomenon wherein a single nut produces more than one seedling (Figure 4.13). This has been reported sporadically in different places and upto five seedlings have reported to emerge from a single nut. Furtado (1927) was the first to conclude that this phenomenon is due to the development of many embryos from one ovule and not due topolycarpy as was previously believed. Davis (1979) has reviewed polyembryony in coconut.

Figure 4.13: Polyembryony in Coconut.

7.2. Branching of Stem

This is a rare phenomenon and has been reported by a number of workers (Ridley, 1907; Burkill, 1923-25; Furtado, 1923-25; Quisumbing, 1926-27; Jacob, 1935; Davis, 1947, 1950a, 1956a; Indiresh, 1992; Mao and Lai, 1993). There are many more unpublished reports, both from India as well as other parts of the world. Branching is found to take place at all stages of growth and from various regions of the stem (Figure 4.14). Branching is a commercially important phenomenon as it can help obtain increased yields with less planting space

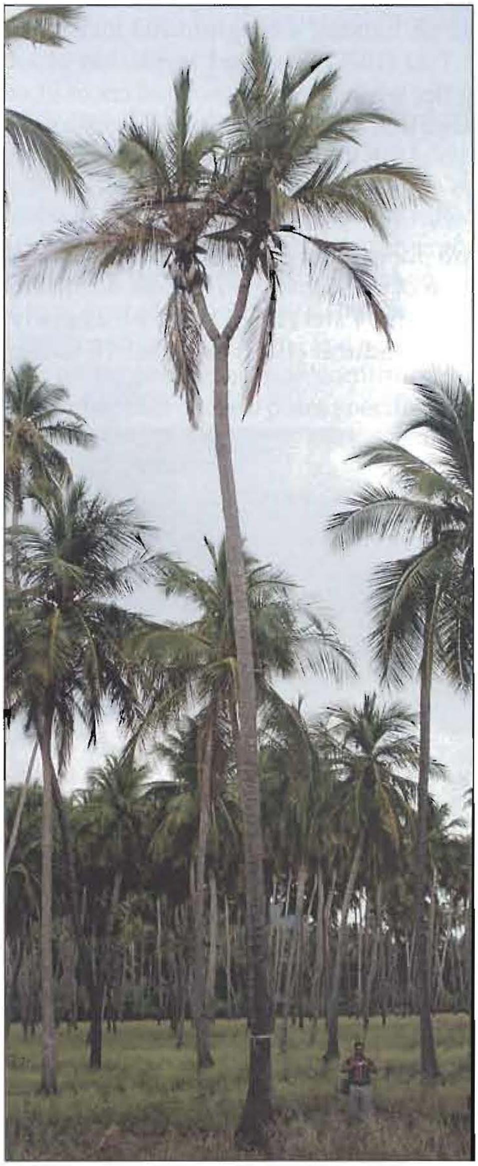

Figure 4.14: Branching.

Branching in coconut has been attributed to a number of causes. In a young palm, when the growing point is injured, from the meristematically active ground tissue of the bole the adventitious buds develop and form a new growing point. Branching is also induced when the terminal bud is injured by lightening, fire, and storm or as a result of some insect/pest attack. Davis (1950a) and Jacob (1935) have reported instances of branching due to dichotomy and stem fascinations, respectively.

Davis (1968) and Balaga (1975) were able to induce branching in coconut seedlings, but with a very limited success. They observed formation of neomeristems of adventitious origin, on making a longitudinal incision in the shoot of young seedlings. Fisher and Tsai (1979) observed formation of a twin shoot, emerging from a single growing tip, while growing isolated coconut embryos *in vitro* (tissue culture). They concluded that this was a case of branching, possibly arising due to an injury to the embryo at the time of dissection and culture.

7.3. Suckering

This is another rare phenomenon, synonymous to branching, but restricted to the underground portion of the stem (bole) (Figure 4.15). Shortt (1885) reported six shoots in a seedling. In India, Patel (1938) reported as many as 40 suckers arising from the base of palm. Aiyadurai (1959) reported 18 suckers. Davis (1956b) and

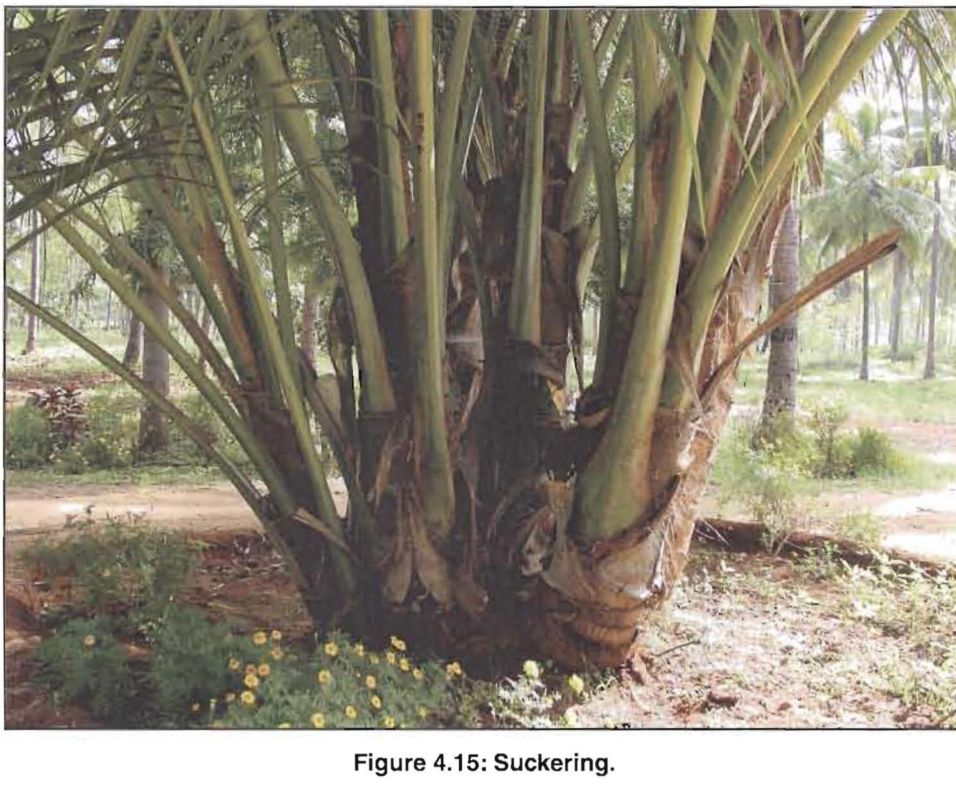

Figure 4.15: Suckering.

Chatterjee (1959) have reported a number of instances of suckering in coconut palms. Recently, at the Central Plantation Crops Research Institute, Research Centre, Kidu, suckering has been observed in three seedlings belonging to three different varieties. Suckering was also observed in a seedling in a farmers garden at Arsikere. Suckering is an economically interesting phenomenon as it offers the possibility for vegetative propagation of the palms through stimulation of the suppressed basal buds. However, what exactly stimulates the development of suckers is still unknown. Davis (1960) and Michael and Varghese (1963) were able to induce 2-3 suckers by causing mechanical injury to the growing point. However, as the number of suckers produced is less, this cannot be used for commercial propagation of palms.

7.4. Bulbils

A naturally occurring, rare bulbiferous coconut palm among West Coast Tall population was identified (Jerard *et al.*, 2014a) at the Central Plantation Crops Research Institute, Regional Station, Vittal in Karnataka State, India. The palm produces only bulbil shoots in leaf axils in place of normal inflorescence (Figure 4.16). The identified palm happened to be twins in which one member was more vigorous than the other, but both of them produced only bulbil shoots instead of floral parts. Morphological and molecular studies on these palms revealed the main palm and their bulbil progenies are genetically uniform. The genetic uniformity of the twin mother palms and their bulbil progenies was confirmed through microsatellite analysis using 10 polymorphic SSR primer pairs specific to coconut and has been well demonstrated to differentiate coconut cultivars. The primary and secondary

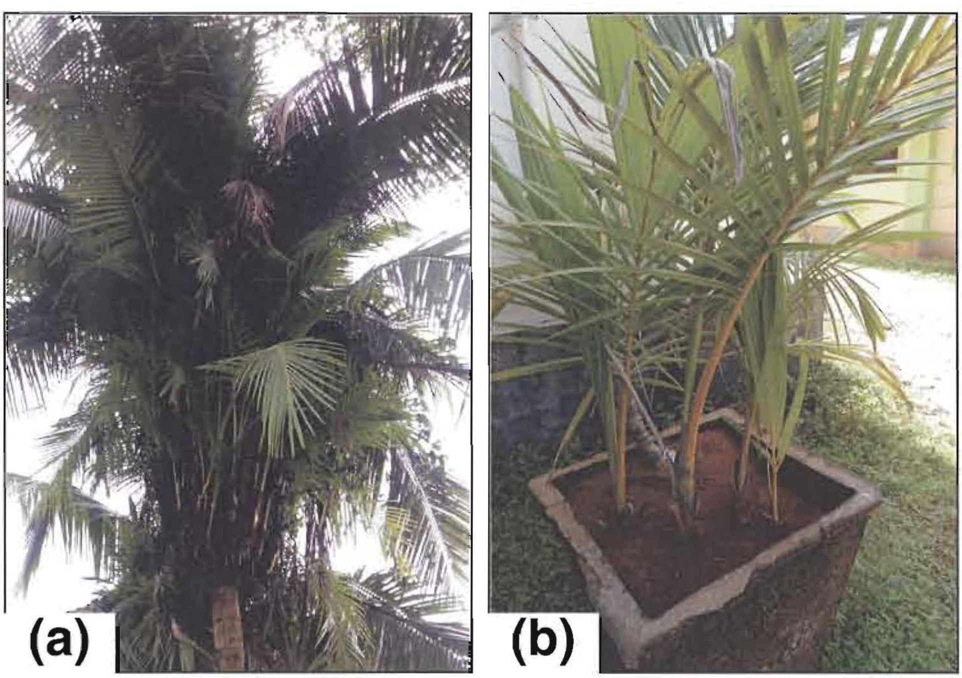

Figure 4.16: Bulbil Producing Coconut Palm (a) and Rooted Bulbil Progenies (b).

bulbil shoots were found to be capable of growing into independent plants making it possible to use them as propagules to develop a homogeneous clonal population hitherto unavailable in coconut. The bulbils showed axillary growth in 6–12^{th} leaf axil which further again develop as secondary bulbils indicating the complete vegetative state of the palm. Comparison of shoot apices of a normal seedling with bulbil shoot revealed variation in cell growth pattern. Conservation of bulbiferous palms as a unique genetic resource needs to be taken up to utilize these rare sources for future breeding programmes, provided their seed-fertility can be restored.

In addition to these three abnormal palms, many more abnormalities have been reported and are summarized as listed in the following pages:

7.5. Albinism

In coconut nurseries, a few albino seedlings (Figure 4.17) are observed at very low frequencies (<0.1 per cent). These seedlings do not respond to manurial treatment and generally die after producing 4-6 leaves. Patel (1938) opinioned that albinism is due to genetic factors, while Furtado (1926-29) believed that albinism in coconut seedlings was the result of chlorosis due to the absence of ferrugineous products in the endosperm. Pandalai and Pillai (1959) concluded that the inability of the plant to utilize the iron in the leaves results in the albinic condition. The mobilization of iron appears to be controlled by recessive gene/genes, since albinism is an inherited character. However, with the advent of modern tools, it should be

Figure 4.17: Albino and Normal Seedlings.

possible to use albino seedlings to identify genes associated with iron metabolism for further genetic manipulations in this crop.

7.6. Rosette Seedling

Arunachalam *et al.* (2001) reported two rosette seedlings in a farmer's garden at Batlagundu village in Dindigul district of Tamil Nadu, India. These seedlings have an unusually high number of leaves, closely arranged giving a rosette like appearance. The collar girth of these seedlings was very high. Such rosette seedlings have been observed in the coconut nursery at ICAR-CPCRI, India at low frequencies (>1 per cent). The growth and development of such seedlings is to be monitored to gain insight into their precocity and bearing habit.

7.7. Chimera

In palms showing chimera, green and yellow variegations are observed in fruits/leaves. This is due to somatic or bud mutation and has been reported from India and Sri Lanka (Satyabalan, 1997). It is possible that variations in colour of the fruits can occur within a bunch (both yellow and green fruits in a bunch) or in different bunches (green fruits in one bunch and yellow fruits in another bunch) of a palm. Recently a young coconut seedling showing chimera was observed at the ICAR-Central Plantation Crops Research Institute, Research Centre, Kidu, wherein part of a leaf was observed to be albino (white/yellowish white) while the rest were dark green. Subsequently produced new leaves also showed this chimeric pattern (Figure 4.18). Chimeras, especially in palms, being rare in nature, garner a lot of demand in the ornamental horticulture sector.

Figure 4.18: Palm Showing Chimera.

7.8. Abnormal Leaves

Abnormality in the leaves is rare. Patel (1938) reported fused leaflets in adult coconut palms, wherein the leaflets are fused and do not separate as in ordinary palms (Figure 4.19a) and attributed it to genetic and environmental factors. Zuninga *et al.* (1970) grouped these palms under the name 'plicata'. The palms with fused leaflets are referred to as plicata in Philippines and India and as Niuyabia in the Fiji Islands (Satyabalan, 1997). Subsequent research workers (Sugimura *et al.*, 1994a; Arunachalam *et al.*, 2001) have observed that plicata palms have reduced leaf length and are poor bearers with a long juvenile period. Moa and Lai (1993) reported sterility in plicata palms. Boron deficiency can also cause the leaflets to remain fused, but in contrast to palms suffering from boron deficiency, the plicata palms do not respond to borax application.

Davis (1956c) described some other abnormalities like forked leaves, twin leaves, fused leaves, multi-leaf etc. Lily (1962) observed formation of secondary midribs in some of the leaflets in a leaf in a 10 year old palm. The secondary midribs

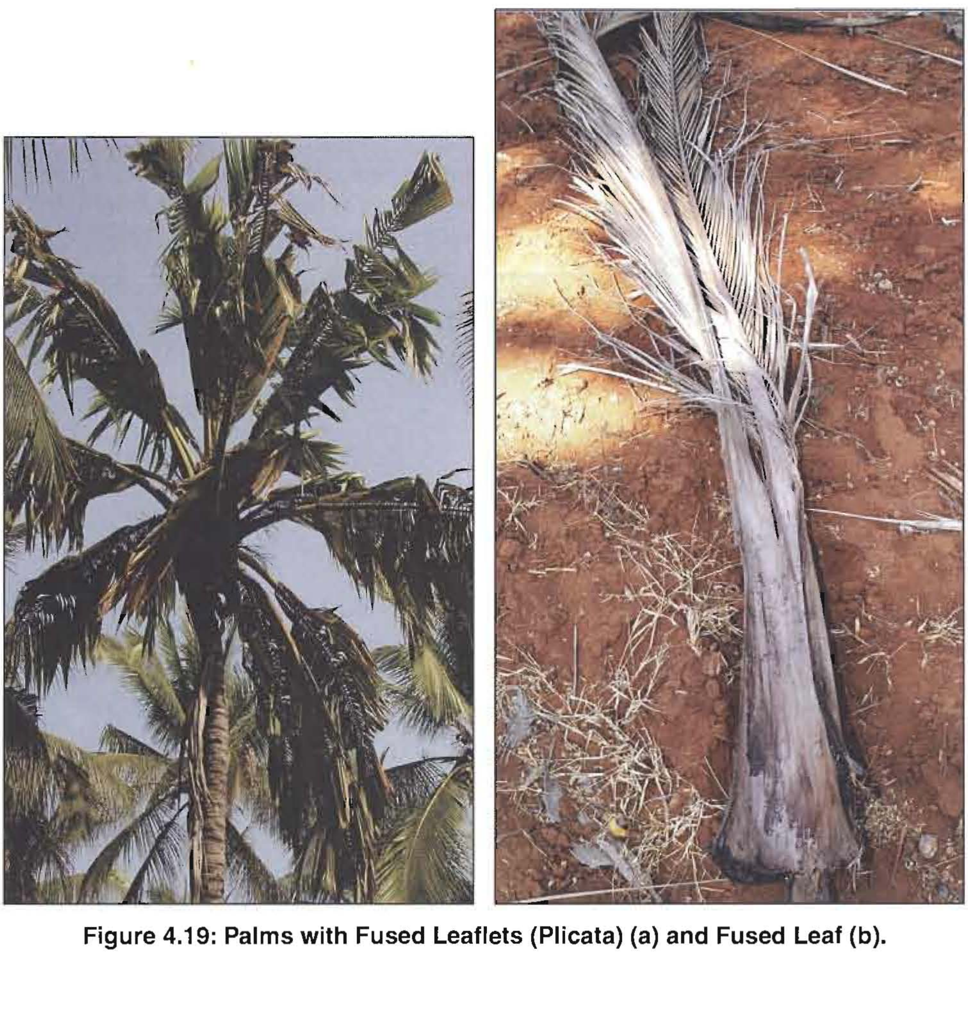

Figure 4.19: Palms with Fused Leaflets (Plicata) (a) and Fused Leaf (b).

were smaller in size than the normal midribs. However, Lily (1962) concluded that this could also be considered as a case of fused leaflets. Recently at ICAR-CPCRI, an abnormal leaf was observed in an otherwise normal palm, wherein the leaf had a single petiole fused at the base but with distinct lamina bearing portion having normal midrib and leaflets (Figure 4.19b).

7.9. Double Spadix

Davis (1957a) first reported the occurrence of a double inflorescence. Each of the two spadices was independent with a fully developed spathe and normal spikelets bearing male and female flowers. However, the outer spathe was common to both the spadices. A palm with double spadices in each leaf axils was also reported recently at Kasaragod of Kerala in WCT population indicating the possibility of natural occurrences of such palms.

7.10. Multispathe

In a normal inflorescence, only four bracts are visible. The third bract enlarges to form a spathe that encloses the spadix. At the base of spathe and extending a third of its length is the second bract that has transformed to a fibrous sheath to protect the spathe during the early stages of development. At the base of the outer spathe is the first/outer bract, which is about 25 mm long and scaly. The fourth bract is a scaly bract at the base of the spadix. Davis and Menon (1952) reported a bispatheate palm wherein all the inflorescences in the palm had two fully developed spathes. In these palms, the fifth/innermost bract develops to the size of the original spathe and both these spathes completely cover the spadix till its emergence. Subsequently many workers from various coconut growing countries have reported the occurrence of bispatheate palms. Thomas and Mathew (1960) reported a trispatheate coconut palm. Michael (1963), however, observed a multispatheate coconut palm wherein the inflorescence had five fully developed spathes, the outer spathe enclosing four closely set inner spathes. Here again, the first and second spathes originated from the third and fourth bracts of the inflorescence. However, the origin of the third, fourth and fifth spathes were unclear and were hypothesized to have originated from the rudimentary bracts generally found at the base of the spadix. The higher number of the spathes offers greater mechanical protection for the spadix and also more protection against insect attacks. Moa and Lai (1993) have reported multispatheate palms at Hainan Island, China.

7.11. Partial Suppression of Spikes

Davis (1957a) reported an inflorescence abnormality, wherein about half the spikes towards the basal end of the inflorescence were reduced and in extreme cases represented by one or two flowers only. However, the spikes at the distal half develop normally and bear male flowers. The main axis is extended and bears numerous female and male flowers. In the recent past, the authors observed a freak palm with abnormal inflorescence, wherein spikelets develop only upto the level of female flowers and the terminal portion where the male flowers are supposed to be produced is completely absent (Figure 4.20). Only a few male flowers are present, located alongside the female flowers. The spicata type also has very few male

Figure 4.20

flowers but they are located on the unbranched spike. Such abnormal palms with reduced spikelets have immense potential in the studying the genes associated in inflorescence development and possibly contribute to the development of female lines, that can serve the purpose of male sterile lines in other crops.

7.12. Secondary Branching of Spikes

This is generally reported in the male inflorescences of the sexually dimorphic palms and the male coconut tree (Figure 4.21a). The male coconut tree has been first reported from India by John and Narayana (1942) and is also referred to as Androgena. The inflorescences bear a larger number of spikes and most of which are branched (Figure 4.21b). In addition, numerous spathes or highly developed bracts are also seen. The male coconut trees have also been reported from China (Mao and Lai, 1993), Jamaica and Markham Valley, New Guinea (Whitehead, 1966). Ninan *et al.* (1960) observed meiotic abnormalities such as aneuploidy in a few cells in Androgena palms. Sugimura *et al.* (1994b) observed secondary branching of spikes in two of the five inbred lines of Markham Valley Tall, but with a normal pre-bearing period.

7.13. Unbranched Spikes

Palms with unbranched inflorescences has been reported very rarely in about all coconut growing regions. Inflorescences of the Spicata palm has a central spike which is unbranched or rarely with 1-2 branches (Figure 4.22). This type of palm was claimed to be discovered and named Spicata by Jacob (1941) But Reyne (1948) contested this claim and reported that such a palm was already described and referred as Spicata by Beccari (1916). Boldingh (1920) also mentioned the existence of such palms called as Kelapa Brol. The inflorescences of the Spicata palms bear a large number of female flowers (125-130) with very few male flowers (50). This

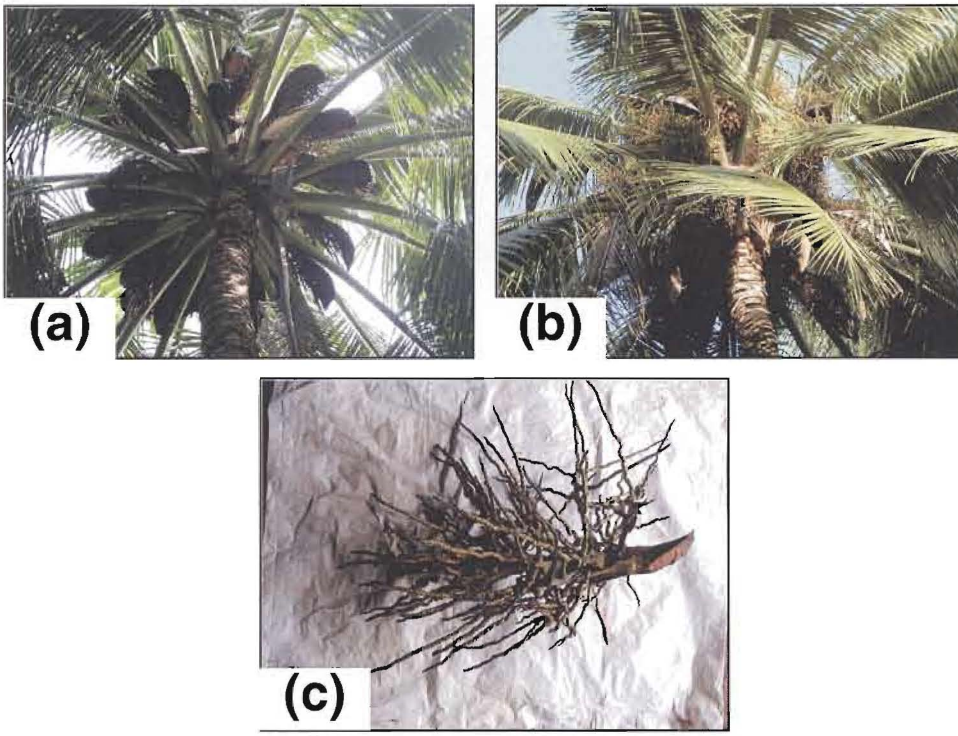

Figure 4.21: Male Coconut Tree (a); A Palm with Branched Spikes (b); Branched Spike (c).

is unlike the normal inflorescences that are branched with 30-35 spikelets carrying innumerable male flowers and few female flowers at the base of each spikelet (0-4). However, the nut set is low, with Jacob (1941) observing 10 per cent setting, while Sugimura *et al.* (1993) reported 4 per cent setting.

The Spicata palms cross freely with other coconut varieties on selfing, John and Narayana (1949) found that only 50 per cent of the progenies breed true to the mother. Whitehead (1965) on crossing a tall parent with pollen of the dwarf Spicata, observed the resultant hybrids to be intermediate in form and precocity. Whitehead (1966). reported that these hybrids had lesser inflorescence branches and therefore, advocated that the spicata character is incompletely dominant or pleiotropic. Ninan and Nambiar (1974) observed that the hybrids from crosses of Tall and Spicata show a low proportion of male flowers per inflorescence, a character associated with Spicata.

Palms with unbranched inflorescences referred to as Spikeless or Spicata have been reported from other coconut growing countries, *viz.* Spicata-Maure from Philippines, NiuTuave from Samoa, NiuYalewa from Fiji Islands, NgohardTapala and Niu Toga from Solomon Islands, Loholohotahia from Tonga Islands and Ma praew from Thailand. Whitehead (1966). noted spicata palms in many islands of Pacific. In New Guinea, in several villages near Madang, this character was observed

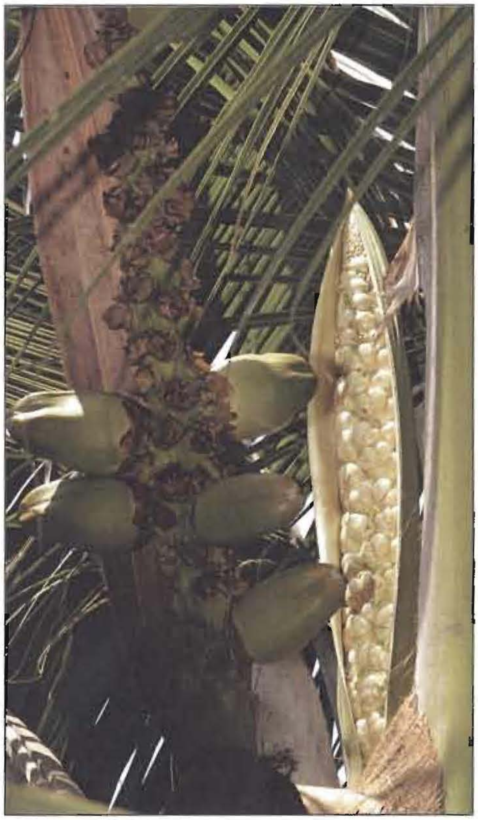

Figure 4.22: Inflorescence with Unbranched Spike.

in the small red fruited dwarf palms; prior to which this trait had not been reported in dwarfs. Whitehead also reported the absence of such palms in Jamaica.

Ninan and Satyabalan (1963) observed meiotic abnormalities and a high degree of pollen sterility in Spicata palms. Subsequently, Ninan and Raveendranath (1972). undertook further cytological studies in these palms and observed that the 15th pair of chromosomes is heteromorphic: one member has an additional terminal knob. Barring this, the chromosomes of this variety are similar to those of the typical tall variety. This heterozygous condition accounts for segregation following open-pollination of Spicata into about 50 per cent tall plants having the normal branched inflorescence and 5000-8000 male flowers and 50 per cent Spicata plants. The homozygous, knobbed condition has not been observed.

7.14. Twin Spikes

This was first observed by Davis (1957b) and appears as branching in a spikelet, resulting in two branches. This is reported to arise either due to the partial fusion of adjacent spikes or partial forking of a spike. They bear both female and male flowers.

7.15. Fasciated Spikes

This was also first observed by Davis (1957b) and also observed subsequently in the coconut population at ICAR-CPCRI (Figure 4.23). It is believed to arise due to injury to the spike, either mechanical or due to insect attack, at the meristematic stage of development, which induces rapid growth and expansion of its surface area. In such fasciated spikes, branching and re-branching is also observed. The fasciated spikes have been reported to bear only male flowers, which are generally sterile and under developed.

Figure 4.23: Fasciated Spike

7.16. Terminal Inflorescence

The terminal inflorescence or hapaxanthic spadix has been reported from India and Indonesia. Here, the inflorescence emerges from the terminal portion and then the palm dies. This is observed in abnormal cases, like the midget palm, which put forth an inflorescence in the seedling stage itself. Davis and Menon (1953). and Davis (1955) first reported the curious phenomenon of coconut seedlings producing inflorescences within twelve months of sowing and referred to then as midget palms.

7.17. Hermaphrodite Flower

Gopala Rao (1948) reported the occurrence of a bisexual flower in coconut. Subsequently, Davis *et al.* (1954). described the occurrence of hermaphrodite flowers along with male and female flowers in an inflorescence. The hermaphrodite flowers are located in between the female and male flowers in a spike and are generally bigger than the male flowers and smaller than the female flowers (Figure 4.24). Some of these hermaphrodite flowers develop into nuts, but of a smaller size than the normal nuts. Bisexual flowers arise due to the development of the staminodes into normal stamens in a female flower.

Figure 4.24: Hermaphrodite Flowers, along with Normal Male and Female Flowers.

Davis *et al.* (1981) recorded at least one hermaphrodite flower in 27 per cent of the MYD palms studied. They reported that at the time of emasculation of these palms for dwarf X tall hybrid seed production, most hermaphrodite flowers are mistaken for female flowers, thereby, leading to production of undesirable dwarf seedlings similar to the seed parent. Another type of bisexual flowers arises due to the rare development of the pistillodes in the male flowers. Furtado (1926-29) and Patel (1938) have reported the occurrence of banana-like fruits amongst the normal nuts in an inflorescence. Based on their position in the bunch, they concluded that these were the result of the development of the normally abortive ovary of the male flowers.

7.18. Apocarpic Ovary

Rare instances of complete or partial apocarpic fruits have been reported in coconut. Under normal circumstances, the three carpels in a female flower are completely syncarpic till receptivity. Even in the fruit, the three carpels develop as a unit and are distinguished by the three ridges running from the stigmatic to the stalk end and the three ridges and three eyes on the endocarp. Apocarpy is considered as a primitive character and therefore their rare occurrence in coconut can be considered as atavism. Gadd (1924) reported an abnormal female flower wherein the three carpels were fused only at the base and free to a larger extent at the apex. Costerus and Smith (1923a) hypothesized that the horns in coconut fruits are formed as a result of the apocarpic nature of the ovary.

7.19. Polycarpy

In a normal coconut fruit, each carpel has a single ovule, but in the tricarpic ovary only one embryo develops and produces a shoot. In rare cases, polycarpy has been observed (Figure 4.25). Jacob (1940) described a two-seeded coconut; wherein the two seeds were separated by leathery septum while, the third ovule was aborted. Davis (1948c) and Daniel Sundararaj (1952) observed a three-seeded coconut with three fertile eyes giving rise to three shoots, one each from each eye. Forbes (1979) reported a nut with 14 carpels, all of which germinated to produce a tree with fourteen stems united at the base.

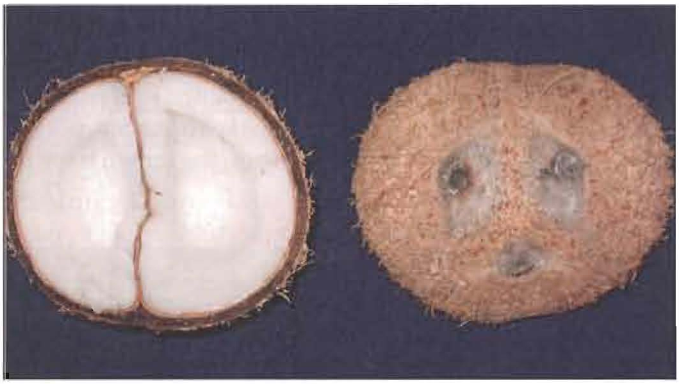

Figure 4.25: Split Open Fruit: a) Normal, b) Polycarpic of Two Seeded Coconut.

7.20. Variation in Number of Carpels

A normal female flower has three syncarpic carpels with an embryonic ovule. In rare instances, mono, bi and tetracarpic fruits have been reported with the fruits being one-seeded (Davis, 1948c). Davis and Menon (1953). observed that some flowers in the midget palm were bicarpellary. The authors during the course of fruit component studies in germplasm at ICAR-CPCRI have come across two and four carpels fruits, but at very very low frequencies. Davis has also observed young coconut fruits having 4-10 carpels (Menon and Pandalai, 1958).

7.21. Variation in Number of Pistillodes, Stamens, Perianth

The male flowers, normally have three valvate petals and three smaller triangular and valvate sepals while the female flowers, have three huge sepals and three smaller and thinner petals and a bract and a bracteole. Davis observed certain flowers with a larger number of perianths, with one flower having 13 perianths. In one particular female flower, Davis and Menon (1957 unpub.) observed seven perianth parts and concluded that the seventh perianth was a developed pistillode. They also observed a male flower with six sepals and six large petals with a single ring of 12 stamens with well-developed anthers and six pistillodes. Certain abnormal male flowers having 7/8/10 stamens and 4/5 pistillodes have also been recorded (Menon and Pandalai, 1958).

7.22 Persestent Inflorescence

Recently, one of the authors, observed female flowers with three whorls of sepals in a coconut population in Assam, India (Figure 4.26). The of this trait in terms of adaptation or tolerance to biotic/abiotic stress is to be expressed.

7.23. Vivipary

Venkataraman (1928) has recorded a rare instance wherein the buttons/young nuts in a spadix instead of developing into normal fruits grew into bulbils somewhat resembling miniature seedlings. This transformation was visible at a very early stage in the development of the inflorescence, even before the spathe had fully opened, as even the unfertilized ovules in the tender inflorescences had started to produce growth primordia. Venkataraman also referred this as a case of parthenogenesis. Das and Thakur (1996). in their article on the production and prospects of coconut in Assam have reported the occurrence of vivipary in certain pockets within the state. At CPCRI, incidences of fruits germinating on the crown have been observed

Figure 4.26: Female Flower with Three Rows of Sepals.

in MYD (Figure 4.27). Viviparous coconuts have also been reported from Indonesia also (Satyabalan, 1997). Vivipary was reported to occur in Andaman Green Dwarf cultivar (Sankaran *et al.*, 2012) and was interpreted as an adaptive reproductive strategy that enables seedlings to establish more rapidly and subsequent dispersal by water or other means. While comparing the viviparous germination in seed nuts of selected dwarfs and WCT, Shareefa *et al.* (2014) reported higher level of vivipary (24 per cent) in MYD followed by MOD and MGD (16 per cent) and the least in WCT (0.6 per cent). They also observed significant positive correlation of that this trait with prevailing climatic conditions like amount of rainfall, number of rainy days and relative humidity during the preceding 30-day of harvest.

7.24. Horned Nuts

A number of workers have reported the occurrence of coconut fruits bearing flat horns ranging from one to six (Figure 4.26). This has been attributed to various reasons, like development of the staminodes (Davis and Menon, 1957), duplication of the segments of the gynoecium (Petch, 1924), apocarpic nature of the ovary (Costerus and Smith, 1923a; Gadd, 1924; Davis and Menon, 1953) and hypertrophy of the perianth parts (Furtado, 1926-29). Nair and Sadanandan (1976) have studied anatomically the development of horn-like structures in some coconut fruits from initiation to maturity. A germplasm accession *viz.*, Andaman Horned Cocos with Distinct Character of Horny Nuts was collected from South Andaman and conserved

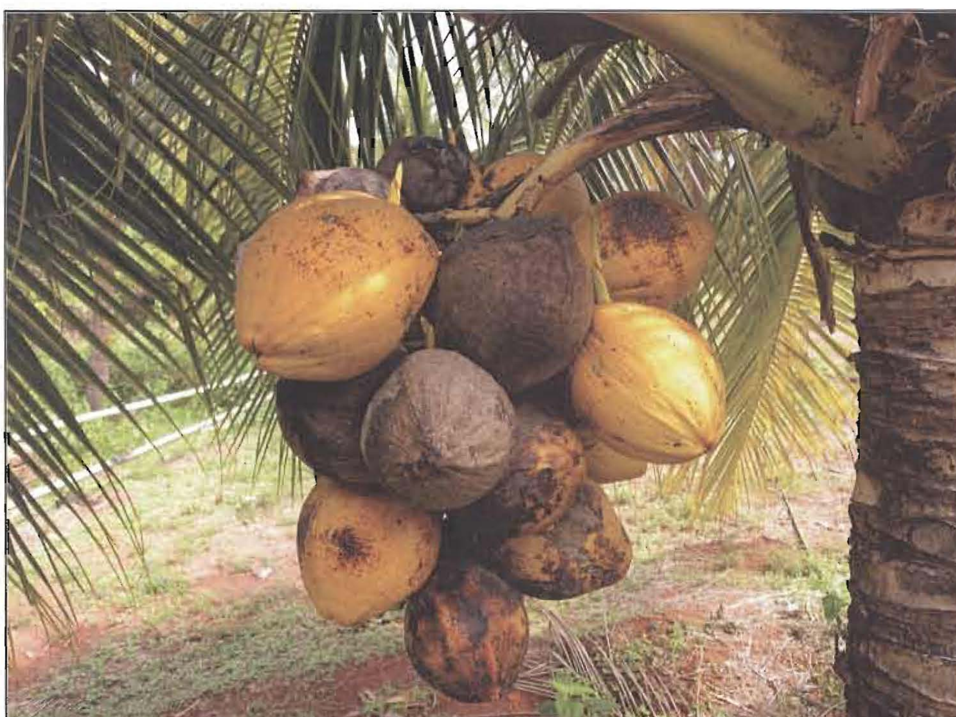

Figure 4.27: Vivipary in Malayan Yellow Dwarf.

at ICAR-CPCRI and the accession has been registered for its distinct trait (Jerard *et al.*, 2014b).

7.25. Double Ovary

Chandrasekharan and Sundararaj (1950) reported a coconut fruit having an additional horn-like structure representing an additional ovary. They observed that on longitudinal splitting of the fruit and the horn, the bigger fruit had a normal epicarp, fibrous mesocarp and hard enocarp enclosing the kernel while the horn also had these three distinct layers of the fruit, except for the fact that the endocarp was a solid structure of 0.25 cm thickness. Because of the presence of the endocarp, the authors attributed this development as an ovary and since both the fruit and horn were covered by a common perianth and ring of staminodes, they considered it as an instance of double ovary.

7.26. Sweet Husk

Menon and Pandalai (1958) have reported certain palms wherein the young buttons have higher sugar content and less tannin content in their pericarp. In normal cases, due to the higher percentage of tannin, the sweetness in the pericarp of young buttons is masked resulting in an astringent taste. In these rare instances, the husk is sweet with less fibre and can therefore be eaten like sugarcane. The nuts of these palms yield very fine white coloured fibre. The retting period required for these husks is also comparatively less. Tampake *et al.* (1982) has reported the occurrence of palms with sweet edible husk in Indonesia. The variety Kaithathali from Kerala is reported to have sweet husk and is chewed by the sea farers as an antidote to sea sickness. Sweet-husked varieties have been reported from other coconut growing countries: Navasi Thembili (Sri Lanka); Kalpa Tebu (Indonesia); Kalpa Logi (Malaysia); Cuyamis, Caumanis, Tabal, Tamisan, Mais (Philippines); Uta (Rotuma, Fiji Islands); Preug-wan (Thailand); Nu wa or Cocos sucre (New Caledonia); Cay dua bong (Vietnam) and Coco gra of Seychelles. During a recent exploration during 2016, the sweet husked type of Kalpeni Island of Lakshadweep was revisited by one of the authors. While the young buttons tasted sweeter with

Figure 4.28: Inflorescence and Fruits of Andaman Horned Coconut.

Figure 4.29: Matured Fruit of Sweet Husked Coconut (Less hard fibres and white dust).

soft fibre, the matured fruits had less number of pale coloured hard fibres and more of pale or white coloured dust when compared to the normal matured coconuts (Figure 4.29). The attachment of the husk to the nut at dry maturity stage was also observed to be loose, gave a soft feeling when pressed and a produced a dull sound when tapped. Similar types were also observed in Nicobar group of Islands.

7.27. Buttery Kernel

The kernel of a mature coconut is normally hard, but in certain palms the fruits have a thicker and softer flesh of a buttery consistency with less liquid endosperm which is viscous (Figure 4.30). Patel (1938) recorded rare instances wherein the internal cavity of the shell was filled with a jelly-like substance of the consistency

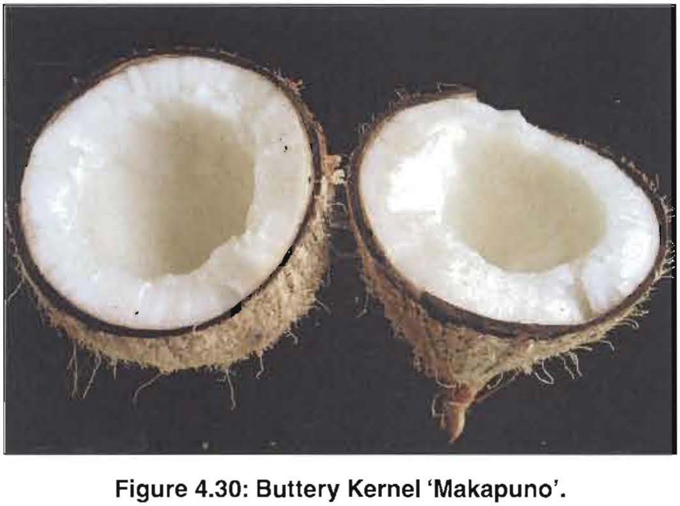

Figure 4.30: Buttery Kernel 'Makapuno'.

of thick curd and locally referred to as 'thairuthengai' (curd coconut). This is similar in consistency to the buttery kernel observed in the 'makapuno' coconut described by Torres (1937). Adriano and Manahan (1931). distinguished three different types of endosperm in such nuts: nuts with a hard outer layer (hard as boiled rice), a soft viscous middle layer and a semi-liquid inner layer of endosperm; nuts with a hard outer layer (hard as boiled rice) and a soft viscous middle layer and nuts with one layer of endosperm, hard as boiled rice, filling the whole central cavity.

Torres (1937) suggested that the Makapuno expression is controlled by a single recessive factor and that the Makapuno palms are heterozygous for this trait as normally only a few fruits in a bunch have buttery endosperm. Zuninga (1953). obtained the expected Mendelian ratios in the progeny of Makapuno. However, Cruz and Ramirez (1968). advocated a more complex behaviour, considering the different types of Makapuno being found and the differences in nuclear behaviour between various Makapuno types. Makapuno nuts are similar to the Dikri nuts of Sri Lanka, Klapadadah of Malaysia, Kelapa kopyor of Indonesia, Coco gra of Seychelles, Cay dua bong of Vietnam and are used in preparation of specific coconut delicacies and fetch a premium prize. The embryos though normal in size do not germinate under natural conditions. However, they germinate in vitro when cultured in appropriate nutrient media. Cedo *et al.* (1984). based on their observations from controlled pollination studies with Makapuno palms derived from embryo culture concluded that makapuno coconuts are homozygous and that pollen produces a xenia effect. Satyabalan (1953). observed that one out of every 10 fruits in a bunch in a palm of the variety Philippines Laguna at C.P.C.R.I., Kasaragod, had rugged/ warty kernel. The kernel was not sweet but had a lesser fibre content and had an oily taste/flavour. However, the embryo was normal. In the recent years, soft kernel types were collected at ICAR-CPCRI from Andaman Islands (Jerard *et al.*, 2013) and Kerala (CPCRI, 2014) belonging to Andaman and WCT coconut populations, respectively. The fruit component studies in the soft kernel types indicated that the fresh kernel is having lesser fibre, oil and sweetness. The tender nut water from

Figure 4.31: Tender Nut Water from Normal and Soft Kernel Coconut Types.

soft kernelled fruits was more viscous due to suspended kernel tissue (Figure 4.31) and recorded higher TSS.

Mujer *et al.* (1983). based on his biochemical studies on normal and makapuno coconut endosperm observed higher galactomannan deposition in makapuno endosperm. Subsequently, Mujer *et al.* (1984a,b) concluded that makapuno is a mutant type and that the makapuno endosperm occurs due to a deficiency in the activity of the enzyme alpha-D-galactosidase. Samonte *et al.* (1989). observed that the activity of three galactomannan degrading enzymes *viz.* alpha-D-galactosidase, beta-mannanase and beta-mannosidase were consistently low during endosperm maturation in the makapuno endosperm as compared to normal endosperm.

7.28. White Testa

The testa in a normal coconut is brownish in colour, while in rare instances the testa has been observed to be white (Tampake *et al.*, 1982).

7.29. Mini Micro Fruit

This is a rare occurrence wherein the palm produces very minature-sized fruits of the size of an arecanut. This was first reported from Lakshadweep by Jacob (Anon., 2000). Such palms have also been reported from Palghat and Coimbatore. The mature fruits of the Mini Micro palm is similar in size to the buttons or immature fruits of a normal tree (Figure 4.32). The nut contains a thick endosperm with a small central cavity. The size of the embryo is similar to that of normal nuts. However, it does not germinate on its own, owing to the limited quantity of endosperm in the nut, but when transferred to culture media, the embryos germinate.

Figure 4.32: Mini Micro Palm and the Fruit.

The inflorescences of the mini micro palms bear a large number of female flowers, even upto 80-100 in a spikelet and 25-30 spikelets in an inflorescence. However, the setting percentage is poor, thereby producing only 30-40 nuts in a bunch. Again, only about 10 nuts in a bunch possess kernel and embryo. The palm is highly susceptible to coreid bug infestation, with almost 100 per cent infestation in the fruits. The kernel is very sweet to taste. An accession of Laccadive Mini Micro

Tall with distinct character of extremely smaller fruits with very low copra content was registered for the trait by ICAR-CPCRI (Jerard *et al.*, 2014c).

In addition to these abnormalities and rarities, a few other exceptional types are: palms producing fragrant endosperm (Klapawangi of Malaysia, Aromatic Dwarf of Philippines, Nam-horn of Thailand etc.), thick shelled nuts (Poropol of Sri Lanka, Tutapaen of Philippines, thick shelled types observed in India, China, Indonesia etc.), thin husked fruits (Kelapa Bawang/Onion Coconut of Indonesia, Lupison of Philippines) and pink husked fruits (Ran Thembili of Sri Lanka, Guelle Rose of Mauritius, pinkish mesocarp types observed in India, China, Indonesia etc.). Another oddity in coconut is the persistence of leaf bases and inflorescences, as seen in certain other palm species like Palmyra palm.

8. Conclusion

Understanding the botany, growth and development of coconut assumes importance due to the versatility of crop for its suitability in different growing conditions and its capability to adapt itself to different management conditions. Perhaps coconut is one of the oldest crops with greater uniformity of appearance, grown in different parts of tropical world. The natural evolution, selection and adaptive traits have helped the crop to overcome the barriers to spread across regions, from sea coast upto 1000 m elevation from MSL. The widely accepted and functional classification of the coconut palm groups all the cultivars into two groups *viz.*, Talls and Dwarfs, on the basis of a few important characters like stature, growth characteristics, precocity in flowering and fruit characteristics. Concerted studies to develop more robust techniques of grouping the populations/cultivars, will facilitate comprehensive characterization of the coconut genetic resources. With growing challenges arising from the vagaries of nature and climate change, further insight into the adaptive traits will facilitate the development of resilient and adaptive varieties to the benefit of the coconut community. The utilization of this useful palm including breeding, production and other aspects of research are elaborated in the subsequent chapters.

References

Abraham, A and Thomas, K.J. (1962). A note on the *in vitro* culture of excised coconut embryos. *Indian Coconut Journal* **15**: 84-88.

Abraham, A. (1963). Chromosome constitution and oil content in the coconut endosperm. *J. Indian Bot. Soc.*, **42A**: 1-3.

Abraham, A. and Mathew, P. M. (1963). Cytology of coconut endosperm. *Ann. Bot.*, **27**: 505-512.

Abraham, A., Ninan, C. A. and Gopinath, P. (1965). Cytology of development of abnormal endosperm in Philippine makapuno coconuts. *Caryologia*, **18**: 395-408.

Abraham, A., Ninan, C. A. and Gopinath, P. (1966). Cytology of endosperm in some varieties of coconut. *Indian J. Genet.*, **26A**: 234-246.

Adriano, F.T. and Manahan, M. (1931). The nutritive value of green, ripe and sport coconut (buko, niyog and makapuno). Philippine Agriculturist, **20**: 195-198.

Aiyadurai, S.G., Mohammed Ibrahim, P.A., Ramanathan, T. (1959). Multiple seedlings from a germinating coconut. *Science and Culture*, **24**: 339.

Anonymous. (2000). Research Highlights 1999. *Central Plantation Crops Research Institute*, Kasaragod, India.

Arunachalam, V., Jerard, B.A., Damodaran, V., Ratnambal, M.J. and Kumaran, P.M. (2005). Phenotypic Diversity of Foliar Traits in Coconut Germplasm. *Genetic Resources and Crop Evolution*, **52:** (8): 1031-1037.

Arunachalam V., Jerard B. A., Elangovan M., Ratnambal M. J., Dhanapal R., Rizal S. K. and Damodaran V. (2001). Unexploited diversity in coconut palm (*Cocos nucifera* L.). *Plant Genetic Resources Newsletter*, **127**: 39-43.

Balaga, H.Y. (1975). Induction of branching in coconut. *Kalikasan*, **4**: 135-140.

Beccari, O. (1916). Il genere *Cocos* Linn. e le palme af-fini. L'agricoltura Coloniale 10: 435-471.

Blume. 1847 on certain domestic Palms found under these names in the Philippines.'

Boldingh, I. (1920). Over de veelvormigheid van der klapper. Mededlingen Afdeling Zaadteelt, Dept. van Landbouw, Nijverheid en Handel. **1**: 1-20.

Burkill, I.H. (1923-25). The fertility of branched coconut palms. *Garden's Bull. Straits Settlement* **3**: 1-2.

Cardena, R., Oropeza, C. and Zizumbo, D. (1998). Leaf proteins as markers useful in the genetic improvement of coconut palms. *Euphytica*, **102:** 81-86.

Carlos, T. (1963). Agronomic studies in some cultivars of coconut in Philippines. M.Sc Thesis, UPLB College, Laguna, Philippines.

Carpio, C.B. (1980). Biochemical studies in *Cocos nucifera*, M.Sc Thesis, Univ. of Birmingham, U.K.

Cedo, L. O; Guzman, E. V.de and Rimando, T.J. (1984). Controlled pollination of embryo-cultured makapuno coconut (*Cocos nucifera* L.). *Philippine-Agriculturist*, **67**: 100-104.

Chandrasekharan, S.N. and Daniel Sundararaj, D. (1950). Double ovary in *Cocos nucifera* L. *Current Science*, **18**: 93-94.

Chatterjee, D. (1959) on multiple seedling of coconut. *Science and Culture* **25**: 370.

Child, R. (1953). Coconut. *New biology*, 15 Penguin Books Ltd., London, 15: 25-42.

Cook, O.F. (1901). Origin and distribution of cocoa palm. *Contr. U.S. Nat. Herb.*, 7: 57-97.

Copeland, E. B. (1931). The Coconut. Macmillan and Co., London.

Costerus, J. C. and Smith, J. J. (1923 *a*). Studies in tropical teratology. *Ann. Jord. Bot. Buitenz.*, **33**: 95.

CPCRI (2014). ICAR- CPCRI Annual Report 2013-2014 Central Plantation Crops Research Institute, Kasaragod, Kerala, 142p.

CPCRI (2015). Annual Report 2014-15. ICAR-Central Plantation Crops Research Institute, Kasaragod. 126p.

Cruz, S.S.D and Ramirez, D.A. (1968). The cytology of the developing endosperm of the normal and the mutant (makapuno) coconut. *Philippine Agriculturist*, **52**: 72-81.

Daniel Sundararaj, D. (1952). Morphology of the normal and abnormal fruits in coconut. *Indian Coconut Journal*, **5**: 149-152.

Das, R.P. and Thakur, A.C. (1996). Production and prospects of coconut in Assam. In: Proceedings of the Seminar on Problems and Prospects of Agricultural Research and Development in North-East India, , 27-28 November 1995, Assam Agricultural University, Jorhat, India. pp. 165-171.

Davis, T.A. (1947). A three crowned coconut palm. *Journal of the Bombay Natural History Society*, **47**: 398-400.

Davis, T.A. (1948c). Abnormal palms of Travancore IV. Polycarpy in a coconut (*Cocos nucifera* L.). *Journal of the Bombay Natural History Society*, **48**: 704-706.

Davis, T.A. (1950a). Branching in some Indian palms. *Indian Coconut Journal*, **3**: 135-145.

Davis, T.A. (1954). Flower bunch yields numerous coconut seedlings. *Coconut Bulletin*, **7**: 202-203.

Davis, T.A. (1955). Meet the smallest member of the family. *Coconut Bulletin*, **8**: 244-246.

Davis, T.A. (1956)a. Branching in coconut palm. *Coconut Bulletin*, **9**: 197-200.

Davis, T.A. (1956b). Freaks of nature. I. Suckering in coconut palms. *Coconut Bulletin*, **9**: 179-180.

Davis, T.A. (1956c). Forked and fused leaves of the coconut palm. *Coconut Bulletin*, **10**: 51-53.

Davis, T.A. (1957a). Spadices with secondary branches or none at all. *Coconut Bulletin*, **10**: 163-165.

Davis, T.A. (1957b). Twin and fasciated spikes. *Coconut Bulletin*, **10**: 231-233.

Davis, T.A. (1960). Clonal propagation in coconuts. *Current Science*, **29**: 273.

Davis, T.A. (1962) Asymmetry and yield in *Cocos nucifera*. *Experentia*, **18**: 321-322.

Davis, T.A. (1968). Difficulties in the genetic improvement of the coconut: A promising alternative method. *Indian Journal of Genetics*, **28A**: 154-164.

Davis, T.A. (1969). Prospects of the clonal propagation of the coconut. *Ceylon Coconut Planters Review*, **6**: 1-5.

Davis, T.A. (1979). Some unusual formations in palms. *Principes*, **23**: 80-83.

Davis, T.A. and Ghosh, S.S. (1983). Phylloidy of palm spadices and flowers. *Indian Coconut Journal*, **13**: 1-5.

Davis, T.A and Menon, K.P.V. (1952). A bispatheate coconut palm.2 *Indian Coconut Journal* **6**: 30-34.

Davis, T.A and Menon, K.P.V. (1953). A midget coconut palm. *Indian Coconut Journal*. **6**: 139-144.

Davis, T.A and Menon, K.P.V. (1957) Morphology and development of horns in coconut (unpublished). Davis, T.A.; Anandan, A.P and Menon, K.P.V. (1954). Hermaphroditism in *Cocos nucifera* L. *Indian Coconut Journal*, **7**: 133-142.

Davis, T.A., Sudasrip, H and Aziz, H. (1981). Significance of hermaphrodite flowers in coconut breeding. *Proceedings of the Indian National Science Academy*, B. **47**: 527-535

de Candolle, A. (1884/1885). *Origin of cultivated plants* Volume 4: Coconut palm (*Cocos nucifera* L). Trench, London.

Dewi Hayati, P.K., Hartana, A., Suharsono and Aswidinnoor, H. 2000. Genetic diversity of Jombang coconut population based on RAPD markers. Internatl. Conf. Science and Technol. For Managing Plant Genetic Diversity in the 21st Century, 12 -16 June, 2000, Kuala Lumpur, Malaysia. P.11 (abst.).

Dutt, M. (1953). Dividing nuclei in coconut milk. *Nature*, **171**: 799-800.

Fernando, W.M.U. and Gajanayake, G. (1997). Patterns of isozyme variations in coconut (*Cocos* nucifera L.) populations. *Plantation, Recherche, Development*, **52**: 256-261.

Fremond Y., Ziller, R. and de Nuce de Lamothe, M. (1966). *The Coconut Palm*. International Potash Institute, Berne, Switzerland.

Fisher, J.B and Tsai, J.H. (1979). A branched coconut seedling in tissue culture. *Principes*, **23**: 128-131.

Forbes, H.O. (1879). Notes on *Cocos nucifera*. *J. Bot.*, **17**: 193-194.

F'urtado, C. X. (1923-25). Branched coconut palms and their fertility. Gdns'. Bull., Singapore, **3**: 274-279.

Furtado, C. X. (1926-1929) Teratological notes. A. Abnormalities in coconut palms. Gdns.' Bull. Singapore, **4**: 78-84.

Furtado, C. X. (1927). Abnormalities in coconut palms. Gdns'. Bull., **4**: 78-86.

Gadd, C. H. (1924) An abnormal inflorescence from a nut. Tear Book, Dept. Agric., Ceylon 21-23.

Gangolly, S.R., Satyabalan, K and Pandalai, K.M.(1957). Varieties of the coconut. *Indian Coconut Journal*, **10**: 3-28.

Ghose, M.(1979) ontogenetic study of stomata and trichomes in some palms. *Phytomorphology*, **29**: 26-33.

Gopala Rao, T. (1948) A note on the occurrence of a hermaphrodite flower in coconut (*Cocos nucifera* L.) *J. Indian Bot. Soc.*, **27**: 208-211.

Harries, H.C. (1970). The Malayan Dwarf supersedes the Jamaica Tall coconut: 1 Reputation and Performance. *Oléagineux*, **25**: 527-531.

Harries, H.C. (1978). The evolution, dissemination and classification of *Cocos nucifera*. *Botanical Review*, **44**: 265-320.

Harries, H.C. (1981). Practical identification of coconut varieties. *Oleagineux*, **36**: 63-72.

Harries, H.C. (1979). Nuts to the garden of Eden. *Principes*, **23**: 143-148.

Huggins, H. D.(1928). Pollination and crop production. *Agri. J., Brit. Guiana* **1**: 164.

Indiresh, K.M. (1992). Branching in coconut. *Indian Coconut Journal*, **22**: 14-15

Jack, H. W. and Sands W. N. (1922). The dwarf coconut in Malaya. *Mal. Ag. J.*, **10**: 4-12.

Jacob, K. C. (1941). A new variety of coconut palm (*Cocos nucifera* Linn.) var. spicata (K.C.Jacob). *J. Bombay Nat. Hist. Soc.*, **41**: 906-907.

Jacob, K. C. (1935). Stem fasciation in the coconut palm. *J. Bombay. Nat. Hist. Soc.*, **37**: 901.

Jacob, K. C. (1940). A bicellular coconut (*Cocos nucifera* L.) *J. Bombay Nat. Hist. Soc.*, **41**: 905-906.

Janaki Ammal, E. K. (1945). In: *Chromosome Atlas of Cultivated Plants*. Allen and Unwin Ltd., London, pp. 317.

Jerard, B.A., Damodaran V., Niral V., Samsudeen K., Rajesh M.K., Sankaran M. (2013). Conservation and utilization of *Thairu Thengai* – soft endosperm coconut accession from Andaman Islands. *Journal of. Plantation Crops*, **41**(1): 14-21.

Jerard, B. A., Rajesh, M. K., Elain, S. E., Sajini, K. K., Shafeeq Rahman, Fayas, T. P and Anitha Karun. (2014a). Scope of novel and rare bulbiferous coconut palms (*Cocos nucifera* L.). *Genetic Resources and Crop Evolution*, **61**: 1-6.

Jerard B. A, Niral V, Dhanapal R, Damodaran V, Arunachalam V, Rajesh M.K, Devakumar K, Samsudeen K, Nair R.V, Kumaran P.M, George V Thomas. (2014b) IND 221 – Andaman Horned Cocos (IC0598221; INGR13063), a Coconut (*Cocos nucifera*) Germplasm with Distinct Character of Horny Nuts. *Indian Journal of Plant Genetic Resources*, **27**(1): 66-89.

Jerard B.A., Niral, V, Samsudeen K, Jacob PM, Devakumar K, Rajesh MK, Anitha Karun, George V Thomas. (2014c). IND 331-Laccadive Mini Micro Tall (IC0598222; INGR13064), a Coconut (*Cocos nucifera*) Germplasm with Distinct Character of Extremely Small Nuts with Very Low Copra Content, not found in any other Coconut Variety. *Indian Journal of Plant Genetic Resources*, **27**(1): 66-89.

John, C.M and Narayana, G. (1942). The male coconut tree. *Madras Agricultural Journal (India)*. **31**: 75-77.

Juliano, J. B. (1926). Origin, development and nature of the stony layer of the coconut (*Cocos nucifera*) *Philipp. J. Sci.*, 30: 187-200.

Kaul, K.N. (1951). A palm fruit from Kapurdi (Jodhpur, Rajasthan Desert) *Cocos sahnii* sp. *Current Science*, **20**: 138.

Lebrun, P. Grivet, L. and Baudouin, L. (1999). Use of RFLP markers to study diversity of coconut palm. In: Oropeza, C., Verdeil, J.L. and Ashburner, G.R. (eds.) *Current Advances in Coconut Biotechnology*. Kluwer Academic Publishers Netherlands. pp. 73-87.

Lebrun, P., N'Cho, Y.P., Seguin, M., Grivet, L. and Baudouin, L. (1998a). Genetic diversity in coconut (*Cocos nucifera* L.) revealed by restriction fragment length polymorphism (RFLP) markers. *Euphytica*, **101**: 103-108

Lily, V.G. (1962). An abnormal coconut leaf. *Coconut Bulletin*, **16**: 333-335.

Lindquist, K. (1960). Cytogenetic studies in the seriola group of *Lactuca*. Hereditas, **46**: 75-157.

Liyanage, D. V. (1974). Report on survey of coconut germplasm in Indonesia. FAO, 26p.

Louis, H.I and Chidambaram, A. (1976). Inheritance studies on the phyllotaxy of coconut palm. *Ceylon Coconut Quarterly (Sri Lanka)*, **27**: 22-24.

Louis, I.H. and Chelladurai, M. (1984). Nature and frequency of insects pollinating the coconut palm (*Cocos nucifera* L.). *Indian Coconut Journal*, **15**: 12-17.

Mao, Y.T. (1959). A preliminary survey of types of coconut palms. FAO Crop *Production and Improvement Branch*, Rome.

Mao, Z.S. and Lai, Y.T. (1993). The coconut germplasm of Hainan Island, China. *Plant-Genetic Resources Newsletter*, **91-92**: 53-57

McPaul, J.W. (1962). Coconut growing in Fiji. Bulletin 38, Dept. Agric, Fiji.

Menon, K. P. V. and Pandalai, K. M. (1958). The coconut palm, a monograph. *Indian Coconut Committee*, Ernakulum, 384p.

Michael, K.J and Verghese, E.J. (1963). Production of suckers in coconut. *Indian Cocon. J.*, **16**: 106-108.

Michael, K.J. (1963). A "multi-spatheate" coconut palm. *Indian Coconut Journal*, **16**: 78-80.

Miquel, F.A.W. (1855). Flora van Neder landsch Indie. III 64-72.

Mondal, H; Mondal, R. K and Biswas, B. B. (1970). Absence of free nuclei in coconut water as revealed from biochemical studies. *Nucleus*, **13**: 10-18.

Mujer, C.V., Arambulo, A.S., Mendoza, E.M.T. and Ramirez, D.A (1983). The viscous component of the mutant (makapuno) coconut endosperm. I. Isolation and characterization. Kalikasan. *Philippine Journal of Biology*, **12**: 42-50.

Mujer, C.V., Ramirez, D.A. and Mendoza, E.M.T. (1984a). alpha-D-galactosidase deficiency in coconut endosperm: Its possible pleiotropic effects in makapuno. *Phytochemistry*, **23**: 893-894.

Mujer, C.V., Ramirez, D.A. and Mendoza, E.M.T. (1984b) Coconut alpha-D-galactosidase isoenzymes: isolation, purification and characterization. *Phytochemistry* **23**: 1251-1254.

Nair, R.B. and Sadanandan, A.K. (1976). A note on horns in coconut fruits. *Journal of Plantation Crops* **4**: 81-82.

Nambiar, M. C and Upadhyaya, M. D. (1961). Prestaining treatment and squashing for somatic chromosomes of the coconut palm. *Stain Tech.*, **36**: 31-32.

Nambiar, M. C. and Prasannakumari. (1964). Effect of root (wilt) diseases on microsporogenesis in coconut (*Cocos nucifera* L.) *Indian Coconut J.*, **17**: 93-100.

Nambiar, M. C. and Swaminathan, M. S. (1960). Chromosome morphology, microporogenesis and pollen fertility in some varieties of coconut. *Indian J. Genet.*, **20**: 200-211.

Nambiar, M.C., Thankamma Pillai, P.K. and Vijayakumar, G. (1970). Cytological behaviour of inbred generation of coconut. *Indian J Genet.*, **30**: 744-752.

Narayana, G.V. (1938). Studies in the anatomy of *Cocos nucifera* Linn. – structural and developmental (unpub).

Narayana, G.V and John, C.M. (1949). Varieties and forms of coconut. *Madras Agric. J.*, **36**: 349-366.

Ninan, C. A and Nambiar, M. C. (1974). Cytology and origin of spicata coconuts (*Cocos nucifera* L. var. *spicata*). In: *Advancing Frontiers in Cytogenetics* (ed.) P. Kachroo, Hindustan Publ Corp New Delhi, India, pp. 175-188.

Ninan, C. A and Raveendranath, T. G. (1965). A naturally occurring haploid in the coconut palm (*Cocos nucifera* L.). *Caryologia*, **18**: 619-623.

Ninan, C. A and Raveendranath, T. G. (1972). Why spicata palms do not breed true? Chromosome studies provide the answer. *Coconut Bull.*, **3**: 2-4.

Ninan, C. A and Satyabalan, K. (1963). Cytogenetic studies in the genus *Cocos*. II. Some observations on the spicata character in coconuts (*Cocos nucifera* L). *Indian Coconut Journal*, **16**: 109-114.

Ninan, C. A; Pillai, R. V and Josy Joseph. (1960). Cytogenetic studies in the genus *Cocos*. 1. Chromosome number in *C. australis* and *C. nucifera* L. varieties. spicata and androgena. *Indian Coconut J.*, **13**: 129-134.

Niral, V., Arunachalam, V., Augustine Jerard, B., Samsudeen, K, and P. M. Kumaran. 2006. Planting material production in coconut through seeds as influenced by genetic variability. In: *Book of abstracts of lead papers and poster papers*, National Symposium on improving Input Use Efficiency in Horticulture, August 9-11, 2006, Bangalore, pp. 64.

Ohler, J.G. (1984). Coconut: Tree of Life. FAO Plant Production and Protection Paper 57, Food and Agriculture Organization, Rome, Italy, 446 pp.

Padmanabhaan, D. (1963). Leaf Development in Palms. *Current Science*, **32**: 537-539.

Padmanabhan, D. (1984). Ontogeny of plications in palm leaf - a new theory. *Journal of Swamy Botanical Club*, **1**: 59-67.

Pandalai, K.M and Pillai, R. V. (1959). Albinism in coconut seedlings. *Nature*, **184**: 1163.

Patel, J. S. (1938). The coconut: a monograph. Madras, Government Press, 311p.

Perera, L., Russell, J.R., Provan, J. and Powell, W. (1999). Identification and characterization of microsatellite loci in coconut (*Cocos nucifera* L.)and the analysis of coconut populations in Sri Lanka. *Molecular Ecology*, **8**: 344-346.

Periasamy, K. (1965) Morphological and ontogenetic studies in palms II. Growth pattern of the leaves of *Cocos nucifera* and *Borassus flabellifer* after the initiation of plications. *Aust. J. Bot.*, **13**: 225-234.

Petch, T. (1913). The flower of the coconut. *Trop. Agriculturist*, **41**: 449-55.

Petch, T. (1924). Homed Coconut. Tear Book, Dept. Agric., Ceylon, 20-21.

Pursglove JW (1985). Tropical crops: monocotyledons, 5th edn. Longman, London

Quisumbing, E. (1926-27). Branching in coconut. *Philipp. Agric.*, **15**: 3-11.

Ratnambal, M.J., M.K. Nair, K. Muralidharan, P.M. Kumaran, E.V.V. Bhaskara Rao and R.V. Pillai. (1995). *Coconut Descriptors. Part. I.* CPCRI, Kasaragod, Kerala, India. 198p

Ratnambal, M.J., Niral, V., Krishnan, M. and Ravikumar, N. (1999) *Coconut Descriptors Part II*, CD- ROM, C.P.C.R.I., Kasaragod, Kerala, India.

Rattanapruk, V. (1970). Thailand. In: *FAO Coconut Breeding* (q.v.). pp. 31-33.

Raveendranath, T.G. and Ninan, C.A. (1973). A study of somatic chromosome complements of tall and dwarf coconuts (*Cocos nucifera* L.) and its bearing on inter-varietal variation and evolution in coconuts. *J. Plant. Crops*, **1**: 17-22.

Raveendranath, T. G., Nair, P. N. and Ninan, C. A. (1975). Chromo-somes of a bulbiferous palm. *Coconut Bull.*, **6**: 2.

Reyne, A. (1948). De cocos palm. In: De landbouw in de Indiche Archipel, IIA, Hall, C.J.J. van, and Koppel, C. van de: Van Hoeve, *The Hague*, pp. 427-525.

Richardson, D.L., Harries, H.C and Balsevicius, E. (1978). Coconut varietés in Costa Rica. Variedades de cocoteros en Costa Rica. *Turrialba*, **28**: 87-90.

Ridley, H.N. (1907). Branching in palms. *Ann. Bot.*, **21**: 415-22.

Rognon, F. (1976). Floral biology of the coconut. Duration and sequence of male and female phases in different types of coconut. *Oleagineux*, **31**: 1, 13-18.

Rohde, W., Kullaya, A., Rodriguez J., and Ritter, E (1995). Genetic analysis of *Cocos nucifera* L. by PCR amplification of spacer sequences separating a subset of *copia*- like *Eco* RI repetitive elements. *J. Genet and Breed.*, **49**: 179 - 186.

Rohde, W., Decker, D; Kullaya, A., Rodriguez, J., Herran, A., Ritter, E. (1999b). Analysis of coconut germplasm biodiversity by DNA marker technologies and construction of a genetic linkage map. In: Oropeza, C., Verdeil, J.L. and

Ashburner, G.R. (eds.) *Current Advances in Coconut Biotechnology*. Kluwer Academic Publishers. pp. 99-120.

Rohde, W., Dowe, J., Kullaya, A., Santos, A., Rodriguez, J., Ritter, E. (1999a). Analysis of genetic biodiversity in palmae by dna marker technology. II International Symposium on Ornamental Palms other Monocots from the Tropics. Edited by M.Caballero Ruano. *Acta Horticulturae*, 486, Tenerife, Spain.

Samonte, J.L., Mendoza, E.M.T., Ilag, L.L., Cruz, N.B. de la and Ramirez, D.A. (1989). Galactomannan degrading enzymes in maturing normal and makapuno and germinating normal coconut endosperm. *Phytochemistry*, **28**: 2269-2273

Sampson, H.C. (1923). *The Coconut Palm*. John Bale, Sons and Danielsson Ltd., London.

Sankaran M., Damodaran V, Singh DR, Jerard B. A. (2012). Vivipary in *Cocos nucifera* L. var. Andaman Green Dwarf. *Curr. Sci.*, **103**(10): 1139-1040

Santos, J. (1929). Cytological study of *Cocos nucifera* Linn. *Philipp. J. Sci.*, **37**: 417-437.

Satyabalan, K. (1953). A note on the occurrence of 'buttery' kernel in coconut. *Indian Coconut Journal*, **6**: 152-154.

Satyabalan, K. (1993). The Coconut palm-Botany and Breeding. *Asian Pacific Coconut Community*, Jakarta, Indonesia. 214 p.

Satyabalan, K. (1997). Coconut varieties and cultivars – Their classification. *Asian Pacific Coconut Community*, Jakarta, Indonesia. 105 p.

Sharma, A. K and Sarkar, S. K. (1956). Cytology of different spe-cies of palms and its bearing on the solution of phytogeny and speciation. *Genetica*, **28**: 361-488.

Shareefa M., Thomas Regi J., Nampoothiri C.K., Karun Anitha(2014). Studies on vivipary in dwarf coconut cultivars. *Indian J. Hort.*, **71**(4): 464-468.

Shortt, J, (1885). *A monograph on the coconut palm or Cocos nucifera* L., Madras Agric. *Coll. Misc. Publ. Govt. Press*, Madras.

Sugimura, Y., Kamata, N., Rocat, D.A., Salud, C.D. and Ceniza, M. S. (1993). Cultivarietal characteristics of 'Spicata' coconut palm. *Jpn. J. Trop. Agric.*, **37**: 264-268.

Sugimura,Y., Rocat, D.A., Salud, C.D. and Kamata, N. (1994a). Characteristics of coconut palm with plicate leaves. *Jpn. J. Trop. Agric.*, **38**: 119-123.

Sugimura,Y., Rocat, D.A., Salud, C.D. and Kamata, N. (1994b). An inflorescence mutant appeared in the inbred line of coconut. *Jpn. J. Trop. Agric.*, **38**: 145-147.

Swaminathan, M. S and Nambiar, M. C. (1961). Cytology and origin of the dwarf coconut palm. *Nature*, **192**: 85-86.

Tampake, H., Kuswara, T. and Davis, T.A. (1982). Coconut germplasm survey of Nusa Tenggara, Timur Province, the initial step towards inducing drought-resistance in coconut strains. *Indonesian Agricultural Research and Development-Journal*, **4**: 52-61

Thankamma Pillai, P. K and Vijayakumar, G. (1972). A note on the cytology of an abnormal palm. *Indian J. Genet.*, **32**: 303-305.

Thankamma Pillai, P. K; Vijayakumar, G and Ravindran, P. N. (1983). Cytology of coconut. In: *Coconut Research and Development*, N. M. Nayar (ed.), Wiley Eastern Ltd., New Delhi, pp. 62-70.

Thomas, C.A. and Mathew, C. (1960). A tri-spatheate coconut palm. Bull. *Indian Central Coconut Committee*, **7**: 256-259.

Torres, J. P. (1937). Some notes on Makapuno coconut and its inheritance. *Phil. J. Agric.*, **8**: 27-37.

Venkataraman, K. (1928). Parthenogenesis in coconut. Yearbook, Dept. of Agric. Madras, pp. 29-32.

Venkatanarayana, G. (1957). On certain aspects of the development of the leaf of *Cocos nucifera. Indian Academy of Sciences*, **6**: 224-231.

Venkatasubban, K. R. (1945) Cytological studies in Palmae: Chro-mosome numbers in a few species of palms of British India and Ceylon. *Proc. Indian Acad. Sci.*, **B 22**: 193-207.

Whitehead, R.A. (1965). Flowering in *Cocos nucifera* L. in Jamaica. *Tropical Agriculture (Trinidad)*, **42**: 19-29.

Whitehead, R.A.W. (1965b). Speed of germination, a characteristic of possible taxonomic significance in *Cocos nucifera* L. *Trop. Agric. Trin.*, **42**: 369-372.

Whitehead, R.A. (1966). Sample survey and collection of coconut germplasm in the Pacific Islands (30 May–5 September 1964). Ministry of Overseas Development, HMSO, London.

Zizumbo Villarreal, D.N. and Arellano Morín, J. N. (1998) Germination patterns in coconut populations (*Cocos nucifera* L.) in Mexico. *Gen. Res. Crop Evol.*, **45**: 465-473.

Zuniga, L.C. (1953). The probable inheritance of the makapuno character of the coconut. *Philippine Agriculturist*, **36**: 402-413.

Zuniga, L.C., Villegas, L.G. and Penaflorida, G. (1970). Collection of coconut cultivars in the Philippines. In: R.G. Emata (Ed.), *Coconut Production in the Philippines.*