MORPHOMETRIC CHARACTERIZATION OF COCONUT GERMPLASM

(A Case Study at BARI Campus)

BY

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A Thesis

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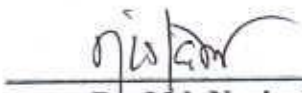

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CERTIFICATE

This is to certify that thesis entitled, **"MORPHOMETRIC CHARACTERIZATION OF COCONUT GERMPLASM"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE in HORTICULTURE**, embodies the result of a piece of *bona fide* research work carried out by **MD. DULAL SARKAR,** Registration No. **05-01814** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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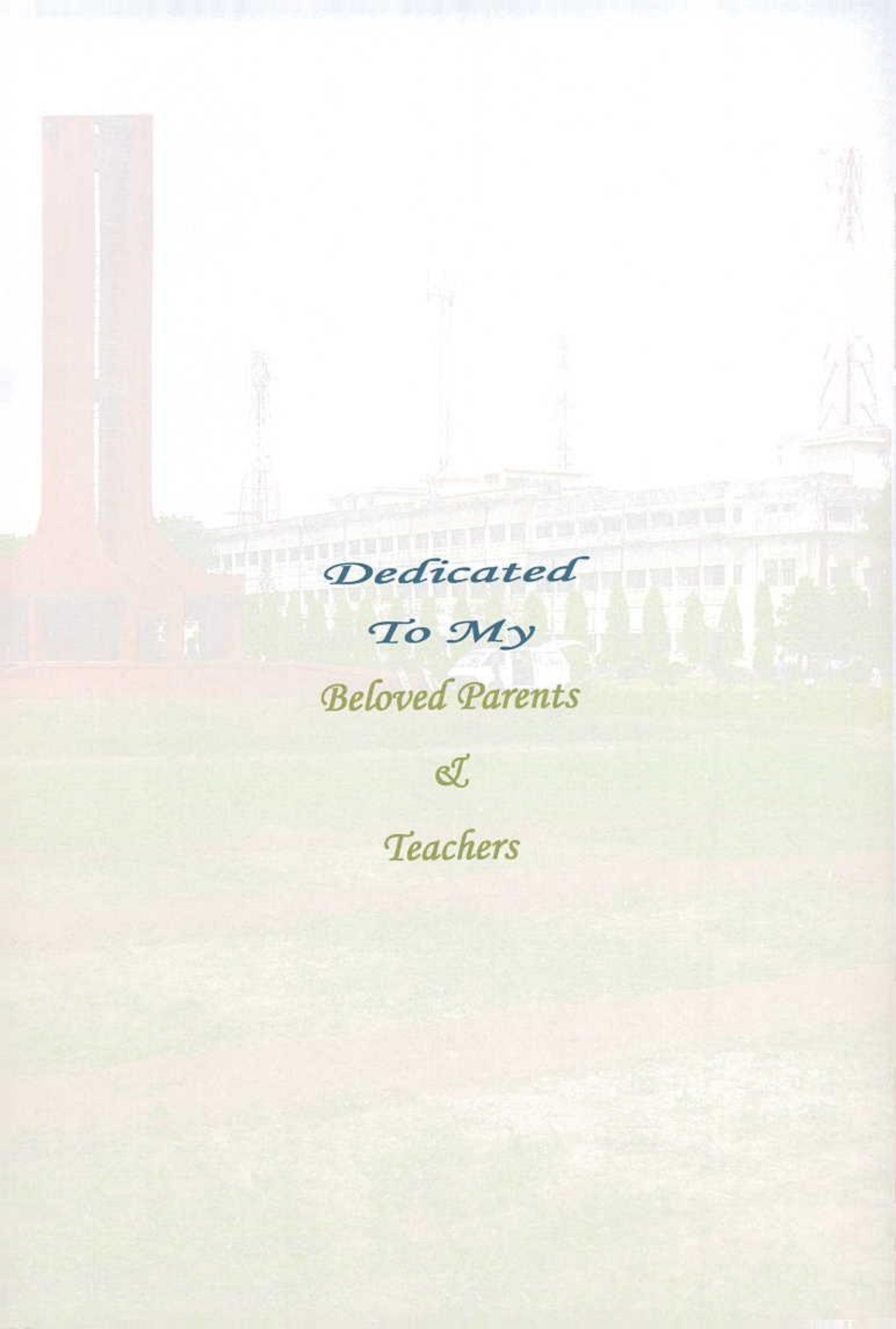

Dedicated

To My

Beloved Parents

&

Teachers

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*All praises are devoted to **Almighty Allah**, the most gracious, the most merciful, the beneficent, the lord of the Day of Judgment and the supreme ruler of the universe, Who enabled the author to complete the thesis successfully for the degree of Master of Science (MS) in Horticulture.*

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ABSTRACT

An experiment was conducted at the Pomology Research Field, HRC of BARI, Gazipur, Bangladesh during the period from September 2011 to February 2012 to evaluate the morphometric characterization of coconut germplasm. High diversity were observed in stem structure (0.97), pigmentation of leaf petiole (0.82), bole category (0.82), number of bunches per palm (0.79), girth at bole (0.77), girth at stem (0.77), length of 11 leaf scars (0.77), number of nuts per bunch (0.76) and number of nuts per palm (0.76). In the inflorescence, variation were high for duration of male phase (0.88), number of spikelets per inflorescence (0.85), length of central axis (0.84) while low diversity was observed in duration of female phase (0.47) and in crown shape (0.43). PCA revealed that days to spathe opening, days to male phase and number of nuts per palm contributed for 66.73% of the observed variation. Twenty seven entries of coconut were grouped into 7 clusters. The largest cluster VII included 9 palms, cluster VI, V and II included 8, 4 and 3 palms respectively while cluster I, III and IV included 1 palm. The inter-cluster values were maximum in between clusters III and VII (82.455) while it was minimum in between II and IV (22.351). The intra-cluster distance was maximum in cluster VII (13.210) while the clusters I, III and IV showed no distance. So, the clusters between III and VII could be used as germplasm for future breeding.

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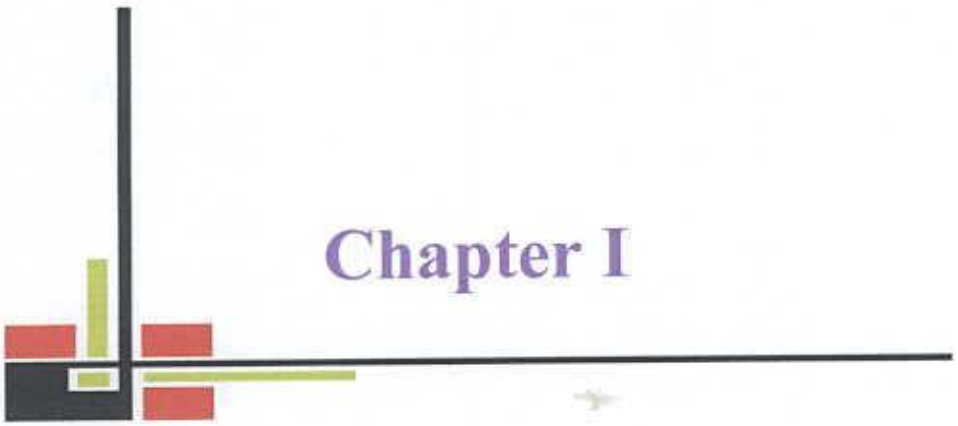
LIST OF ACRONYMS

ABBREVIATIONS	ELABORATIONS
%	Percent
@	At the rate
°C	Degree centigrade
µg	Microgram
ADB	Asian Development Bank
AEZ	Agro-Ecological Zone
Anon.	Anonymous
ANOVA	Analysis of Variance
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BBS	Bangladesh Bureau of Statistics
BSMRAU	Bangabandhu Sheikh Mujibur Rahman Agricultural University
COGENT	Coconut Genetic Research Network
CV	Coefficient of Variation
D^2	Diversity indices
df	Degrees of Freedom
DNA	Deoxyribonucleic acid
e.g.	Example
et al.	And others
etc.	Etcetera
FAO	Food and Agriculture Organization
H′	Diversity index
H_0	Nul Hypothesis
HRC	Horticulture Research Centre
IPGRI	International Plant Genetic Resources Institute
J.	Journal
MoP	Muriate of Potash

ABBREVIATIONS	ELABORATIONS
ns	Non Significant
OM	Organic manure
PCA	Principal Component Analysis
PCR	Polymerase Chain Reaction
PGR	Plant Growth Regulator
pH	Hydrogen ion concentration
Res.	Research
RH	Relative humidity
SAU	Sher-e-Bangla Agricultural University
SPSS	Statistical Package for Social Studies
SWDI	Shannon Weaver Diversity Index
UNDP	United Nations Development Program
UPGMA	Unweighted Paired Group Method Arithmetic Average
UPLB	University of the Philippines, Las Baños
UPMAC	University of the Philippines Makapuno Coconut
σ	Standard deviation
χ^2	Chi-square



Chapter I

Introduction

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INTRODUCTION

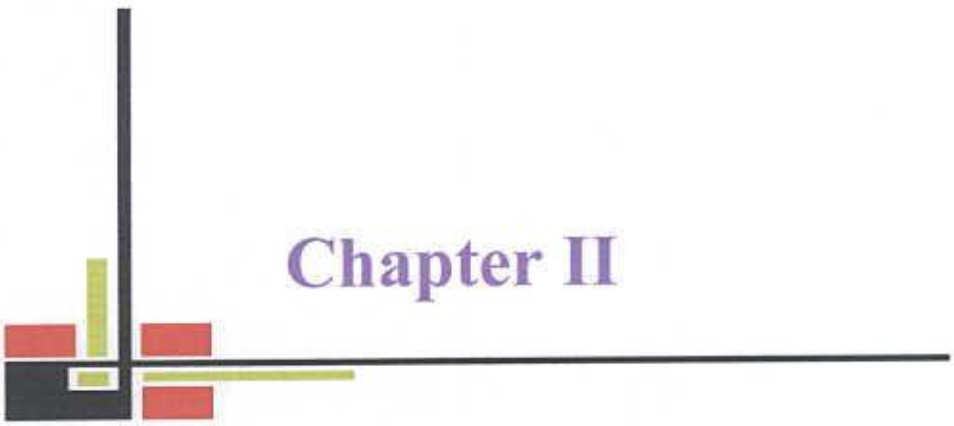
Coconut (*Cocos nucifera* L.) is a monocotyledonous plant species belonging to the family Palmaceae (Arecaceae), subfamily Cocoideae and the monospecific genus *Cocos* (Uhl and Dransfield, 1987). It is widely distributed throughout the tropics between 20° N and 20° S latitude covering about 11.6 million hectares over 86 countries (FAO, 1998). Asia and the Pacific produces 85 % of the total world coconut production. It has occupied an important place in the livelihood and culture of the people of many countries of the world for a long time. It is a homestead crop and grown sporadically throughout the country. Orchards of coconut are often found in the coastal areas as well as in offshore islands of Bangladesh. Bangladesh produces about 100 million nuts annually weighing about 90,000 tons in an area of 30,000 hectares (BBS, 2002). About 80% of coconut in Bangladesh consumed as fresh fruit and tender nut for drink purpose. Only 9 % is available for processing in oil mills (BBS, 2002). As a result, production of coconut in Bangladesh is insufficient to meet the national demand.

Coconut palm is capable of sequestrating carbon-dioxide and causing soil bio-diversification of farm product and nutrient recycle. It is a food source which provides supplement for body fluids and minerals. Every parts of coconut are important in our daily life. The main product of coconut in the world is copra, the dried kernel for extracting oil. Bangladesh hardly can produce 5000 tons of coconut oil against its yearly demand of 30,000 tons (BBS, 2002). Tall type cross-pollinated coconut is widely cultivated in Bangladesh (Ahmad, 1982). Due to cross-pollination and human selection, variations are noticed in coconut germplasm of Bangladesh. The yield of nut in Bangladesh is very low on an average 21 nuts per palm per year as compared to many other coconut growing countries in the world (BBS, 2002).

With a view to improving coconut, Bangladesh Agricultural Research Institute (BARI) collected germplasm from home and abroad during early 60s (Tabibullah and Ahmad, 1976). After a long and systematic evaluation, BARI recommended two of them for cultivation throughout the country in 1996 (BARI, 2000).

Tall type cross pollinated coconut is grown in Bangladesh for its long productive life and nut quality. Pollination habit of tall type coconut offers a chance of natural evolutionary process continuously. Collection, conservation and evaluation of germplasm offer an opportunity of exploiting advantages of natural diversity for crop improvement. Hence, an initial study on the diversity of coconut of the country is essential for documenting the genetic diversity of coconut in Bangladesh. Therefore, the study was undertaken for characterization and evaluation of coconut germplasm collected and planted at BARI head quarters, Joydebpur, Gazipur under following objectives:

1. To know the diversity of coconut germplasm conserving at BARI campus
2. To select the highly diversified coconut germplasm for cultivation and breeding purpose



Chapter II

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

2.1 Botany of the coconut

A flower cluster of inflorescence holding both male and female flowers is produced in every leaf axis after reaching a normal bearing stage of the palm (Thampan, 1993). Persley (1992) stated that male flowers, which are situated at the top portion of the spikelet and open first. The female flower situated at the base of the inflorescence and pollinated by the male flowers of the same inflorescence (incase of dwarf and hybrid) or by the other inflorescence of the same palm or other palm. Once pollination and fertilization occur, the fruit sets and develops to maturity in 11-12 months (Persley, 1992).

Child (1974) stated that, palm is a diploid with 32 chromosomes (2n=2x=32). It is monocotyledonous, with no taproot or root hairs and has a swollen base termed as the 'bole'. Its stem develops from a single growing point and reaches to a height of 12-30 m. According to Santos *et al.* (1992), the first leaves of coconut seedlings are pinnate and fused together, thus appearing as entire leaves. These unopened leaves are called spear leaves. After 8-10 leaves have been formed; subsequent leaves tend to split into leaflets. They further stated that the leaf stalk encircles the trunk and supports the weight of the bunch of nuts and is neatly abscised leaving behind a scar. These leaf scars are used to estimate the age of an adult palm. The palm's approximate age is determined by dividing the number of scars on the stem with 13 (Santos *et al.* 1992).

Coconut is a diploid with 2n=32 chromosomes. Coconuts do not form taproots, but continuously produce adventitious roots from the base of the stem. The stem is un-branched, gray, smooth and erect or slightly curved which forms a swollen bulb at the base, which is termed as bole. In Tall varieties, the boles are well-developed. Dwarf varieties have no boles. Semi-dwarf varieties (intermediate) have somewhat larger boles, when grown under favorable condition (IPGRI, 1996a). A single terminal bud located at the top of the stem

from where stem growth takes place. Internodes length increases slowly until the full width of stem is reached, a process that can take up to four years depending on the variety. At the terminal end of the stem 30-40 compound leaves were found depending on the variety and growing conditions, (Ohler, 1984).

Flowering between 3-10 years after planting depending on the cultivar. Male and female flowers are produced on a spathe and spadix type inflorescence, which emerge from the leaf axil. Cross-pollination readily occurs, producing various hybrids. Crossing between Dwarf and Tall varieties generally express heterosis (hybrid vigor) over both parents (Woodroof, 1979). Pollen fertility is very high in Tall and Hybrid and low in Dwarf and Semi-dwarf varieties (Ohler, 1999).

The fruits, basically fibrous drupes, have colors ranging from dull green, brown, brilliant-orange, yellow to ivory colored (gray color) when ripe. They are very large and come in unusual forms of ellipsoidal to broadly ovoid. They are distinctly 3-angled, stripped of its fibrous mass, the mesocarp, 3 large and slightly sunken basal pores with operculum are found (Uhl and Dransfield, 1987). To imaginative folks, this would resemble a face. The Spanish used the term 'coco 'to mean monkey (or grotesque) face. A hard shell encloses the significant embryo with its abundant endosperm, composed of both meat and liquid (Uhl and Dransfield, 1987).

2.2 Reproductive biology

A male flower is invariably shed within 24 hrs of its opening. The receptivity of the female flowers begins usually from the 20th day (after the opening of the spathe), thus enabling the female phase to alternate the male phase (Varkey and Davis, 1960). The female phase in tall populations, however, begins about 3 days after the male phase lapses and lasts only about 1-3 days (Liyanage, 1950), 3-5 days in tall and 8-15 days in dwarfs (Santos *et al.* 1992; Patel, 1938). The receptivity of the female flowers of the previous inflorescence, lapse when a new inflorescence opens and for this reason, tall populations are largely cross-pollinating (Liyanage, 1950). In some dwarfs, particularly the Malayan dwarf overlapping of the male and female phases and between spadices usually takes place, promoting selfing. Hence, the dwarfs are reasonably homozygous (Santos *et al.* 1992; Patel, 1938). The pollinating agents are insects, honeybees (*Apis indica*) and mites playing a major role (Perera, 1999).

The coconut palm is essentially monoecious having both the male and female flowers distributed in the same inflorescence (Thampan, 1993), although Davis *et al.* (1954) had recorded instances where hermaphrodite flowers are produced. The coconut inflorescence is enclosed in a double sheath or spathe, the whole structure known as a spadix, which is borne singly in each of the leaf axils (Santos *et al.* 1992). According to Thampan (1993), the inflorescence bears 30-35 spikelets bearing male and female flowers. The male flowers might number about 250-300 per spikelet so that there were about 8,000-10,000 male flowers per inflorescence. The female flowers are produced at the base of the spikelets and each of the spikelets may carry one or few female flowers. The female flowers are produced as an inflorescence which is a highly variable factor and is influenced by the season, soil condition, variety and the yield potential of the palm. In general, the number of female flowers per inflorescence varies within a wide range of 10 to 50, though figures outside this range are also not very uncommon (Thampan, 1993).

The male flowers start opening as soon as the spathe covering the spadix bursts open, thereby indicating the commencement of the male phase. This phase continues for about 18-20 days after which no live male flower is usually seen on the spadix (Varkey and Davis, 1960). Patel (1938) observed that most of the male flowers had opened by the fifteenth day after opening of the spathe. In both tall and dwarf populations, the male phase usually lasts 18-22days, starting from the opening of the spadix (Liyanage, 1950), 20 days in most palms but this may vary according to season and variety (Santos *et al.* 1992).

2.3 Fertilization, fruit set and development

Jayasuria and Perera (1985) reported that rapid increase in endosperm weight up to10 months. Accumulation of dry matter in the endosperm ceased after 11 months and increase in dry weight of whole nut ceased indicating no assimilate transported in to the nut.

Satyabalan (1953) reported a peculiarity of endosperm of normal nuts in the Laguna Tall in the Philippines, which is described as makapuno. Instead of normal endosperm, the kernel is white, soft and buttery. De Guzman and Del Rosario (1964) studied the *in vitro* germination of excised makapuno embryos and reported that the makapuno contains anatomically and physiologically normal embryo, which can be germinated in the *in vitro* propagating media.

The endosperm of coconut is composed of 95 % water and 1% oil when immature, and 50 % water and 30-40 % oil at maturity (Ohler, 1984). Coconut water forms in the third month of fertilization and reaches its maximum volume at eight months and a large coconut may contain 600 milliliters water, 30 gram sugars (fructose and sucrose) and 2 g potassium (Ohler, 1999). Thereafter, non-reducing sugars appear, but the total concentration of sugar falls to about 2 % in the fully ripened nut (Child and Nathanael, 1950). During the early stage of germination, the concentration of reducing sugar continues to fall but total sugar remains fairly constant until four months of germination.

The fruit develops from a tri-carpelate ovary giving rise to the "eyes" on stalk end of the nut. After fertilization the husk and shell grow in size and the embryo sac grow considerably. Approximately after six to seven months of fertilization, the embryo sac is filled with liquid and endosperm develops against the inner wall of the nut cavity. The endosperm at this stage is jelly-like in composition (Ohler, 1999). At the age of eight months, the weight of coconut as well as its volume is maximal but the fruit itself is still is unripe. The endosperm becomes hard and white towards the later stages of ripening. Drying up of the husk occurs coinciding with the loss of water from the cavity (Ohler, 1984).

Veloso (1983) reported that weight of whole nut decreased from10-11 months of maturity and explained that the weight loss was due to reduction of water volume with maturation drying. Water is lost through evaporation (Copeland, 1931) and volume of water in nut decreased towards the end of maturity (Menon and Pandalai, 1958 and Child, 1974).

2.4 Origin of coconut

Child (1974) and Ohler (1984) noted that the coconut originated in Southwest Pacific and reached Africa later. Seafarers, pirates and currents of sea brought coconut in to Africa during early centuries. Coconuts are also present in the uninhabited islands of Seychelles and Mauritius indicating the natural dispersal of coconut (Saur, 1967). Thus the origin of coconut is still in dispute.

Entomological evidences based on the life of rubber crab (*Birgus latro*) living entirely on coconut in Melanesia (Asia and Australia) lead to the believe that coconut originated in this area (Lepesme, 1947).

It appears from the consecutive historical and cultural evidences that coconut originated in Southwest Pacific, and has subsequently reached Africa. The references to coconut in local languages and the presence of wild type coconut in these areas support this theory.

Second theory of origin is the Indo-Pacific areas. The area spread from Zanzibar to New Caledonia, Madagascar to the Philippines, Tropical Africa, Ceylon, India, and Southeast Asia. Small fossils of *Cocos* (*Cocos Zeylantica)* discovered in Pliocene deposit about 1-115 M years before the presence in North Auckland. However, the fossils discovered in the New Zealand and Auckland does not indicate the origin of coconut. Coconut might be transferred in these areas from the place of its origin by sea current.

The origin of coconut in the world is controversial. Several theories have been proposed in this regard. Presence of wild species in America and Madagascar suggests that coconut originated in South America (Cook, 1910). But the theory has been refuted based on the difference of genus *Cocos* and *Syargus*. At the same time, coconut was discovered in the Africa and North Auckland, New Zealand. *Zeyargus* was believed to be a wild type of coconut. But presence of long pistilate flowers with round sepals and petals of *Syargus* differ from genus *Cocos* that reject the presence of ancestor of coconut in this area.

2.5 Distribution of coconut

Coconut distribution is pan-tropical, consisting of countries such as Central and South America, East and West Africa, Southeast Asia, West Indies, Oceanea and the Pacific Islands (Thampan, 1993). Coconut dissemination is due to seed nuts being transported by sea currents and later by human migration and travel (Bourdeix *et al.* 1990).

Coconut is widely distributed throughout the pan-tropical regions, of which 90 % are found in a band 20° N and 20° S latitude (Persley, 1992). Primarily seawater played an important role in dispersion of coconut by floating it to distant places. Tsunami, tidal waves, typhoons, washed ashore and carried coconut to new islands where it readily established itself on sandy beaches (Ohler, 1999; Woodroof, 1979). The thick fibrous husk facilitates the fruit to float and retain its viability until it germinates. Harries (1978) suggested fruit structure as an evolutionary process for dissemination by floating. Moreover, man has contributed to its transportation and cultivation. There are evidences in recorded history of the Indo-Pak subcontinent dating around 300 B. C. (Woodroof, 1979).

Harries (1978) reported that dissemination by floating due to fruit structure is both the result and the force of the natural selection in the process of evolution before domestication. He also reported that the evolution of the large-fruited coconut from a small-fruited progenitor could be attributed entirely to a natural selection without human intervention. The thick and fibrous husk facilitates the fruit to float and remain viable until it germinates (Harries, 1978).

Harries (1978) reported that natural dissemination by floating in sea currents could occur in seed-nuts, which were long and thick husked. This thick husk protected the coconut and therefore, germination was not affected. Edmondson (1941) found that coconut was capable of germinating after having floated in the sea for periods up to 110 days. The author also observed that during that period of time the coconut could travel about 4800 km in favorable currents. On the other hand, Harries (1978) observed that the average time to germinate was 170 days with a range of 110-230 days. The angular shape also prevents the fruit from rolling and shifting in the surf so that it remains on the beach to root and does not easily wash away again (Harries, 1978).

Harries (1978) reported that the coastal fishing communities, expectedly who were come in contact with the naturally disseminated coconut; value it as a source of liquid refreshment. He stated that the "Water" in the immature fruit was not merely portable; it was very palatable and conveniently portable when the water would inside the fruit. The author further stated that the Polynesian travelers had been noted to have selected and carried coconut as a source of water for their journey and established them, either accidentally or deliberately, on arrival. The Portuguese also carried on coconut for refreshment during voyage by ships 500 years ago (Harries, 1978). Any unconsumed nuts would be sold as curiosities in Lisbon that gave way to the establishment of coconut plantations in Brazil. According to same author, Spaniards utilized coconut in the same way and sold unconsumed fruits in the Caribbean Islands disseminating coconut to Puerto Ricu. Similarly, ships sailing to America from the Philippines, and also coastwise traffic to and from the Peruvian gold mines, would require fresh coconuts (Harries, 1978).

2.6 Classification of coconut

Cocos nucifera L. has been classified into several varieties based on morphological characters and growth habit. Menon and Pandalai (1958) primarily categorized Tall and Dwarf coconut based on the stature and their breeding habit. According to their classification, the Tall coconuts grows to a height of 20-30 m and are allogamous, late flowering and producing medium to large-sized nuts. They are slow maturing and flower 6-10 years after planting with a life span of 60-70 years. Tall coconuts are adaptable to a wide range of environmental conditions. The Dwarf coconuts grow to a height of 10-15 m and are autogamous, early flowering, and produce large number of small nuts with distinct colors and forms.

Harries (1978) identified two main types of Tall: Niu kafa, which evolved naturally and disseminated by ocean current and Niu vai, which evolved as a result of selection of Niu kafa under cultivation and was disseminated by man. Fruit components, time from ripening to sprouting and diagnostic morphological characters of Niu Vai and Niu Kafa could be distinguished from each other (Harries, 1978; Harries 1981; Gruezo and Harries, 1984).

Introgression of these two varieties and further selection and dissemination by man produced the wide range of coconut varieties, as well as their pan tropical distribution (Harries, 1978).

Niu kafa is a primitive type, possessing a high proportion of husk, thick shell and low water content, which had evolved through natural selection. Niu Vai has low proportion of husk and shell, high water content. Harries (1982) advocated that the Niu Vai type was a product of continuous selection by human for its desirable traits.

The Tall variety consists of three types namely *Typica, Spicata* and *Androgena*. The Dwarf variety consists of *Nana* and *Javanica*. This classification of Narayana and John (1949) is widely adopted in coconut breeding.

2.7 Genetic diversity

According to Brown (1989), genetic diversity is a complex, multi-dimensional structure that results in associations of characters in plants, thus describing the structure of genetic diversity through relationships. The information derived from genetic diversity studies is used to: 1) trace centers of crop diversity and routes of domestication (Brown, 1989), 2) determine the degree of relatedness among cultivars released from breeding programs (Xiao *et al.* 1996), 3) determine the relationships between the environment and diversity, 4) determine the association between plant traits and the overall patterns of relationships within and among germplasm from different regions or areas of origin (Yee *et al.* 1999), 5) resolve the phylogenetic and evolutionary history of

plant species (Croft *et al.* 1999), and 6) determine the usefulness of wild germplasm materials (Borromeo, 2000; Zhang *et al.* 1999).

Batugal (1999) stated genetic diversity as a major factor that determines yield security in future. He further stated that much diversity which contains the desirable genes for developing better varieties has been lost through planting of hybrids with narrow genetic base, high pest and disease pressures, natural calamities, urbanization and acute need for coconut lumber in the housing industry due to depleted forest resources. Therefore, he suggested to urgently locate, collect and evaluate these precious genetic materials and to conserve them before they are forever lost (Batugal, 1999).

Diversity of coconut germplasm being conserved at different Regional and Sub-stations of the Bangladesh Agricultural Research Institute (BARI) was estimated during 2001-2002 by Islam (2009). Diversity indices (D^2) ranged from 1068.96 to 171.93. Maximum diversity was observed between BARI Narikel-2 and Rahmatpur Yellow Dwarf. Genotypes of Regional Agricultural Research Station, Jessore and BARI Narikel-2 were found morphologically similar. Populations under conservation at Jamalpur and Ishwardi stations were found close to BAR Narikel-l. Similar relationships among the genotypes were reflected when they were grouped into several clusters. Out of six clusters, the members of cluster II were homogenous, while that of cluster IV showed heterogenicity.

Eyzaguirre and Batugal (1999) reported that there are two levels of diversity in coconut. One is diversity between populations resulting from human and natural selection in different environments. This is the source of much of the diversity we still need to understand and conserve for improving the adaptability and pest and disease resistance of coconut. The other is the diversity found within out-crossing populations with high levels of diversity, although a limited amount of autogamy has been identified in some populations (Bourdeix 1988; Bourdeix *et al.* 1990). According to Foale (1991), many populations have high diversity as a result of recent addition of new genetic

material by plant breeding programs through introgression. Dwarfs are less variable due to their autogamous breeding system (Foale, 1991).

Genetic diversity is the extent to which the heritable traits differ within a group of plants (Hintum, 1995). High level of out-crossing within the populations, human selection, introgression and hybridization enhanced variability and diversity. The information derived from genetic diversity is useful to determine the relationship within and among germplasm (Yee *et al.* 1999).

Genetic diversity is the sum of all variations found in cultivated species as well as in their wild relatives and this is altogether called crop genetic resources (Carcallas, 2001). Brown (1989) referred to crop genetic resources as the raw materials for plant breeding, which are very important components in any breeding program. According to the same author, these resources once assembled must be characterized and evaluated and ultimately made available to breeders and other users. Genetic diversity is not evenly distributed in space; it changes with time, and is not all equally useful to a user at a given time (Guarino *et al.* 1998).

Guarino *et al.* (1998) stated that genetic diversity in coconut is the result of species evolution taking place in the plant. One of the features that led to variation and diversity is that only a few individuals established the initial populations, which resulted in founder effect and genetic bottleneck (Guarino *et al.* 1998). These populations, however, came from a variety of sources. The low but continuing levels of gene migration among the wild-type populations are another aspect leading to coconut evolution (Guarino *et al.* 1998). High levels of out-crossing within populations, human selection, introgression and hybridization have further enhanced variability, and therefore diversity (Guarino *et al.* 1998).

Islam *et al.* (2007) assessed genetic diversity in 22 cultivars of coconut in Bangladesh and found that fruit weight (18%) and nut weight (16.5%) contributed significantly to the variation in the populations. They also stated that fruits characters are key factors in distinguishing coconut populations.

Islam *et al.* (2007) assessed genetic diversity using Mahalanobis D^2 statistic in 22 cultivars of coconut in Bangladesh. They found enormous variability in the test material. The genotypes were grouped into six clusters. Maximum inter-cluster distance (990.917) was observed between the clusters II and IV. Individuals of Clusters II (Chinashukhania) and IV (Bhola) were important for selecting parents of hybridization. Population in Cluster VI (Buikara) were found to be important for weight of fruit and husk while that of cluster IV (Bhola) were important for weight of nut, weight of nut without liquid endosperm and liquid endosperm.

Metro-glyph analysis was done by Raveendra *et al.* (1987) in a group of 23 genotypes of coconut (*Cocos nucifera* L.). The varieties came under two groups based on morphological characters. Three groups were recognized when the classification was made on the basis of nut characters. The exotic cultivars, in general, had relatively higher expression for morphological and nut characters. The possibility of obtaining heterotic hybrids from divergent parental combinations was indicated.

Morphological and molecular characterization conducted by Emmanuel (2002) revealed that variation existed between coconut from the original collecting site and the duplicate site. He reported that the inflorescence, shape of the bole, nut and fruit traits were good indicators to identify relationship and determine duplicates in the collection.

Santos *et al.* (1992) have documented standardized techniques of studying genetic diversity through morphometric methods. They used seven parameters for comparison like; stem morphology, over-all appearance of shape of crown, leaf morphology, inflorescence and flower morphology, fruits appearance and

fruits component analysis. The data gathered are subject to simple analysis of variance (ANOVA).

The variability of 39 coconut accessions collected from Tagoloan, Misamis Oriental, and Mindanao Islands in the Philippines were examined by Sugimura *et al.* (1997). Three botanical and agronomical traits identified the variation between and within the cultivars *typica*, *nana* and *javanica*. According to them *typica* and *javanica* showed high variability, *nana* was an aggregate group and *javanica* was distantly related to *typica* while, *javanica* was considered the intermediate group.

Two types of diversity are observed in coconut (Foale, 1992). One is between the population resulting from human and natural selection and from different environment. This is the source of the diversity we still need to understand and conserve for it crop improvement like pest and disease resistance. The other source is the diversity found within the out crossing populations. Populations of tall varieties are under this category of allogamous population with high levels of diversity.

Uddin (2003a) used morphological characters to assess diversity of six Tall populations in northern Luzon, Philippines Islands and found that nut weight and husk weight contributed significantly to the variation in the populations. He also stated that fruits characters are key factors in distinguishing coconut populations.

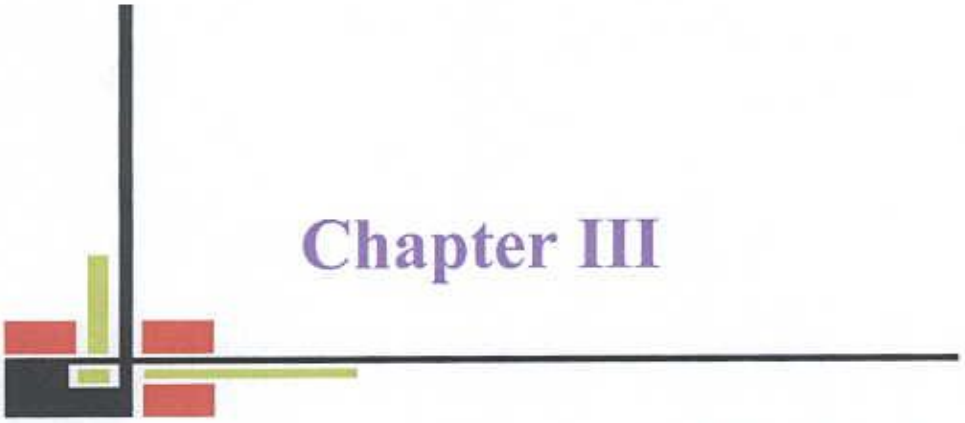
Vargas and Blanco (2000) evaluated coconut cultivars from the Pacific Coast of Costa Rica and the Philippines. They evaluated the fruit components of coconut populations and found heterogeneity in San Ramon Tall, Tagnanan Tall and Laguna Tall.

Villareal and Pinero (1998) examined the variation in germination traits of 20 cultivars to distinguish coconut populations in Mexico. They were able to distinguish three groups among the 20 cultivars.

Zizumbo-Villareal and Arellano-Morin (1998) examined the variation in germination traits of 20 cultivars to distinguish coconut populations in Mexico. They were able to distinguish three groups among the 20 cultivars.

2.8 Germplasm collection, conservation and utilization

Coconut (*Cocos nucifera* L.) has a recalcitrant seed. The size and low dormancy of seed are the main constraints in collecting and conservation of the coconut germplasm. So, it is generally conserved in the field where the risk of loss via exposure to environmental factors such as pests and diseases is a problem. *In vitro* techniques are now firmly established for collecting, propagation, distribution and storage of germplasm, which are vegetatively propagated (Ashmore, 1998). Ashmore (1997) highlighted the use of *in vitro* technique of zygotic embryo culture in the development of slow growth culture for germplasm conservation, the development of disease eliminating techniques, the development of cryopreservation technique and the application of optimal techniques for storage and distribution of germplasm. Kumaunang (2002) successfully chryopreserved the embryos of Laguna Tall coconut by two cryogenic procedures using liquid nitrogen with complete germination of up to 47% after thawing.



Chapter III

Materials and Methods

CHAPTER III
MATERIALS AND METHODS

This chapter describes the materials used and methods of the experiment done in the field to study the morpho-physiological attributes of coconut. The materials and methods that were used and followed for conducting the experiment presented under the following headings:

3.1 Experimental site and duration

The experiment was conducted at the Pomology Research Field, Horticulture Research Centre of Bangladesh Agricultural Research Institute (BARI), Gazipur under the agro-ecological zone of Modhupur Tract (AEZ No. 28) during the period from September 2011 to February 2012. The location of the site was about 35 km North of Dhaka city with 24.9^0 N latitude and 90.26^0 E longitude and elevation of 8.40 m from the sea level (Khan, 2009).

3.2 Climatic condition of the experimental site

The climate of the experimental site was under the subtropical climate, characterized by three distinct seasons, winter season from November to February and the pre-monsoon or hot season from March to April and the monsoon period from May to October (Edris *et al.* 1979). Details of the meteorological data during the period of the experiment were collected from the Bangladesh Agricultural Research Institute, Gazipur and presented in Appendix I.

3.3 Characteristics of soil

The soil of the experimental area belongs to the Modhupur Tract (UNDP, 1988) under the AEZ No. 28. Soil of the experimental field was silty clay loam in texture and acidic in nature. Soil sample of the experimental plot was collected from a depth of 30 cm before conducting the experiment and analyzed in the Soil Science Division, Bangladesh Agricultural Research Institute (BARI), Gazipur and have been presented in Appendix II.

3.4 Plant Materials

Coconut germplasm were collected from different Agro Ecological Zone of Bangladesh which was planted at BARI campus in 1998-2001 among which 27 palms of different population was selected. These entries were considered as the treatments. Coconut palms were about 10 years. Morphological and nut characters were recorded for the study.

3.5 Design and layout

The experiment was non replicated. Plant to plant distance was 8 m.

3.6 Intercultural operations

Irrigation was done 3 times during the study at an interval of thirty days. Fertilizer was applied @ 10 kg cow dung, 428 g urea, 214 g TSP, 856 g MoP (BARI, 2003).

3.7 Data collection

3.7.1 Girth at base: Girth of selected palm was recorded at 50cm height from ground level and expressed in centimeter (cm).

3.7.2 Girth at stem: Girth of selected palm was recorded at 1m height from ground level and expressed in centimeter (cm).

3.7.3 Length of 11 leaf scar: Length of 11 leaf scar was measured with the help of meter gauge and expressed in centimeter (cm).

3.7.4 Number of leaves per plant: Total number of leaves per plant were counted and recorded.

3.7.5 Length of central axis of leaves: Length of central axis of leaf was measured from the point of initiation of frond and expressed in centimeter (cm).

3.7.6 Girth of leaf petiole: Girth of leaf petioles were measured at the point of initiation of frond and expressed in centimeter (cm).

3.7.7 Width of leaf petiole: Width of leaf petiole were measured at the point of initiation of frond and expressed in centimeter (cm).

3.7.8 Length of petiole: Length of petiole of palm were measured from leaf base to initiation point of frond and expressed in centimeter (cm).

3.7.9 Number of leaflet per leaf: Total number of leaflet was counted and recorded by one side of the leaf axis.

3.7.10 Length of leaflet: Length of longest leaflet were measured from middle portion of leaf axis and expressed in centimeter (cm).

3.7.11 Width of leaflet: Width of longest leaflet was recorded from the leaflet which was selected for measuring length.

3.7.12 Number of bunches per palm: Number of bunches per palm were counted at the time of data record.

3.7.13 Length of peduncle: Length of peduncle was recorded from the base of stalk to the point of initiation of spikelets and expressed in centimeter (cm).

3.7.14 Girth at peduncle: Girth at peduncle was recorded at the base of inflorescence and expressed in centimeter (cm).

3.7.15 Width of peduncle: Width of peduncle was recorded at the point of initiation of inflorescence and expressed in centimeter (cm).

3.7.16 Length of central axis of inflorescences: Length of central axis of inflorescence was recorded from the point of initiation of spikelets to the end of peduncle and expressed in centimeter (cm).

3.7.17 Number of spikelets per inflorescence: Spikelets per inflorescence were counted and recorded.

3.7.18 Number of female flowers: Total number of female flowers of inflorescence were counted and recorded.

3.7.19 Spikelets with female flowers: Spikelets with female flowers were counted and recorded. The scars of female flower at the spikelets also considered while counting the number of female flower per inflorescence.

3.7.20 Spikelets without female flower: Spikelet without female flowers was counted and recorded.

3.7.21 Length of longest spikelet: Length of longest spikelet of inflorescence was recorded and expressed in centimeter (cm).

3.7.22 Number of nuts per bunch: Number of nuts per bunch were counted and recorded during the study.

3.7.23 Number of nuts per palm: Number of nuts per palm were counted and recorded. Fist size nut with confirm fertilization were considered during the study.

3.7.24 Days to spathe opening: Days to spathe opening were counted from the date of floral bud initiation to that of splitting spathe.

3.7.25 Days to male phase: Days to male phase was counted from the date of opening of spathe until the shedding of male flowers.

3.7.26 Duration of male phase: Data was recorded after the floral bud opening to the dried up.

3.7.27 Duration of female phase: Data was recorded from the first female reception to the last female reception of an inflorescence.

3.7.28 Crown shape: The shape of crown was observed on the basis of visual observation. The crown shape considered X-shape when leaf were absent at the middle of crown and present at the lower and upper portion of the crown represented like as English alphabet X. When the leaves cowered at the lower, middle and upper portion of crown represent spherical crown shape.

3.7.29 Bole category: Bole category was counted on the basis of visual observation. Bole category was considered when the adventitious root becomes swollen above the soil surface.

3.7.30 Base of the stem: Stem category was considered on the basis of visual observation of swollen of stem.

3.7.31 Pigmentation of spathe: Different color of young spathe was recorded.

3.7.32 Pigmentation of inflorescence: Different inflorescence color was recorded by visual observation.

3.7.33 Pigmentation of petiole: Different color of petiole was recorded.

3.7.34 Immature nut shape (polar view): Nut shape was recorded by viewing the nut through the polar end.

3.7.35 Immature nut shape (equatorial view): Nut shape was recorded by viewing the nut through equatorially.

3.8 Data Analysis

The morphological characters (descriptive and quantitative) were studied to assess the diversity within the population. Chi-square (χ^2) test, Shannon Weaver Diversity Index (SWDI), Principal Component Analysis (PCA) and descriptive statistics were used to analyze the variability in the coconut germplasm.

3.8.1 Chi-square (χ^2) Test

Chi-square (χ^2) test was used to compare the observed and the expected frequencies for each character. To calculate the expected frequencies for a uniform distribution, total of the observed frequencies was divided by the number of categories. The critical value (χ^2_c) at 95 % level of significance was determined on the basis of degree of freedom (df) and inference was made

under the following decision: Reject H_0 if χ^2 *> χ^2_c (χ^2 * is the calculated value, df = k-1 where k is the number of categories)

3.8.2 Multivariate Analysis

Multivariate analysis methods, including principal component analysis (PCA), clustering and discriminate analysis were carried out to assess the pattern of morphological variation and to group the population into classes. Differences among classes were revealed based on a set of quantitative variables.

3.8.3 Shannon Weaver Diversity Index

Phenotypic diversity for both qualitative and quantitative traits was determined by using Shannon-Weaver Diversity Index (H'). H' ranges from 0 to 1, where 1 indicates the maximum diversity (Yu Li *et al.* 1996). H' is defined as:

$H' = -\sum P_i \log_2 P_i$ where

P_i is the proportion of the total number of genotypes belonging to the i^{th} class. The exact descriptor states define the classes for the qualitative characters while the classes for quantitative characters are defined according to the procedure suggested by Yu Li *et al.* (1996) where each H' value was standardized.

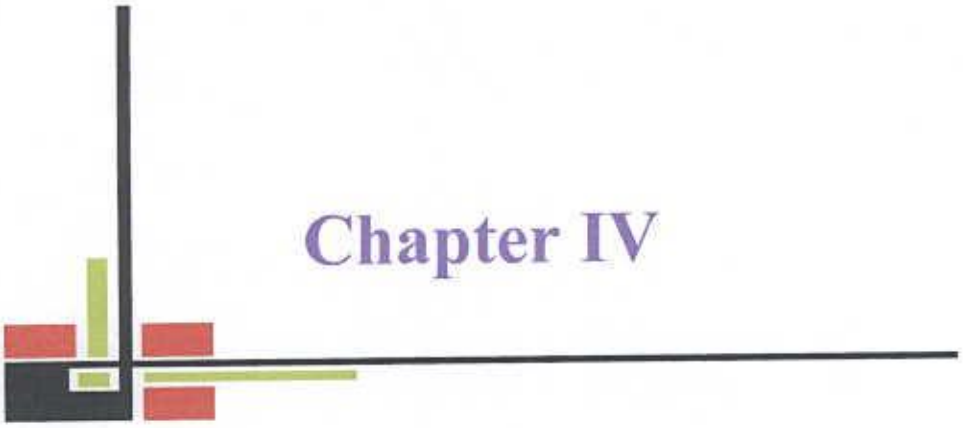
For the quantitative characters, the overall genotypes mean ($\overline{X}$) and standard deviation (σ) was used to subdivide the population values (x_i) into 10 frequency classes ranging from class 1 (if $x_i \leq \overline{X} - 2\sigma$) to class 10 (if $x_i \leq \overline{X} + 2\sigma$), the class interval being 0.5σ. The relative frequencies for the different classes were used to calculate the diversity index. The H' for each character was calculated using MS Excel. Test statistic H_0: H'=0. H' was classified as low, intermediate and high (Jamago, 2000).

3.8.4 Principal Component Analysis (PCA)

PCA estimates the structure of the correlation between the variables within a data set. It can identify the main variables (s) that significantly contribute to the variation within the data set.

3.8.5 Genetic Distances

Genetic distances of the population were determined based on morphological characters. Average distances and dendrograms were computed and constructed using SPSS package. Cluster analysis based on similarity matrices using the Unweighted Pair Group Method Arithmetic Average (UPGMA) was done. Relationships within genotypes or classes were visualized as dendrograms.



Chapter IV

Results and Discussion

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Distribution of phenotypic characters

4.1.1 Bole category

Bole is the swollen lowermost part of the coconut stem where the roots are generally localized (Figure 1). Among the palms studied, three different categories of boles were found, namely (1) no bole, (2) low bole and (3) high bole. Distributions of frequencies of bole category were found independent. The expected number of bole category for an equal distribution was 9 (Table 1 and Appendix III).

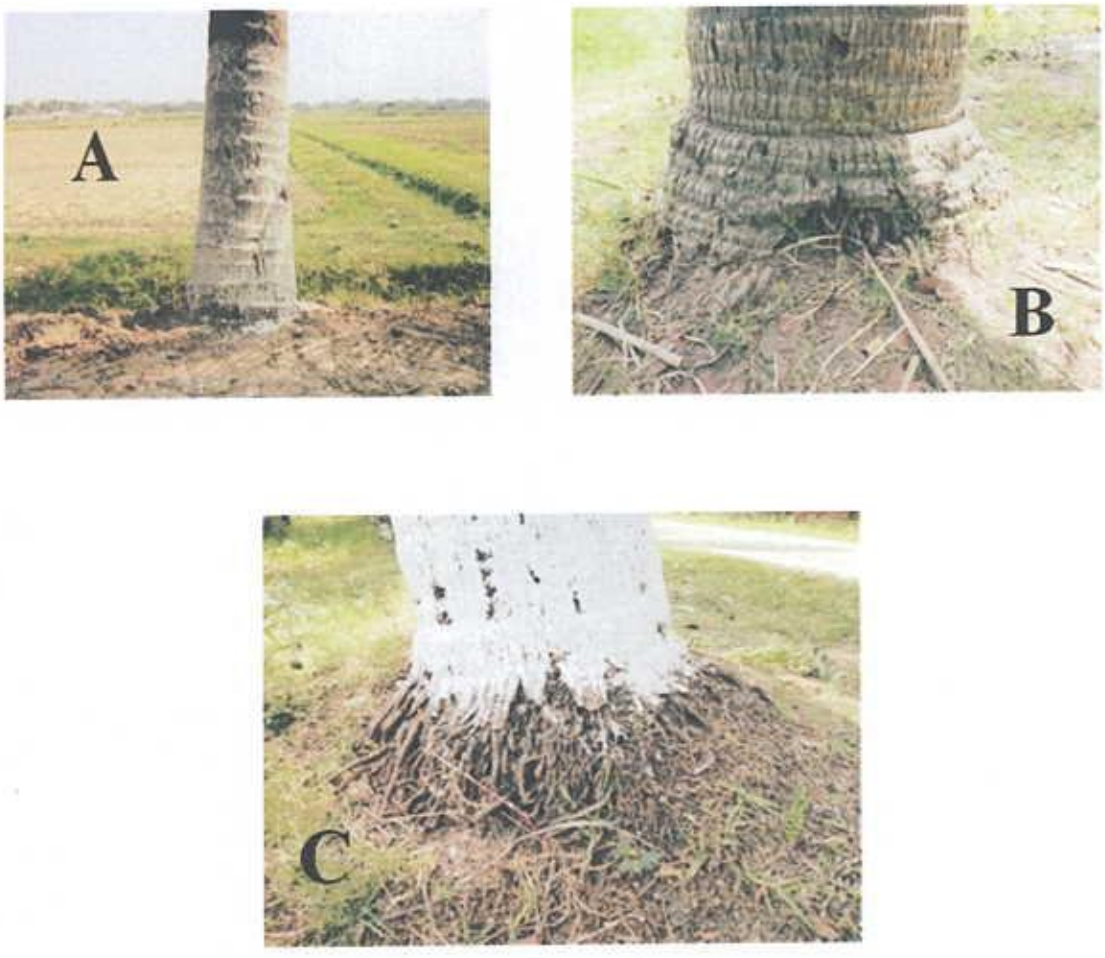


Fig. 1. Bole category of coconut population
(A-no bole, B-low bole and C-high bole)

Table 1. Bole category, stem and crown shape of coconut population

Descriptor	Observed phenotype	Number of palms		χ^2	Probability	Level of significance
		Observed	Expected			
Bole category (N=27)						
	No bole	17 (63)	9			
	Low bole	6 (22)	9	10.89	0.00	**
	High bole	4 (15)	9			
Base of the stem end (N=27)						
	Slight tapering	7 (26)	9			
	Tapering	12 (44)	9	1.55	0.46	ns
	Cylindrical	8 (30)	9			
Crown shape (N=27)						
	Spherical	23 (85)	13.5	13.36	0.00	**
	X-shaped	4 (15)	13.5			

Numbers in the parentheses are the percentages of observed values; ns = non significant; ** = significant at 1% probability

4.1.2 Stem base

Base of the palms under investigation were cylindrical, slight tapering and tapering (Figure 2). Tapering stem base was found to dominate over slight tapering and cylindrical stem base (Table 1 and Appendix III).

Fig. 2. Shape of stem base of coconut population (A-cylindrical; B-slight tapering and C-tapering)

Tapering stem base was found dominant in the population while high bole category was found minimum. These two characters distinguish Tall from Dwarf coconut (Child, 1974). However, distribution of these two characters might be due to climatic conditions, cultural practices or both. Heterozygous characters of the parents could have also contributed to the observed variation in the stem base (Foale, 1992).

4.1.3 Crown shape

Spherical and X-shaped crown were observed in the collection (Figure 3). The distribution of palms under these two categories was independent to each other and spherical shape of crown was found to dominate over X-shape (Table 1 and Appendix III).

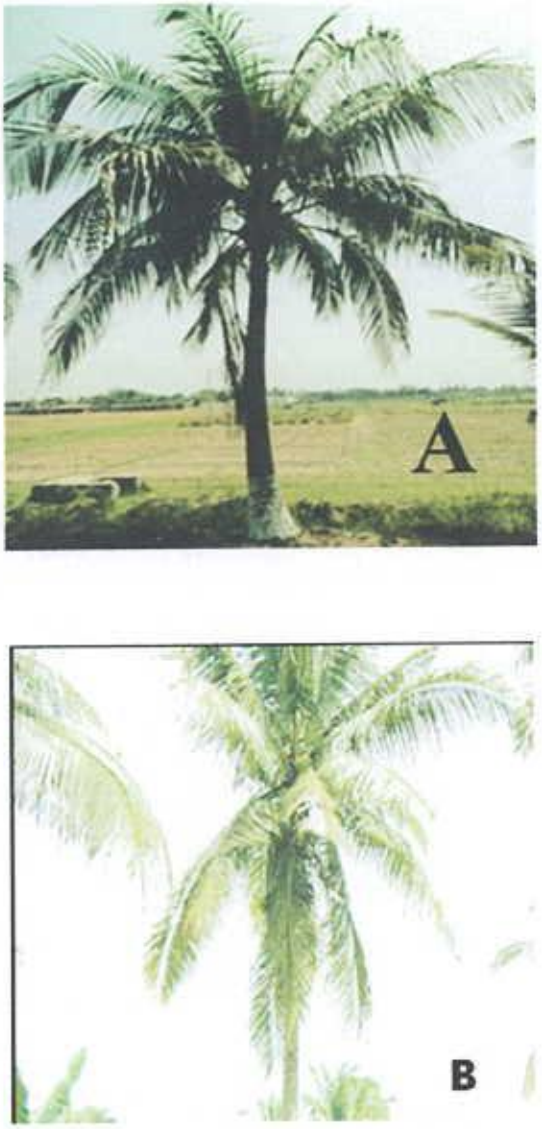


Fig. 3. Crown shapes of the coconut population
(A. spherical and B. X-shaped)

Crown shapes are the result of evolutionary process and adaptation against strong wind. The X-shaped crown could have evolved as a way of minimizing potential wind damage particularly in sea shores and elevated hills. Since, the population under study is away from the sea. The observed variation in crown shape might be inherited from the parents of diverse origin. Uddin (2003b) reported coconut populations far from the sea to have X-shaped crown too.

Table 2. Pigmentation of leaf petiole, young inflorescence and immature nuts of coconut population

Descriptor	Observed phenotype	Number of palms		χ^2	Probability	Level of significance
		Observed	Expected			
Pigmentation of petiole (N=27)						
	Green	17 (63)	9			
	Reddish green	4 (15)	9	10.89	0.00	**
	Yellowish green	6 (22)	9			
Pigmentation of young bud (N=27)						
	Yellowish green	3 (11)	13.5	13.36	0.00	**
	Green	24 (89)	13.5			
Pigmentation of young inflorescence (N=27)						
	Reddish green	5 (19)	9			
	Whitish green	3 (11)	9	16.89	0.00	**
	Yellowish green	19 (70)	9			
Pigmentation of immature nuts (N=27)						
	Green	18 (67)	9			
	Reddish	3 (11)	9	14.00	0.00	**
	Yellowish- green	6 (22)	9			

Numbers in the parentheses are the percentages of observed values; ** = significant at 1% probability

4.1.4 Petiole colors

Green, reddish green and yellowish green petioles were observed in the coconut collection (Table 2 and Appendix IV). Observed distribution of frequencies of palms of different petiole colors were found statistically different from the expected number of palms of an equal distribution (9). Green color petiole was found to dominate over reddish green and yellowish green petioles.

4.1.5 Bud colors

Green and yellowish green buds were observed in the palms collection under study (Appendix VIII). Observed distribution of palms having bud colors was statistically significant where the expected number of palms for an equal distribution 13.5 (Table 2 Appendix IV). Green bud color was found to dominate over yellowish green bud.

4.1.6 Inflorescence colors

Three distinct spadix (inflorescence) colors, reddish green, whitish green and yellowish green were observed in the collection at early stage of growth (Appendix IX). The distribution of observed inflorescence color was independent as compared to the distribution of these expected numbers. Expected number of palms for an equal distribution was 9 (Table 2 Appendix IV). Yellowish green inflorescence dominated in the population.

4.1.7 Colors of immature nuts

The observed colors of the immature nuts in the coconut collection were green, reddish and yellowish green. Palms with green nuts were dominated in the collection (Table 2 Appendix IV). The distribution of palms for each group of color was statistically different from the expected number of equal distribution 9.

Although pigmentation of immature nuts, bud, inflorescence and petioles does not improve yield or fruit quality, it can easily be transmitted to the off springs after cross pollination (Bourdeix, 1988; Ashburner *et al.* 2001), thus making it a convenient marker for selection of hybrid at the seedling stage. Bright colors of inflorescence attract insects and birds and this facilitates cross-pollination and ensures fruit set (Davis *et al.* 1954; Ashburner *et al.* 2001). Higher percentage of nut yield is ensured if a palm is pollinated by another palm.

4.1.8 Shape of immature nuts

According to IPGRI (1996b) nut shapes are described through polar and equatorial view. Three shapes round, pear and elliptical were recorded under polar view (Table 3). Under equatorial view the shapes were round, angular and flat were found (Table 3). The distributions of different types of nuts were independent to each other. Similar analysis was found in an equatorial view of nut shape. The expected numbers of palms for equal distribution of nut shape were 9 (Table 3 and Appendix V). Elliptical shape under polar view was found to dominate over pear and round shape while angular shape were dominated over flat and round shape under equatorial view of nut.

Table 3. Shape of immature nuts of coconut population

Descriptor	Observed phenotype	Number of palms		χ^2	Probability	Level of significance
		Observed	Expected			
Polar view of nuts (N=27)						
	Elliptical	16 (59)	9			
	Pear	4 (15)	9	8.66	0.01	*
	Round	7 (26)	9			
Equatorial view of nuts (N=27)						
	Angular	18 (67)	9			
	Flat	2 (7)	9	14.88	0.00	**
	Round	7 (26)	9			

Numbers in the parentheses are the percentages of observed values; ** = significant at 1% probability; * = significant at 5% probability

4.2 Descriptive statistics

Variation in the descriptive statistics can be validated with χ^2 test and SWDI. The descriptive statistics were used to determine variability in quantitative characters. Likewise, the Shannon Weaver Diversity Index (SWDI) was calculated to determine diversity for each descriptor. The H′ was based on the classification of Jamago (2000) where it is high when $H' \geq 0.75$, moderate when $H' = 0.50\text{-}0.75$ and low when $H' \leq 0.50$.

The descriptive statistics of stem, leaf and inflorescence characters revealed the existence of substantial variation in the collection (Tables 4-5). Variation in stem characters were observed in number of bunches per palm (42.58%), number of nuts per bunch (27.36%), number of nuts per palm (27.36%) and length of 11 leaf scars (32.36%). Highest percentage of coefficient of variance indicated the high percent of variation. Among the plant characters number of bunches per palm was highly variable while the petiole girth (7.82%) showed minimum variation (Table 4 and Appendix VI).

In inflorescence characters, high variation was noticed in the number of spikelets without female flower (111.64%), number of spikelets with female flowers (49.09%) and peduncle length (26.30%) while the peduncle girth showed minimum variation of 12.98% (Table 5 and Appendix VII).

Table 4. Plant and leaf morphology of coconut population

Characters	Minimum	Maximum	Mean	Standard Deviation	CV (%)
Plant					
Girth at bole (cm)	88	205	148.96	±33.73	22.64
Girth at stem (cm)	72	111	93.11	±10.31	11.07
Length of 11 leaf scars (cm)	42	160	71.62	±23.18	32.36
Number of leaves	22	49	32.88	±7.71	23.44
Number of bunches per palm	7	30	16.25	±6.92	42.58
Number of nuts per bunch	4	10	6.03	±1.65	27.36
Number of nuts per palm	20	50	30.18	±8.26	27.36
Leaf					
Petiole length (cm)	109	164	140.11	±13.78	9.83
Petiole width (cm)	2.3	4.5	3.22	±0.55	17.08
Petiole girth(cm)	15	21	18.40	±1.44	7.82
Length of central axis (cm)	231	430	334.59	±35.86	10.71
Number of leaflet	66	112	91.77	±11.88	12.94
Leaflet length (cm)	98	155	119.07	±14.15	11.88
Leaflet width (cm)	3	6	4.82	±0.67	13.90

Table 5. Inflorescence characters of coconut population

Characters	Minimum	Maximum	Mean	Standard Deviation	CV (%)
Peduncle length (cm)	17	52	28.25	±7.43	26.30
Peduncle width (cm)	2	3.6	2.87	±0.44	15.33
Peduncle girth (cm)	10	17	13.25	±1.72	12.98
Length of central axis (cm)	27	70	45.96	±9.86	21.45
Number of spikelets with female flower	15	109	43.85	±21.53	49.09
Number of spikelets without female flower	0	72	13.74	±15.34	111.64
No. of spikelets per inflorescence	31	57	40.40	±6.25	15.47
Length of longest spikelets (cm)	30	60	44.29	±9.19	20.74
Duration of male phase (days)	27	48	38.35	±5.51	14.36
Duration of female phase (days)	3	5	3.96	±0.80	20.20

4.3 Phenotypic Diversity Index (H′)

4.3.1 Qualitative characters

High phenotypic diversity was observed in base of stem end (0.97), polar view of nut shape (0.85), pigmentation of leaf petiole (0.82) and bole category (0.82). Moderate diversities were observed in pigmentation of young inflorescence (0.54) and equatorial view of nut shape (0.74). Low diversity was observed in crown shape 0.43 (Table 6).

Table 6. Shannon Weaver Diversity Index (SWDI) for qualitative characters

Descriptor	SWDI
Bole category	0.82 (H)
Base of stem end	0.97(H)
Crown shape	0.43(L)
Pigmentation of leaf petiole	0.82(H)
Pigmentation of young inflorescence	0.54(M)
Immature nut shape (Polar view)	0.85(H)
Immature nut shape (Equatorial view)	0.74(M)

H = high, M = medium, L= low

4.3.2 Quantitative characters

High values of H′ were recorded in petiole length (0.85), number of leaves (0.84), number of leaflet (0.84), petiole width (0.82), leaflet width (0.79), number of bunches per palm (0.79), girth of bole (0.77), girth at stem (0.77), length of 11 leaf scars (0.77), number of nuts per bunch (0.76), number of nuts per palm (0.76). Moderate diversity indices were observed in girth at petiole base, length of central axis of leaf and leaflet width followed by 0.72, 0.72 and 0.71respectively (Table 7).

Table 7. Shannon Weaver Diversity Index (SWDI) for quantitative vegetative characters

Descriptor	SWDI
Girth at bole (cm)	0.77 (H)
Girth at stem (cm)	0.77 (H)
Length of 11 leaf scars (cm)	0.77 (H)
Number of leaves per palm	0.84 (H)
Petiole length (cm)	0.85 (H)
Petiole width (cm)	0.82 (H)
Girth at base of petiole (cm)	0.72 (M)
Length of central axis of leaves (cm)	0.72 (M)
Number of leaflets per leaf	0.84 (H)
Leaflet length (cm)	0.79 (H)
Leaflet width (cm)	0.71 (M)
Number of bunches per palm	0.79 (H)
Number of nuts per bunch	0.76 (H)
Number of nuts per palm	0.76 (H)

(H) = high, (M) = Medium

In the inflorescence, variation was high for duration of male phase (0.88), width of peduncle (0.85), number of spikelets per inflorescence (0.85), length of central axis (0.84), peduncle length (0.81), girth of peduncle (0.80) and length of longest spikelet (0.78) while moderate variation was noted for spikelets with female flower (0.69) and spikelets without female flower (0.63). Low diversity (H′= 0.47) were observed in duration of female phase (Table 8).

Table 8. Shannon Weaver Diversity Index (SWDI) for inflorescence characters

Descriptor	SWDI
Peduncle length (cm)	0.81(H)
Peduncle width (cm)	0.85 (H)
Girth at peduncle (cm)	0.80 (H)
Length of central axis (cm)	0.84 (H)
Number of spikelets with female flower	0.69 (M)
Number of spikelets without female flower	0.63 (M)
Number of spikelets per inflorescence	0.85 (H)
Length of longest spikelets (cm)	0.78 (H)
Duration of male phase (days)	0.88 (H)
Duration of female phase (days)	0.47 (L)

(H) = high, M = Medium, L = Low

High variation were recorded in girth at bole and stem, length of 11 leaf scars, number of leaf, length and width of petiole, number of leaflet, leaflet length, number of bunch per palm, number of nuts per palm, number of nuts per bunch, bole and stem category, pigmentation of young inflorescence and shape of immature nuts. Based on H′ of individual characters, it is clear that most of the characters have the moderate to high diversity except crown shape and duration of female phase. The similar results were found in the findings of Kete (2001) and Namia (2002). High diversity in the characters indicating the population was highly heterogeneous and could be an important source of desirable traits for coconut varietal improvement.

4.4 Principal Component Analysis

To examine the relationship among quantitative variables, principal component analysis (PCA) was carried out. First three components contributed 66.73% of the observed variation (Table 9). The rest of the components contributed for 33.27% of variation.

Table 9. Eigenvalues of the Covariance Matrix of 10 principal components for quantitative characters of coconut population

	Eigenvalues	Difference	Variance (%)	Cumulative (%)
PRIN1	3.400	0.765	28.336	28.336
PRIN2	2.635	0.662	21.955	50.290
PRIN3	1.973	0.906	16.443	66.734
PRIN4	1.067	0.160	8.892	75.626
PRIN5	0.907	0.045	7.561	83.187
PRIN6	0.862	0.362	7.184	90.371
PRIN7	0.500	0.161	4.165	94.537
PRIN8	0.339	0.109	2.829	97.365
PRIN9	0.230	0.144	1.917	99.282
PRIN10	0.086	0.06	0.718	100.000

Prin = Principal component

In Prin1, number of nuts per palm and number of nuts per bunch contributed to the highest loading 87% followed by 77%, 66% and 58% for girth of peduncle, number of female flowers and length of central axis of inflorescence respectively. In Prin2, girth at stem contributed highest loading 83% followed by 82% an 59% for girth at bole and width of leaflet respectively (Table 10).

Contributions of characters towards divergence were estimated through canonical variate analysis. The coefficients pertaining to the different characters in the first two canonical roots presented in Table 10. The positive absolute values of the two vectors revealed that days to spathe opening, days to male phase, number of nuts per palm, number of nuts per bunch, length of central axis of inflorescence, number of spikelets per inflorescence, number of female flowers and girth of peduncle had the greatest contribution to genetic divergence. On the other hand, the negative absolute values of vector-1 and positive absolute value for vector-2 for the characters of Girth at bole, Girth at stem, Width of leaflet and Width of petiole indicated the responsibility of secondary differentiation.

Table 10. Eigenvector of 12 characters in the first three Principal Component

Variable	PRIN1	PRIN2	PRIN3
Days to spathe opening	0.114	0.570	-0.781
Days to male phase	.0114	0.570	-0.781
Number of nuts per palm	0.870	0.013	-0.159
Number of nuts per bunch	0.870	0.013	-0.159
Length of central axis of inflorescence (cm)	0.578	0.172	0.250
Number of spikelets per inflorescence	0.434	0.359	0.292
Number of female flowers	0.661	0.092	0.423
Girth of peduncle (cm)	0.770	0.239	0.192
Girth at bole (cm)	-0.310	0.823	0.294
Girth at stem (cm)	-0.299	0.834	0.145
Width of leaflet (cm)	-0.152	0.596	0.467
Width of petiole (cm)	-0.317	0.178	0.116

Prin = Principal component

4.4.1 Cluster analysis

4.4.1.1 Number of clusters and cluster members

Twelve variables of 27 palm collections were selected on the basis of principal component analysis subjected to Unweighted Paired Group Method Arithmetic Average (UPGMA) for cluster analysis using SPSS.

From the resulting dendrogram in 1-5 scale measurement (Figure 4), the populations were grouped into seven clusters, which were presented in the Table 11. The cluster VII was the largest, containing nine palms followed by cluster VI, which included 8 palms. Cluster V consisted of 4 palms while cluster II included 3 and cluster I, III and IV represents 1 palm (Table 11). Similarity in many phenotypic characters of the genotypes brought them in a particular group. The observed diversities in the collections might be resulted from natural and human intervention (Foale, 1992).

Table 11. Cluster grouping of 27coconut population

Cluster Number	Palm Number	Total Genotypes
I	22	1
II	2, 8, 17	3
III	25	1
IV	24	1
V	13, 14, 18, 21	4
VI	1, 3, 9, 12, 20, 23, 26, 27	8
VII	4, 5, 6, 7, 10, 11, 15, 16, 19	9

Average intra and inter cluster distance of seven clusters were presented in Table 12. The magnitude of intra cluster distances indicated the extent of genetic diversity among genotypes within the cluster whereas inter cluster distances depicted the extent of diversity among genotyped between the clusters. It was reported that clusters with lesser magnitude of divergence showed instability, while widely divergent clusters remained distinct in different environments (Somayajulu *et al.* 1970; Raut *et al.* 1985 and Singh *et al.* 1980).

The higher value of inter cluster distances than intra cluster distances indicated that diversity presents more in between clusters that within clusters. Genetically distant parents usually able to produce higher heterosis (Falconar, 1960; Jagadev and Samal, 1991; Islam *et al.* 2007; Moll *et al.* 1962 and Mian and Bhal, 1989). Keeping this in view, the findings from the present study indicated that the maximum inter-cluster distance was obtained in between clusters III and VII (82.455) indicated the wider genetic divergence between these two clusters. It was followed by the distance between the clusters I and III (72.894), III and IV (70.825), III and V (58.362), II and III (64.855). It was observed that, the cluster III had the highest distance from the rest indicated that the genotype in the cluster III was distinctly different from others. Parental material selection from these clusters would give high manifestation of heterosis as well as wide spectrum of variation when they are hybridized. Endang *et al.* (1971) stated that the clustering pattern could be utilized in choosing parents for cross combinations which likely to generate the highest possible variability for effective selection of various economic traits.

Parents for hybridization could be selected on the basis of large inter-cluster distance for isolating useful recombinants in the segregating generations. Increasing parental distance implies a greater number of constraining alleles at the desired loci and then to the extent that these loci recombing in the F_2 and F_3 generations, following a cross of distantly related parents, the greater will be the opportunities for successful selection for any character of yield interest (Ghaderi *et al.* 1984).

The minimum distance was obtained in between clusters II and IV (22.351) indicated that the genotypes belonging to these clusters were comparatively less diverse. Thus crossing of genotypes from these two clusters may not produce high level of heterotic expression in the F_1's and broad spectrum of variability in segregating (F_2) population. The maximum intra-cluster distance was in cluster VII (13.210) while the clusters I, III and IV showed no distance because each of them included only one palm in each cluster (Table 12).

Table 12. Intra and inter cluster distances among the various clusters of coconut population

Cluster	I	II	III	IV	V	VI	VII
I	**0.00**	26.021	72.894	16.808	16.204	49.530	25.014
II		**12.910**	64.855	22.351	24.226	37.471	23.486
III			**0.00**	70.825	58.362	27.690	82.455
IV				**0.00**	23.896	46.903	18.435
V					**11.550**	35.654	33.177
VI						**4.472**	56.378
VII							**13.210**

Girth at bole, girth at stem and number of female flowers in all the clusters were found to contribute maximum diversities (Table 13). The cluster mean of 170.00 cm was recorded maximum for girth at bole in cluster III followed by 153.77 cm in cluster VII, 150.75 cm in cluster V and minimum of 128.33 cm in cluster II. The cluster mean of 99.00 cm was highest for girth at stem in cluster III followed by 96.11 cm in cluster VII, 96.00 cm in cluster I and least of 85.00 cm in cluster II. Cluster means 109.00 for the number of female flowers was highest in cluster I followed by 82.00 in cluster II, 45.00 in cluster III and minimum of 15.00 in cluster IV. In cluster IV, number of nuts per palm, number of nuts per bunch and number of female flowers were minimum for 20, 4 and 15 respectively.

Table13. Intra-cluster means for 12 characters of coconut population

Characters	Cluster number						
	I	II	III	IV	V	VI	VII
Days to spathe opening	31.00	34.33	30.00	33.00	31.50	32.00	43.55
Days to male phase	31.00	34.33	30.00	33.00	31.50	32.00	43.55
Number of nuts per palm	40.00	38.33	50.00	20.00	23.75	31.87	33.33
Number of nuts per bunch	8.00	7.67	10.00	4.00	4.75	6.87	6.67
Length of central axis of inflorescence (cm)	70.00	53.33	29.00	36.00	34.50	50.00	45.33
Number of spikelets per inflorescence	37.00	48.00	43.00	31.00	40.00	40.87	38.77
Number of female flowers	109.00	82.00	45.00	15.00	42.50	30.75	39.22
Girth of peduncle (cm)	17.00	15.00	13.00	10.00	11.50	13.25	13.44
Girth at bole (cm)	150.00	128.33	170.00	150.00	150.75	147.50	153.77
Girth at stem (cm)	96.00	85.00	99.00	91.00	91.50	92.25	96.11
Width of leaflet (cm)	5.40	4.93	5.00	4.00	5.00	4.72	4.80
Width of petiole (cm)	3.00	3.10	3.20	3.00	3.20	3.32	3.24

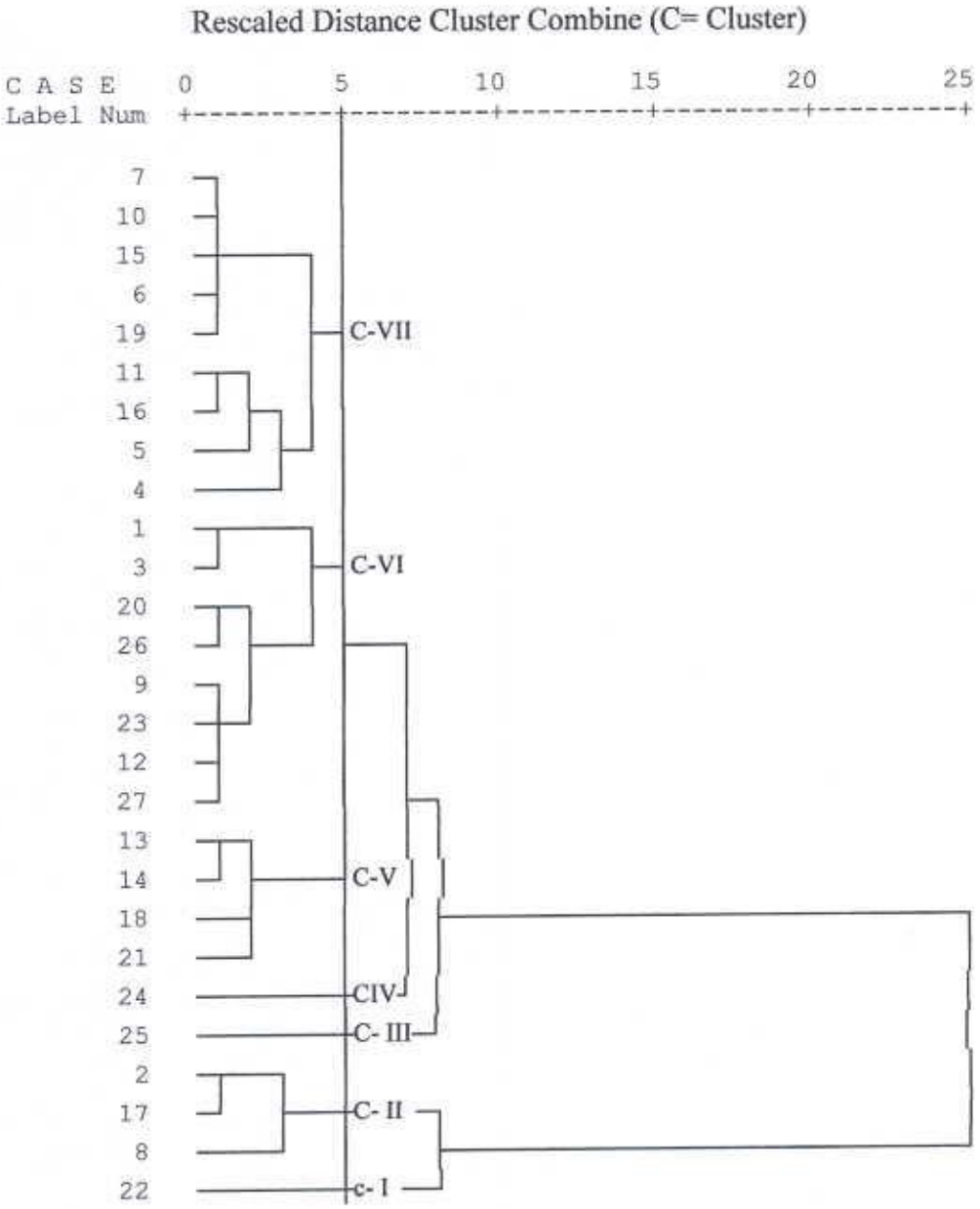


Fig. 4. Dendrogram showing average linkage cluster analysis (UPGMA)

4.5 Correlation coefficient

The correlation coefficient were determined to find out the inter relationship among the characters studied. Genotypic correlation coefficients of 12 quantitative characters of coconut population are presented in table 14.

Table 14. Correlation coefficient between quantitative variables

	DASPOP	DAMAPH	NUNPPA	NUNPBU	LECEAINF	NUSPIKEIN	NUFF	GATPED	GATBOL	GATST	WLFLT	WATPET
DASPOP	1.00	1.00**	0.146	0.146	0.046	0.013	-0.110	0.085	0.148	0.254	0.008	-0.015
DAMAPH		1.00	0.146	0.146	0.046	0.013	-0.110	0.085	0.148	0.254	0.008	-0.015
NUFPEPA			1.00	1.00**	0.239	0.331	0.402*	0.560**	-0.228	-0.192	-0.190	-0.156
NUFPEBU				1.00	0.239	0.331	0.402*	0.560**	-0.228	-0.192	-0.190	-0.156
LECEAINF					1.00	0.391*	0.460*	0.544**	-0.018	-0.078	0.023	-0.142
NUSPIKE						1.00	0.311	0.229	0.289	0.165	0.064	-0.012
NUFF							1.00	0.581**	-0.082	-0.133	0.225	-0.103
GAINFS								1.00	-0.040	0.020	0.187	-0.251
GATBOL									1.00	0.885**	0.544**	0.205
GATSET										1.00	0.475*	0.158
WLFLT											1.00	0.184
WATLBA												1.00

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level

Legend:

- DASPOP = Days to spathe opening
- DAMAPH = Days to male phase
- NUNPPA = Number of nuts per palm
- NUNPBU = Number of nuts per bunch
- LECEAINF = Length of central axis of inflorescence (cm)
- NUSPIKEIN = Number of spikelets per inflorescence
- NUFF = Number of female flower
- GATPED = Girth at peduncle (cm)
- GATBOL = Girth at bole (cm)
- GATST = Girth at stem (cm)
- WLFLT = Width of leaflet (cm)
- WATPET = Width at petiole (cm)

Days to male phase showed positive and significant correlation with days to spathe opening.

Number of nuts per palm showed positive and insignificant correlation with days to spathe opening and days to male phase.

Number of nuts per bunch showed positive and significant correlation with number of nuts per palm. Number of nuts per bunch showed positive and insignificant correlation with days to spathe opening and days to male phase.

Length of central axis of inflorescence showed positive and insignificant correlation with days to spathe opening, days to male phase, number of nuts per palm and number of nuts per bunch.

Number of spikelets per inflorescence showed positive and significant correlation with length of central axis of inflorescence. Number of spikelets per inflorescence showed positive and insignificant correlation with days to spathe opening, days to male phase, number of nuts per palm and number of nuts per bunch.

Number of female flowers showed positive and significant correlation with number of nuts per palm, number of nuts per bunch and length of central axis of inflorescence. Number of female flowers showed positive and insignificant correlation with number of spikelets per inflorescence.

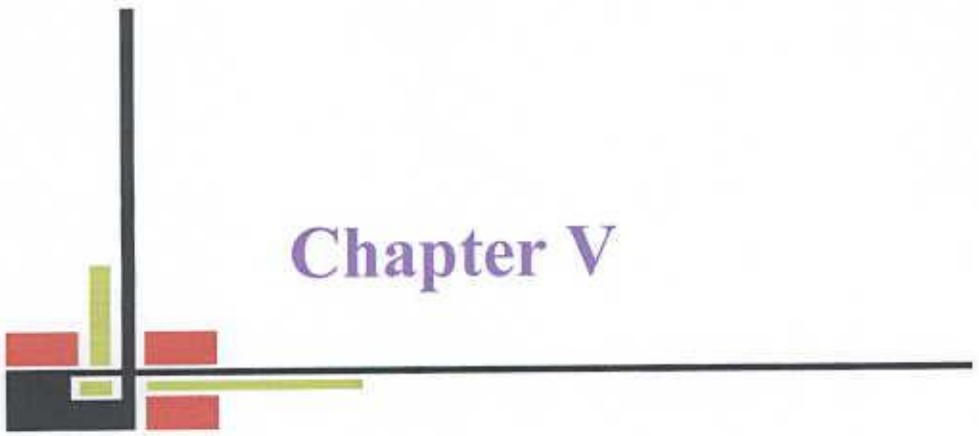
Girth at peduncle showed positive and significant correlation with number of nuts per palm, number of nuts per bunch and length of central axis of inflorescence and number of female flowers. Girth at peduncle showed positive and insignificant correlation with days to spathe opening, days to male phase and number of spikelets per inflorescence.

Girth at bole showed positive and insignificant correlation with days to spathe opening, days to male phase and number of spikelets per inflorescence.

Girth at stem showed positive and significant correlation with girth at bole. Girth at stem showed positive and insignificant correlation with days to spathe opening, days to male phase and number of spikelets per inflorescence.

Width of leaflet showed positive and significant correlation with girth at bole and girth at stem. Width of leaflet showed positive and insignificant correlation with days to spathe opening, days to male phase, length of central axis of inflorescence, number of spikelets per inflorescence, number of female flowers and girth at peduncle.

Width of leaflet showed positive and insignificant correlation with girth at bole, girth at stem and width of leaflet.



Chapter V

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY

Morphometric characterization reveals that substantial amount of variations exist in the coconut collections particularly with respect to bole category, crown shape, length of 11 leaf scars, number of nuts per bunch, number of nuts per palm, number of spikelets with female flower and without female flower.

The analysis of variance showed significant diversities among the entries in most of the characters. Bole category and crown shape were highly significant. No bole category (63%) and spherical crown shape (85%) were dominated over low and high bole and X-shaped crown respectively. Pigmentation of petiole, bud, inflorescence and nuts were significant where green petiole (63%), green bud (89%), yellowish green inflorescence (70%) and green nut (67%) were dominated. Nut shape under equatorial view was highly significant where angular nut shape (67%) was dominated over flat (7%) and round shape (26%).

The descriptive statistics of stem, leaf and inflorescence characters revealed the existence of substantial variation in number of bunches per palm (42.58%), number of nuts per bunch (27.36%), number of nuts per palm (27.36%) and length of 11 leaf scars (32.36%). Among the plant characters, number of bunch per palm was highly variable while the petiole girth (7.82%) showed minimum variation. Number of spikelets without female flower (111.64%), number of spikelets with female flowers (49.09%) and peduncle length (26.30%) had showed maximum variation while the peduncle girth showed minimum 12.98%.

High phenotypic diversity was observed in base of stem end (0.97) and low diversity was observed in crown shape 0.43. Petiole length (0.85), number of leaves (0.84), number of leaflet (0.84), petiole width (0.82), leaflet width (0.79), number of bunches per palm (0.79), number of nuts per bunch and number of nuts per palm showed higher diversity.

In principal component analysis, first three components explained 66.73% of the observed variation. In Prin1, number of nuts per palm and number of nuts per bunch contributed to the highest loading 87% followed by 77%, 66% and 58% for girth of peduncle, number of female flowers and length of central axis of inflorescence respectively. In Prin2, girth at stem contributed highest loading 83% followed by 82% an 59% for girth at bole.

Twenty seven entries of coconut were grouped into seven clusters. The largest cluster VII included 9 palms and second largest cluster VI included 8 palms. Cluster V included 4 palm, cluster II included 3 and cluster I, III and IV included 1 palm. The inter-cluster values were maximum in between clusters III and VII (82.455) while it was minimum in between II and IV (22.351). The inter-cluster distance was greater than the intra-cluster distance. The intra-cluster distance was maximum in cluster VII (13.210) while the clusters I, III and IV showed no distance because each of them included only one palm in each cluster.

The inter cluster mean for girth at bole, girth at stem and number of female flowers in all the clusters were found to contribute maximum diversities. The cluster mean of 170.00 cm was recorded maximum for girth at bole in cluster III and minimum of 128.33 cm in cluster II. The cluster mean of 99.00 cm was highest for girth at stem in cluster III and least of 85.00 cm in cluster II. Cluster means 109.00 for the number of female flowers was highest in cluster I and minimum of 15.00 in cluster IV.

The correlation coefficient were determined to find out the inter relationship among the characters studied. Most of the characters were significantly correlated with each other. Number of female flowers and number of nuts per palm, number of female flowers and number of nuts per bunch, number of female flowers and length of central axis of inflorescence, girth at peduncle and number of nuts per palm, girth at peduncle and number of nuts per bunch, girth at peduncle and length of central axis of inflorescence, girth at peduncle and number of female flowers were positive and highly significant.

CONCLUSION

SWDI, Cluster, PCA, and correlation analysis revealed that inflorescence and nut characters are the most important components contributing to the observed variation. Selections based on these characters might be of immense value in the improvement program.

Modern crop varieties have been reported to be genetically uniform and have narrow genetic base due to limited genotypes used in hybridization and human selection for specific characters. It should be noted that 27 palms were brought from the different regions of Bangladesh. It was observed that individual palms in this study were exhibited high variability in number of female flowers, number of spikelets with and without female flowers, number of bunch per palm, number of nuts per palm, number of nuts per bunch and length of central axis of inflorescence characters. So, nut yield and quality improvement in coconut would be achieved through selection of these characters. But these collections not yet reached in full bearing stage. So, further studies should be conducted to evaluate the nut characters, bearing habit and yield of selected entries of coconut.

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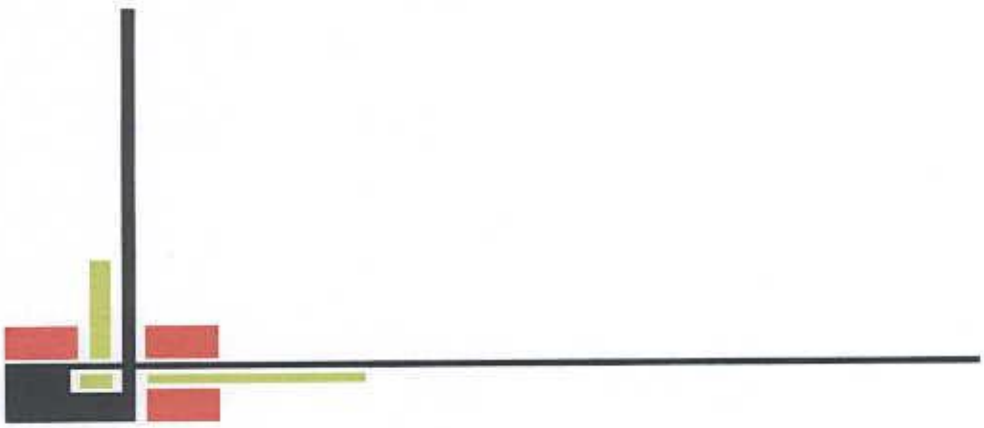

Appendices

APPENDICES

Appendix I. Mean monthly weather data during September 2011 to February 2012

Year	Month	Air temperature (°C)		Relative Humidity (RH) (%)	Rainfall (mm)
		Max.	Min.		
2011	September	31.50	27.00	86.50	208.45
2011	October	29.75	26.80	85.28	183.40
2011	November	26.22	22.75	80.17	08.50
2011	December	19.90	15.45	89.05	0.00
2012	January	15.00	11.00	90.15	00.00
2012	February	22.25	17.74	85.60	07.10

Source: Bangladesh Agricultural Research Institute, (BARI), Gazipur.

Appendix II. Analytical data of soil sample at HRC field of BARI

Year	p^H	Total N	OM	Ca	Mg	K
		%		meq/100g		
2011	6.1	0.077	1.46	4.76	1.97	0.15
Critical level				2.0	0.8	0.2

Appendix II. Cont'd.

Year	p^H	P	S	B	Cu	Fe	Mn	Zn
		µg/g						
2011	6.1	15	38	0.32	6.0	232	10	3.30
Critical level		14	14	0.2	1.0	10.0	5.0	2.0

Source: Soil Science Division, Bangladesh Agricultural Research Institute, (BARI), Gazipur.

Appendix III. Analysis of data with the bole category, stem and crown shape of coconut population

Palm Number	Observed phenotype of bole category	Observed phenotype of stem base	Observed phenotype of crown shape
1	LBL	STP	SPH
2	NBL	CYL	SPH
3	LBL	CYL	SPH
4	LBL	TP	SPH
5	NBL	CYL	SPH
6	NBL	TP	SPH
7	NBL	TP	X
8	NBL	TP	SPH
9	NBL	TP	SPH
10	NBL	STP	X
11	NBL	STP	SPH
12	NBL	CYL	X
13	NBL	CYL	SPH
14	NBL	STP	SPH
15	NBL	STP	SPH
16	NBL	TP	SPH
17	LBL	CYL	SPH
18	HBL	STP	SPH
19	LBL	TP	X
20	NBL	TP	SPH
21	HBL	TP	SPH
22	HBL	CYL	SPH
23	HBL	TP	SPH
24	NBL	STP	SPH
25	LBL	TP	SPH
26	NBL	CYL	SPH
27	NBL	TP	SPH

	NOBPM	NEXPM	NOBPM	NEXPM	NOBPM	NEXPM
	NBL 17	9	STP 7	9	SPH 23	13.5
	LBL 6	9	TP 12	9	X 4	13.5
	HBL 4	9	CYL 8	9		
	χ^2	10.89**	χ^2	1.55 ns	χ^2	13.36**
df 2	Probability	0.00	Probability	0.46	Probability	0.00

ns = non significant; ** = significant at 1% probability

Abbreviation stand for

NBL	= No bole	STP	= Slight tapering
LBL	= Low bole	TP	= Tapering
HBL	= High bole	CYL	= Cylindrical
NOBPM	= Number of observed palm	χ^2	= (Observed value - Expected value)^2 ÷ Expected value
NEXPM	= Number of expected palm	df	= Degrees of freedom
SPH	= Spherical	X	= X-shaped

Appendix IV. Analysis of data with the pigmentation of leaf petiole, young inflorescence and immature nuts of coconut population

Palm Number	Observed phenotype of pigmentation of petiole	Observed phenotype of pigmentation of bud	Observed phenotype of pigmentation of inflorescence	Observed phenotype of pigmentation of immature nuts
1	RG	G	RG	R
2	YG	G	YG	R
3	RG	G	YG	G
4	G	G	WG	G
5	G	G	YG	G
6	G	G	WG	YG
7	YG	G	RG	G
8	G	G	YG	G
9	YG	G	YG	YG
10	G	G	YG	G
11	G	YG	RG	G
12	G	G	YG	G
13	YG	G	WG	YG
14	G	G	YG	G
15	RG	G	YG	G
16	G	G	RG	YG
17	G	G	YG	G
18	YG	G	YG	R
19	G	G	YG	G
20	G	G	RG	G
21	G	YG	YG	G
22	YG	G	YG	G
23	RG	G	YG	YG
24	G	G	YG	G
25	G	YG	YG	YG
26	G	G	YG	G
27	G	G	YG	G

	NOBPM	NEXPM	NOBPM	NEXPM	NOBPM	NEXPM	NOBPM	NEXPM
	G 17	9	YG 3	13.5	RG 5	9	G 18	9
	RG 4	9	G 24	13.5	WG 3	9	R 3	9
	YG 6	9			YG 19	9	YG 6	9
	χ^2	10.89**	χ^2	13.36**	χ^2	16.89**	χ^2	14.00**
df 2	Probability 0.00		Probability 0.00		Probability 0.00		Probability 0.00	

** = significant at 1% probability

Abbreviation stand for

G	= Green	WG	= Whitish green
YG	= Yellowish green	R	= Reddish
RG	= Reddish green	χ^2	= (Observed value - Expected value)^2 ÷ Expected value
NOBPM	= Number of observed palm	NEXPM	= Number of expected palm
df	= Degrees of freedom		

Appendix V. Analysis of data with the shape of immature nuts of coconut population

Palm Number	Observed phenotype of polar view of nuts	Observed phenotype of equatorial view of nuts
1	Elliptical	Angular
2	Round	Round
3	Round	Round
4	Elliptical	Angular
5	Pear	Flat
6	Elliptical	Angular
7	Round	Round
8	Pear	Angular
9	Pear	Flat
10	Elliptical	Angular
11	Round	Round
12	Pear	Angular
13	Elliptical	Angular
14	Round	Round
15	Elliptical	Angular
16	Elliptical	Angular
17	Elliptical	Angular
18	Elliptical	Angular
19	Round	Round
20	Elliptical	Angular
21	Elliptical	Angular
22	Elliptical	Angular
23	Elliptical	Angular
24	Round	Round
25	Elliptical	Angular
26	Elliptical	Angular
27	Elliptical	Angular

	NOBPM	NEXPM	NOBPM	NEXPM
	Elliptical 16	9	Angular 18	9
	Pear 4	9	Flat 2	9
	Round 7	9	Round 7	9
	χ^2	8.66*	χ^2	14.88**
df 2	Probability 0.01		Probability 0.00	

** = significant at 1% probability, * = significant at 5% probability

Abbreviation stand for

NEXPM = Number of expected palm
NOBPM = Number of observed palm
χ^2 = (Observed value - Expected value)^2 ÷ Expected value
df = Degrees of freedom

Appendix VI. Analysis of data with the plant and leaf morphology of coconut population

Palm number	Girth at bole (cm)	Girth at stem(cm)	Length of 11 leaf scars (cm)	Number of leaves	Number of bunches per palm	Number of nuts per bunch	Number of nuts per palm
1	145	98	160	37	13	9	45
2	88	79	80	28	11	7	35
3	91	75	78	34	13	6	30
4	125	79	89	30	13	4	20
5	115	78	73	27	11	5	25
6	155	96	85	25	13	6	30
7	165	96	73	22	8	8	40
8	188	96	89	27	10	6	30
9	195	102	71	38	14	5	25
11	140	103	86	27	22	6	30
12	159	98	88	31	21	9	45
13	93	72	42	25	18	6	30
14	119	84	66	34	21	4	20
15	139	92	58	34	24	5	25
16	130	94	60	28	13	6	30
17	195	110	96	34	26	7	35
18	109	80	60	43	23	5	25
19	140	94	69	43	27	4	20
21	200	111	61	35	10	6	30
22	161	94	58	41	8	4	20
23	205	100	63	49	12	7	35
24	150	96	77	45	30	8	40
25	180	101	57	35	17	6	30
26	150	91	50	22	13	5	25
27	170	99	57	45	30	10	50
Mean	148.96	93.11	71.62	32.88	16.25	6.03	30.18
Stdev	33.73	10.31	23.18	7.71	6.92	1.65	8.26
CV%	22.64	11.07	32.36	23.44	42.58	27.36	27.36

Stdev = Standard deviation, CV= Coefficient of variation

Appendix VI continued...

Palm number	Petiole length (cm)	Petiole width (cm)	Petiole girth(cm)	Length of central axis (cm)	Number of leaflet	Leaflet length (cm)	Leaflet width (cm)
1	126	2.8	18	231	89	120	5
2	150	2.9	19	300	76	127	4.4
3	150	2.3	15	325	66	110	3
4	145	2.5	19	350	95	118	4
5	135	2.9	20	340	104	100	5
6	136	3.8	20	300	83	128	5
7	145	3.1	18	350	104	133	6
8	143	3.8	19	380	98	132	5.4
9	140	4.5	20	360	102	131	5.2
11	160	3.3	20	370	83	140	4
12	143	3.8	20	430	96	155	4.2
13	116	4.4	21	333	81	104	4.2
14	143	4.2	20	330	69	130	5
15	140	3.1	17	325	106	138	5.5
16	125	3.1	18	355	102	114	4
17	145	3.1	20	365	104	112	6
18	113	2.6	17	330	95	116	5
19	128	2.9	17	310	90	102	4.5
21	156	3.6	19	300	85	104	5
22	164	3.5	17	350	102	108	5
23	135	2.6	16	320	80	100	5
24	109	3	17	340	94	115	5.4
25	144	3	18	350	80	111	5
26	155	3	18	300	84	98	4
27	135	3.2	18	340	112	126	5
Mean	140.11	3.22	18.40	334.59	91.77	119.07	4.82
Stdev	13.78	0.55	1.44	35.86	11.88	14.15	0.67
CV%	9.83	17.08	7.82	10.71	12.94	11.88	13.90

Stdev = Standard deviation, CV= Coefficient of variation

Appendix VII. Analysis of data with the inflorescence characters of coconut population

Palm number	Peduncle length (cm)	Peduncle width (cm)	Peduncle girth (cm)	Length of central axis (cm)	Number of spikelets with female flowers
1	30	2.9	14	55	28
2	29	3.4	15	52	80
3	26	3.2	14	50	30
4	38	3	14	55	52
5	35	3.1	14	52	40
6	37	3	15	48	35
7	29	3.1	14	40	32
8	25	3.2	15	62	90
9	20	2.4	13	50	25
10	26	3.7	14	43	28
11	27	2.6	13	42	48
12	21	2.3	11	43	36
13	27	2.6	11	28	40
14	25	2.7	12	27	40
15	20	2.7	12	42	28
16	17	3	14	40	51
17	30	3.3	15	46	76
18	23	2.4	12	40	50
19	26	2.6	11	46	39
20	23	3.2	12	55	35
21	24	2.4	11	43	40
22	28	3.4	17	70	109
23	30	3.6	14	47	30
24	42	3	10	36	15
25	23	2.4	13	29	45
26	30	2.3	12	56	25
27	52	2	16	44	37
Mean	28.25	2.87	13.25	45.96	43.85
Stdev	7.43	0.44	1.72	9.86	21.53
CV%	26.30	15.33	12.98	21.45	49.09

Stdev = Standard deviation, CV= Coefficient of variation

Appendix VII continued...

Palm number	Number of spikelets without FF	Number of spikelets per inflorescence	Length of longest spikelets (cm)	Duration of male phase (days)	Duration of female phase (days)
1	24	52	46	47.5	5
2	36	44	42	42	4
3	8	38	42	39	3
4	13	39	43	37	5
5	1	39	40	30	3
6	5	40	39	38	4
7	6	38	31	46	4
8	33	57	56	39	3
9	19	44	60	40	3
10	11	39	30	33	4
11	8	40	50	43	5
12	0	36	53	37	4
13	7	33	41	44	5
14	9	31	31	45	4
15	10	38	52	48	5
16	16	35	49	32	3
17	33	43	52	34	5
18	2	48	35	35	3
19	2	41	59	37	4
20	11	46	51	27	3
21	8	48	52	41	4
22	72	37	56	39	5
23	13	43	40	33	4
24	16	31	32	39	3
25	2	43	30	39	3
26	6	31	40	42	5
27	0	37	44	29	4
Mean	13.74	40.40	44.29	38.35	3.96
Stdev	15.34	6.25	9.19	5.51	0.80
CV%	111.64	15.47	20.74	14.36	20.20

FF = Female flower, Stdev = Standard deviation, CV= Coefficient of variation

Appendix VIII. Pigmentation of young bud of coconut population

Plate-1. Green colored bud

Plate-2. Yellowish green colored bud

Appendix IX. Pigmentation of inflorescence of coconut population

Plate-1. Yellowish green colored inflorescence

Plate-2. Reddish green colored inflorescence

Plate-3. Whitish green colored inflorescence

Appendix X. Plate of inflorescence, bunch and length of 11 leaf scars of coconut population

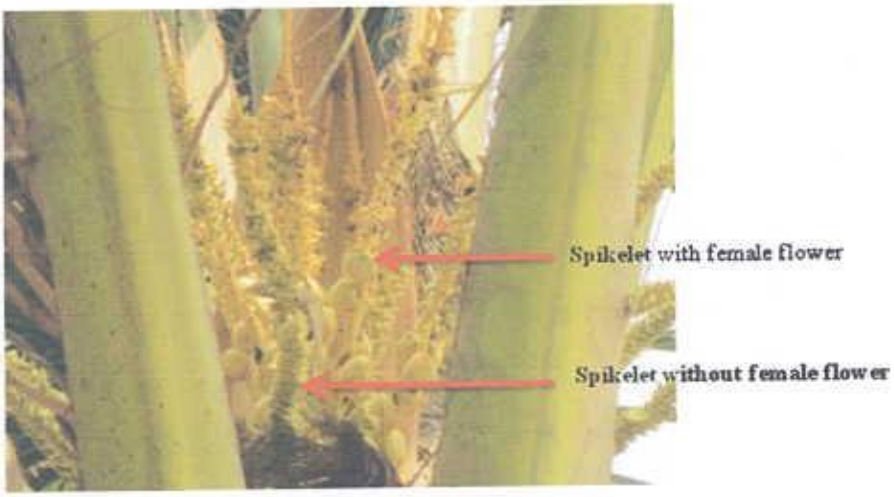

Plate-1. Spikelet of coconut population with and without female flowers

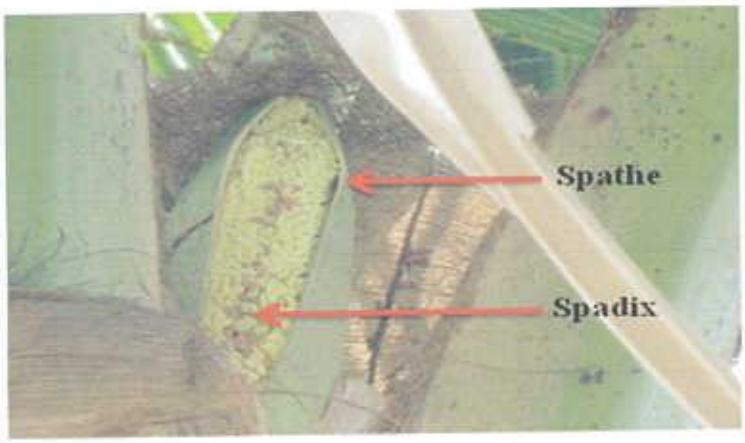

Plate-2. Inflorescence of coconut population with spathe and spadix

Plate-3. Bunch of a coconut population

Plate-4.Length of 11 leaf scars of coconut population