COCOA

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FOREWORD

Cocoa (*Theobroma cacao* L.) belonging to family Sterculiaceae is an important plantation crop. It is an indigenous crop to South America and presently grown in Brazil and African countries and south East Asia. It is a perennial tree, normally grown under the diverse shade cover of rain forests. Cocoa has the important potential of serving economic, social and environmental ends. It also enhances the soil quality by adding organic matter through leaf fall and pruning.

The crop was introduced to South India during the past century. It was found that coconut and arecanut gardens are ideal for cultivating cocoa as the shade is conducive for its growth. The systematic cultivation started in 1970s. At present it is grown in Kerala, Karnataka and Andhra Pradesh. It has a great potential to be introduced in other states where coconut and arecanut are grown to increase the economic returns of the farmers. Since the requirement of cocoa products are likely to enhance substantially during the next five years there is much scope of increasing the cultivated area of cocoa to meet the domestic demands. Presently, cocoa is the only plantation crop which has shown an upward trend in the prices of the cocoa beans.

In the ICAR system, Central Plantation Crops Research Institute at its Regional station Vittal, started research on cocoa along with areca nut. The systematic research on cocoa production technologies was started in 1970 at the Regional Station and the introduction of cocoa as a mixed crop of areca nut and coconut has provided for sustained production models. The Institute pioneered in the introduction, evaluation, breeding, agronomy and plant protection technologies. Besides this Institute, research on cocoa was also initiated in 1979 at Kerala Agriculture University where substantial work on crop improvement, management and breeding programmes with objectives of high yield and tolerance to Vascular Streak Die back (VSD) disease were taken up. Thus cocoa research is going on in India for nearly 30 years.

The book on Cocoa has brought together the information available on cocoa research in various countries with an emphasis on work done in India and other East Asian countries. I am glad to know that the book is being brought out on the occasion of National Seminar on Technologies for Enhancing Productivity in Cocoa on 29-30 November 2002. The national seminar is intended to take stock of research advances made during the past three decades. I am sure that this valuable book will be useful for all those concerned with cocoa research and development in the country.

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PREFACE

Cocoa (*Theobroma cacao* L.; family Sterculiaceae) is indigenous to South America. The Amazon basin is supposed to have been the origin of cocoa tree. The Mayas, Toltecs and Aztecs knew the plant more than 3000 years ago. There is evidence to show that the Mayas in South America were cultivating cocoa. Cocoa thus has one of the oldest histories among crops cultivated by man. It was only during seventeenth and eighteenth centuries that the cocoa tree was introduced to many other sub-tropical countries. As a perennial tree crop, it is traditionally and still predominantly cultivated beneath a diverse shade cover. The crop is cultivated in small land holdings. Cocoa has the important potential of serving economic, social and environmental ends. Cocoa trees have adapted to varying conditions and is cultivated in a number of countries of the humid tropics. The shaded system enhances the soil, protects it from erosion, provides non-cocoa products to the farmer and a refuge to an array of animal groups like birds, insects, small mammals, and reptiles as it provides a fine biodiversity within the system. The sustainable cocoa production thus, not only benefits farmers and manufacturers, but also contribute to conservation of forest ecosystems.

Cocoa is consumed world over for the flavour and textural properties of chocolate. The international cocoa community classifies the beans into two broad types viz., Forastero and Criollo. Foresteros with highly pigmented beans are used in the manufacture of cocoa butter and high volume chocolates. These beans constitute over 95 % of the world production. The Criollo cocoa grown in South America has white or pale violet beans used in manufacture of high quality chocolates. Forestero cocoa had higher yields, more resistant to diseases, required less care and therefore cultivated in most of the countries. Hybrids called Trinitarios rarely bred true and reverted to Forestero types and did not find popularity in production.

Cocoa was introduced to Southern India during the present century mainly as an intercrop of coconut and arecanut gardens as it was found that the climate within the gardens is conducive to cocoa growth. The systematic cultivation started in 1970s. At present it is grown in the States of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. It has great potential to be introduced in other States where coconut and arecanut are grown.

Central Plantation Crops Research Institute, Regional Station at Vittal came into existence in 1970, with a mandate to carry out research on arecanut and cocoa. The Central Arecanut Research Station was started in 1956. Consequent to establishment of CPCRI in 1970, the CARS became Regional Station of the Institute. The systematic research on cocoa production technologies were started as early as 1970 and the introduction of cocoa as a mixed crop of arecanut and coconut has provided for sustained production models. The Institute pioneered in the introduction, evaluation, breeding, agronomy and plant protection technologies.

Cocoa research at Kerala Agricultural University was initiated in 1979. The research was strengthened substantially in April 1987 with sanctioning of a collaborative research project with funding from Cadbury India Ltd. The Cadbury-KAU Co-operative Cocoa Research Project was aimed at strengthening and continuing the ongoing work on crop improvement, continuing the long-term experiments on management and taking up work on diseases of the crop. Breeding programme at Kerala Agricultural University is one of the strongest in the world with the biggest assembly of germplasm collection in India. The main breeding objectives are yield and tolerance to VSD.

This book is intended to bring together the information available on cocoa research in various countries with an emphasis on the work done over last thirty years in India.

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1. BOTANY

K.S. Ananda

INTRODUCTION

Cocoa is one of the important commercial crops of the world and mainly grown in the tropical regions viz., Africa, America, West Indies, Asia and Oceania countries. The species of *Theobroma* are widely seen in the evergreen rainforests of the Western hemisphere from 18°N to 15°S (Wood, 1985). Cocoa belongs to family Sterculiaceae, a group of small trees, which occurs in the wild in the Amazon basin and other tropical areas of South and Central America. Though there are about 22 species identified in the genus, the commonly cultivated species is *Theobroma cacao* L. The *Herrania, Guazuma* and *Cola* are other related genera of cocoa.

ORIGIN, DISTRIBUTION AND DOMESTICATION

The primary centre of diversity or origin of the crop is generally accepted to be the upper Amazon basin where a considerable and useful variation is recorded (Toxopeus, 1985). Apart from the variation in the morphological characters of the pods and beans, resistance, and in some cases increased susceptibility to Witches broom disease, *Phytophthora* pod rot, canker and cocoa swollen shoot virus has been found. The tropical part of Central America qualifies as a secondary center of diversity on account of the differences between and the variation within the populations.

The main cocoa areas at the beginning of the sixteenth century were Tabasco, which borders the Gulf of Mexico, Soconusco on the Pacific Coast of Mexico and to Nicaragua, Costa Rica, and Caribbean Coast of Honduras. There is no evidence for the distribution of cocoa from place of origin Amazon to Central America. Columbus carried cocoa to Old World during 1502 (Bergmann, 1969). The type of cocoa cultivated in Central America was Criollo since it was used in preparation of palatable drink with little or no preliminary fermentation (Thomson, 1956). There is no evidence that cocoa was cultivated in South America or in the Caribbean during sixteenth century but wild beans were used for ceremonial purposes in Western Venezuela. After the conquest of Mexico, cocoa cultivation spread to Caribbean Islands and parts of South America. During sixteenth century Venezuela, Jamaica, Trinidad, Martinique and Haiti are countries, which started cultivating this crop traditionally. Criollo cocoa was taken across the Pacific to the Philippines about the year 1600; from there it spread to Sulawesi and Java. It is evident that the first introduction of cocoa to Sri Lanka and India came from the East Indies and there is also evidence of an introduction of Criollo cocoa to India from Ambon in the Moluccas during 1798 (Ratnam 1961).

The entire production of cocoa in the sixteenth and seventeenth centuries were Criollo type only, but during the eighteenth century Forastero types began to be cultivated and used. The first countries to produce Forastero cocoa were Brazil and Ecuador. Apart from these centuries, the commercial growing of cocoa has extended from its center of origin in South and Central America to West Africa, the Far East and Oceania.

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Presently cocoa has become an important commercial crop throughout the humid tropics, mainly in Africa (Cameroon, Ghana, Nigeria, Ivory Coast and Cameron), America (Bolivia, Brazil, Colombia, Costa Rica, Mexico and Venezuela), West Indies (Cuba, Grenada, Haiti, Jamaica, Trinidad) and Asian and Oceania countries (Indonesia, Malaysia, Papua New Guinea, Philippines, Sri Lanka and India) (Fig.1).

TAXONOMY

Cocoa belongs to the family Sterculiaceae and *Theobroma cacao* was the name given to the cocoa tree by Linnaeus in the first addition of his *Species Plantarum*. Cuatrecasas (1964) divided the genus *Theobroma* into six sections containing 22 species. *Theobroma cacao* is the only species, which is being cultivated widely. *T. angustifolium, T. bicolor, T.grandiflorum, T. microcarpum, T. mammosum, T. simiarum, T. speciosum and T. subincanum,* are other better-known species. *Theobroma cacao* is a diploid species with a chromosome number of 2n=20, and has been subdivided into two subspecies by Cuatrecasas (1964), viz., (1) *Theobroma cacao* ssp. *cacao* consists of the Criollo populations of Central and South America; (2) *Theobroma cacao* ssp. *sphaerocarpum* includes all the other populations.

MORPHOLOGY AND GROWTH

Cocoa is a soft wooded tree with tap root system. Cocoa trees grow to a height of 4-10m depending on spacing and the degree of shade. Under heavy shade of the forest they may grow upto 20 m. The stem is erect, hard and woody with stellate hairs having two types of branches; the side branches referred as 'fan'branches and upright branch referred as 'chupons'. Mucilage ducts are found in the stem. Leaves are simple with dimorphic phyllotaxy character corresponding to the different types of stem on which they arise. The 'fan' branches have an alternate leaf arrangement where as the 'chupons' have spiral leaf arrangement. Flowers arise on the old wood, which is referred as 'Cauliflory'.

Plant growth

On germination the rootlet grows out first and the hypocotyl raises the closed cotyledons about 3 cm above ground level. There are no buds on the stem of the hypocotyl, a point of significance when budding, below these cotyledons is present, which will avoid any shoots arising from the stock.

The second phase commence from opening of cotyledons, thereafter exposing the plumule and ends with the hardening off of the first leaves having short internodes so that the leaves are at the same level (Fig.2). Leaves are arranged in spiral manner and each leaf axil has got bud at an interval of approximately six weeks. Vertical growth continues until the plants reach a height of 1-2m at which point the plant enters its third growth phase when vertical growth ceases. During this phase on the terminal end of the stem, five buds with very short internodes grow out sideways simultaneously and point at which branches occurring is called the 'jorquette'. The side branches will grow at an angle of 0-60° to the horizontal, and have an alternate leaf arrangement and are called fan branches. Usually cocoa tree shows dimorphic growth where vertical stem being orthotropic and the fan branches plagiotropic (Fig.3). The upright shoots are called chupons. The chupons have capability of forming a jorquette in due course. As the trees mature the chupons may develop on the trunk just below the jorquette and this is more likely to occur when light penetrates

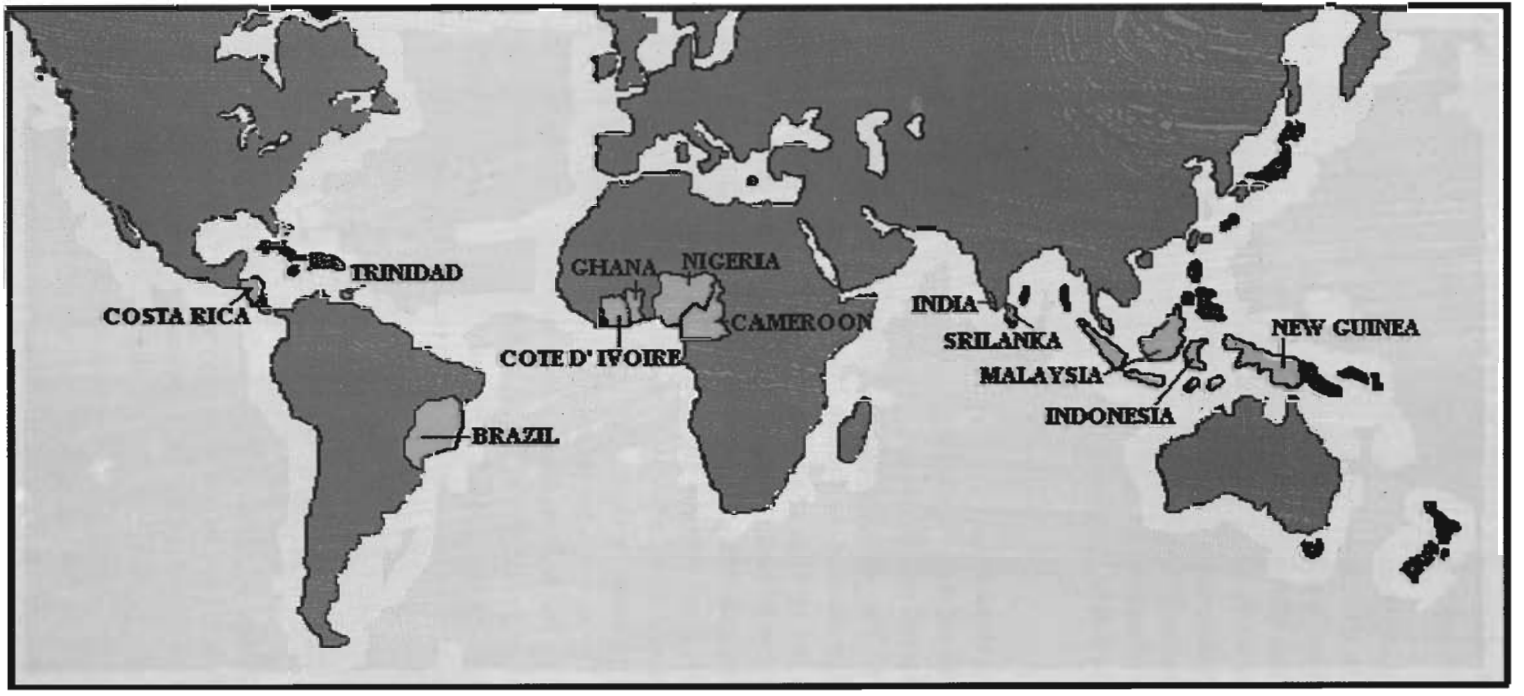


Fig.1. World map showing distribution of cocoa cultivation

the canopy and strikes the jorquette. These chupons will reach above the main tree's canopy to form new jorquettes, ultimately the first jorquette will cease growth and the same process may be repeated several times and as a consequence the canopy height increases.

Seeds from plants representing the progenies of four genetically distinct cultivars of Forastero type were assigned to six classes according to specific gravity to study the influence of specific gravity of seeds on early seedling growth and development in cocoa (Ravindran, 1981). The percentage distribution of seeds among the classes differed in the four lots. Apart from the class with specific gravity <1.0, which germinated poorly, germination rate and the time required for germination showed little dependence on specific gravity, but the growth of shoots and roots was more vigorous in material with higher specific gravity, though the correlation varied with the genotype. Selection of seed for specific gravity is recommended, as a means of ensuring the better establishment and growth of cocoa seedlings.

Leaves

The cocoa leaves show dimorphic characters in respect of different types of stem on which they arise. The leaves present on the chupons have long petioles with symmetrical arrangement. The petioles have marked pulvinus or swelling at each end which allows the leaf to be oriented in relation to the light. The leaves on the fan branches have shorter petioles and are slightly asymmetrical. Leaf production on the fan branch is by a series of 'flushes' during which the terminal bud grows out rapidly, producing 3 to 6 pairs of leaves which are pale green to red in colour depending on the intensity of shade. They are soft and delicate but gradually harden on the fan branches, while red-pigmented leaves also become green during hardening. After the flush has expanded, the terminal bud remains dormant for a period determined by various environmental factors and then produces another flush, which indicates good state of nutrition of the tree. Flushing in mature trees is stimulated by environmental factor viz., temperature, moisture stress, rainfall and light intensity. The stomata are present on the under surface leaf only and their number per unit area is affected by the light intensity which also influences the size and thickness of leaves. The leaves are larger and green under shaded condition than the full sunlight. Emergence of new flushes demands more nutrients, which is partially met from the older leaves by translocation. The healthy tree is determined by the extent to which old leaves are lost when flushing occurs (Alvim, 1977).

Cocoa leaves are produced in periodic flush cycles (Fig.4). Studies on flushing, flowering and pod setting of hybrid cocoa hybrids/cultivar under different shade and spacing over a period of four years (Ampofo and Bonaparte, 1981) showed that they tended to flush with a similar periodicity from year to year. But the period of flushing peaks differed slightly from year to year. Intensity of flushing also differed from year to year within the same plot and between plots. There were generally five flushing peaks in a year with a fairly dormant period in August. The effect of shade and spacing on the periodicity of flushing, flowering and pod setting was negligible but the onset of flushing was delayed slightly by shade. Shading and close spacing suppressed both flowering and pod setting. The results are discussed in relation to microclimatic records taken in the plots and it is concluded that although the periodicity in flushing and flowering may be controlled by endogenous factors, microclimatic parameters influence and modify these responses.

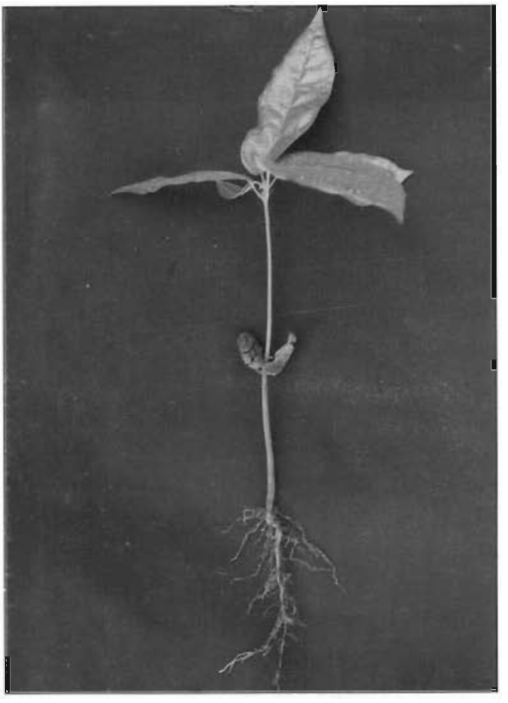


Fig.2. Seedling with leaves and primary roots

Fig.3. Mature tree with jorquetting

Fig.4. Leaf flushing

Root pattern

The cocoa tree has a tap-root system which can penetrate to a depth of 1.5 m or more in young trees and a mat of lateral roots arise from the top 20-30cm of the tap-root. The taproot develops rapidly after the seed germinates and it will grow 1cm in length to 25cm after three months. Thereafter the growth of the taproot decreases and it takes two years for attaining 50cm length (Himme, 1959). The taproot will grow straight if there are no physical obstructions. While the bulky part of the taproot may not exceed 1m, finer roots may penetrate to twice that depth and provide physical support, where lateral roots are main channel for moisture and nutrients. They divide repeatedly ending in tufts of rootlets and root hairs (Mc Creary *et al.,* 1943). The lateral roots form woven mat far beyond the limit of the canopy.

Pod development

Cocoa pod is an indehiscent drupe varying considerably in length, shape, surface texture and colour. The shape varies from spherical to cylindrical and surface from warty and deeply furrowed to smooth (Fig.5). The pod has ten ridges of which 5 alternate ones are more pronounced than the others. The ridges may be very shallow to deeply furrowed. The surface of the pod may vary from smooth to warty. A basal constriction may be present or absent. A point may be present or absent and when present it may vary from long acute to blunt and indented as shown. The colour of the developing pod may vary between a very pale green to dark green, and red to deep purple and possible combinations of these basic colours. In intermediates the colour describes as splashes of red on a white or green base indicating that the ridges are red and the furrows pale green or green. When the pod ripens, green pods turn yellow and red ones turn orange.

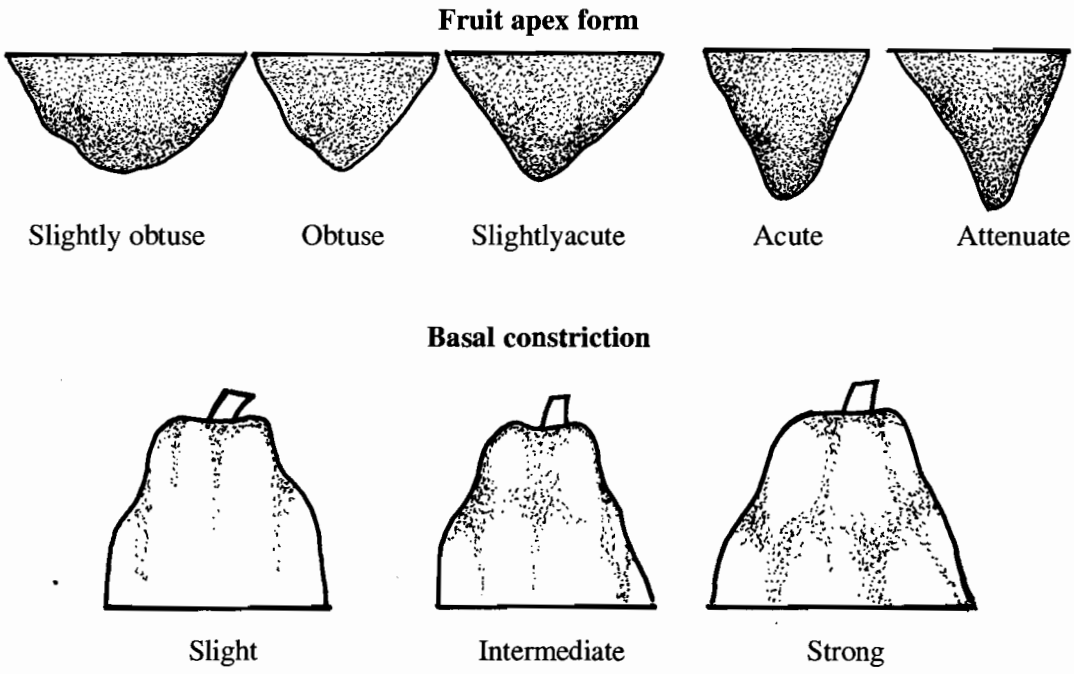


Fig.5. Variability in cocoa pod structure

After the completion of pollination, the first phase of pod growth takes 75 days to complete. During the second phase ovule growth slow down at the expense of embryo growth (Fig.6). The ovule is filled with a jelly like endosperm, which is consumed by the embryo about 140 days after pollination. The ripening of the pod takes place with 5-6 months from pollination (Mc Kelvie, 1956). The pod is attached with a peduncle to the tree. The ridges are continued from base to tip. The pods are green, pale yellow and reddish brown in colour depending on the cultivars/genotype. The husk thickness varies appreciably among genotypes. Each bean is surrounded by mucilaginous pulp (Fig.7). The number of beans per pod usually ranges between 30 and 40 attached to central placenta, which varies with respect of genotypes (Toxopeus and Wessel, 1970). Each seed or bean consists of two convoluted cotyledons and a small germ, which is enclosed in the testa. The colour of the cotyledons varies from white to dark purple. The colour of the pod/bean is depends upon the male/female parents fertilized. Pods from crosses between white beaned and purple-beaned trees contain either 75% or 100% purple beans (Wellensiek, 1932).

Bean characters

Bean weight, shell percentage and fat content are the major physical characteristics of cocoa beans. The dry bean weight is mainly determined by the male and female parental trees and other environmental factors (Toxopeus and Wessel, 1970). The weight of dry bean ranges from 0.5g to 1.5g. The cocoa bean contains 45 to 65 per cent fat, which depends on genotype. The shell is the product of testa and remnants of mucilage after fermentation and drying and the shell percentage should be as low as possible. The Forastero beans have got good strong chocolate flavour while Criollo beans give a mild or weak chocolate flavour and Trinitario beans usually give a good chocolate flavour.

Floral biology

Flower

The flowers are cauliflorous formed on the trunk and branches (Fig.8). The flowers are generally pink with darker tissue in the staminodes and the petals. Flowering commences when the tree are two to three years old. There is considerable variation between cultivars in the size and colour of the flowers. Flower-bud development in natural Criollo-Forastero hybrids was a slow process, taking 21-24 days for a newly emerged flower to mature. The flowers are borne on long pedicels and having five free sepals, five free petals, ten stamens and ovary with united carpels (Fig.9). The floral formula is K5 C5 A5+5 G (5). The petals are very narrow at the base but expanded into a cup shaped pouch and end in a broad tip or ligule. The ten stamens, which form the androecium or male part of the flower, are in two whorls. The outer whorl consists of five long non-fertile staminodes and inner whorl of five fertile stamens. The stamens bear two anthers, which lie in the pouch of the corresponding petal. The ovary has five parts containing many ovules arranged around a central axis. The style has the appearance of a single style and is about twice as long as the ovary.

When a bud matures the sepals split during the afternoon and continue to open during the night. In the following early morning the flowers are fully opened and the anthers release their pollen. Anthesis commenced between 14.00 and 16.00 hrs and was completed between 02.00 and 04.00 hrs the next day. Anther dehiscence commenced between 04.00 and 06.00 hrs and was completed between 08.00 and 10.00 hrs. The style matures a little later. Stigma receptivity was high between 12.00 and 14.00 hrs and this day is best day for pollination and failure of fertilization on this day

Fig.6. Stages of cocoa development

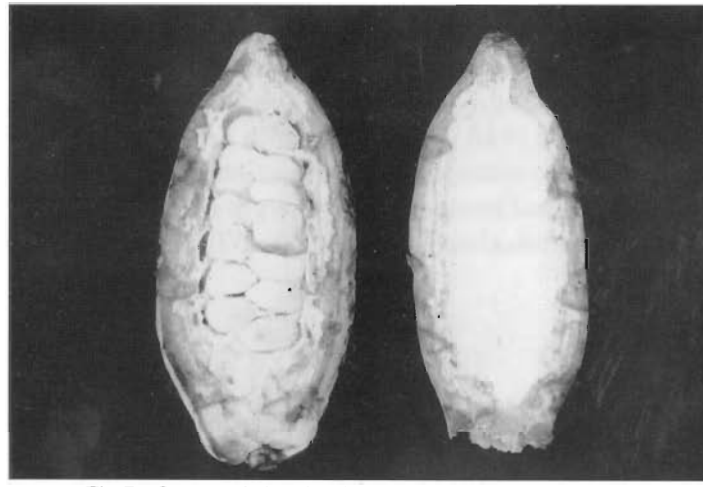
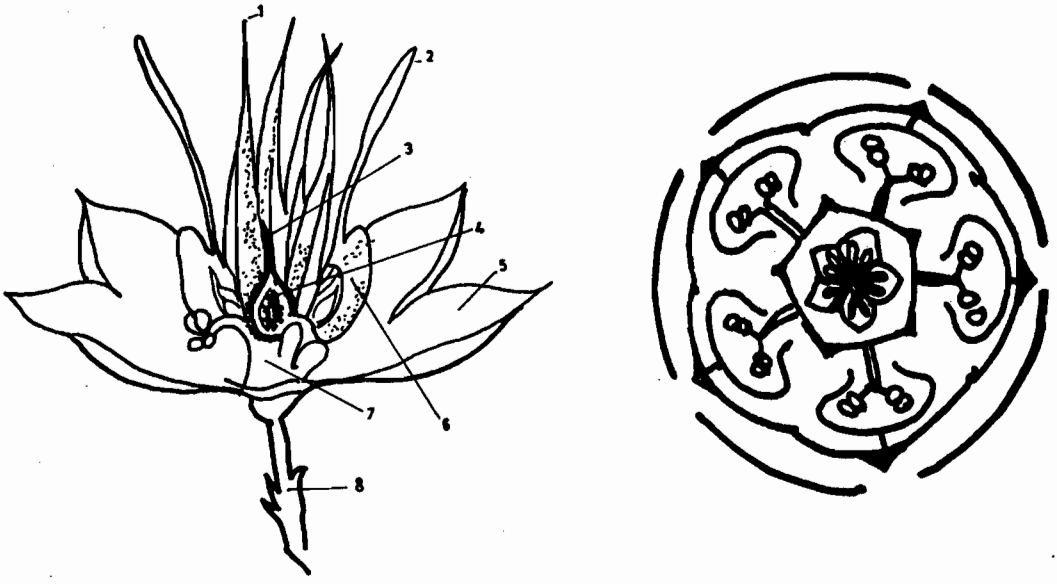


Fig.7. Open pod showing beans surrounded by mucilage

Fig.8. Flower cushion on tree trunk

will cause the flower to abscises the following day (Zamora *et al.*, 1960). The Fruit set did not occur in bagged flowers, indicating the requirement for an external pollinator. Pollen viability was found to be 97.1% by the acetocarmine staining method, and in vitro pollen germination was 66.25% (Rajamony and Mohankumaran, 1995).



Longitudinal section **Floral diagram**

1. Staminode 2. Ligule (petal) 3. Style 4. Ovary 5. Sepal 6. Cup (Petal)
7. Filament 8. Peduncle

Fig.9. Floral structure

Pollination

Cocoa is a cross- pollinated crop and is generally assisted by various small insects. The most prominent pollinating insects are midges belonging to several genera of the family *Ceratopogonidae.* A number of species of the genus *Forcipomyia* (family Ceratopogonida) are the common pollinators. Cocoa flowers are visited by many insect viz. ants, aphids, fruit flies (*Drosophila* spp.) and thrips (Winder 1977). Seven insects species belonging to the order Diptera, and five species belonging to the order Hymenoptera were identified as flower visitors. Only female Forcipomyia midges have been clearly implicated in cross-pollination. Flights between pollinations are often short but some foreign pollen may be deposited at least 75m into a plot, and pollen may be carried over much greater distances through intervening forest. Flight distances seem greater in the open conditions below the canopy of mature cocoa than within the canopy or in dense young cocoa. Both distance and direction of flight seem to depend on air-movement (Glendinning, 1972).

Insects visiting the flowers will collect pollen on their thoracic hairs, when feeding on the dark purple guidelines on the petal, which leads to the anthers resting inside the petal hood. While leaving the petal the insect may crawl down the inner surface of the staminodes rubbing off pollen grains onto the style. The staminodes are parallel with style in freshly opened flowers and pollination

will be effected, but as the flowers aged the staminodes bend away from the style, which prevents the pollination (Kaufmann, 1975). Cocoa trees produce large numbers of flowers but only 1-5% of the flowers are successfully pollinated to produce pod. The pod settings are found more in trunk and main branches (Posnette and Entwistle, 1958).

High setting rates and high rates of pod recovery were achieved through hand pollination at weekly intervals on 3 self-incompatible Upper Amazon cocoa clones over a period of two years. The flowering patterns of the 3 clones varied, as also did their relative intensities of flowering. Seasonal variations in pollinator populations and in flowering patterns influenced the levels of pollination from adjacent cross-compatible clones. Average bean numbers from hand-pollinated pods varied seasonally. Further it is confirmed that natural pollination cannot be relied upon to produce seedpods at times of the year when they are needed for planting (Edwards, 1973).

In the study of the seasonal fluctuation in pollination and fruit formation in cocoa by insect pollinators at Ivory Coast, the number of insects caught in traps indicated a density of 1.6 individuals/ flower, which suggested that these insects were poor fliers (Paulin *et al.,* 1983). Some 20 species were identified, of which the most frequently caught were the aphid *Toxoptera aurantii* (Boy.), ants of the genera Crematogaster and Pheidole, Homoptera especially *Empoasca* spp, the thrips *Selenothrips rubrocinctus* (Giard), Cecidomyiids and the Psyllid *Mesohomotoma tessmanni* (Aulm.). The population fluctuations of these species showed peaks during May-June and November-December, which coincided for brief periods with the greatest abundance of flowers. Fruit-set increased in the years when the insect abundance was more. It is suggested that the period in which large numbers of flowers and pollinators are present together could be prolonged, and cocoa production increased, either by releasing laboratory-bred insect populations during the peak of the flowering period or by breeding cocoa cultivars with flowering periods concentrated in the rapid multiplication period of the insects.

The variations in natural pollination of the cocoa and influence on the pod seed filling rate were studied (Cilas *et al.*, 1987).The mean number of pollen grains produced in the stamens varied with time and was negatively correlated with the percentage of unpollinated flowers. The number of insects trapped in the flowers influenced pollination; the numbers of microdipterans, thrips and ants were negatively correlated with the pollen scarcity index calculated from the distribution of pollen grains on the styles, implying that an increase in these insect populations leads to better pollination. Aphids did not seem to be involved in cocoa pollination. The pollen scarcity index was also correlated with the index calculated from the distribution of seeds/pod observed 5 months later.

Cytogenetics

During meiosis bivalent formation was observed in the diploid species of T. *cacao* and although there was a low apparent chiasma frequency, disjunction was regular (Martinson, 1975). In the two colchicine-induced autotetraploids studied, there was a high frequency of bivalents compared with trivalents and quadrivalents. Pollen fertility was between 38% and 64% in the tetraploids and between 90 and 98.5% in the diploids; fruit set was between 11.5 and 19.1% in the tetraploids and was 74% in the diploids, and mature bean number was 50% of the ovule number in the tetraploid and 90% of the ovule number in the diploid. It is suggested that an improvement in the yield of the autotetraploid might be achieved by crossing induced tetraploid individuals selected on the basis

of the frequency of bivalent formation as well as on the basis of uniformity in pollen size and fertility.

Cytological analysis of four clones revealed the presence of strict bivalent pairing in over 400 meiotic cells in the diplotene, early diakinesis, and metaphase I stages; two nucleolus organizer region chromosomes per nucleus and a maximum of two nucleoli per root tip nucleus and two chromosomes associated with the nucleolus at the diplotene stage and early diakinesis. When a low-copy cocoa DNA probe was used, telomeric *in situ* hybridization sites were located on 2 homologous mitotic chromosomes in the nucleus and at 1 telomeric site on 1 pachytene bivalent in the nucleus. It was concluded that *T. cacao* is a diploid, not an autotetraploid (Glicenstein and Fritz, 1989).

In another study of the self-compatible clones ICS1, UF667 and UF29 and hybrids of these with the self-incompatible SCA6 and IMC67, UF667 and UF29 showed more bivalents than ICS1, indicating a greater uniformity of pollen mother cells division in these two. The hybrids had a low frequency of bivalents. Univalents and trivalents were also observed in both cases. No relationship was found between pollen viability and the frequency of bivalents (Carletto, 1974).

Lanaud (1987a) studied the monogenic and polygenic inheritance in eleven doubled haploid families derived by colchicine treatment of spontaneous haploids. Nine families showed Mendelian segregation for 6 monogenic enzyme markers (for which the original clones were heterozygous) and 2 showed distorted segregation. All expected alleles were found in the doubled haploid families. Polygenic characters (ovule number, fruit set and seed characters) varied widely in the doubled haploid families, values being generally lower than in the original clones. The results indicated that it is likely to be difficult to predict the value of doubled haploids as parents for the production of novel hybrids.

Induced doubled haploids by colchicine treatment from spontaneous haploids of two clones varied widely for pollen and ovule fertility, but were generally less fertile than the original clones. Low ovule fertility was not affected by the pollinator used and was not improved by grafting. Pollen fertility showed more seasonal variation in the doubled haploids than in the original clones. Low ovule fertility appeared to be caused by lack of differentiation of embryo sacs. These characters were not observed in the progeny of doubled haploids. The low fertility is attributed to inbreeding depression that may hinder the use of DHs for the production of novel hybrids (Lanaud, 1987b).

A new haploidy in cocoa has been identified in the form of "Flat beans" (Dublin, 1973). The pods of African Amelonados contained the lowest percentage of flat or shriveled beans while hybrids from *T. cacao* x *T. grandiflorum* and *T. cacao x Herrania* contained the highest percentage. Among surviving seedlings from flat beans, 3.1% were haploid. Only chromosome counts on leaves or buds gave a reliable method of verifying haploidy. However, the average length of stoma guard cells or the numbers of chloroplasts contained in them are not useful for identifying haploid characters.

Compatibility mechanism

Self-compatibility

It is the process of fertilization of female gamete by pollen of the same tree that is seen in Amelonado populations of cocoa. Natural pollination of self-compatible trees is inadequate and it

cannot be applied to self-incompatible trees. Pollination by flying insects results in 25-50% cross pollination on self compatible trees but the proportion of flowers pollinated is comparatively less (Posnette, 1950; Voelcker, 1940). Self-compatibility is also observed in three accessions viz., PA 7 x NA 32, Landas 365 and Landas 357 among the ten collections studied (CPCRI, 1993).

Self-incompatibility

This is a well known process occurring in cocoa wherein failure to set with the pollen from the same plant (self-incompatibility) or with pollen from other plants (cross- incompatibility) occurs in cross fertilizing plants, which means that certain trees could not set fruit with their own pollen or with one another (Pound, 1932). Here the pollen of the same tree will not fertilize the flower of other same genotype/cultivar. Sometime self-incompatible trees often become cross compatible. The incompatibility in cocoa is gametophytic, where the pollen tubes develop normally but the male gamete does not fuse with the female gamete. A genetic mechanism controlling the fusion of gametes has been proposed, consisting of a series of S factors (Cope, 1962). Five S alleles controlling selfing and crossing between many cultivars are proposed viz., Sa=Sb=Sc>Sd>S. Due to incompatible pollination, the proportion of non-fusion between the gametes is 25-100% where flowers fall off within three or four days. The degree of incompatibility varies between the different populations where the Amazon cultivars are all self-incompatible but cross compatible. Trinitario cultivars have a high proportion of self-incompatible trees, which will not cross with other self-incompatible trees, requiring pollen from self-compatible trees for successful pollination. Self-incompatibility is made use in seed gardens to ensure that seed of a certain parentage is produced.

The evolution of selfing versus out breeding has been of major interest to plant population biology. The independent historic introductions of self-compatible and self-incompatible genotypes of cocoa in Trinidad have been used to study the selection acting upon an unnatural breeding system polymorphism (Warren *et al.,* 1995). Field observations of an abandoned cocoa plantation indicated that the self-incompatible phenotype had slightly increased in frequency within a single generation. The self-compatible trees produced significantly fewer flowers but still set more pods than did the self-incompatible trees, although compatibility types did not differ in tree size or mature seed production. Greenhouse observations suggested that the apparent failure of self-compatibility to increase in the population is related to inbreeding depression resulting from selfing, expressed as reduced seedling establishment.

Variations in compatibility among the accessions at Vittal have been noticed (CPCRI, 1988; Nair and Rekha, 1996). Compatibility reaction of several cocoa accessions maintained in the germplasm revealed that different trees belonging to the same accession might not be identical with regard to their compatibility react ion.

DIVERSITY

There are three types of populations identified in cocoa namely Criollo, Forastero and Trinitario as proposed by Cheesman (1944). Certain morphological characters of pods and beans are used as the basis for clarification such as varieties, cultivars, types or populations of the cocoa. Variations of the cocoa populations are to be expected in view of the out breeding nature.

Criollo

The Criollo populations are characterized by various traits such as the soft pod texture with red

colour (Fig.10) and purple/ivory cotyledons. The average number of beans per pod ranged from 20-30 with white coloured beans fermenting very quickly. Criollos typically lack vigour with small leaves borne on fan branches. Criollo populations are extremely susceptible to disease like bark canker (*Phytophthora* sp.) and *Ceratocystis* and mirid bugs. These populations are subdivided into two geographical groups Central American Criollos and South American Criollos.

Forastero

The Forastero populations are large group that contains cultivated, semi-wild and wild populations of which the Amelonado populations are the most extensively planted. The Forastero populations are distinguished by the green colour of the pod with hard texture of husk (Fig.11). The number of beans present per pod is 30 or more and the cotyledons are pale to deep purple in colour. The common Forastero populations are Amelonado (Fig.12), Comum, West African Amelonado, Nacional, Matina or Ceylan and Guiana wild Amelonado populations.

Trinitario

The Trinitario populations are considered to be intermediates of the Forasteros and Criollos (Cheesman, 1944; Cuatrecasas, 1964). They are the populations evolved from initial crosses between Criollo and Forastero. Trinitarios are not found in the wild state. The pod husk texture is hard and variable in colour. The pod contains 30 or more beans with variable colour rarely white. This variability of the pod and bean colour may be due to the intermediate characters of Criollo and Forastero populations. The first cross gives very vigorous, prolific, hardy trees and these characters continue for a few next generations, but later the vigour declines. However, the vigour may remain higher than the old Criollo trees. Trinitario populations are usually variable in pod and bean characters because the parents have highly contrasting characters and the populations partly red coloured pod found in Fiji Islands.

Classification of cocoa cultivars were done based on cluster, principal component analyses and simple statistical methods using 39 characters to group 294 cultivars. These distributions corresponded roughly to the traditional classification into Criollos, Forasteros and their subdivisions. As the majority of new cultivars are hybrids between these 'genetic' groups, a new classification based on ten characters were described (Engels, 1986).

Molecular markers

Genetic diversity was assayed by 57 informative random amplified polymorphic DNA (RAPD) marker loci among the southern Mexican populations and horticultural collections of cocoa (*T. cacao*). These were obtained from the extremes of its geographic range including archaeological sites in southern Mexico (Whitkus *et al.*, 1998). A unique sample of the total diversity found in this study exists in the southern Mexican populations. These populations were significantly different in RAPD profile to the other populations studied, including Criollo varieties, their morphological and geographical group. A population of cocoa found in a sinkhole (cenote) in northern Yucatan with genetic affinities to populations in Chiapas suggests the Maya maintained plants far away from their native habitat.

Based on molecular studies using random amplified polymorphic DNA (decamer primers) it was found that 'wild' *Theobroma cacao* populations from Mexico were genetically distinct from South American wild plants and modern cultivars. Criollo cultivars are more similar genetically to

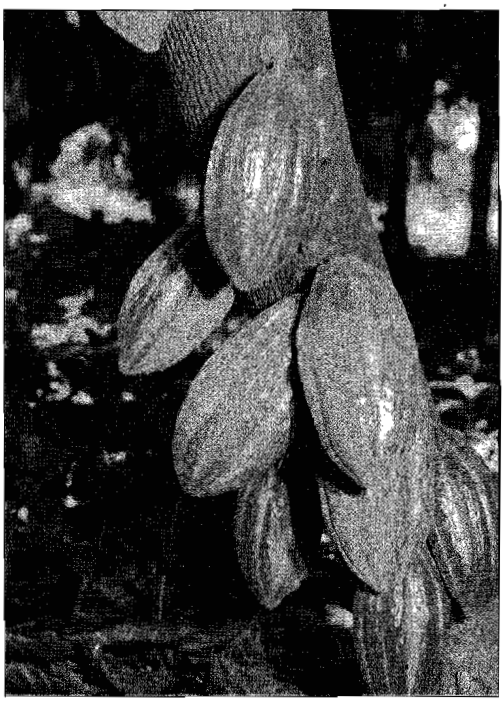


Fig.10. Criollo pods

Fig.11. Forastero pods

Fig.12. Amelonado tree with pods

South American germplasm than to Mesoamerican 'wilds'. Recently found 'wild' Yucatan plants in Maya 'sacred groves' are most probably the closest living representatives of an ancient Maya cultivar (Cruz *et al.*, 1995).

The diversity of nuclear genome in 203 cocoa clones belonging to the presumed morphogeographical groups Criollo, Trinitario, Lower Amazon Forastero and Upper Amazon Forastero was surveyed for RFLPs using four restriction endonucleases and 31 seed cDNA probes (Laurent *et al.*, 1994). A high level of polymorphism was found and confirmed the general distinction of the Upper Amazon Forastero group on one hand and the Lower Amazon Forastero, Trinitario and Criollo groups on the other. These results combined with previously obtained nuclear rDNA and mtDNA data allow the proposal of new hypotheses on the origin and evolution of the different cocoa populations. The existence of 2 distinct subspecies, sub spp. *cacao* and *sphaerocarpum* is proposed, and it is suggested that Forastero differentiated from the Upper Amazon region into Upper Amazon Forastero and Lower Amazon Forastero, whereas Criollo differentiated independently on the other side of the Andean barrier.

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2. BREEDING AND GENETICS

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ORIGIN AND SPREAD

Cocoa (*Theobroma cacao* L.) is a native species of tropical humid forests on the lower eastern equatorial slopes of the Andes, in South America (Cheesman, 1944). It was domesticated and the produce used for consumption for the first time by the Mayas and Aztecs. The first Europeans to encounter cocoa drink was the Spanish who invaded and conquered the empire in Mexico in the 16th century. They found that cocoa beans were stored in large quantities and were even used as currency. The Spanish learnt from the 'Aztecs' the technique of making 'xocoatl', a drink made from cocoa beans after roasting and grinding. The word 'chocolate' is considered to have originated from 'xocoatl'. The word 'cacao' also was used by the Spanish and it has probably originated from 'cacahuatl', a word that Aztecs used for cocoa beans. Even before the Spanish conquest, cocoa was taken to different regions by the Mayas, Aztecs and Pipil- Nicaraos (Young, 1994).

From the centre of origin, the species spread out creating the two main groups: the "Criollos" which resulted from dissemination through the Andes towards the lowlands of Venezuela, Colombia and Ecuador and towards the north to central America and Mexico and the "Forasteros" which resulted from dissemination towards the Amazon valley in Northern Brazil and the Guayanas (Alvim, 1987). Cuatrecasas (1964) assume that in early times, a natural population of cocoa was spread throughout the central part of Amazonia – Guiana westwards, and northwards to the south of Mexico and that these populations developed into two different forms geographically separated by the Panama isthmus. According to Purseglove (1968), Criollos might have originated as mutations and the homozygous recessive characters have been fixed in populations on the periphery of distribution and these were then maintained through geographic isolation and selection.

Criollo types spread to Central America and to large number of Caribbean Islands, including Trinidad in 1525 and thereafter to Jamaica. The dissemination to Venezuela and Costa Rica was made by the Spanish (Pittier, 1933). Introduction to Martinique and Haiti was by the French. Planting in Belem and Bahia in 1750 was attempted by the Portuguese.

Trinitario arose out of natural hybridization between Criollo and Forastero. According to Pound (1945), Criollo population from Venezuela and the Amelonado type Forastero from Guayana could have been involved in hybridization leading to the production of Trinitario. In 1727, much of the Criollo populations in Trinidad were destroyed by a "blast", which may be a hurricane or an epidemic outbreak of pests or disease (Cheesman, 1944). Re-establishment of plantations was done using seeds from Eastern Venezuela, which may be either Amelonado or Trinitario. Hybrids arose out of natural pollination, which were superior in terms of yield and disease resistance and the Criollo types were gradually replaced by these hybrids. Trinitario was distributed to Venezuela about 70 years later. Similarly Ecuadorian cocoa was introduced in Mexico. The types from the

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mouth of Amazon moved to Central America and Amazon varieties were taken to Colombian Criollo plantations in the 19th century.

During the period from 1930 to 1934 Pound made a survey of cocoa in Trinidad and Tobago and identified 100 superior trees, Imperial College Selections (ICS), using the criteria, yield of not less than 1 ton of dry fermented beans per acre per year, yield of pods/ tree, the area it occupied and wet bean weight of not less than 3.5 g. Only 95 selections satisfied the above criteria and ICS 90 to ICS 100 had smaller beans, but with high yield. These selections included the three types, Forastero, Criollo and Trinitario. As importance was given for large bean size, most of the ICS selections had Criollo ancestry. These included both self compatible and self incompatible types. These ICS selections were distributed all over the world. The current populations in Central America and Venezuela are very heterogeneous. They comprise a population of hybrids of varying degrees of introgression between Forastero and Criollo.

"Nacional' type is indigenous to Eastern Ecuador (Pound, 1945). These resemble Criollos rather than Forasteros. But it is distinct from both. Nacional cocoa is characterized by the specific 'arriba' flavour (Enriquez, 1993). Venezuelan cocoa was introduced to Ecuador by 1890. These materials were more vigourous and precocious even in poor soils and as such acquired popularity among the planters. As a result, there was significant genetic mixing between the different types and pure types gradually disappeared (Soria, 1970)

During 1822, cocoa seeds were taken from Portuguese colonies of South America to the island, Sao Tome of the West Coast of West Africa. It also spread to the neighbouring island, Principe and these two islands together continued as the leading producers of cocoa in West Africa upto 1910. Cocoa cultivation was started in the neighbouring African island of Fernando Po in 1840, where it flourished. The attempt to begin cocoa cultivation in the mainland of Africa was first made by the Dutch missionaries in 1815. Due to unsuitability of the selected location in Ghana, this introduction was almost a failure. The Bassel missionaries tried another introduction in 1857, which was more successful. The most successful introduction into African mainland was, however, made by the Ghanaian, Tetteh Quashie in 1879. He brought a pod from Fernando Po and the early population of cocoa in Ghana is considered to have originated from this pod. From Ghana, it spread to other African countries; the most important of which are Ivory Coast, Nigeria and Cameroon. In these countries, there was immediate extension in area and they eventually turned out to be the largest producers of cocoa in the world. As it is today, about 68 per cent of the total world production of cocoa beans come from these African countries where this crop was introduced relatively very late. A characteristic of African cocoa used to be, especially upto the 1950's, the homogeneity of cocoa populations with respect to pod characters. This was to be normally expected as the entire original African population had derived from practically a single pod. The pods were relatively smooth on the surface with 'melon' shape. It was this pod shape that has resulted in the African cocoa being designated as the 'Amelonado' type.

Cocoa was introduced in the 16th century into Asia and the Pacific (Wood, 1991). Venezuelan Criollo was introduced into Celebes by the Dutch in 1560. They also introduced the crop into Java. The Spanish took Criollo types from Mexico to Philippines in 1614. It was introduced into Sri Lanka also from Trinidad at about 1798. From Sri Lanka, cocoa was taken to Singapore and Fiji in 1880, Samoa in 1883, Queensland in 1886 and Bombay and Zanzibar in 1887. Cocoa was introduced into Malaysia in 1778 and in Hawaii in 1831.

Cocoa was introduced in India in the early 20th century, but its cultivation was limited to a few Government farms. Both Criollos and Forasteros were introduced into the country. In the 1930's, it was decided to remove all Forastero plants in the country to maintain the genetic purity of the Criollos, which are superior in terms of quality of the produce. The Criollos, which were maintained in the farms, failed to come up well and many plants were damaged by pests and diseases. Some continued to survive, though their yields were low. Cocoa cultivation was resumed in a big way in the 1960's with pods of Forastero type. The initial introductions were made as pods mainly from Malaysia. These were then followed by introductions from African countries.

GENETIC STRUCTURE

Theobroma cacao L. includes a large number of highly variable populations. There are self compatible and self- incompatible types in the population. The existence of incompatibility leads to cross pollination in many populations. The genetic diversity in the cultivated species has been studied using morphological, isoenzyme and molecular markers. Cheesman (1944) recognized two major groups: the Criollos and the Forasteros. The Criollos were divided into Central American and South American Criollos and the Forasteros into Amazonian Forasteros and Trinitarios (Cheesman, 1944; Hunter, 1990). Amazonian Forasteros were subdivided into two groups, the Lower Amazonian Forasteros and the Upper Amazonian Forasteros, the latter being morphologically more variable (Toxopeus, 1989). A detailed review of the genetic structure of cocoa has been given by Lanaud *et al.* (2001).

Diversity in Criollo, Forastero and Nacional

Using isoenzymes, Lanaud (1986a and b) showed a higher diversity in Upper Amazon Forasteros in comparison with Lower Amazon Forasteros. RFLP study on cytoplasmic DNA revealed that Upper Amazon Forasteros were less variable than Lower Amazon Forasteros as against morphological and isoenzyme studies (Lanaud, 1986b). The study also showed higher diversification of the Criollo types. Hybrid nature of Trinitario especially UF, ICS and UIT is confirmed by RFLP studies. French Guiana (GU), Amelonado and Catongo Forastero (C 361) varieties and certain Criollo clones (LAN, COL, Guasare, POR and PSL) corresponding to ancient cultivars displayed a high homozygosity although significant morphological diversity has been observed in terms of pod shape (Lachenaud and Sallee, 1993). Certain Upper Amazon Forastero types also appeared to have a relatively high degree of homozygosity, for instance the EBC clones collected from Colombia, certain Ecuadorian clones LCTEEN and SCA 6.

Motamayor and Lanaud (2002) detected a very small proportion of polymorphic loci in ancient Criollo types. Within the group hardly any molecular difference was observed despite the highly contrasting morphotypes collected from Venezuela and Mexico. The modern Criollo clones taken from different locations exhibited variability. Around 90% of modern Criollos and Trinitario types resulted from hybridization and subsequent introgression between two genetically uniform types: homozygous Amazon Forastero on one side and homozygous modern Criollo on the other side. That is why in most of the cases, only the same two alleles are found on each locus in the modern Criollo/ Trinitario hybrid groups. Genotypes belonging to these groups therefore represent different levels of recombinations of the Criollo and Lower Amazon Forastero parental genomes. Several studies have shown the Criollo to form a distinct group (N'Goran *et al.*, 1994; Laurent *et al.* 1993a; 1993b; and 1994). Studies on genome size also showed that the Criollo genome is smaller

than that of Forastero. The Criollo accessions of Colombia and Ecuador, however, are more genetically distinct as compared to Forastero populations.

In old plantings of Ecuador, a highly homozygous Nacional type was identified (Lerceteau *et al.*, 1997). These trees probably represent the homozygous ancestor as the origin of all the current hybrid varieties resulted from Trinitario introgressions into this ancestral type.

The Forastero group comprises a large number of both wild and cultivated types. It includes vigorous trees and numerous disease resistant sources. The results from multivariate analysis suggested a close relationship between the Trinitario and Lower Amazon Forastero groups (Dias and Kageyama , 1997).

The genetic variability within a Forastero population has been studied by many. Variability in yield expressed as dry weight or wet weight of beans (Nair *et al.*, 1990; Pound, 1932,1933; Tan, 1981; Subramoniam and Balasimha, 1982), pod value (Lockwood and Edward, 1980)), seed size (Cilas *et al.*, 1989; Vello *et al.*, 1972) pod characters, number and weight of seeds (Soria *et al.*,1974), pod and bean characters (Soria, 1975; Subramoniam and Balasimha, 1982; Tan, 1981) and floral traits (Castro and Bartly, 1982) was very high. Certain Upper Amazon populations such as LCTEEN and IMC are very variable. According to Russel *et al.* (1993), within population diversity was greater than between population variability in IMC, PA and LCTEEN.

Studies have clearly indicated that genetic base of cocoa is very narrow especially in Criollo, Forastero, Trinitario, Nacional and Amelonado varieties. The Upper Amazon Forastero types collected by Pound was included in cocoa breeding programmes from 1950 onwards. However, only a part of this material has so far been utilized in breeding programmes. Attempts are underway to exploit the available variability in all cocoa producing countries of the world. Certain Forastero types like GU clones, LCTEEN and EBC clones have not yet been used in breeding. Collection of variable types need to be continued to broaden the genetic base of the crop.

GERMPLASM COLLECTION

Breeders need germplasm containing sufficient diversity to allow them to produce varieties with good economic characteristics. Collection, conservation, characterization, cataloguing and distribution are all important in germplasm. Distribution of cocoa germplasm must be through internationally recognised agencies like IBPGR, which designated the International Cocoa Genebank, Trinidad and the collection at Centro de Ensenanza y Investigacion de IICA, Turrialba, Costa Rica (CATIE) as "universal collection depositories". The core of Trinidad collection is Pound's Ecuadorian and Peruvian collection, the 1952 Anglo Colombian collection, representatives of Chalmer's and Allen's material and selections from cultivated cocoa in Trinidad and other Caribbean Islands. The core of Turrialba collection is selections from cultivated cocoa, especially the United Fruit Company clones and their derivatives from Costa Rica, similar material from other American countries and Criollo. Large collections of primary material are also maintained in Colombia, Ecuador, French Guiana, Venezuela and Brazil. Field collections are maintained in Puerto Rico, Cote d' Ivoire, Jamaica, Malaysia, Grenada, Nigeria, Papua New Guinea, Ghana and India.

The germplasm has been distributed from Trinidad and Costa Rica. Large quantities of seed were distributed from Trinidad to Ghana in 1944 and to Nigeria and Papua New Guinea in the

sixties. Long distance distribution is done using intermediate quarantine facilities at the Royal Botanical Gardens, Kew (University of Reading, from 1983) and the United States Department of Agriculture in Miami, Florida. Cocoa cultivation is still largely dependent on traditional varieties or landraces domesticated more than 150 years ago. Less than one third consists of hybrid and clonal cultivars developed by breeding initiated since 1940s first in Trinidad and subsequently in Ghana. These breeding programmes were quite successful in utilizing the variability for vigour and yield between a limited number of genotypes originally collected by Pound from 1937 to 1942. Though yield increase was spectacular, the level of resistance to most threatening diseases was not satisfactory. This is because of the fact that the sources conferring resistance are limited in the germplasm. In order to make resistance breeding fruitful, broadening the genetic base is very important.

The expeditions held since 1949 to collect cocoa germplasm in primary and secondary centers of genetic diversity indicate serious concern in preserving as much genetic diversity as possible before it is lost due to deforestation and other socio-economic causes. Lachenaud and Ducamp (1996) detected high levels of host resistance to Witches' broom in germplasm collected in 1987 in French Guiana. This confirms that systematic screening of all available cocoa germplasm is likely to be successful. Because of the prevalence of serious diseases of cocoa in different geographical zones, such as 'witches broom' on the American continent and 'swollen shoot' in Africa, precautions must be taken during any transfer of plant material from one country to another.

GENETICS OF IMPORTANT TRAITS

Very little is known about the genetics or heritability of the more important characters such as yield, vigour and disease resistance. However, the genetics of the incompatibility mechanism and of three useful characteristics that are often used as marker genes are clearly understood.

Axil spot is a red anthocyanin colouration at the junction of the petiole with the main axis. The intensity varies considerably from petioles that are completely dark red to those with a spot of red at the junction. This characteristic is caused by two complementary factors A and B (Harland and Frecheville, 1927). The bean colour of cocoa varies from violet to different shades of purple and white. One major gene locus is involved, purple being dominant over white (Wellensiek, 1932). Albinism was discovered in Ghana by Posnette (1945), who located a tree which was heterozygous for this character. The inheritance proved to be monogenetic. The recessive state of gene produces albino plants. The number of ovules/ fruit is a heritable character, controlled by poly genes (Lopez *et al.*, 1988).

In all cocoa growing countries, yield improvement was the primary objective. With the spread of diseases like Witches' broom, CSSV, vascular streak die back, black pod etc., which are difficult to be managed with chemicals, more thrust is now being laid for evolving disease tolerant types.

METHODS OF BREEDING

Selection

Selection is one of the oldest breeding methods and is the basis of all other crop improvement methods. The efficacy of selection is dependent on the presence of genetic variability. There is ample scope for selection in cocoa because of the highly heterozygous nature of the crop. Immense variability exists in the seedling populations. The variability is so high that in a seedling population,

about 75% yield is obtained from 25% of the trees. Rest of the trees will be of low productivity. The yield is influenced by changes in environmental conditions. Yield /tree varies with spacing, shade, soil conditions, nutrient supply etc. Longworth and Freeman(1963) suggested to consider tree yield along with trunk diameter for better efficiency in selection. In addition to pod production, the weight of cured beans/ pod also may be considered for selection. Number of beans/ pod is a trait, which is not influenced by environment but the bean weight is influenced by the environment to a considerable extent (Pound, 1931). However, seasonal influence is very high, the beans produced during summer season being small.

An easy approach to yield improvement in cocoa is to select plants superior in yield and their subsequent development into clones. For selecting individuals from the populations, certain criteria have been fixed. Plants yielding not less than 100 pods/tree/year, each pod weighing 350-400 g or more with a pod value of not more than 10 and with 35-40 beans having a fermented dry weight of 1.0 g are selected as parents. In general, cocoa is well adapted to vegetative propagation by grafting, budding or cuttings.

A number of superior clones have been selected throughout the world and these are getting very high acceptability among the growers. The Kerala Agricultural University has initially selected 70 clones, out of which seven (CCRP 1 to 7) were released for cultivation as clonal blends.

Hybridization

Hybrid vigour between parents showing good combining ability can be readily exploited in cocoa. Large number of crosses has been made in countries like Trinidad and potentialities of the parents have been assessed. Posnette (1951) demonstrated interpopulation heterosis in cocoa. The initial crosses involving Pound's seedling collection showed exceptional vigour, precocity and high yield in Ghana. These observations and similar ones in Trinidad were attributed to hybrid vigour (Bell and Rogers, 1956). These led to seeking heterosis through crossing between divergent parents.

Significant yield improvement in first generation hybrids and heavy demand for improved planting material led to explorative crossings in many cocoa producing countries. However, the programmes had severe limitations in that crossing was taken up using parents of illegitimate origin and these were not backed by knowledge on genetics of the crop and inheritance of economically important characters. As the results of such programmes were far from satisfactory, Kennedy *et al.* (1987) gave more importance to breeding for resistance to pests and diseases. Although some results on resistance breeding have been demonstrated, breeding has been rated as ineffective.

Experimental evidence now suggests that direct approach to breeding for yield is successful. In trials with diverse crosses in Brazil, Costa Rica, Ghana, Ivory Coast, Nigeria and Papua New Guinea, there were significant additive components for yield. Heritability estimates ranging from moderate to high and large additive components of variation indicate easy progress towards high yields, at least in the early years of the programme. Glendinning (1963) in Ghana showed that the number and size of beans were highly heritable. Heritability assessment by Soria *et al.* (1974) showed higher values for fruit length (55%), fruit diameter (63%) and total weight of fruits (57%). The traits like pod length, diameter, weight, number of beans, wet bean weight, husk weight and pod and bean indices had high heritability (Ramirez and Enriquez, 1988). The number of pods/tree

registered low heritability (Napitupulu, 1992), but the values were high for bean size and bean weight per pod. However significant variation was detected in a number of crosses over different environments in Ivory Coast.

Method of hand pollination

In artificial pollination, a flower bud which will open the following day, recognised by its whitish colour and swollen appearance, is selected. The bud is covered with hood of plastic tube/ hose pipe piece 5 cm x 1.5-2 cm, which is sealed to the bark using materials like plasticine/glaze putty. The tube is covered with muslin cloth at the top, kept in place with a rubber band. This ensures circulation of air and exclusion of insects. Opened flowers are collected from the desired male parent and stamens are carefully taken out by pushing the corresponding petal. One entire anther with a part of the filament is deposited on the stigma. One or two staminodes may be pinched off to give access to the stigma. Emasculation is not necessary due to the presence of self-incompatibility. For selfing also, hand pollination is done using stamens from the same flower (Fig.1). The pollinated flowers are labelled using tin foil pieces fixed in the cushion using ball pins. The hoods are removed 24 h after pollination and in three to five days, fertilisation is confirmed by the visual swelling of the ovary. In order to prevent undue shedding and wilting of fruits from hand pollinations, it is usual to remove all the developing fruits on the tree produced by open pollination. Developing pods are covered with wire mesh after six to eight weeks to protect them from mammalian pests (Fig.2). The pods are collected at maturity, beans are extracted and sown in the nursery.

Preselection method

In cocoa, relationship between vegetative characters and yield was positive (Enriquez, 1981; Glendinning, 1966; Ngatchou and Lotode, 1971; Paulin *et al.*, 1993). However, Francies (1998), Sridevi (1999) and Verghese (1999) recorded contradictory results. After bearing, vegetative growth slows down and the correlation between growth reduction and yield became positive. At the Kerala Agricultural University, the hybrids are screened in the nursery based on HD^2 (H- Height, D-Diameter) values and only those with higher values are carried forward to the progeny trials.

Selection of superior hybrids

The seedlings selected based on vigour/ disease tolerance are field planted. On attainment of steady yield, the hybrids are evaluated for their performance. The highest yielding hybrids with other desirable attributes are multiplied and released as new clones. The parents selected in hybridization programmes are tested for both their GCA (general combining ability) and SCA (specific combining ability). To test the GCA, all the selected clones are crossed with a standard variety and the progenies are evaluated both in the nursery and in the field. A few best combiners are then selected and crossed in all possible combinations to assess their SCA. Parents of promising hybrids are identified as best combiners. The best combiners are multiplied and used as parents in seed gardens for the production of quality hybrid seeds.

Clonal Seed gardens

Seed is the cheapest and most convenient planting material in cocoa. Seedlings develop into trees with a convenient habit of growth. However, seedlings resulting from open-pollination show large variability. The purpose of a seed garden is to produce seeds of known parentage and proven

performance. Therefore, the parents used in the seed gardens are selected based on the results of progeny trials. The search for best combiners involves large number of crosses, their screening and selection both at the seedling and adult stages. Having selected the parents, they are propagated vegetatively. The female parent should be self incompatible. The desired crosses can be ensured either by hand pollination or by the proper design of the seed garden where natural pollination is relied. With two self-incompatible parents, all the pods resulting from cross-pollination can be used for seed. Where one parent is self-incompatible, seed is collected only from the self-incompatible parent and in such cases, pollen parent is planted in a ratio of one to five female parent trees. Seed garden must be isolated to some extent from other cocoa and a distance of 200 m is considered sufficient to prevent unwanted cross pollination.

Inbreeding

Inbreeding often forms a part of the breeding activities not only to breed parents with some degree of homozygosity for the production of hybrids but also to breed materials homozygous for such desirable traits like disease resistance. Often, the incidence of self-incompatibility tenders inbreeding difficult or impossible. In cocoa certain self compatible trees are encountered in a population and in these plants selfing is possible. The selfing needs to be continued upto 6 to 7 generations to attain homozygosity and thereafter these can be utilized for crossing to exploit hybrid vigour.

The self-compatible types upon selfing produce S_1. The extent of inbreeding depression varies with the genotype. In some, many weaklings are observed which may perish in the nursery. But in some genotypes, normal seedlings are produced though slightly less vigorous than hybrids of the same age. The number of such first generation inbreds will be high to be carried forward to the field. Hence selection of inbred seedlings in the nursery becomes essential. If vigourous seedlings among the lot are selected, the homozygous ones will be lost and if weaker seedlings are used, the plants may perish in due course. Hence at Kerala Agricultural University, India, twenty vigourous seedlings are field planted, their incompatibility position ascertained on attaining flowering and self compatible ones are selfed again to produce second generation inbreds. This process is to be continued till 6 to 7 generations. One of the observations is that some genotypes cannot be carried forward to advanced generations due to absence of compatible plants in the selfed generations. In advanced generations of selfing, the main stem often forks into 2 to 4 at very low heights.

BREEDING FOR RESISTANCE TO DISEASES

Cocoa is cultivated in 57 countries of the world. Ninety five per cent of the world production comes from 12 countries. Five major diseases viz., Witches' broom (WB), black pod (PP, BP), Moniliasis pod rot (MO), cocoa swollen shoot virus (CSSV) and vascular streak die back (VSD) affect the crop causing about 40% yield loss per year. Selection for disease resistance under field conditions is time consuming and environmental factors plus genotype x environment interaction may affect the genotypic variation in host resistance. Screening tests on seeds (CSSV, Ghana), young seedlings (WB, Brazil) and seedlings (VSD, India) are of practical use in selection programmes. But these are not simple and efficient. Inoculation tests on leaves/ leaf discs to detect resistance to WB and BP perfected by CRU and CIRAD are more efficient.

Selection for host resistance requires standardization of the environment and inoculation methods

to reveal maximum genotypic expression of major components of host resistance. There should be a close correlation of the results of preselection test with mature plant resistance.

The use of molecular markers in germplasm management and identification of genetically divergent populations has been studied by many workers (Christopher and Sounigo, 1995; Lanaud *et al.* 1992; N' Goran *et.al.*, 1994). The small genome size of cocoa with very little repetitive DNA and presence of considerable polymorphism in cocoa have facilitated the construction of genetic linkage maps of medium to high density at CATIE and at CIRAD. Fritz *et al.*(1995) performed a QTL (Quantitative Trait Loci) linkage analysis on a BC_1 derived from a cross between a resistant (Pound 12) and a susceptible (Catongo) clone. They found within reasonable probability that three QTLs were associated with 43% of the phenotypic variance in BP resistance. Further research is expected to detect individual resistance genes.The establishment of close linkages between molecular markers and such genes would make MAS (Marker Assisted Selection) very effective. Tagging of resistance genes by markers will provide early selection for the desired genotype.

Black pod (*Phytophthora palmivora and P. megakarya*)

World wide, the most important disease of cocoa is black pod or pod rot. For many years it was thought that black pod is caused by only one species *Phytophthora palmivora.* Turner and Asomaning (1962) recorded involvement of more than one species and now it is recognized that several species are involved with different species being dominant in different regions (Kellam and Zentmyer, 1986). *Phytophthora palmivora* occurs in the centre of origin of cocoa and causes 44 % global crop loss. *Phytophthora megakarya* is restricted to Cameroon, Nigeria, Togo and Ghana causing 10% global crop loss. *P. capsici* infects cocoa in Central and South America. It is the predominant cause of pod rot in Brazil where it is less aggressive than *P. palmivora. P. citrophthora* also attacks cocoa in Brazil.

Much progress has been made recently in the study of nature of variation in host resistance as evidenced by field scores and artificial inoculation tests on *Phytophthora palmivora* in Trinidad (Warren and Pettit, 1994; Iwaro *et al.*, 1997a, b, c; 1999) Costa Rica (Phillips-Mora, 1999) Brazil (Luz *et al.* 1999) and Papua New Guinea (Tan and Tan, 1990). Similar studies have been conducted on *Phytophthora megakarya* in Cameroon (Nyasse *et al.*, 1999). A large proportion of the variation in disease incidence under field conditions is caused by environmental effects. The nature of resistance appears to be of a quantitative nature and no genotypes have been detected with complete resistance to *Phytophthora palmivora and Phytophthora megakarya.* Further studies are needed on the genetic background of BP resistance. Selfings of the best clones for BP resistance like P-7, PA –150, EET-59, IMC –47, SCA –6 and K-82 have consistently been found to be resistant at different locations. These may yield F_2 families for genetic analysis. Although the resistance is supposed to be polygenic (Crouzillat *et al.*, 2000) and additive, recent data obtained in Papua New Guinea suggested that there may some form of interaction between genes (Efron *et al.*, 2002). None of the presently available cocoa genotypes have an adequate level of tolerance to *Phytophthora palmivora and Phytophthora megakarya.* Higher levels of tolerance may be achieved by recombination crosses between resistant genotypes of different origin. While some selections like Scavina 6, 12, Pound 7 and Catongo (Lawrence, 1978) and K 82 (McGregor, 1981) have shown resistance, these have not been exploited so far.

Witches' broom (*Crinipellis perniciosa*)

This is endemic to wild cocoa and is restricted to the Western Hemisphere, causing 21 % crop loss. It is prevalent in the center of diversification of cocoa in the Amazon and Orinoco River basins, Ecuador, Bolivia, Peru, Venezuela, Guyana and Surinam, Brazil, Trinidad, Tobago and Grenada. The disease caused dramatic decline in cocoa production in these countries upto the extent of 30%. The disease occurs in all species of *Theobroma* and closely related genus *Herrania*. The fungus spreads through seeds also and hence quarantine measures should be strictly enforced.

Host resistance is the only long-term answer to this devastating disease as adoption of chemical control measures is only partly effective and uneconomic. The search for resistance started with Pound's expedition to the Amazon basin and was continued in Trinidad. The research findings on the disease have been carried out in Brazil (Pires *et al.,* 1999 a and b), Trinidad (Laker *et al.*, 1987), Ecuador (Aragudi *et al.*, 1987) and in the UK (Muse *et al.*, 1996; Wheeler and Mepsted, 1988).

Field screening of more than 700 accessions showed very large variation in disease symptoms. More than 60% of the accessions of different origin within Amazon basin appeared to have medium to high level of resistance. GU accessions in French Guiana showed high levels of resistance (Lachenaud and Ducamp, 1996). Resistance has been found in Scavina 6 and 12 and several ICS clones also. There are no genotypes completely immune to WB infection and the resistance is generally of a quantitative and incomplete nature. Some indications of the role of a few major genes are also available. The degree of aggressiveness between group A isolates from Ecuador and group B isolates from Trinidad and Bahia varies considerably. The level of resistance of SCA–6 to WB has remained the same for more than 60 years. However, under Ecuadorian conditions, SCA–6 shows lower level of resistance.

Cocoa Swollen Shoot Virus (CSSV)

Several viruses are found in cocoa (Brunt and Kenten, 1971), such as the cocoa necrosis virus in Ghana and the cocoa swollen shoot virus in Sierra Leone. The disease is the most serious disease in Ghana, Nigeria and Togo. It occurs also in Ivory Coast and Sri Lanka. In Ghana, SS caused severe economic and political problems. Over 200 million trees were killed in eradication programme, still the disease persists. In other West African countries, the virus strains have been less aggressive and it has been possible to live with the disease. Mild strains of CSSV have been found in Trinidad, Sri Lanka and some Trinitario clones in Indonesia.

Work on CSSV at Tafo (Adu-Ampomah *et al.*,1996; Kenten and Lockwood, 1977; Sackey, 2001; Thresh *et al.*, 1988), Nigeria (Williams and Akinwale, 1994) and Togo (Djekpor *et al.*, 1994) showed that there is no immunity or high level of field resistance but in some Upper Amazon genotypes with IMC, PA, NA parentage. Amelonado cocoa is generally more susceptible to African CSSV than Upper Amazon and Trintario types. Some resistance sources have been reported in Upper Amazon types. So far, only a limited number of CSSV resistant genotypes have been utilized.

Seed inoculation test is very effective in early screening for host resistance to CSSV. The method involves removing the testa of the seed and allowing 4 to 6 virus infected nymphs of mealy bug vector to feed on the seed for infection, subsequent growth of seedlings in a nursery and

recording symptoms on the first growth flush. Molecular cloning methods have enabled the isolation of full length infectious clones of severe isolates. Mild isolates of the virus with potential uses in cross-protection have been isolated. These have been used to infect cocoa beans and young seedlings by particle bombardment and/ or *Agrobacterium* mediated microinjection. With these tools, it is now possible to quantify virus inoculum used in challenging cultivars in virus resistance breeding programmes.

Vascular Streak die back (*Oncobasidium theobromae*)

It is the most important disease in Indonesia, Malaysia and Papua New Guinea causing 9% crop loss. It nearly destroyed plantations in 1960s within the first ten years of the introduction of the crop in Papua New Guinea. More recently, it has spread to all South East Asian Countries. It is now reported to be severe in Kerala in India (Fig.3), Malaysia, Philippines, Indonesia and Papua New Guinea. Inadequate plant quarantine measures appear to have played an important role in the rapid spread over these countries. The threat of the disease to the cocoa industry in SE Asia is very much reduced with the detection of partial levels of resistance in several Upper Amazon and Trinitario genotypes.

Exposure of nursery plants to natural inoculum from surrounding trees or infected seedlings has been used for screening for VSD resistance in breeding populations. This technique has been successfully used in Kerala for screening hybrid seedlings for tolerance to the disease. In many crosses, SCA 6 was used as one of the parents (Mallika *et al.*, 2000).

In Sabah, an *in vitro* dual culture system of cocoa callus and the pathogen, using mycelial colonization and callus growth as parameters for resistance/ susceptibility of the genotypes was developed. This method is very effective in early screening in selection/ hybridization programmes and for accurate studies on host- pathogen interactions (Ang and Shepherd, 1980; Lamin *et al.*, 1999).

The nature of resistance appears to be of a quantitative and incomplete nature. A high level of resistance exists in SCA-6 and 12, NA-33 and KA 2-106. The resistance is inherited in an additive manner and heritability is high. Resistance has been reported in Trinitario cocoa grown in Papua New Guinea (Prior, 1979) and upper Amazon selections. The resistance has been stable over 25 years and its use controlled the spread of VSD in Papua New Guinea (Prior, 1977,1978 and 1985, Tan and Tan, 1988).

The high level of resistance found in hybrids derived from crosses with one resistant parent indicates the presence of only a few major genes with dominance effect and this requires further confirmation. As sources of resistance are available, VSD is one of the diseases which can be tackled easily through resistance breeding and a number of clones or hybrids with adequate levels of tolerance have been produced. About 1500 tolerant hybrids are undergoing field evaluation in the Kerala Agricultural University.

Moniliasis or Frosty pod rot (*Moniliophthora rorei*)

The fungus is endemic on wild *Theobroma* and *Herrania* species. This disease is becoming increasingly serious in Ecuador, Colombia, and Central America causing 5 % crop loss. It is also prevalent in Peru, Venezuela, Panama and Costa Rica. MO was first reported in 1979 in Costa Rica. Ecuador is the worst affected country and its impact was dramatic. Until 1920, Ecuador was

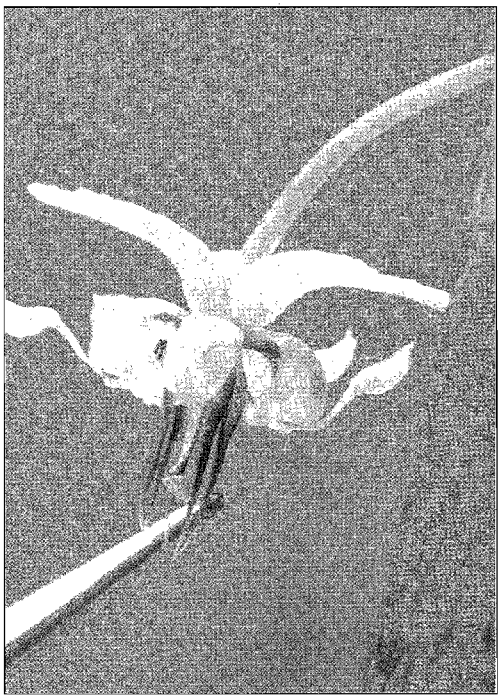

Fig. 1. Hand pollination in cocoa

Fig. 3. A VSD infected cocoa twig

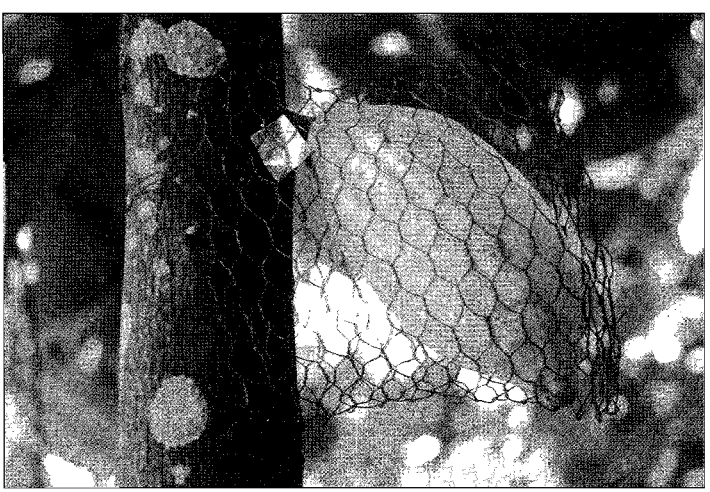

Fig. 2. Hybrid pod protected from mammalian pests

the second largest producer of cocoa after Ghana, but this production was cut by two-thirds in 1930's by the attack of witches' broom and *Moniliophthora* (Wood, 1985). Selection for host resistance is recognized as the only effective way of controlling the disease (Aragundi *et al.*, 1987).

Ceratocystis wilt *(Ceratocystis fimbriata)*

This has been very destructive in the center of diversity of cocoa. It has spread to Ecuador, Venezuela, Colombia and causes severe loss. It was one of the major diseases in Trinidad till 1950's. It has now spread to South East Asian countries also. Upper Amazon selections IMC 67 and Pound 12 are resistant (Lass and Wood, 1985). Criollo types are highly susceptible.

Utilization of biotechnological tools in cocoa breeding

The advent of new technologies greatly influences the ability of the breeders to effect further improvement in yield and disease resistance. The use of biotechnological tools aids in clone identification and paternity analysis, the assessment of genetic affects of clones, and ultimately will allow gene based evaluation of the agronomic value of clones. Molecular markers can be effectively utilized to verify mislabeling, to evaluate genetic diversity and develop core collections and to search for candidate genes in germplasm collection (Ahnert, 2001; Clement *et al.*, 2001; Crouzillat *et al.*, 2001 a and b; Lanaud *et al.,* 2001; Pires *et al.*, 2001; Risterucci *et al.* , 2001; Saunders *et al.*, 2001; Sounigo *et al.*, 2001 a and b). So far various markers have been used viz., isoenzymes, RFLP, RAPD, AFLP, 1-SSR and SSR. Protocols for sample collection, shipment and analysis have been developed. The use of microsatellites (SSR) is the way forward in the short term for finger printing, to provide anchor points for mapping populations and for studies using linkage disequilibrium to investigate origins of stocks and gene flow between populations. Researchers at CIRAD have made much progress in this area and have already developed 69 microsatellite primers.

COCOA BREEDING PROGRAMME IN DIFFERENT COUNTRIES

Indonesia and West Irian

During the period from 1912- 1916, Van Hall selected 33 trees visually for their high pod yield and white or pale bean colour in three plantations in Central Jawa. These were multiplied clonally and planted. Cohan Stuart and De Haan in 1927 took over and selection work was continued. Most of these were lost during the war. In 1945, three of the original material selected by Van Hall, the clones DR1, DR2 and DR38 (Djati Roenggo selections) were supplied for commercial use. These had a pod value of 18-22 and dry yield potential of 1000-1500 kg/ ha. Breeding work with a fresh approach to yield selection and subsequent testing of selections was started in 1947 and trials with the selected materials were planted. But this work suffered a set back due to political changes in the country. Material from most important selections was maintained in the glass house of the Laboratory for Tropical Crop Husbandry at Wageningen. This material was sent to West Irian, where breeding work had been initiated since 1940s. Here cultivation of cocoa was taken up in a big way by introducing material from Australian Papua and New Guinea known as 'Keravat bulk', a variable sturdy Trinitario. In 1955, sixty plants named 'Wageningen seedlings' derived from a cross between two unselected seedling plants, one from the cross DR 1 x DR 38, and the other from DR 8 x DR 38 were planted. Selection was continued based on yield in these hybrids. The open pollinated progeny of Amelonado showed significantly better performance in this area.

Trinidad

The cocoa breeding programme of the Imperial College of Tropical Agriculture in Trinidad was initiated in 1930. Selection work was carried out with the objective of producing high yielding trees with large bean size. About 50,000 trees located in farms and those grown by the farmers were visually scored from which 1000 were provisionally selected and their pod values were evaluated. This resulted in selection of 100 superior trees, which were multiplied clonally and planted in clonal trials for evaluation from 1937 onwards (Cheesman, 1943; Pound, 1932). The clones numbered were as ICS 1 to 100. Based on yield potential, ICS 6, 8, 38, 40, 43, 49, 60, 84, 89, 95 and 98 were selected which recorded yield of above 1000 kg/ha with a pod index of 25-30. However, these did not exhibit the typical Trinidad flavour. Crosses within high yielding and divergent ICS clones did not produce any high yielding progenies and there was little improvement in yield over their parents. Forty six ICS clones were observed for their field resistance to Witches' broom disease, of which ICS 95 was outstanding. In an attempt to produce witches' broom resistant hybrids, SCA 6 and SCA 12 which were immune to the disease were crossed with ICS 1, ICS 6 and ICS 60. The progenies were highly resistant, particularly when SCA 6 was one of the parents. Progenies from these crosses have been outstanding in terms of yield, particularly ICS 6 x SCA 6. This hybrid started yielding from the second year and is capable of giving yield as high as 1000 lb. of dry cocoa in their fourth year and over 3000 lb/ acre in the seventh year. There was also an improvement in pod and bean characters over the Amazon parents. The quality was not typical Trinidadian, but more acceptable than that of the ICS clones. By interplanting SCA clones or any other self incompatible parent with the desired cross-compatible male parent in isolated blocks, with one of the latter and four of the former, all pods of the self incompatible parents could be harvested for seed purposes. It was estimated that four acres of such a planting will produce 1 million seed annually at full bearing. The distribution of hybrid seedlings began in Trinidad in 1953.

Search for witches broom resistant clones revealed SCA 6 to be immune and IMC 67 (Iquitos) SCA 12 and six Parinari selections to be very resistant. Unfortunately these had poor bean size and flavour was different from that of traditional Trinidad cocoa (Montserrin, 1955). Breeding programme to evolve disease resistant hybrids with desirable bean characters using ICS clones and progenies of SCA 6 x ICS 1, IMC 67 x SCA6 and inter Parinari crosses is on.

The recent advances of cocoa breeding in Trinidad are reported (CRU, 2001). About 2000 accessions had been planted in the International Cocoa Germplasm, Trinidad (ICG, T). Studies on characterization using molecular markers like RAPD and SSR were initiated in 1990.

Nigeria

The breeding work was started in 1931 (Voelcker, 1936). Out of a population of 1500 plants, 17 trees were selected based on yield. Selfed and crossed progeny of these selections were planted in a series of trials (West, 1945). But none of the progenies showed improved vigour. The selfed progeny of N 28 had large bean weight. Crosses were made using this type with the material of Trinitario type. The two progeny trials planted in 1942 and 1945 recorded higher vigour and yield than N 28. By 1956, biclonal seed gardens containing N 28 and one of the Trinitario selections had been planted. However, the Series II hybrids developed by WACRI proved much better than Nigerian- Trinitario hybrids.

Much further progress has been made in development and improvement of cocoa (Olatoye and Esan, 1992) and selection of parents and making controlled crosses using Nanay and Parinari clones were made. Three way crosses involving SCA 6 x DR 1 x DR 38 were also made. Two clonal selections T 85/5 and T19/9 with low black pod incidence have been utilized in breeding programmes.

Ghana

The West African Cocoa Research Institute (WACRI) established in 1944 had the objective of tackling cocoa swollen shoot virus (CSSV) disease, the most severe disease infecting cocoa in Ghana and Nigeria. As chemical control of the disease is difficult, the only way to deal with the disease is to replace susceptible types of cocoa with tolerant ones. A large number of infected trees were cut and removed to reduce the CSSV inoculum. The cocoa population in the country exhibited little variability in respect of the disease. This necessitated introduction of diverse types from Trinidad and planting of these was taken up in 1945. The open pollinated progeny of Upper Amazon types so introduced were comparatively more vigourous than healthy Amelonado types, but susceptible to CSSV. Multiplication of the Upper Amazon types was carried out through open pollination of the Approved Upper Amazon families and planted out in observation plots in 1949. The progeny showed a performance similar to that of their parents and these plots were converted into seed multiplication plots. The pods from these plots were supplied to growers. This progeny which is a ' semi synthetic variety' is a good multipurpose variety well adapted to most local conditions and is generally called F3 Amazon.

The trees selected from these plots and from 1945 introductions were called 'C-clones' and between 1955 and 1958, a number of inter C-clone progenies were planted. The crosses between local Ghanaian and Upper Amazon selections called 'Series II Varieties' gave higher yield than F3 Amazon or cross between Upper Amazon selections (Glendinning, 1963). Biclonal seed gardens were planted in Ghana and Nigeria for large scale production of seed of the best Series II Varieties.

At present, these clonal gardens have become old and are to be replanted. In recent years, black pod losses are reported to be very high and even total loss due to the disease is now being recorded in the country. Breeding for resistance to this disease has now become the major thrust (Adu-Ampomah, 1996). The germplasm of the institute has about 740 clones. A lot of attention to breeding for resistance to CSSV has been made. Since stronger sources of resistance to CSSV and BP are lacking, the present strategy is to breed for varieties that will establish quickly and give the farmer adequate economic yield before destruction by CSSV.

Adomako and Adu-Ampomah (2000), examined the causes of low yields of the hybrids and they concluded that hybrids with low yields were intra- population crosses involving NA and IMC parents, indicating effects due to inbreeding depression.

India

Cocoa breeding in India is taken up at Central Plantation Crops Research Institute, Vittal, Karnataka and Kerala Agricultural University, Thrissur, Kerala.

Central Plantation Crops Research Institute

Cocoa research was started in early 1970's and this has been the pioneer institute to start cocoa research in India with its mandate of introduction, selection, hybridization and evaluation. The

germplasm collection at CPCRI maintained at Vittal station has 137 accessions. They had their origin from Cocoa Research Institute, Nigeria; Malaysian Plantations; Kew Gardens etc. The important genotypes include ICS 6, SCA 6, NA 33, IMC 10 (Fig.4), IMC 67, LANDAS 358 etc. Nineteen superior types were identified from the germplasm and among these the type Amelonodo x Na 33 (Fig.5) was found to be the best. An evaluation of clonal progenies showed that Pa7 x Na32 and Jerangau Red Axil (Fig.6) were superior in yield. Plants selected based on yield were used for clonal propagation and distribution.

Hybridization programme was started at Vittal in 1980 and this involved selection of desirable parents and production of first generation hybrids. Three sets of hybrids were produced at Vittal and planted under progeny trials during 1983, 1984 and 1987 (Bhat *et al.*, 1999). Subsequently two more progeny trials were started, which was evaluated for yield and drought tolerance (Table 1). The parents in the first progeny trial included Na 31, Na 33, SCA 6, ICS 6, ICS 95 and IMC 67. Progeny trial II had total of 17 hybrids and Progeny trial III had 12 hybrids. A promising hybrid in Progeny trial II was Jerangau Red Axil x Landas 357. A comparison of parents and hybrids in progeny trials indicated that parents are less vigorous and their yield was low .

Table 1. Cocoa progeny trials at CPCRI

Trial	Progenies (nos)	Date of planting	Objective
Progeny I	5	1983	Yield
Progeny II	17	1984	Yield
Progeny III	9	1987	Yield
Progeny IV	9	1992	Yield, Drought tolerance
Progeny V	18	1996	Yield, Drought tolerance

Work was also done at Vittal in breeding for drought tolerance. The germplasm were screened for physiological parameters like stomatal resistance, chlorophyll fluorescence, proline accumulation under stress and seed germination under low osmotic potential. The Nigerian collections were found to be good source for drought tolerance. Balasimha *et al.* (1985) observed considerable genotypic difference in specific leaf weight and epicuticular wax content and those with high values were found to perform better under stress conditions. Five accessions selected for drought tolerance were NC 23, NC29, NC31, NC39 and NC42 (Fig.7).

The soft wood grafting for clonal multiplication of selected accessions have also been done. The clonal materials are supplied for cultivation. Six bi-clonal and two poly-clonal gardens have been established for the supply of F1 hybrid seedlings.

Kerala Agricultural University

Cocoa research at Kerala Agricultural University was initiated in 1979. Cocoa research was strengthened substantially in April 1987 with sanctioning of a collaborative research project with funding from Cadbury India Ltd. The Cadbury-KAU Co-operative Cocoa Research Project was aimed at strengthening and continuing the ongoing work on crop improvement, continuing the long-term experiments on management and taking up work on diseases of the crop. Breeding programme at Kerala Agricultural University is one of the strongest in the world with the biggest assembly of germplasm collection in India. Approximately 10, 000 experimental hand pollinations are made every year. The main breeding objectives are yield and tolerance to VSD.

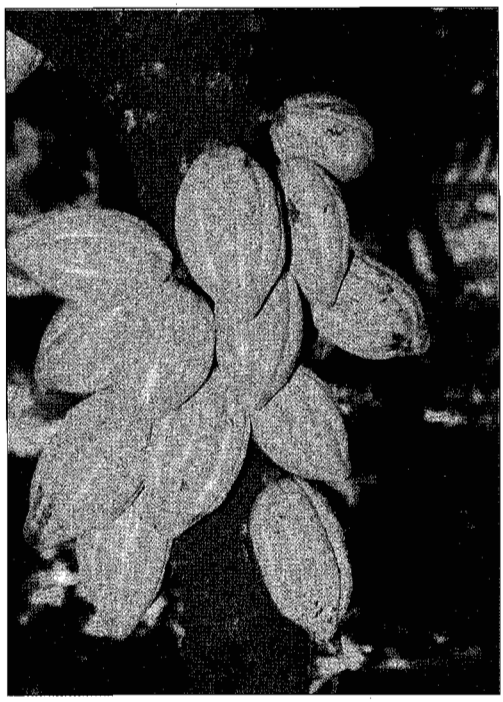

Fig. 4. High yielding accession IMC 10

Fig. 5. High yielding hybrid Amel x Na33

Fig. 6. High yielding accession Jerangau Red Axil

Germplasm

The collection located at the main campus of the Kerala Agricultural University at Vellanikkara has six sets of plants. Four were from seeds and the last two, cloned material. Germplasm I consists of plants arising from open pollinated pods of 15 plants introduced from the Cocoa Research Institute of Ghana. Germplasm II to IV were from pods of promising plants from the bulk populations from all over the country and Germplasm V and VI, clonal material from the different types available in the various research stations and those directly introduced from the University of Reading, UK. Starting from 1990, systematic introduction of clonal material was made and the total number of such clones introduced through 21 consignments comes to 411 so far. One hundred and twenty six of them have been successfully field established and forty are undergoing quarantine procedure. Many of the introduced clones did not survive as the bud wood was damaged due to delay in transit. Some of the important clones available at Vellanikkara are IMC 67, Na 31, MUG 413, SIAL 93, IMC 10, EET 272, ICS 6, SCA 6, PA 7 x NA 32, Landas 36 & 357, Amel x Na 33, Pa 37, T 7/12, P7 x P6, P 7 c, C 42 etc. The newly added clones are regularly evaluated for yield, pod and bean characters, and self- incompatibility.

Screening and selection

Selection of superior plants was continued from 1987 from germplasm collection and hybrids produced from time to time and four comparative yield trials were established (Table 2) . Based on performance and tolerance to VSD, seven clones (CCRP 1 to 7) were recommended for cultivation in India.

Table 2. Cocoa comparative yield trials at KAU

Trial	Clones (nos)	Date of planting	Objective
CYT I	26	1988	Yield
CYT II	45	1993	Yield
CYT III	39	1994	Yield, VSD tolerance
CYT IV	45	1998	Yield

Hybridization and selection of superior hybrids

Search for self-incompatible parents with high yield and bean size was being continued from 1984 onwards. Crosses involving self-incompatible parents were made from 1984. The hybrid seedlings were screened in the nursery for vigor and the most vigorous seedlings derived from 158 crosses were planted in different progeny trials during the period from 1986 to 1995. Planting was taken up during 1986, 1987, 1988 and 1992 which are designated as Series I, Series II, Series III and Series IV hybrids (Table 3). The progenies included in Series I, II and III include first generation hybrids and those in Series IV are plants resulting from test for general combining ability. The hybrids planted in replicated trials are designated as Progeny Trial I (1989), II & III (1994) and IV (1995) respectively. PI and PII have single cross hybrids while in PIII and PIV, double cross hybrids are planted, their parents being selected from already produced hybrids. The hybrids under PII are the progenies for testing the specific combining ability. Test for SCA led to the conclusion that crossing in diallele combinations is not possible in cocoa due to cross incompatibility of some parents. Evaluation of hybrids for 10-12 years from Series I, Series II and Progeny Trial I led to the

release of three hybrids with high yield and tolerance to VSD (CCRP 8 to 10) for cultivation in India during 2002 (Figs. 8-12).

Table 3. Hybrid trials at KAU

Trial	No. of crosses	No. of crosses planted	Date of planting	Objective
Series I	24	7	1986	Yield
Series II	61	12	1987	Yield
Series III	24	5	1988	Yield
Progeny I	119	29	1989	Yield
Series IV	59	29	1992	General combining ability
Progeny II	45	25	1994	Specific combining ability
Progeny III	48	22	1994	Yield
Progeny IV	67	29	1995	Yield

Production of homozygous plants through selfing

The objective of this programme is to produce fully homozygous plants for utilization in the breeding programme. This programme was initiated in 1987 using high yielding self-compatible plants. Inbreeding has now reached up to S4 generation in one genotype, S3 in four genotypes, S2 in eight genotypes and SI in 37 genotypes. Marked inbreeding depression was observed in successive generations. The inbreds exhibited different morphological abnormalities. Many seedlings were weak with stunted growth and reduced leaves and they died in the nursery. Dwarfing as well as forking of the stem were observed in successive generations.

Progenies of some self-compatible parents were found to be completely incompatible in different generations of selfing. Thus many of superior genotypes could not be carried to advanced generations. Self-incompatible plants observed among the inbreds were utilized in breeding programme by producing hybrids between highest yielding plants of different S_1 and S_2 lines (S_1 x S_1 and S_2 x S_2). These crosses were field planted in 1995 and 2002 respectively. Hybrids are being derived from parents of various degrees of inbreeding since it is found desirable to reduce the variability usually encountered in the progeny of non-inbred parents.

Breeding for resistance to VSD

As the vascular streak dieback began to spread in all cocoa growing tracts of the country, apart from yield and bean size thrust was also given for breeding for resistance to VSD from 1994 onwards. Elaborate breeding programme was undertaken during the period from 1994-95 to 1998-99 using 137 such parents. Two hundred and thirty eight crosses were made producing 927 hybrid pods and 19,505 hybrid seedlings. Disease screening was done by exposing the seedlings to natural inoculum in a net house converted to a humid chamber. Exposure of nursery plants to natural inoculum from surrounding infected seedlings has been successfully used for screening for resistance to VSD. Of these, 2042 seedlings survived after screening and 917 of them are now in their fourth year of growth in the field. Hybrid seedlings from hand pollinations done every year are field planted only after screening for resistance to VSD since 1999.

Biclonal Seed Garden

In order to produce good quality hybrid seeds, a biclonal seed garden with six self-incompatible

Fig. 7. Drought tolerant accession NC 42

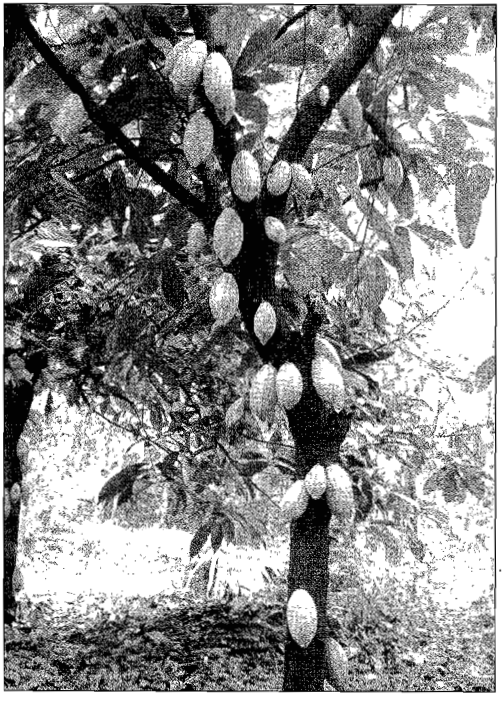

Fig. 8. A high yielding hybrid in progeny trial I of KAU

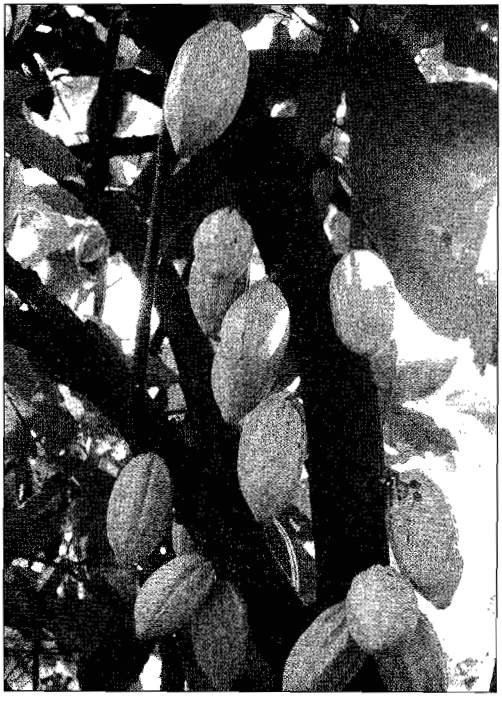

Fig. 9. CCRP 7, a high yielding clone released by KAU

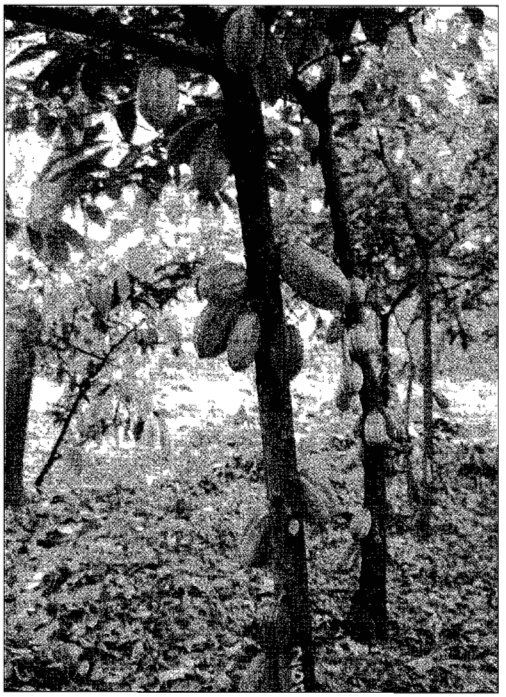

Fig. 10. An accession in germplasm VI with VSD tolerance

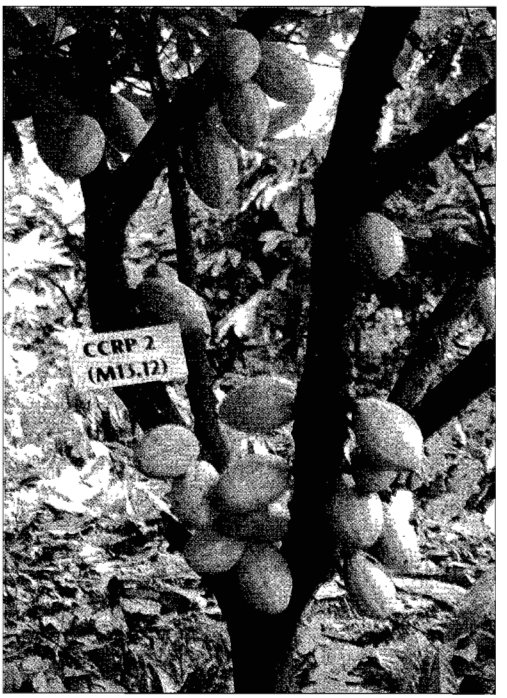

Fig. 11. CCRP 2, a clone released from KAU

Fig. 12. VSD tolerant hybrid

parents with high specific combining ability has been raised. These are planted in such a way that four different hybrids are produced. Eight rows of parents are left as border to prevent unwanted cross- pollination. Hybrid pods can be collected from 1243 plants. The pods from this garden can produce around five lakh seedlings per year.

CONCLUSION

Though a lot of work is done on improvement of the crop since seven decades, the progress achieved in terms of yield is not very substantial. The world cocoa production is remaining stagnant over the past 20 years. This is due to restricted genetic base of the crop. The need for explorative search in centers of diversity is highly essential to make any breakthrough in crop improvement.

Cocoa cultivation in many countries is facing severe threat by major diseases, the control of which are not feasible by conventional methods. It is now time to concentrate on breeding for resistance to diseases. Over the past 50 years efforts have been made to identify effective resistance to major diseases and incorporate these into the varieties for commercial use. It is now generally considered that the effort has largely been ineffective and for most of the serious diseases sufficiently strong resistance remains to be identified and incorporated. It has also been argued that the focus on disease resistance has been at the expense of the all- round performance of modern varieties.

There appears to be considerable scope for successful breeding of cocoa cultivars with satisfactory levels of resistance to one or more important diseases according to national priorities. Some achievement in crop improvement programme has been obtained by recurrent selection schemes with distinct sub-populations. The genotypic components of variation for all major agronomic traits are shown to be mainly due to additive gene effects and maximum gene dispersion over sub-populations will increase the chances of detecting transgressive hybrids.

It is imperative that conventional breeding programmes be maintained and indeed expanded for quantitative traits such as yield and horizontal resistance. The reasons for this are (1) all the desirable genes in a polygenic system cannot be assembled in a single plant in a single generation (2) it is impractical to screen using gene markers when many genes producing small effects upon the trait are involved (3) quantitative traits tend to be greatly influenced by genotype/ environment interactions, thus screening for such traits has to be done locally.

In most of the breeding programmes, the breeder neglects the aspect of flavour. This aspect is of paramount importance as the flavour of the finished product is determined primarily by the variety or type used. Assessment of flavour is not very easy in cocoa. However, certain simple procedures for assessment of flavour have been developed recently. Hence, flavour improvement must find an important position among the future thrusts in breeding. Considerations should be given to redesigning the tree architecture to improve photosynthetic efficiency and harvest index. The progress in the molecular biology also will help in the crop improvement programmes.

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3. CLIMATE, SOIL AND AGRONOMY

Ravi Bhat

INTRODUCTION

Cocoa (*Theobroma cacao* L.) was introduced into India around late eighteenth century. The commercial cultivation of cocoa has been commenced from 1960's only. Cocoa, being an introduced crop into the subcontinent, received an appreciable attention from both research and farming community due to its compatibility as an intercrop in arecanut and coconut gardens.

CLIMATE

Cocoa is grown under wide climatic conditions. But majority of the cocoa area is in the humid tropics where the climate shows relatively little variation throughout the year, especially in terms of temperature, solar radiation and day length. In the majority of producer regions the pluviometric regime is the factor showing the greatest degree of variation in a year and is the major influence on growth, flowering and distribution of harvests. In studies of annual yield distribution, it was found that seasonal variations in both rainfall and temperature influenced pod setting (Alvim, 1988). In India the climatic conditions suited for cocoa cultivation were found to be under palms in Southern India (Lass and Wood, 1971; Shama Bhat and Bavappa, 1972). The climatic conditions are different in these regions, with well-distributed rainfall in Southern Kerala compared with long dry spells during summer months in Northern Kerala and coastal Karnataka. The drought intensity is more pronounced in northern regions of Kerala and coastal Karnataka extending up to 5-6 months subjecting plants to severe stress especially when they are grown as intercrop in rainfed coconut gardens. However, the situation is slightly better in arecanut gardens, which are irrigated. But non-availability of water towards end of summer exposes the plants to stress. Two dissimilar crop patterns are observed under rainfed and irrigated conditions (Alvim, 1976).

In India cocoa yield was significantly correlated with the number of rainy days in the previous year, and sunshine hours and maximum and minimum temperatures of the current year (Vijayakumar *et al.,* 1991). It has been observed that relative humidity, temperature, sunshine hours, rainfall and rainy days have maximum correlation with yield during the five months lag period, which is the flowering period of cocoa. Relative humidity, minimum temperature, rainfall and rainy days during the flowering period have significant negative correlation with yield and sunshine hours and maximum temperature have positive correlation with yield. Thus it can be concluded that weather at flowering stage is an important factor influencing the yield of cocoa (CPCRI, 1995). The influence of 16 climatic components on number of pods and bean fresh weight was studied using step-wise multiple regression and 3 models of yield function. The number of rainy days, evening temperature and wind speed occurring 6 months earlier together contributed 69.65% of the variation in the number of pods, and these 3 indices, occurring 7 months earlier, contributed 66.92% of the variation in bean fresh weight. The climatic components alone were not considered sufficient for predicting the yield potential of bulk cocoa (Manurung *et al.*, 1988).

Cocoa, 2002. (Ed. Balasimha, D.), CPCRI, Kasaragod 671 124.

Rainfall

Rainfall and its distribution is one of the most important climatic factors deciding the cocoa cropped area. The pattern of cropping in mature cocoa is clearly related to the rainfall distribution. The annual rainfall in most of the cocoa growing areas lies between 1,250 and 3,000 mm. If rainfall is less than 1,250 mm the crop needs irrigation during the rainless period. Annual rainfall in excess of 2,500 mm may lead to problems such as black pod disease due to more humid conditions. In Papua New Guinea the incidence of vascular streak dieback is more when rainfall exceeds 2,500 mm. The distribution of rainfall is of more importance than the total rainfall. Usually dry spells longer than four months are detrimental to the crop under rainfed conditions. Thus most of the cocoa growing areas have a short mild dry season. In Ghana cocoa is limited to the areas which receive more than 250 mm of rain during November to March (Adams and McKelvie, 1955). Several studies have shown that the production curve is related to the rainfall five months earlier (Alvim, 1967; Bridgland, 1953).

Temperature

The temperature in most of the cocoa growing areas lies between a maximum of 30-32°C and a minimum of 18-21°C. Several studies have been conducted to see the limits of temperature. In Bahia, where there is no clearly defined dry season, the relatively low temperatures during the months of June through August are responsible for the lack of a harvest during the period January to March, i.e. 7 months after the cool period (mean temperatures lower than 23°C) (Alvim, 1988). Experimental data are presented showing that low temperatures have an inhibiting effect on cambium growth, which is linked to flowering, and that this is the reason for low yields 7 months later. In the State of São Paulo cocoa has been planted in places where the mean monthly minimum is about 10°C and the absolute minimum drops to 4-6°C (Alvim, 1977). At Malawi, cocoa when grown under a mean minimum temperature of 13-14°C yielded up to 2000 kg per ha, but when the temperature fell to 10°C for several consecutive days yields were reduced by about 50 per cent (Lee, 1974). Cocoa can tolerate a mean monthly maximum temperature up to 33°C and the optimum range is 30-32°C.

Wind

Heavy persistent wind damages the cocoa plants. Young cocoa leaves get physically damaged by persistent movement caused by steady wind. This finally leads to defoliation. In West Africa, the distribution of cocoa is influenced by the wind, which blows from the Sahara from variable period between December and March. The effect of wind damage will be severe when cocoa is grown without shade. If proper protection from wind is provided the cocoa can be grown without shade like in valleys.

Altitude and latitude

Most of the cocoa growing areas lies below 300 m. However, cocoa can be grown successfully up to a height of 1100-1200 m. Cocoa can be grown within 20° of the equator. However, over 75% of the world's cocoa lies within 8° of the equator.

Relative humidity

Cocoa areas have uniformly high humidity, often 100% during night falling to 70-80 per cent by day. This may go still lower during dry seasons. The plants grown at lower relative humidity produce small leaves and tend to be curled and withered at the tip.

SOIL

Soil is the storehouse of nutrients to grow any crop. It supports the plants and provides water, air and nutrients to the plants. It is essential that the soil should be suitable for the crop being grown on that (Smyth, 1975). Cocoa is grown on a variety of soils throughout the world. The soil orders on which cocoa can be grown are listed by Smyth (1980). The Entisols and Inceptisols, which are of world wide occurrence and suitable for cocoa if not too wet or too shallow. The Ultisols found in humid tropics are also adequately suitable for cocoa growth. However the Alfisols and Ultisols may not be ideal for cocoa.

The rooting pattern of a crop indicates the soil requirement for that crop. In a red yellow podzolic-red yellow latosol intergrade, 61.6% of the roots of 12-yr old cocoa trees were distributed within the first 30-cm soil layer, 21.4% occurred between 30 and 60 cm, 13.6% between 60 and 90 cm and 3.4% between 90 and 120 cm. In a podzolized soil the corresponding figures for the distribution of the roots of 5-year old trees were 70.8, 20.4, 6.5 and 2.3%. The physical characteristics of both soils allowed good root development to a lower depth than is usually observed in the traditional cocoa growing areas of Bahia and Espirito Santo (Zevallos and Coral, 1972).

In India, cocoa when grown as monocrop the maximum concentration of the roots was within 25 cm radius from the tree. The lateral spread of all roots, thick and fine roots within 50 cm radius were 81, 86 and 69 per cent of total respectively. There was sharp decrease in the dry weight of all categories of roots beyond 150 cm radius from the tree. The vertical penetration of cocoa roots was up to 350 cm, though 68 per cent of all roots and 60 per cent of fine roots were within the first horizon of 50 cm depth. The zone up to 100 cm contained 87 per cent of total and 74 per cent of fine roots. Under mixed cropping situation, 42 per cent of total and 24 per cent of fine roots were confined to 25 cm radius. The zone up to 75 cm contained 67 per cent of total roots and 55 per cent of fine roots. There was a rapid decrease in the spread of roots beyond 75 cm radius. The first 50 cm depth contained 40 per cent of total and 30 per cent of fine roots. The depth up to 100 cm contained 72 per cent of total and 43 per cent of fine roots. The ramification of all roots rapidly decreased beyond 100 cm depth, though they could be traced up to 480 cm below ground level (CPCRI, 1991). Root activity studies on rainfed cocoa by Wahid *et al.* (1989) in Kerala indicated that the maximum absorption of applied ^{32}P occurred from a depth of 30 cm. This soil layer accounted for 42 per cent of the total root activity within a soil column of 2.5 m radius. The relative densities of active roots at 0.0 to 20.0cm, 20 to 40cm, 40 to 60 cm and 60 to 350 cm depths were 23.3, 33.5, 18.5 and 24.7%, respectively. Lateral spread of active roots was mainly restricted to one meter from the plant, which accounted for 75 per cent of the total root activity. An area of 1.5 m radius around the plant had about 85 per cent of the root activity.

The above studies indicate that the depth of soil ideally should be about 1.0-1.5 m with sandy or alluvial texture. Organic carbon should be above 2.0 per cent with a C/N ratio not less than 9. It is also important that adequate rainfall and good water holding capacity are present for proper growth of cocoa.

A study of soil factors in adjacent high-yielding (990 kg/ha) and low-yielding (335 kg/ha) areas showed that conditions known to affect root development, such as soil resistance (shear strength) and clay content (reduced aeration), were the most important factors limiting yield in areas of lower productivity (Cadima and Alvim, 1973).

Comparisons were made between thirteen cocoa plantations on oxisols and eleven on alfisols or ultisols in southeastern Bahia, with respect to physical and chemical soil properties, the degree of shading, management practices and fertilizer applications. It is concluded that low yields of cocoa on oxisols are a result of low soil fertility, excessive or deficient shading and poor management practices. Where management efficiency, shading and fertilizer applications are adequate, yields on oxisols approximate those achieved on alfisols and ultisols (Santana and Zevallos, 1981).

At Bunisari estate, West Java, growth was better on regosols as they contained more bases and had a higher CEC. The high clay content of latosols reduced their suitability. The slope did not affect soil suitability but the steeper the slope the lower was the efficiency of N and K fertilization and the higher the possibility of erosion (Hardjono, 1986). The ideal soil for cocoa should have depth-1.5m, organic matter-3.5%, C/N ratio->9, Base exchange capacity->12 me/100g soil, base saturation->35%.

AGRONOMY

Propagation

Seed propagation

It is the simplest method of propagation of cocoa. Special seed gardens are established for getting quality seeds. The parents used in the seed gardens are selected based on the results of progeny trials. These parents should be multiplied by vegetative budding onto a seedling rootstock. Female parents or both the parents should be self-incompatible so that all the pods can be used for sowing since all the pods are produced by cross-pollination.

Cocoa seeds lack dormancy period. So the seeds have to be sown immediately after removal from the pods. Studies have been conducted to keep the seeds without germination for transporting to longer distances for seed purpose. The seeds are kept in the pods for 7-10 days without any loss in germination. When the seeds have to be transported to a long distance, the beans are mixed with sawdust and the testas are removed; the peeled seeds are treated with a fungicide. The treated seeds are then packed in polythene bags, each bag holding about 1 kg. The seeds preserve their viability without germinating for 3-4 weeks. The seeds stored by this method gave 70% germination after 28 days of removal from the pod (Hunter, 1959). Further IRCC has described method for storing the beans for transport to longer distances. The beans separated from pods harvested before they were fully ripe, were treated with an enzyme mixture (5 g hemicellulase and 10 g pectinase/ 30 kg fresh beans) for 20 min to remove the mucilage. Then they were coated with a powdery mixture of slaked lime, charcoal and orthodifolatan (captafol) to protect against moisture loss and fungal attack. After coating, the beans were sun- or fan-dried for 15 or 30 min, then placed in 6.5-litre polystyrene boxes together with expanded polystryene beads. Using this method of preparation, seed was sent from the Ivory Coast to Gabon and Sao Tome; the germination rate after a 10-15-day transport and storage period was 85% (Duris, 1989).

The seeds are sown in nursery, which is provided with shade, water and wind breaks. A nursery of 1000 seedlings will need about 90-115 litres of water at each watering. A variety of containers *viz.,* woven split cane, bamboo, veneer tubes etc. have been used. But the normal container used is perforated polythene bags of size 25 cm x 18 cm of 150 – 250 gauge. Different types of potting mixture have been used in many countries. In West Africa topsoil after sieving and removal of

roots is used as potting mixture. In Ghana sawdust was found detrimental and 3:1 of soil and sand or 1:1 of soil and cocoa shell were found best media for achieving better germination (Ahenkora and Halm, 1976). In Malaysia, a mixture of topsoil and 20% coarse sand is recommended (Shepherd et al., 1976). It was found that sandy loam topsoil was better as compared to mixture of alluvial clay and sand. In India topsoil, sand and FYM are mixed in 2:1:1 ratio for potting mixture. A medium consisting of 25% fine coconut husk and 75% sand by volume was also found best in terms of seedling growth (Erwiyono and Goenadi, 1990). The seedlings can be planted after 4-6 months in the nursery (Fig.1).

Vegetative propagation

This can overcome the high degree of variability exhibited by the seedling progenies. The propagation is usually through rooted cuttings, budding and soft wood grafting.

Rooted cuttings

The rooting of cuttings depends on various factors like age of stem, season, hormones, medium and environment. The plants produced from rooted cuttings have a low, spreading habit of growth, which makes cultural operations and harvesting more difficult during the early years. The closed bin is generally used for rooting the cuttings. The bins are constructed of bricks or concrete blocks covered by glass. Proper shade is provided for the entire unit. Stones or gravel are placed in the bottom of the bins to provide drainage. Rooting mediums generally used are composted sawdust, coconut fibre dust or sand.

Stem cuttings with four or five leaves are taken from the nursery trees early in the morning. The leaves are trimmed to half their normal size and the cut end of the stem is dipped in solution of NAA and IBA. The flushes should be at softwood to semi-hardwood stage and should have one or two buds on them. Percentage rooting was highest in cuttings taken 7-8 weeks after the initiation of flushing. The treated cuttings are placed in the rooting bins with cut ends about 6 cm below the surface. The rooting bins are watered three or four times a day. After four weeks the rooted cuttings are removed from the bin and planted in potting mixture. These potted cuttings are kept in hardening bins for a further two weeks. The cuttings are daily watered in the hardening bins, which are kept closed for the first 7-10 days. The bin is opened afterwards and the cuttings will be ready in another 5-7 days. About 50% success is reported by this method. Mass multiplication of cocoa clones on a semi-industrial scale in Brazil has been described (Palacios and Monteira, 2001).

Hernandez and Leal (1997) reported that when treated with indole butyric acid the softwood cuttings produced better roots than semi-hardwood cuttings. Hegde *et al.* (1990) reported that trench-grown cuttings rooted better than the chamber-grown cuttings. Thus the cost of rooted cuttings can also be reduced. Though air layering produced substantial rooting (58%) (Somappa and Rao, 1983), it is not commercially practiced (Hulamani *et al.*, 1989).

Budding

The advantages of using budwood are easy transportation over long distances and obtaining more material from a given source. Different methods of budding are practiced like T budding with 80% success rate, inverted T budding with a success rate of 77% (Ascenso, 1968), patch and modified Forket method on young seedlings where the stocks were budded below the cotyledons avoiding the possible growth of chupons from the stock (Shepherd *et al.*, 1981).

The modified Forket method involves making a horizontal cut 5 mm wide below the cotyledon scar. The bark is peeled downwards exposing an area of cambium 3-4 mm wide and 3-4 cm long. The flap of the bark is trimmed to 1 cm long which will enable the bud patch to be held in place. A bud patch slightly smaller than the exposed cambium is cut off from the budstick and is then applied directly to the panel on the stock. The budpatch is held in place by transparent polythene tape 1.5 cm wide, the whole area below the budpatch to 3 cm above being covered. After 14 days the tape is removed and the stock decapitated 7-10 cm below the growing point. One week later the rootstock is partially severed by an upward sloping cut 6-8 cm above the budpatch, and at the same time the stock is bent over away from the bud. When the scion develop normally the stock is cut off 2 cm above the budpatch by the time the first scion leaves have hardened. About 90% success rate can be achieved by this method. Budding is done in the nursery when the seedlings are 2.5-3.5 months old.

Patch budding is also used commercially in many places. Root stocks of 6-12 months old are selected in this method. This method consists of removing a patch of about 2.5 cm length and 0.5 cm width from the root stocks, preparing a bud patch of 2.5 cm length and 0.5 cm width from the bud wood and inserting it into the rootstock and tying firmly with polythene tape. After three weeks, if there is budtake, polythene tape is removed, a vertical cut is made half way through the stem above the bud and stock portion is snapped back. The snapped root stock portion is cut back after the bud has grown to a shoot and at least two leaves have hardened. It is then allowed to grow for a further period of three to six months after which they are transplanted. Under normal conditions, success can be around 70 - 90 per cent. Green patch budding on young cocoa root stocks have also been reported (Yow and Lim, 1994).

Generally the bud woods are selected from the chupons as the bud woods from the fans develop into bushy plants with spreading habit and require considerable pruning to maintain the shape of the tree.

Grafting

Soft wood grafting is also one of the most preferred vegetative methods for commercial production of planting material under Indian condition. Rootstocks of 2-3 month old are shaved off their top portion and given a vertical cut at the top with the grafting knife to a length of 2-3 cm down. The scion stick with leaves removed but precured buds at top is given slanting cuts at the bottom so as to give a 'V' shape of around 2 cm length. The scion-stick will be around 12-14 cm long and will be secured in the stock cut held tight together with the help of a polythene tape 1.5 cm wide. The plants will be ready in 5-6 months for transplanting (Fig.2).

Tissue culture

More attention is now being given to tissue culture for propagation of cocoa. Since cocoa can be multiplied by vegetative methods, the use of tissue culture in cocoa will have different objectives, which include multiplication of elite genotypes, germplasm movement, conservation and genetic transformation systems. First somatic embryogenesis in cocoa was reported by Esan (1977). Recently efficient system of somatic embryogenesis have been reported (Guiltinan and Maximova, 2001; Li *et al.*, 1998; Maximova *et al.*, 2002). These methods have potential application of tissue culture for cocoa breeding programmes.

Planting

Spacing

It is one of the important factors, which has a direct bearing on the yield of the crop. The optimum spacing for cocoa is one, which will give maximum economic returns. The spacing followed varied from as low as 1.0 m x 1.0 m in Trinidad to as high as 5.0 m x 5.0 m in Sri Lanka. The objective of adopting lower spacing was to reduce weeding and pruning, dispose of overhead shade and obtain high yields with less labour. Most of the experiments point towards high yields with low spacings, but as the canopy develops and the soil becomes fully exploited, the yield advantage in low spacing nullifies. The optimum spacing is influenced by the type of cocoa being grown and management practices. Experimental work at the Cocoa Research Institute of Ghana has indicated that for the Amelonado cocoa, a close spacing in the range from 1.7 m x 1.7 m to 2.7 m x 2.7 m was the optimum. Within this optimum range, closer spacing was advantageous in the early years, especially for the unshaded cocoa. For the Amazonian types, a wider spacing in the range from 2.7 m x 2.7 m to 3.3 m x 3.3 m is recommended in Ghana. The Amelonado types, which are less vigorous with long pre-bearing period, can be planted with lower spacing. Since they do not need costly inputs the higher population is beneficial. For the Amazonian types where costly inputs are given higher population will not be beneficial especially in the early years. After reviewing the trials on spacing world over, Wood and Lass (1985) concluded that optimum spacing for cocoa is between 2.3 m x 2.3 m and 3.0 m x 3.0 m.

Cocoa as an intercrop

Cocoa is generally grown as an intercrop under other plantation crops like coconut (Fig.3), arecanut (Fig.4) and oil palm in Asian countries. Interplanting of coconuts is popular in Papua New Guinea, Malaysia and India. In Papua New Guinea, where the coconuts are usually spaced at 9.0 m, cocoa is planted at 4.5 m intervals between and within the rows of palms, which gives 360 trees per ha. In Malaysia, coconut palms are planted at 8.0 or 9.0 m and two rows of cocoa seedlings are planted between the rows of palms. The cocoa spacing is maintained to achieve a population of 1040 trees per ha. In India the general recommendation is one row of cocoa in between two rows of coconut planted at 7.5 m x 7.5 m. If the spacing of coconut is wider two rows of cocoa can be planted. In India, a trial was conducted to study the spacing for cocoa under coconut. In a coconut garden spaced at 7.6 m x 7.6 m, cocoa was planted as single row in between two rows of coconut and two rows in between two rows of coconut. The spacing within the row was 3.0 m in both the systems. In double row system the row-to-row spacing was 2.5 m with staggerd planting. The population of cocoa with single row was 350 plants per ha and that with double row was 600 plants per ha. The yield of coconut was increased up to 164% due to planting of cocoa in both the systems (Nelliat *et al.,* 1979). When the coconut spacing was wider (9.0 m x 9.0 m) cocoa planted in two systems of single hedge and double hedge with a spacing of 3.65 m, it was found that the double hedge system was superior over the single hedge system (Abdul Khader *et al.,* 1984). The two crops were found compatible and the yield of coconut did not reduce but the increase in some cases may be due to less weed competition and application of additional fertilizers (Shepherd *et al.,* 1976).

When oil palm is planted at a spacing of 9.9 or 10.5 m in triangular method the cocoa planted with a spacing of 2.4 m in triangular method gave significantly better growth and yield compared

Fig. 1. Cocoa nursery

Fig. 2. Softwood grafting in cocoa

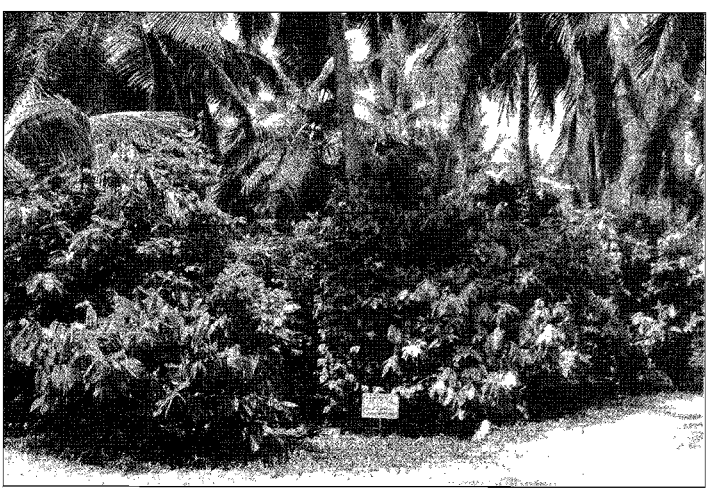


Fig. 3. Cocoa under coconut palms

to oil palm planted with a spacing of 8.7 m (Amoah *et al.,* 1995). This indicates that cocoa can be grown in oil palm only when the oil palm is planted with wider spacing.

In India cocoa is extensively grown under arecanut also. The arecanut is planted at a spacing of 2.7 m x 2.7 m. The microclimate under arecanut is congenial for cocoa cultivation. Studies have been conducted to standardize the spacing for cocoa under arecanut. Shama Bhat (1988) concluded that considering the normal spacing of arecanut 2.7 m x 2.7 m as well as combined yield of the two crops and the revenue expected, it is safe to select the spacing of 2.7 m x 2.7 m for both the crops and 2.7 m x 2.7 m for arecanut and 2.7 m x 5.4 m for cocoa. But since the yield difference between these two is not appreciable and in view of the operational advantages combination of 2.7 m x 2.7 m for arecanut and 2.7 m x 5.4 m for cocoa is preferable over 2.7 m x 2.7 m for both the crops (Table 1).

Table 1. : Average yield of interplanted cocoa and arecanut (7th to 11th year)

Sl. No.	Spacing (m x m)		Yield ('000 kg/ha)		
	Areca	Cocoa	Areca (Nuts)	Cocoa (Pods)	Combined
1.	2.7 x 2.7	2.7 x 2.7	6.6	17.7	24.3
2.	2.7 x 2.7	2.7 x 5.4	7.8	15.0	22.8
3.	2.7 x 2.7	5.4 x 5.4	9.6	9.2	18.8
4.	3.9 x 3.9	3.9 x 3.9	4.5	13.6	18.1
5.	3.3 x 3.3	3.3 x 3.3	5.9	19.2	25.1
6.	1.8 x 5.4	3.6 x 5.4	6.2	13.0	19.2
	Mean		6.8	14.6	21.4
	CD (P=0.05)		1.89	3.14	2.9

Holing and planting

Like other plantation crops cocoa also is planted after digging a pit in the soil. The rooting pattern of cocoa indicates the depth of planting. But several countries have their own pit dimensions for planting. In Trinidad the usual practice was to dig a pit of 40 x 40 x 24 cm, mix the soil with pen manure and return it to the hole at planting time. In Sao Tome where big pits of up to 200 cm are dug, filled with soil and manure and seedlings planted. In Ghana, seeds are just only pushed into the soil or seedlings planted in pits that are just big enough to contain the ball of earth of the polybag seedling. Under Indian conditions, the pits of 50 cm^3 are dug, refilled with mixture of topsoil and organic manure and the seedling planted in the center. The main objective of digging pit is to break the hard pan if present in the sub-surface and to loosen the soil in the root rhizosphere for better root growth.

Time of planting

This depends on the climatic condition of the place. The young seedlings need moisture for better establishment. The seedlings cannot withstand excess water also. So in areas where rainfall intensity and amount is less planting will be done on the onset of monsoon. In areas of heavy rainfall the planting will be done at the end of the monsoon. If the moisture can be maintained by irrigation, planting can be done at any time of the year.

Shade

Traditionally cocoa is a forest crop grown under the trees. So cocoa needs shade for its better development and yield. But the intensity of shade requirement varies from place to place and growth stages. The crop in the cocoa producing countries has been grown under the shade varying from 30 to 80%. The studies in different cocoa growing countries have shown that cocoa seedlings need more shade (more than 50%) and as they mature the shade requirement reduces. Shade and the nutrient application are related in cocoa. The recent experiments have shown that shade can be dispensed with where the cocoa trees can obtain adequate nutrient and moisture throughout the year. The study conducted in India by Nair *et al.* (1996) indicated that the girth of stem and yield increased with increase in illumination levels. The results suggested that it is possible to cultivate cocoa without shade under Kerala conditions and that the productivity will be the highest under shade – free situations. The yield of the shade free cocoa trees may be good in the early years. But in long run the yield declines drastically. The shade in young plants has a major role to play as it decides the early growth of the crop. Low light intensities with heavy shade leads to long internodes and few side branches and the high light intensity make the plant bushy. So appropriate shade is essential for the young seedlings for better canopy formation.

In traditional cocoa growing countries two types of shade trees are defined *viz.*, permanent shade trees and temporary shade trees. The permanent shade trees are grown at wider spacing and the temporary shading trees are planted at the same spacing as that of cocoa. The important permanent shade trees are *Terminalia ivorensis* in Ghana, Larel (*Cordia alliodora*) and Erythrina in Costa Rica (Fassbender *et al.*, 1988; Morera, 1996). Other trees grown are *Leucaena leucocephala* in Papua New Guinea, Indonesia, *Gliricidia sepium* in Central America, West Indies, Malaysia and Indonesia. Tree cassava and banana are some of the temporary shades. The combination of permanent and temporary shade plants provides shade for better vegetative growth of cocoa. Once the cocoa canopy develops, the temporary shade is removed and the increased light stimulates the production.

Apart from these multipurpose trees are also being used as shade trees especially in Asian countries. Coconut (Nelliat *et al.*, 1974; Shepherd *et al.*, 1976), arecanut (Shama Bhat and Bavappa, 1972; Shama Bhat, 1988) and rubber (Blencowe, 1968) are used as shade trees in Malaysia, India and Brazil. Because of the high proportion of light, which penetrates through the canopy of palms, they are considered most suitable as shade tree for cocoa.

Nutrition

Nutrient requirement of cocoa depends upon the type of soil it is being grown, and the cultivation practices being followed. So the nutrient application varies with different cocoa growing countries. In general the nutrient application is made based on analysis of soil or plant or both. In Malaysia, the fertilizer requirement of cocoa was found to be 200 kg N, 25 kg P, 300 kg K and 140 kg Ca (Thong and Ng, 1978). The results of the fertilizer experiments conducted in Nigeria revealed that the annual fertilizer rates for cocoa are 120-204 kg/ha N, 30-60 kg/ha P, 67 kg/ha K and 6 g B/tree (Ojeniyi, 1982). In Southern Bahia, Brazil the cocoa yield was highest with N, P_2O_5 and K_2O, at 90:90:90 kg/ha (Cabala *et al.*, 1982), where as on soils of Amazonia, (Yellow Latosols) annual application of 60 kg/ha of N, P_2O_5 and K_2O was found optimum (Morais, 1988). The fertilizer dosage for cocoa crop based on trials conducted in different countries are summarised in Table 2.

The nutrient removal by the crop also makes the basis of fertilizer application to cocoa. Nutrient removal by cocoa in different countries is given in Table 3. The quantities of N, P and K removed by cocoa pods per kg of dry beans will work out to 43.8, 8.0 and 64.3 g, respectively. For a crop yielding about 2 kg of dry beans per plant (about 60 pods) per year, the average crop removal by pods would be around 85, 37 and 154 g each of N, P_2O_5 and K_2O. The fertilizer recommendation for cocoa under average management is 100:40:140 g of N, P_2O_5 and K_2O per plant for a year, which tallies with the crop removal figures (Shama Bhat, 1988).

Table 2. Fertilizer recommendation for mature cocoa.

Country	Fertilizer				Remarks	References
	N	P_2O_5	K_2O	Mg O		
Sarawak	27.3	27.3	38.5	4.5	g/tree	Ebon et.al., 1978
Nigeria	120-204	30-60	67	-	kg/ha	Ojeniyi, 1982
Brazil	50-100	25	85	15	kg/ha	Hardy, 1960
Malaysia	200	25	300	70	kg/ha	Thong and Ng, 1978
India	100	40	140	-	g/tree	Shama Bhat, 1988

Table 3. Nutrients (kg) removed in a crop of 1000 kg dry beans.

Country	Type of Cocoa	N	P	K	Ca	Mg
Nigeria	Amazon	39.8	6.3	85.6	-	-
Nigeria	Amelonado	38.3	5.7	76.9	-	-
Cameroon	Trinitario	34.2	6.3	72.6	8.2	6.8
W. Malaysia	Amazon	31.0	4.9	53.8	4.9	5.2
India		43.8	8.0	64.3	-	-

Visual symptoms of nutrient deficiency can also indicate the fertilizer requirement of cocoa. Several studies have been conducted to know the symptoms of nutrient deficiency and toxicity. Based on these works Murray (1975) has given simple key for identification of symptoms (Table 4).

Table 4. Symptom appearance in cocoa plants

Whole plant		Older leaves		Young leaves	
Deficient	Toxic	Deficient	Toxic	Deficient	Toxic
Nitrogen	Boron	Calcium	Aluminium	Iron	Zinc
Sulphur		Magnesium	Chlorine	Manganese	Manganese
Phosphorus		Potassium	Iron	Copper	Copper
			Zinc		
			Boron		
			Molybdenum		
			Calcium		

Nitrogen deficiency: Leaves are pale yellow in colour, reduced in size, older leaves showing tip scorch, internodes compressed and petioles showing acute angle with stem.

Sulphur deficiency: Leaves of whole plant pale yellowish or yellowish green in colour, but no

marked reduction in size. Yellow blotches on older leaves. New flush leaves normal in size, at first bright yellow in colour with no green associated with the veins, later becoming pale yellowish green as in older leaves, plant frequently preferentially attacked by insect pests.

Phosphorus deficiency: Plant somewhat stunted in growth, mature leaves paler towards tip and margin, followed by tip and marginal scorch. Young leaves markedly reduced in size, often showing interveinal pallor, stipules frequently persisting after leaf abscission, young leaves showing acute angle with stem, internodes compressed.

Boron toxicity: Older leaves showing pronounced marginal scorch and necrotic areas in vicinity of wounds, younger leaves cupped downwards, showing green in vicinity of veins, with broad chlorotic interveinal areas later greening slightly and developing necrotic tip and margin.

Calcium deficiency: Necrotic areas commencing in interveinal region near leaf margin quickly fusing into continuous marginal necrosis of older leaves. No necrotic lesions in advance of main marginal necrotic zone, unaffected area showing oak leaf pattern.

Magnesium deficiency: Necrotic areas commencing in interveinal region near leaf margin, quickly fusing into continuous marginal necrosis of older leaves. Prominent bright yellow zone in advance of necrotic area and islands of necrotic tissue often appearing in advance of main wave of necrotic tissue. Unaffected areas of the leaf paler green than usual and forming oak leaf pattern.

Potassium deficiency: Pale yellow areas formed in interveinal region near leaf margin, quickly becoming necrotic but only fusing with each other after some time, progress of marginal necrosis much more rapid between veins, yellow zone on inner surface of invading necrotic zone.

Aluminium toxicity: Paler or yellowish areas in the interveinal region of the distal end (tip) of leaf with tip scorch progressing very slowly. Rarely, some blackening of the interveinal region towards the base of the leaf. All symptoms confined to older leaves only.

Chlorine toxicity: Pale yellow areas developing in the marginal interveinal regions quickly fusing to form a continuous scorch, advancing more rapidly in interveinal areas. Tissues in advance of scorched area showing various shades of dark green and grey. Scorch proceeding slowly and necrotic areas in vicinity of wounds. This can be confused with the calcium deficiencies above.

Iron toxicity: Pale yellow zone on each side of the midrib of older leaves, rapidly spreading necrotic areas formed in vicinity of wounds, no marginal or tip necrosis.

Iron deficiency: Younger leaves showing darker green veins against paler green background, or showing green tinted veins against pale yellowish white or almost completely white ground, developing tip scorch. Symptoms less marked in leaves of previous flush - older leaves frequently showing narrow marginal and tip scorch.

Manganese deficiency: Younger leaves pale yellowish or yellowish green, later developing blurred chlorotic pattern in which the tissues in the vicinity of the midrib, main laterals and tertiary veins are prominently green against pale background, followed by scorching of the tip and distal margin.

Copper deficiency: Leaves on young flush small but normal in shape, young shoots frequently showing signs of wilting. Sudden collapse of tissues at tip of leaf, collapsed tissues remaining green for some time, later forming brown edge with apex directed towards midrib. No marked chlorotic pattern.

Zinc deficiency: Very young leaves showing prominent dark red veinlets with considerable distortion, leaf very narrow in proportion to length, margin often wavy and leaf sometimes sickle-shaped with small chlorotic patches in distinct row on each side of midrib and main lateral veins.

Boron deficiency: Young leaves reduced in size, pale, hardening with marked reflexed curvature and/or spiral twisting, thick to the touch and brittle; old leaves of healthy appearance.

Molybdenum deficiency: Young leaves thin and translucent, developing mild chlorotic mottling more marked in interveinal region, later developing marginal scorch.

Zinc toxicity: Young leaves showing olive green appearance or pale green areas scattered over surface of leaf.

Manganese toxicity: Youngest mature leaves showing irregular pale green or yellowish areas on darker green background with or without some veinal necrosis, no tip or marginal scorch and no symptom on older leaves.

Copper toxicity: Young leaves showing dark olive green colour with upraised veinlets and puckering of lamina along midrib. Younger mature leaves showing pale green areas distributed at random over leaf surface.

Nutrient recycling

Cocoa also adds nutrient to the soil through the litter fall and through fall and stem flow. Varghese *et al.* (1978) concluded that cocoa when grown under coconut adds organic material in the form of litter fall to the extent of 818 and 1985 kg/ha/year. In southwestern Nigeria the nutrient added through litter fall was estimated as 175.6 kg N, 7.7 kg P, 98.0 kg K, 179.5 kg Ca, 48.2 kg Mg, 10.2 kg Fe, 0.3 kg Cu and 0.4 kg Zn per ha. The quantities in through fall and stem flow were 20.1 kg N, 2.8 kg P, 74.7 kg K, 38.9 kg Ca, 9.6 kg Mg, 2.3 kg Fe, 1.0 kg Cu and 0.7 kg Zn per ha (Opakunle, 1989). The wastes available from the cocoa gardens if recycled can supply 540.11, 71.86 and 243.94 tonnes of nitrogen, phosphorus and potassium annually (Biddappa *et al.,* 1996). The cocoa leaves from the garden can be converted into compost using earthworms (Chowdappa *et al.,* 1999). The composted leaves were found rich in nutrients, including micronutrients, which was more than the normal compost (Table 5). A recovery percentage of 74% was obtained.

Table 5. Nutrient composition of cocoa leaves, normal compost and vermicompost.

Nutrients	Cocoa leaves	Normal compost	Vermicompost
Organic carbon (%)	47.1	28.0	24.4
N (%)	1.27	1.29	1.65
P (%)	0.17	0.19	0.19
K (%)	0.27	0.27	0.32
C:N ratio	37.00	21.90	14.78
Cu (ppm)	32.66	70.54	83.60
Fe (ppm)	1157.41	2580.00	2593.00
Zn (ppm)	228.39	354.7	367.7
Mn (ppm)	363.1	546.41	679.84
Moisture (%)		29.35	29.94
pH		8.0	7.5

Calcium deficiency was found to cause cherelle wilt in cocoa. The Ca and Mg were higher in healthy pods than in wilting pods at corresponding growth stages. Foliar and soil application of calcium resulted in decreased cherelle wilt and increased the number of cherelles carried to maturity (Uthaiah and Sulladamath, 1980).

Disorders due to micronutrients are also reported in cocoa. Important micronutrient disorders reported under field conditions are Zinc (Zn), and Boron (B) deficiency. There are reports of Iron (Fe) deficiency and Aluminium (Al) toxicity also. Aluminium toxicity is reported from the acid soils in the State of Bahia, Brazil. Of all these disorders Zn deficiency is found in many of the cocoa growing countries. The symptoms of Zn deficiency include chlorosis, crinkling of leaves with wavy margin, little leaf, sickle leaf, premature defoliation and die back of twigs. The earliest remedy for Zn deficiency given was foliar spraying with a solution of 300 g of zinc sulphate and 150 g of lime in 100 litres of water (de Geus, 1973). Nair *et al.* (1980) and Chandramohanan *et al.* (1981) have reported Zn deficiency from India. Foliar spraying of zinc sulphate at 1.0 and 1.5% corrected the deficiency symptoms. But supplemental Zn application to cocoa plants did not help in improving the yield ((Nair *et al.*, 1994a). In Karnataka the deficiency was corrected by foliar spray of a mixture of 0.3% zinc sulphate and 0.15% (w/v) lime (Chandramohanan *et al.,* 1981). Boron deficiency has been reported from Ecuador (Mestanza and Lainez, 1970) and Ghana and Nigeria (Omotoso, 1977). The main symptoms include short internodes and small, distorted leaves and sometimes malformation of pods. Monthly spraying of Solubor corrected the deficiency. Iron deficiency is occasionally seen in nurseries and can be cured by repeated spraying of 1 per cent aqueous iron sulphate solution.

Method and time of application of nutrients

The root studies have shown that majority of the feeding roots of cocoa are concentrated on the surface and horizontally they traverse from 1.0 to 1.5 meters. Thus nutrient has to be applied on the surface of the soil in the cocoa basin and mixed in the soil without damaging the roots to prevent the nutrient losses. The basin size will be smaller for young cocoa plants. The fertilizer should be applied when the soil has sufficient moisture.

The time of application is decided by the moisture availability in the field and stage of the crop. In unirrigated crop fertilizers can be applied just before monsoon coinciding the months of May-June and after monsoon (September-October). When the crop is irrigated the pre-monsoon application can be advanced to February-March. As far as possible the fertilizers should be applied before main flush period, before flowering and two months before the peak of the main harvest.

Cocoa in the first year of planting should be given 1/3rd of the recommended dose of fertilizer for adult tree. In the second year 2/3rd of the recommended dose and from third year onwards, full dose of fertilizer should be given.

Irrigation

Cocoa is generally a rainfed crop in the traditional cocoa growing countries. But studies have been conducted about the effect of supplemental irrigation to cocoa during the period of drought. In Ghana the overall responses to sprinkler irrigation during 2 years when the rainfall was average were 12 and 17%. In a year with a very severe dry season irrigation increased yield by over 40%, to the level obtained in years with favourable rainfall. Irrigation suppressed flushing but stimulated

flowering and setting. Cherelle wilt was reduced by irrigation, particularly at the end of the dry season, but it had very little effect on the phenology and cropping pattern (Hutcheon *et al.*, 1973). The studies conducted later on showed that drip irrigation was better than sprinkler irrigation with respect to growth of the cocoa plants (Jadin and Chauchard, 1976). Khan *et al.* (1988) reported an increase in cocoa yield by 28% due to drip irrigation, which replaced 75 and 100% moisture lost due to evapotranspiration. In India it is grown under coconut and arecanut as an irrigated crop. Under these conditions since the rainfall occurs only from June to October, the remaining period remains dry. The crop has to be irrigated during this period. A study was conducted to find out optimum water requirement through drip irrigation at various levels of fertilizers. The study concluded that 20 liters of water per day per tree through drip irrigation at recommended level of fertilizer (100:40:140 g $N:P_2O_5:K_2O$/tree/year) was optimum for achieving maximum yield from cocoa when it is intercropped with arecanut (Abdul Haris *et al.*, 1999; Figs.5,6).

Pruning

It is an important operation in cocoa especially when it is grown as an intercrop. It is a regular practice in all the cocoa growing countries except in West Africa. The main objective of pruning is to maintain the shape of the cocoa plant to make it more productive and efficient. Formation pruning and maintenance pruning are the two types of prunings generally practiced in cocoa.

Formation pruning

This is practiced for the young cocoa plants. The objectives of this pruning are adjustment of height of the first jorquette and control of vertical growth. Generally first jorquette is formed at a height between 1 and 2 meters. For easy operations in the field the preferable jorquette height is 1.5 to 2.0 meters. Normally the height at which the jorquette is formed depends upon the shade condition in the garden. Low shade intensity leads to jorquette formation at lower height. When the jorquette is formed at lower height it will be removed at an early stage to facilitate upward growth. This is practiced mainly in Malaysia to achieve a jorquette height of 1.6 m (Leach *et al.*, 1971). The jorquettes have five fan branches. In some countries only three fan branches will be left per jorquette. But added advantage of cutting the fan branches is not seen unless the branches are weak. Cocoa plants derived from fan branches tend to produce low and brushwood like canopy. Under such circumstances, the best formation pruning method is to leave 3-4 branches low down (Prawoto, 1996). The decision to control vertical growth depends upon the cropping system and the convenience of the farmer. Generally the vertical height is restricted to first jorquette. All the chupons arising from below the jorquette have to be cut regularly to maintain the height. If there is any damage to the jorquette, then on of the chupons is left for the development of next jorquette. Studies have been conducted to know the effect of pruning on yield of cocoa. The trees with pruning though produced less yield in the initial years at later years the advantage of not pruning was not significant (Nair *et. al.*, 1994a).

Maintenance pruning

This pruning is done on mature trees to maintain the health and vigour of the tree by cutting all the diseased and unproductive branches, which is called sanitary pruning and to maintain the structure of the tree, which is called structural pruning. Sanitary pruning includes removal of all unnecessary chupons, dead branches, epiphytes, climbing plants, ant nests, diseased and rodent damaged pods, and over ripe pods.

Fig. 4. Cocoa under arecanut palms

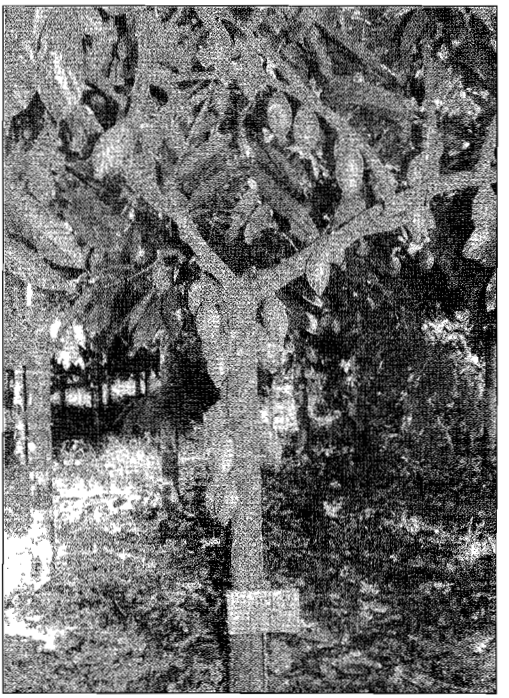
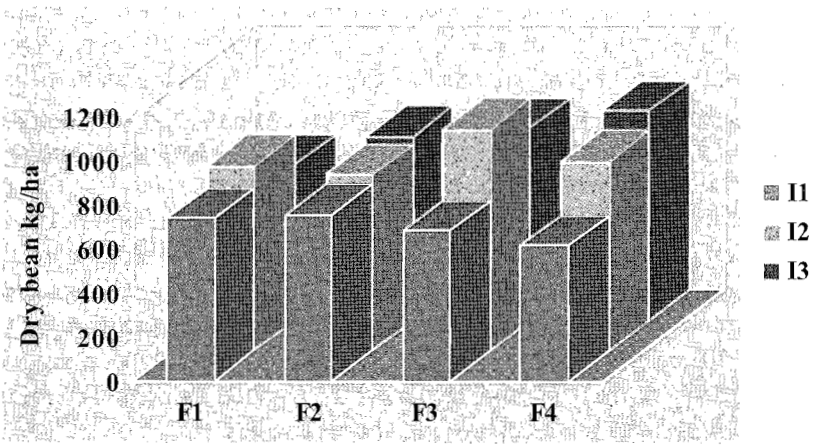


Fig. 6. Drip irrigation to cocoa



Fertilizer levels: 0/0/0(F1), 50/20/70(F2), 100/40/140(F3), 150/60/210(F4) NPK
Irrigation levels: 10l(I1), 20l(I2), 30l(I3) per day

Fig. 5. Dry bean yield in response to drip irrigation and fertilizers

Weed control

Weeds are problematic in cocoa gardens in the initial years. A trial was conducted in Ghana to see the effect of weeds on the growth of cocoa seedlings in nursery. It was found that after 22 weeks, the average dry matter production of cocoa was only 1.83g and total dry weight of weeds was 5.00 tonnes per ha in the plot without weeding. The plot, which was weeded once in 2 weeks, produced cocoa plants with average dry weight of 9.04g and the weed biomass was only 0.27 tonnes per ha (Ruinard, 1966). Once the canopy develops in cocoa the weed problem will not be serious. So to keep the field free of weeds several methods have been tried. They include mechanical, manual and chemical methods. Some of the common herbicides used are MSMA, 2,4-D, 2,4,5-T, Paraquat, Atrazine, Simazine, Diuron, Dalapon and Glyphosate. Paraquat was applied to cocoa from 6 month to 44 months of planting and compared with manual weed control methods (Bonaparte, 1981a). It was found superior over manual weed control methods in terms of girth increment in cocoa. Paraquat treatments led to 100% flowering in 40 months and the manual treatments in 50 months (Bonaparte, 1981b). Paraquat treatment outyielded the other weed control treatments in the 3 harvest seasons. The initial superior growth and early yields as a result of paraquat treatment were still being maintained after 6 years. The cost of weed control with chemicals was also less as compared to other methods. Gestin and Roux (1974) reported that the cost of weeding with Gramoxone (paraquat) at 1.5 l/ha 6 times a year was two-thirds that of manual maintenance. But he also found that symptoms of Zn deficiency were induced in trees treated with MSMA. This indicates that the choice of weedicides is important in cocoa gardens.

Top working in cocoa

This is a method by which an old garden or a tree damaged by pest or disease can be rejuvenated. A poor yielding tree can also be converted into a high yielding one. The technique of top working has been given by Nair *et al.* (1994b). The technique consists of snapping back the desired trees below the jorquette after cutting half way. The snapped canopy continues to have contact with the trunk. A number of chupons would arise below the point of snapping and this is triggered by the breakage of apical dominance and continued connection with the snapped canopy. Patch budding as described earlier is done on three to four vigorous and healthy shoots using scions from high yielding, disease resistant clones and the remaining chupons are removed. The polythene tape is removed three weeks after budding and the stock portion above the bud union is snapped back. The snapped portion is removed after two hardened leaves develop from the bud. When sufficient shoots are hardened, canopy of the mother tree can be completely removed. Because of the presence of an established root system and the trunk with reserve food, the top worked trees grow much faster and give prolific yield one year after the operation. Though top working can be done on all seasons, it is preferable to do it in rainfree period in irrigated gardens. For rainfed situations, it may be preferably done after the receipt of pre-monsoon showers.

The top worked trees start yielding heavily from the second year onwards. About 50 per cent improved yields are obtained in second year and about 100 per cent increase in the third year. Loss of crop for one year during the operation is compensated by bumper crop in the coming years. The main stem will continue to belong to the older plant and the fruits borne in this area belong to the poor yielder. Better yields are however obtained from the fan branches of the high yielding clone used for top working.

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4. PHYSIOLOGY

D. Balasimha

INTRODUCTION

Among plantation crops, in cocoa the physiology is studied extensively. This has facilitated a better understanding of the basic physiological processes, which determine productivity of the crop. The vegetative and reproductive growth of cocoa is influenced by a complexity of environmental factors. The plants being shade tolerant are generally grown as an understorey crop. With information available on physiology, it is possible to take an analytical approach to increase yield by incorporating them into breeding programmes. Yield is not limited by photosynthesis alone, as other climatic and genetical factors also play important roles.

GROWTH AND DEVELOPMENT

Seedling growth

The early vigorous growth of seedlings is very important for better establishment and higher yield potential at maturity. There is definite advantage to seedling growth due to seed weight but this disappears with age (Ascenso and Bartley, 1966; Ravindran, 1981). Although quantitative relationships between seedling vigour and yield of trees have not been fully established, it is known that less vigorous seedlings are late bearers and tend to be unproductive (Glendinning, 1960).

Progenies, which are more vigorous, have capacity for high yield but it depends on the effective dry matter partitioning between pod production and vegetative growth (Hutcheon, 1978). The seedling vigour or root/shoot ratios were not correlated with drought resistance (Hutcheon, 1984). The maintenance of better growth, leaf turgidity and metabolic activities was reported in cocoa seedlings under drought when treated with potassium or proline (Balasimha, 1984).

Root growth

Cocoa trees possess a strong taproot system extending up to 1.0 - 1.5 m depending on soil conditions. The laterals are mainly horizontal and concentrated to upper 30 cm of soil. When plants are raised from cuttings, 2-3 main roots develop and the root distribution is restricted to the soil surface layer. The fine roots of cocoa account for major portion of nutrient uptake as the roots of 1-3 mm diameter are often suberized.

The growth of cocoa tree is characterized by 'flush cycles'. Vogel (1975) reported a rhythmic root growth in cocoa. The phase of high root activity was associated with low leaf growth and *vice versa* (Hardwick *et al.*, 1982; Kummerow *et al.*, 1982). The developing shoots function as stronger carbohydrate sinks during rapid leaf expansion periods (Hardwick *et al.*, 1982). It is still not clear whether this is a major phenomenon or growth inhibitors are also involved, as ABA level is shown to be high during this phase (Orchard *et al.*, 1980). Soil moisture, carbohydrate availability and

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changes in ABA levels seem to interact in the regulation of root and shoot growth. This biphasic episodic growth follows the theory of Borchert (1973) that flushing is a consequence of interaction between shoot and root growth, where the absolute rate of one exceeds the other.

Canopy development and dry matter accumulation

Studies on canopy development and growth rates in cocoa seedlings indicated some genetic differences (Alvim, 1977; Hutcheon, 1984). Alvim and Grangier (1966) reported a higher leaf growth rate and relative growth rate (RGR) in more productive cultivars than unproductive ones, but no difference was noted in net assimilation rate (NAR). The increase in mean growth rate (on dry weight basis) was slow during the first year, but faster from second year onwards. The increase in canopy area was also similar. This is expected because the seedling development is dependent on cotyledon reserves for about two months (Hutcheon, 1984). Also there is shock due to transplantation usually done at 3-6 months age, and seedlings take some time for establishment. The trunk diameter increases gradually in accordance with dry matter accumulation. Yields of cocoa varieties were correlated with rate of increase in trunk diameter during prebearing phase (Glendinning, 1966).

Partitioning of dry matter is affected by environmental variables, especially rainfall. Variations in bearing of trees from year to year can be explained from the moisture availability of successive years (Glendinning, 1966; Hutcheon, 1978). Seasonal changes in the stem diameter are useful indicators of internal stress (Hutcheon, 1977).

Estimates of leaf area index ranged between 3.7 to 5.7 in Brazil (Alvim, 1967) and 1.5 and 6 in Ghana (Hutcheon, 1976). Though no quantitative information is available on relationships between canopy, LAI and yield, a good canopy in the range of 4 to 6 LAI is expected to give high yield (Alvim, 1977). Canopy architecture showed varietal differences and cultivars adopted for higher radiation levels did not perform well under dense shade conditions (Hadfield, 1981).

Flushing rhythm and leaf growth

The leaves are dimorphic in nature. The first leaves on chupons have long petioles while leaves on fan branches have shorter petioles. Cocoa, like some tropical trees, shows a rhythmic growth of leaf called 'flushing' and a flowering periodicity. The phenomena can be described as seasonal as they are repeated at about the same time of the year, varying according to the region. In Brazil, the main flush occurs in September-October followed by two or three minor flushes (Alvim et al., 1974a). Flushing has two characteristic peaks with major peak in January-February and minor one in April-June in Ghana (Hutcheon, 1977; Owusu *et al.*, 1978). In India, two major peaks occur during January-February and September-November (Balasimha, 1987).

The flushing behaviour is controlled by internal factors as well as external environmental conditions. Studies have indicated that flushing is correlated with soil moisture and atmospheric relative humidity (Alvim, 1967; Lemee, 1955; Machado and Alvim, 1981) and that flushing, leaf fall, stem diameter changes were interrelated (Alvim, 1967, 1975; Boyer, 1974). Flushing is inhibited by water stress (Hutcheon, 1977) and is stimulated after rewatering. The role of temperature in control of flushing appears to be limited (Greenwood and Posnette, 1950; Humphries, 1944; Sale, 1968). Removal of shade results in a more intensive flushing and this may be because of better photosynthesis and sugar availability (Alvim, *et al.*, 1974a; Owusu *et al.*, 1978).

The most significant endogenous factor that controls flush growth is the level of growth hormones, notably abscisic acid (ABA). Alvim *et al.* (1974b) reported that ABA levels declined with initiation of flushing. In the young expanding leaves of cocoa, the level of ABA was very low but increased gradually with maturity resulting in bud dormancy (Abo-Hamed *et al.*, 1981; Orchard *et al.*, 1980). Moisture stress, which is one of the important environmental factors controlling the plant growth, results in accumulation of ABA and can thus cause bud dormancy (Alvim *et al.*, 1974b; Sale, 1970). In marked contrast to ABA levels, cytokinin and auxin levels were high during leaf expansion and declined as leaves matured (Abo-Hamed et al., 1984; Orchard et al., 1981). The leaf expansion is completed by about 20 days. The leaf elongation rates varied among accessions of cocoa under irrigated and stress conditions, but were not related *per se* to drought tolerance (Balasimha, 1984). The young expanding leaf has high demand for carbohydrates. The expansion of leaf is not accompanied by either increased chlorophyll (Baker and Hardwick, 1973) or photosynthetic activity (Bird and Hardwick, 1982) resulting in a carbohydrate stress to the plant. The young leaves, having not attained their complete photosynthetic ability, are mostly dependent on translocation of assimilates from mature leaves (Baker and Hardwick, 1975; Sleigh *et al.*, 1981). This may partly explain the intermittent leaf growth.

Flowering

Cocoa flowering is cauliflorous, giving the impression that the flowers originate directly from bark of the plant. The flowers are borne on long pedicels having 5 sepals, 5 petals, 10 stamens and ovary of 5 united carpels. The ovary has five parts with ovules arranged around a central axis. Flowers are pink to white in colour. The structure, biology and factors affecting flowering have been reviewed (Alvim, 1984). The flowering cycle follows seasonal patterns. In India, flowering occurs from November to April with a peak in January-February. The peak flowering in Brazil also is similar to this pattern (Alvim, 1967) while in Ghana two peaks are recorded in January-February and April-June (Owusu *et al.*, 1978). In Costa Rica, flowering peaks varied at different locations studied, which coincided with the beginning of rainy season (Young, 1984). Apart from rainfall, solar radiation is another major factor in influencing flowering. Removal of shade results in an increase in flower production and pod yield (Hurd and Cunningham, 1961). A clear relationship between sugar levels and solar radiation could be established (Owusu *et.al.*1978) indicating that light is limiting factor in shaded cocoa plants for photosynthesis. Depletions in sugar content coincided with peak reproductive growth (Owusu *et al.*, 1978). The stem girdling experiments have also confirmed the relationship between photosynthate supply and flowering (Alvim, 1984).

Neither irrigation nor fertilizer application affected the number of ovules per ovary or ovular fertility (Jadin and Paulin, 1988). Water deficit, especially when more pronounced, reduces pod setting by inhibiting flowering and by causing loss of young pods through physiological wilt (Alvim, 1988a). Flowering and leaf fall were positively correlated with both rooting of cuttings and graft strikes, while for leaf flush this correlation was negative (Flores and Vera, 1988). In India cocoa grown under *Areca catechu* and irrigated from December to May showed a mean annual fruit set of 3%, with only about one quarter of these fruits reaching maturity. Under controlled pollination, pollination of the style gave a higher fruit set (82%) than pollination of the stigma (66.5%) (Ravindran, 1982).

Monthly patterns of flowering and fruit set were studied in plantations with various kinds of shade cover near La Virgen (Heredia Province), Turrialba (Cartago Province) and Siquirres (Limon

Province). In all 3 areas a short dry season occurs, usually between January and March. In all areas, and regardless of shade cover, there was a marked decline in flowering near the end of the rainy season when rainfall was very high. Quantitative seasonal patterns were difficult to determine due to large inter-tree variations in monthly levels of flowering and fruit set in each area (Young, 1984).

The pattern of pod setting closely followed the pattern of flower production. The effect of shade and spacing on the periodicity of flushing, flowering and pod setting was negligible but the onset of flushing was delayed slightly by shade. Shading and close spacing suppressed both flowering and pod setting (Ampofo and Bonaparte, 1981). Flowering was affected by rainfall distribution than by any other climatic factor. In most regions rainfall distribution is also the main factor controlling phenological phenomena in cocoa, including flushing cycles and crop distribution. The absence of flowering in Bahia from June/July to September/October was found to be closely associated with absence of cambium activity. Both phenomena appear to be controlled mainly by internal growth correlations, the presence of large quantities of fruits during that period having a strong inhibitory effect on flowering. Relatively low temperatures during the period also appear to have a depressing effect on flowering (Alvim, 1981).

Water stress generally inhibits flowering (Alvim, 1964; Hutcheon, 1977; Sale, 1970). Rains after a long dry period resulted in profuse flowering called 'crazy' flowering (Alvim, 1967; Hutcheon, 1977). In Brazil, decrease in flowering also resulted from low temperatures during winter months (Alvim, 1967). There was also an internal competition for flowering especially when growing fruits were present. From the data so far available, it appears that 'hydro periodicity' of the environment and internal competition between fruits and flowers for assimilate supply are two basic factors which control flowering.

Anthesis occurs between 14.00 and 16.00 h and completed between 02.00 and 04.00 h the next day. Anther dehiscence commenced between 04.00 and 06.00 h and was completed between 08.00 and 10.00 h. Stigma receptivity was high between 12.00 and 14.00 h. Seven insect species belonging to the order Diptera, and 5 species belonging to the order Hymenoptera were identified as flower visitors. Pollen viability was found to be 97.1% by the acetocarmine staining method, and *in vitro* pollen germination was 66.25% (Rajamony and Mohanakumaran, 1995). Several small insects largely effect pollination in cocoa flowers. Among them midges belonging to family Ceratopogonidae are more common. Species of genus Forcipomyia are important pollinators. Many other insects also are involved in pollination including ants, aphids, Drosophila and thrips.

Fruit development

The fruits or pods of cocoa take about 5 months on an average for full development, the pod growth following a sigmoid curve. Generally the early sets of the season survive well compared to late ones (Hutcheon, 1977; Uthaiah and Sulladmath, 1985). The rate of dry matter accumulation is slow initially but attains a peak at about 100 days with around 3 g $day^{-1}pod^{-1}$. The fall in survival rate in fruits which are set late may be because of internal competition for assimilates. Temperature also influenced fruit growth, the fruits grow faster in warmer months (Alvim, 1967). Water stress not only reduced crop yields, but also significantly reduced the pod value (Subramonian and Balasimha, 1981). Fruits, which developed under a condition of inadequate water availability, had lower pod-value factors.

Yields of cocoa vary with different geographical locations, cultural practices and planting material. The mean annual yields vary from 300 to 500 kg dry bean ha^{-1} in farmers plots to as high as 2000 kg ha^{-1} in experimental farms (Alvim, 1977). The record annual yield of 3700 kg ha^{-1} reported by Ahenkorah *et al.* (1974) may be considered as nearing the maximum potential yield of presently known cultivars. Spacing is equally important and it has been shown that annual yields can be as high as 2000 kg ha^{-1} when planted at 2.7 x 2.7 m spacing under arecanuts which is almost double of 5.4 x 5.4 m spacing, used for open planting. However, individual tree yields are better with wider spacing (Shama Bhat, 1988).

Photosynthesis

Photosynthetic efficiency is a primary determinant of cocoa productivity. The primary photosynthesis can be estimated by the techniques or growth analysis, or by determining the photosynthetic rates of seedlings or individual leaves and ascertaining the canopy structure.

Cocoa has a relatively low net assimilation rates (Alvim and Grangier, 1966; Goodall, 1950; Murray, 1953) that ranges from 5 to 20 mg dm^{-2} day^{-1}. However, the rate is reported to increase with light intensity upto certain level (Lemee, 1955). Measurements of photosynthetic rates have been conducted by Baker and Hardwick (1973, 1976), Baker *et al.* (1975) and Okali and Owusu (1975). Studies conducted on 22-year-old cocoa trees cultivated under the shade of arecanut palms showed that chlorophyll synthesis increased after leaf expansion was complete. This increase in chlorophyll synthesis was matched by increases in fluorescence indices (Fo, Fv and Fm) indicating enhanced rates of photosynthesis (Balasimha and Daniel, 1995; Table 1). The high photosynthetic rate is associated with thick leaves or high specific leaf weight (SLW) which is characteristic of vigorous trees. This was also shown by a positive relationship between high yield and high SLW (Balasimha *et al.*, 1988). The light response curve varies with the type of tree growth reaching a saturation point at PAR of about 400 mmol $m^{-2}s^{-1}$ (Balasimha *et al.*, 1991; Fig.1).

Table 1. Leaf area, fluorescence (arbitrary units) parameters, chlorophyll pigment contents and Pn in cocoa.

Age (days)	Leaf Area (cm^2)	F_O	F_M	F_V	F_V/F_M	Chl a (mg/g)	Chl b (mg/g)	Carot-enoid (mg/g)	P_n (m molm^{-2} s^{-1})
2	16.3	459	1010	551	0.545	0.171	0.077	0.049	Nil
5	62.3	631	1540	912	0.591	0.269	0.121	0.064	Nil
10	137.7	775	2191	1416	0.646	0.303	0.136	0.073	Nil
15	180.2	679	2753	2074	0.753	0.536	0.227	0.098	1.679
30	200.3	665	2925	2265	0.772	0.958	0.378	0.222	5.134
CD (P=0.01)	67.1	102	342	335	0.062	0.223	0.010	0.033	1.285

Cocoa has an unusual development of photosynthetic apparatus. The photosynthetic units viz., chlorophyll, carotenoids, and enzymes do not develop until after the termination of leaf expansion (Baker and Hardwick, 1973, 1976; Baker *et al.*, 1975). With the development of chloroplast lamellae and chlorophyll synthesis, the level of ribulose bisphosphate carboxylase activity and the photosynthetic rate increase. As a result of such pattern in photosynthetic machinery, the soluble sugar concentrations rises only after leaf expansion is complete (Baker *et al.*, 1975).

A simulation model was used to investigate the potential photosynthetic productivity of cocoa (Ng, 1982). Shade leaf area index had considerable effect on photosynthesis, the rates declining by 25% and 50% with shade canopy leaf area index of 0.5 and 1.0 respectively. The productivity of vigorous trees was 7-16% greater than that of a moderately vigorous tree.

Cocoa is relatively tolerant to shade. This is shown by studies on light compensation points and by responses in net assimilation rates (Alvim, 1967, 1977) and photosynthetic rates (Guers, 1985) to varying light regimes. Cocoa adapts to shade by modifications in leaf thickness and higher chlorophyll contents. The plants grown under light limiting conditions always recorded higher chlorophyll contents on weight/area basis demonstrating more energy investment in the production of light-harvesting system. The nitrate reductase (NR) activity, however, was not affected in shade and open conditions showing that light is not limiting for this key enzyme of nitrate assimilation. However, the response to fertilizers varied with light intensity (Ahenkorah *et al.*, 1974; Cunningham and Arnold, 1962). The initial increase in yield with removal of shade is always followed by a subsequent marked decline. Hence for optimal growth, photosynthesis and yield of cocoa trees, shade is advantageous which helps in preventing unfavourable ecological factors like low soil fertility, wind damage evapotranspiration and water stress.

Drought Tolerance

Among plantation crops, cocoa is regarded as one of the most sensitive ones to water stress. Water stress affects several physiological processes leading to reduction in crop yield. Water potential of leaf is a major quantitative characteristic used to assess water stress. Cocoa plants show changes in water relations when soil moisture drops to 60-70% of available range (Alvim, 1960; Lemee, 1955). The onset of drought decreased water potential and relative water content (Balasimha, 1982, 1983a; Hutcheon, 1977). The relative water content (RWC) of leaves of rainfed cocoa plants was lower than those of irrigated plants. This tends to decrease with progress of summer months. The decrease in RWC even in irrigated plants may be because of progressive increase in daily mean temperature and lower relative humidity leading to higher transpiration rates. During drought, NR activity and chlorophyll content decreased while proline accumulated in the leaves. Diurnal variation exists in water potential; however a plateau in water potential is reached once the stomata close beyond -1.5 Mpa (Hutcheon, 1975). This is the stage when the turgor pressure falls and leaves start wilting. The changes in osmotic potential of cocoa during different months were not as marked as water potential (Balasimha, 1982, 1983a).

Drought decreased RWC (to 80%) and water potential, increased stomatal resistance and the level of ABA (Abo-Hamed *et al.*, 1985). There was a direct relationship between stomatal resistance and ABA content indicating that ABA regulates stomatal closure (Balasimha and Anil Kumar, 2000). The leaf elongation rates were severely inhibited under drought. As the intensity of drought increased metabolic processes and RWC were also affected (Balasimha, 1984). Water potential may vary due to leaf age and position (Alvim *et al.*, 1974a). The water potential was appreciably lower in exposed leaves as compared to shaded ones, presumably due to higher temperature and lower relative humidity in the exposed area than those in the shade.

The leaf morphology, water relation-components, stomatal behaviour and biochemical factors were studied in cocoa germplasm collection (Balasimha, 1983a; Balasimha *et al.*, 1985; Balasimha and Rajagopal, 1988). The leaf morphological characteristics showed significant differences among

accessions, noteworthy being SLW and epicuticular wax content (Balasimha *et al.*, 1985). Data so far available, indicate that thick leaf, higher wax content, efficient stomatal closure and high tissue elasticity were responsible for better adaptation of plants to drought conditions (Table 2). Based on these characteristics drought tolerant accessions have been identified (Balasimha *et al.*, 1988).

Table 2. Changes in leaf characteristics

Parameter	Tolerant		Susceptible	
	Unstressed	Stressed	Unstressed	Stressed
Epicuticular wax (mg/cm^2)	24.78	38.86	18.01	31.66
Total lipid (mg/g FW)	10.46	7.39	9.97	6.27
Neutral lipid (%)	69.40	77.20	66.40	78.00
Glycolipid (%)	20.90	19.10	22.80	17.00
Phospholipid (%)	9.70	3.70	10.70	4.90
Total sterol (%)	3.50	4.40	3.60	4.80
Sterol/phospholipid ratio	0.36	1.19	0.34	0.98
Electrolytic leaching (%)	15.56	20.19	17.96	27.66

Breeding for drought tolerance using high yield and tolerant trees have resulted in some promising hybrids which showed similar traits (Balasimha *et al.* 1999). Earlier, it was reported that drought resistance was associated with closure of stomata (Nunes, 1967; Joly and Hahn, 1989) and lesser transpiration rate (Segbor *et al.*, 1981). Studies conducted with trees of drought-tolerant and drought-susceptible accessions (cultivars) grown as a mixed crop with arecanut palms showed that the net photosynthetic rate (Pn), transpiration rate and stomatal conductance varied significantly with season. Pn was highest during periods of low evaporative demand (low VPD). Diurnal patterns of these parameters indicated transient midday water deficits that reduced Pn. Drought-tolerant accessions maintained higher leaf water potential than did drought-susceptible accessions in dry months. The tolerant and susceptible types showed no significant difference in Pn (Balasimha *et al.*, 1991; Table 3).

Table 3. Seasonal changes in P_n and other parameters in relation to drought tolerance

Parameters	Accession types	Month					Mean
		Feb	Apr	May	Jun	Oct	
P_n	Tolerant	3.47	1.98	2.16	3.50	4.17	3.06
(mmol m^{-2}s^{-1})	Susceptible	2.41	2.48	2.20	2.73	3.89	2.74
g_s	Tolerant	0.14	0.07	0.07	0.18	0.27	0.15
(mol m^{-2}s^{-1})	Susceptible	0.10	0.09	0.08	0.14	0.31	0.14
E	Tolerant	2.77	1.91	2.44	1.82	3.54	2.50
(mmol m^{-2}s^{-1})	Susceptible	1.86	2.39	2.45	1.84	5.37	2.78
WUE	Tolerant	1.31	1.03	0.90	2.10	1.25	1.32
(mmol CO_2/mmol^{-1} H_2O)	Susceptible	1.31	1.03	0.91	1.76	0.88	1.18
γ (-Mpa)	Tolerant	0.55	0.69	0.93	0.40	0.63	0.64
	Susceptible	0.54	0.91	1.03	0.43	0.70	0.73

The application of chlorophyll fluorescence as a tool to screen cocoa for drought tolerance has also been used (Balasimha and Namboothiri, 1996). The ratio of variable to maximal fluorescence (Fv/Fm) was found to be higher in drought tolerant than susceptible cocoa accessions. However, stomatal frequency or size did not show any correlation with drought tolerance (Balasimha *et al.*, 1985). It is possible that the ability to tolerate drought results from stomatal regulation, thus reducing transpirational water loss. The tissue elasticity is also higher as shown by lower bulk elastic moduli. Osmotic adjustment does not appear to be a major contributor as changes in osmotic potential were not high, compared to many other crops. The solutes, like sugars and proline, which are major contributors for leaf osmoticum, do not accumulate substantially in drought tolerant accessions (Balasimha, 1984). The NR activity showed higher stability under drought in tolerant accessions, possibly because adequate energy pools were available since leaf turgidity was maintained (Balasimha, 1983a, 1984).

However, the rate at which water stress develops within the plant is dependent on external factors like relative humidity, soil conditions and cropping pattern. If the soil is deep with high water holding capacity stress develops gradually and water is still available to the roots for a long period. The capacity for water uptake and transport may also differ because of resistance to water flow. Since hydraulic flow resistance is expected to be relatively low for cocoa (Hutcheon, 1977) it may not be a limiting factor. The overhead shade of cocoa decreases the evapotranspiration thereby reducing water consumption by cocoa plants to some extent. Trees without shade exhibit a high transpiration and low leaf water potential.

SHADE

Cocoa has evolved as an understorey crop in the Amazonian forests. It was therefore traditionally grown in thinned forests in West Africa (Hammond, 1962) and Brazil. However for modern commercial cultivation of cocoa various permanent shade trees have been grown in different countries. The search for tree species, which provide both adequate shade and high quality products to increase the farmer's income, has been one of the main targets in cocoa cultivation. Some of the symbiotic nitrogen fixing leguminous shade species like *Erythrina* sp, *Leucaena leucocephala* and *Gliricidia sepium* have been used. Larel (*Cordia alliodora*) and *Erythrina* have been grown as shade trees for cocoa in Costa Rica (Alvim, 1988b; Fassbender *et al.*, 1988; Morera, 1996). Only in a few cases have multipurpose tree crops been extensively used for shading cocoa, such as the use of coconut (Anwar and Hutomo, 1984; Shepherd, 1976; Nelliat *et al.*, 1974), arecanut (Shama Bhat and Bavappa, 1972; Shama Bhat, 1988) and rubber (Blencowe, 1968) in Malaysia, India and Brazil. The profitability of cocoa shaded with coconuts was compared with that of cocoa shaded with *Leucaena* species (Daswir *et al.*, 1988). Because of the high proportion of light that penetrates through the canopy of palms, they are considered most suitable for various crop combinations in agroforestry systems. Peach palm (*Bactris gasipaes*) as a potential multipurpose shade species for cocoa has been used in Brazil. Bamboo (*Bambusa vulgaris*) is normally grown to prevent wind damage in young cocoa plantations but adverse effects on the crop have been noticed (Pinho and Muller, 1987).

On a farm scale, planting cocoa without shade leads to heavy pest and weed infestation. In a trial with hybrid cocoa (High Amazon x Amelonado) and Horn plantains, 6 interplanting combinations were compared. The combinations recommended (where rainfall is adequate) are 1 row of cocoa to 1 row of plantains planted at the same time, or the same combination with cocoa

planted 7 months after the plantains. Where rainfall is insufficient, the plantains could compete with cocoa. Fertilization must ensure that the K and P removed by the crops are replaced. The economic advantages of the combinations are outlined (Lachenaud.1987). For productive results it was found that proper pruning of shade trees were necessary. In trials during 1974-84, cocoa cultivar F3 Amazon was grown alone, grown in blocks of 25 plants in squares formed by 8 oil palms (*Elaeis guineensis*), grown as single or double rows between rows of *Cola nitida*, or grown between *Terminalia ivorensis*. Cocoa yields were 718 kg dry beans/ha when grown alone, 1199 kg when grown with oil palm, 611 and 699 kg when grown in single and double rows between *C. nitida* and 207 kg when grown between *T. ivorensis*. In Malaysia cocoa has been under-planted with oil palm to increase productivity (Amoah *et al.*, 1995). It is concluded that heavy shade and root competition depressed yields of cocoa intercropped with *C. nitida* or *T. ivorensis* (Egbe and Adenikinju, 1990).

Shade has pronounced influence on CO_2 assimilation and nutrition. Light saturation occurs even at 20% of light in Ghana (Okali and Owusu, 1975). The manurial and shade experiments in Ghana have shown that light intensity is vital for nutrient response. The response to NPK fertilizer increased with shade removal. However yield declined after ten years of unshaded condition. This is attributed to nutritional stress in trees, depletion of exchangeable bases in soil, unfavourable environment and insect incidence involving dieback (Ahenkorah *et al.*, 1974).

IRRIGATION

Cocoa is usually grown in areas where water availability is adequate. But in some areas although plenty of rainfall is received long periods of dry period ranging from 3 to 6 months are common. Areas that are affected by periodic droughts are Trinidad, Ghana, Ecuador and India. Due to this the decrease in soil moisture results in reduced photosynthesis and yields. Various methods of irrigation have been used like sprinkler, furrow, and drip irrigation (Jadin and Chauchard, 1976). Under-canopy sprinkler irrigation, aimed at maintaining the soil near field capacity, was superimposed on an existing shade and fertilizer trial of mature Amelonado cocoa for 3 consecutive years. The overall responses during 2 years when the rainfall was average were 12 and 17 per cent. In a year with a very severe dry season irrigation increased yield by over 40 per cent, to the level obtained in years with favourable rainfall (Hutcheon *et al.*, 1973). Water supplies improve growth and development of cocoa. It was shown that drip irrigation was superior to sprinkler irrigation (Jadin and Chauchard, 1976). Khan *et al.* (1988) reported that yield was significantly increased due to drip irrigation. In India drip irrigation enhanced yield and 20 litres of water per day was required for cocoa grown as a mixed crop in arecanut (Balasimha *et al.*, 1996; Abdul Haris *et al.*, 1999). Stomatal resistance was higher in I1 (10l/day) level, which reduced photosynthesis and transpiration, but there was no mesophyll limitation due to water stress.

PRUNING

In young cocoa it is necessary to have formation pruning. This is done mainly to adjust the height of first jorquette. The jorquette is allowed to form at a height of 1-2 meters that will help in easy cultural operations. Pruning in mature cocoa includes two types viz., sanitary pruning and structural pruning. In sanitary pruning diseased or unnecessary branches are removed. It is also necessary to prune infected branches with diseases like witches broom or vascular streak dieback. Structural pruning is done to shape the canopy to desired size and architecture. For optimum

productivity proper canopy management to maintain shape and size is required. Maximum leaf area should be maintained with pruning practices to avoid self-shading of leaves. Martin and Prasad (1983) reported a pruning experiment with three types of pruning. Discretionary pruning showed higher yield. Pruning experiments in Ghana showed that during early years the pruned trees yielded slightly more than unpruned trees, but after ten years from planting, the unpruned trees started to yield more (Bonaparte, 1966).

In studies on canopy architecture and yield where five different types of canopy architecture were maintained in cocoa, it was found that big canopy with spreading nature seems to be ideal for cocoa (Thomas and Balasimha, 1992). In order to understand and elucidate optimum canopy shape and structure of cocoa, different spacing and canopy sizes were studied. Cocoa was grown as intercrop with arecanut. The relative heights of areca and cocoa was measured during growth (Fig.2). The canopies did not compete with each other and the areca crown overtook the cocoa. There were three spacing and three canopy size treatment (small, medium and large) in a split plot design. The results showed that there was significant difference in growth and canopy architecture with reference to treatment. Light interception varied among different treatments. The net photosynthesis, transpiration, stomatal conductance and internal CO_2 did not vary significantly among the treatments (Table 4). Chlorophyll fluorescence parameters showed variations at different spacing. The dry bean yield showed significant variations, highest yield being obtained in S1P3 and S2P3 treatment (Table 5). When grafts are used similar results were obtained with highest yield being recorded at S1P3 and S2P3 treatments (Fig.3). It is concluded that cocoa requires comparatively big and spreading canopy for high yield as shown from the positive correlation of leaf area to yield. The average land equivalent ratio (LER) for different treatments ranged from 0.82 to 1.74 which showed the advantage of mixed cropping of areca and cocoa (Table 6). Similar results have been reported with reference to spacing and fertilizer experiment (Shama Bhat, 1988). The maximum LER was found in S2P3 treatment. Considering the LER and combined yields it is advantageous to grow areca and cocoa at S2 spacing. Pruning of canopy is necessary for maintenance of optimum leaf area index in cocoa. Relationship between vegetative growth and photosynthesis are important in determining yield. This depends on nutrient supply and carbohydrate reserves. Photosynthesis occurs on leaves exposed to light and leaves inside the canopy are considered parasitic as they import photosynthates from outer leaves. Thus pruning is absolutely necessary for productivity.

Table 4. Photosynthesis characteristics in cocoa in relation to canopy size

Treatment	Pn (μmol $m^{-2}s^{-1}$)	Transpiration (mmol $m^{-2}s^{-1}$)	Gs (mol $m^{-2}s^{-1}$)	CO_2 internal (ppm)
Spacing				
S1 2.7x2.7m	3.96	3.76	0.175	299
S2 2.7x5.4m	3.70	3.51	0.163	290
S3 5.4x5.4m	4.22	3.76	0.176	285
Pruning				
P1 Small	3.94	3.90	0.191	298
P2 Medium	4.13	3.60	0.164	284
P3 Large	3.81	3.53	0.6163	292

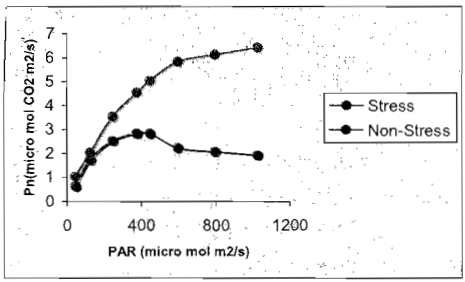

Fig.1. Light saturation of photosynthesis

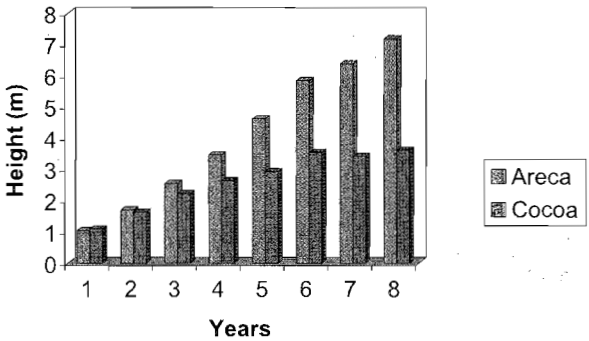

Fig. 2. Relative growths of arecanut and cocoa in mixed crop

Fig.3. Canopy architecture of cocoa grafts in S2P3 pruning treatment

Table 5. Dry bean yield (kg/ha) in cocoa (mean of 6th to 8th years)

Treatment	P1	P2	P3	Mean
S1	326.25	585.85	645.59	519.23
S2	233.72	403.28	610.94	415.98
S3	120.94	275.37	310.63	235.64
Mean	226.97	421.50	522.38	
CD (5%)				
Spacing	76.26			
Pruning	83.97			

Table 6. Land equivalent ratio (LER) in areca-cocoa crops

Treatment	P1	P2	P3	Mean
S1	1.13	1.34	1.68	1.38
S2	1.34	1.38	1.74	1.48
S3	0.82	1.53	1.67	1.34
Mean	1.09	1.42	1.70	

GROWTH REGULATORS

The early vigorous growth of seedlings is very important for better establishment and higher yield potential at maturity. Management practices to prevent seedling deaths after field planting are available. Folicote increased stomatal resistance considerably, without directly affecting physiological processes (Hutcheon, 1984). Another antitranspirant 'mobileaf' also reduced transpiration rates in 6-month old seedlings, which suits the time of transplanting (Lima Filho and Alvim, 1978). The application of cycocel and abscisic acid (ABA) imparted drought tolerance in seedlings as shown by growth and metabolic amelioration (Balasimha, 1983b; Balasimha and Subramonian, 1984). Paclobutrazol was applied to (5, 15, 45 and 90 ppm) the soil of 5-month-old seedlings growing in 5 kg polyethylene bags ((Valle *et al.*, 1989). Plant height was the parameter most affected by the treatments. Paclobutrazol at the highest rate reduced seedling height by 32 per cent, compared with control plants. Individual leaf area, with the 2 higher doses, was significantly lower than in the control and the 5 and 15 ppm treatments. Total dry weight of plants treated with Paclobutrazol at the highest rate was 21 per cent lower than in the control. The highest dose also changed the partitioning of photosynthates, decreasing the root: shoot ratio.

Growth retardants were applied to cocoa trees before or during flowering with the object of reducing cherelle wilt by reducing shoot competition, thereby improving fruit retention. Treatment before flowering with 500 ppm CCC (chlormequat)] increased yield by 57 per cent, and similar treatment with a mixture of 500 ppm B9 (daminozide) and 600 ppm Fruitone (NAA) increased it by 60 per cent. Treatment during flowering with 500 ppm CCC did not affect yield but increased the number of beans/pod by 51per cent (Snoeck, 1976).

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5. DISEASES

R. ChandraMohanan

INTRODUCTION

Cocoa (*Theobroma cacao* L.) was introduced into India in the early 20th century with very limited area under cultivation in some of the Government farms. At that time, both 'Criollo' and 'Forastero' varieties were introduced and later importance was given to Criollo cultivation due to its superiority in the quality of produce. However, this variety is highly susceptible to pests and diseases. Thus, the Criollo plants were almost completely damaged by pests and diseases. Hence, much attention was given to Forastero type.

Commercial cultivation of cocoa started with the Forastero type. With the expansion of area under cocoa and with the increase in the age of the plantations, pests and diseases are becoming more important. Crop losses due to diseases have been identified as one of the major production constraints in all cocoa growing countries. Hale (1953) estimated that losses were about 21 per cent of production. Padwick (1956) reported that global losses due to cocoa diseases to be 29.4 per cent. According to Crammer (1967), the losses were 20.8 per cent. There are some reports of heavy losses due to certain diseases from some of the cocoa growing countries. A detailed survey of cocoa gardens in Kerala, Karnataka and Tamil Nadu during 1980 revealed that diseases caused by *Phytophthora* and *Colletotrichum*, vascular streak dieback and zinc deficiency can be considered as the major problems in India based on the extent of damage and nature of disease (ChandraMohanan and Kaveriappa, 1981).

NURSERY DISEASES

Seedling dieback

Seedling dieback also known as seedling blight is very common in the cocoa nurseries of Kerala, Karnataka and Tamil Nadu during rainy season. Intensity of the disease varies from locality to locality as well as with the age of seedlings. Younger seedlings are more susceptible to the disease. Defoliation and dieback of seedlings are the characteristic symptoms of the disease. Generally the infection starts from the tip of the stem and proceeds downwards as dark brown to black water-soaked linear lesions. The lesions also extend to the leaves through the petioles resulting in wilting and subsequent defoliation of the seedlings. The infection also initiates from the collar region, cotyledonary stalk or leaves as dark brown to black discoloration. In all the cases, the infection spreads to the entire stem causing wilting, defoliation and ultimate death of the seedlings.

Phytophthora palmivora Butl. has been found to be the causal organism of this disease (ChandraMohanan, 1979). Severe infection of grafted and budded seedlings caused by *P. palmivora* has also been observed in India. In such cases, infection mainly starts from the grafted or budded region and proceeds upwards and downwards. Infection continues to spread internally after the rainy season leading to high mortality (ChandraMohanan and Chowdappa, 1999). Pre- emergence

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damping off of the seedlings was also noticed in several nurseries especially when sowing of beans was carried out during rainy season. Pre-emergence death of seedlings is mainly due to the inoculum present in the soil. Primary source of inoculum for the seedling blight is through soil splashes. Later, infected seedlings serve as the source of inoculum for the spread of the disease in the nursery. Removal and destruction of infected seedlings from the nursery are very important management practices to check the secondary spread of the disease. The disease incidence can be considerably reduced by improving the drainage facilities in the nursery and by providing proper shade. Drenching the seedlings with Bordeaux mixture or Copper oxychloride just before the onset of monsoon and thereafter at frequent intervals is essential in the effective management of the disease in nurseries with high disease intensity. A combination of seed dressing and soil drench with Kocide at a concentration of 0.91 kg in 45 litres of water has been found to be very effective in controlling pre and post emergence seedling deaths caused by *P. palmivora* (Asare-Nyako *et al.*, 1972).

Other seedling diseases

Foliar infection caused by *Colletotrichum gloeosporioides* Penz. is common in almost all nurseries. However, it has been noticed as a serious problem only in some of them. Seedlings with *C. gloeosporioides* infection look very unhealthy due to leaf blight, crinkling of leaves and stunted growth. White thread blight caused by *Marasmius scandens* Massee leading to dieback of six month old seedlings has been reported as a problem in nurseries with high humidity, poor aeration and low availability of sunlight (ChandraMohanan, 1994). Zinc deficiency symptoms are also reported from some of the nurseries.

POD ROT

Pod rot diseases cause direct loss in yield year after year. Pod rots caused by *Phytophthora palmivora* and *Colletotrichum gloeosporioides* have been recorded as the major diseases occurring in India. Charcoal pod rot caused by *Botryodiplodia theobromae* Pat. occurs throughout the year. However, it has not been observed as a serious problem.

Black pod disease

Black pod disease was first noticed in Guyana and West Indies and referred as black cocoa (Jenman and Harrison, 1897). At present, it is prevalent in all the cocoa growing countries (Zentmyer, 1988). Black pod disease was reported for the first time from India in 1965 (Ramakrishnan and Thankappan, 1965). ChandraMohanan and Kaveriappa (1981) reported black pod as the major disease of cocoa in India based on the districtwise distribution of cocoa diseases and the percentage of gardens showing disease incidence. Losses from black pod vary from country to country; Nigeria (30%), Brazil (30.8%), Ghana (25-30%), Cameroon (95%), Dominican Republic (10-20%) and Togo (10-80%) (Lass, 1985). In India, the incidence of this has been found to vary from 12.93 to 29.78%, depending upon locality and garden (ChandraMohanan, 1985). Thus, black pod is the most serious disease owing to the heavy economic loss involved.

Black pod disease occurs during rainy season when humidity is high and the temperature is constantly optimum. In India, this disease is a serious problem during south-west monsoon period (June-September). Pods of all ages are susceptible to the disease. The infection appears as one or more small, chocolate brown circular lesion(s) anywhere on the pod surface. Within four to seven

days, the lesion enlarges assuming an elliptical shape. As the lesion advances, a whitish growth of the fungus consisting of mycelia and sporangia is produced over the dark brown pod surface. The lesion increases rapidly and covers the whole pod surface. After about 15 days of infection, the whole pod and beans are invaded by the fungus and the pod turns black in colour (Fig.1). By this time, several saprophytic microorganisms colonize the rotten pod. The beans in ripe pod may escape partly or wholly from infection as the beans get separated from the pod husk on ripening (Gregory, 1974; Thorold, 1975).

Phytophthora palmivora (Butl.) Butl., *P. capsici* Leonian, *P. megakarya* Brasier and Griffin and *P. citrophthora* (Smith and Smith) Leonian are the major *Phytophthora* species causing this disease in various cocoa growing countries (Zentmyer, 1988). In addition to these four major species, several other species of *Phytophthora* viz., *P. heveae* Thompson, *P. botryosa* Chee, *P. meadii* Mc Rae, *P. drechsleri* Tucker, *P. nicotianae* Breda de Hann var. *nicotianae* Waterhouse, *P. nicotianae* var. *parasitica* (Dast.) Waterhouse, *P. megasperma* Drechsler and *P. katsurae* Ko and Chang have been described as minor pathogens of cocoa (Liyanage and Wheeler, 1989; Waterhouse, 1974a and b; Zentmyer, 1988).

When the disease was first reported from India in 1965 the causal organism was identified as a species of *Phytophthora*. Further studies on Phytophthora diseases of cocoa were not carried out for about 14 years. This may be, probably, because of the reason that large-scale cocoa cultivation in India started only during 1970's. The species of *Phytophthora* causing cocoa diseases in India was first identified by ChandraMohanan *et al.* (1979) as *P. palmivora* based on detailed studies on Phytophthora diseases of cocoa. *P. palmivora* colony on carrot agar appears as smooth combed with sharply defined edge. Sporangia are produced in a sympodial pattern. They are pappillate, caducous, ovoid to ellipsoidal with round base and short, broad and occluded pedicel (Fig.2). The pedicel length ranges from 2.7-3.9 mm. The length/breadth ratio varies from 1.3-2.2, usually 1.5 or 1.6. Chlamydospores are terminal or intercalary. They are spherical when terminal and slightly ellipsoidal when intercalary. Oogonia are spherical and hyaline. Antheridia are spherical to slightly cylindrical thin walled, hyaline, amphygynous and persistent. Oospores are spherical and plerotic.

Sastry and Hegde (1989) found *P. meadii* as the species causing black pod disease in certain localities of Uttara Kannada district of Karnataka state. *P. capsici* and *P. citrophthora* were isolated from black pod affected cocoa pods in very few localities in Kerala state. But, they were not recorded as the major pathogens of cocoa (Chowdappa *et al.*, 1993; Chowdappa and ChandraMohanan, 1996 and 1997). Thus, *P. palmivora* has been found to be the predominant species causing black pod disease of cocoa in India. Though, A_1 and A_2 mating types occur in India, A_2 is the predominant mating type in *P. palmivora* population in this country. The occurrence of two mating types of different species in same locality raises the possibility of intra-and inter-specific hybridization between them in nature and formation of new strains.

Soil phase of *Phytophthora* is very important. Under favourable climatic conditions, spores are liberated to the soil surface and rain splashes carry these spores to the pods, which are at the lower part of the trunk causing infection. Pods, which are touching the soil surface, get infected directly. Sporangia are produced abundantly when there is high humidity, rainfall and constant optimum temperature. The pods thus infected act as the source of inoculum for the secondary spread of the disease. The sporangia are spread by rain splashes, insects and rodents (Thorold, 1975). Tent building ants and scolytid beetles have also been reported as agents carrying sporangia from diseased

pods to healthy pods (Mc Gregor and Moxon, 1985). Thus, the disease spreads, from pods at the lower part of the trunk to that at the upper part and branches in a climbing up pattern.

Phytosanitation, fungicidal application and host resistance are the three major aspects in the management of black pod disease. Since infected pods form the main source of secondary infection, all the diseased pods should be removed at weekly intervals or during each harvest and buried in the soil. Proper spacing between plants and pruning are also important to regulate the shade. Periodic removal and destruction of infected pods alone will help to reduce the disease incidence to the extent of 50%. Spraying of Bordeaux mixture (1%) at 15 days interval starting from the onset of south- west monsoon along with periodic removal of infected pods is effective in controlling the disease in severely affected gardens. Experiments conducted during last several years revealed that the disease can be effectively controlled by the use of copper based fungicides.

From the results of screening of 51 cultivars for *P. palmivora* resistance in Costa Rica, nine cultivars viz., EET 59, EET 376, UF 713, UF 715, SCA 6, SCA 12, Pound 7, Catongo and Diamantes 800 have been found to be exhibiting promising degree of resistance (Lawrence, 1978). As *P. palmivora* is the only species reported in Costa Rica, the results may still be valid for that country. Studies conducted in Java have indicated that the cocoa accessions DRC 16, SCA 6, SCA 12, and ICS 6 were resistant to Phytophthora pod rot. However, in India, the cocoa Accession C 78 has been found to be comparatively less susceptible to wound inoculation by *P. palmivora* (ChandraMohanan, 1982).

Cherelle rot

The young developing fruit (pod) is known as 'cherelle'. Large number of young pods of 2-3 months age dry up and remain on the tree as mummified fruit and this type of drying of pods is commonly referred as 'cherelle wilt' (Fig.3). Such 'cherelle wilt' where no pathogen is involved is considered as a physiological thinning mechanism. Detailed studies on the involvement of pathogen in cherelle rot revealed that a considerable percentage of drying and mummification of young pods, hitherto considered as cherelle wilt, is caused by *Colletotrichum*. The symptom of cherelle rot mostly starts from the stalk end, particularly at the point of attachment of the stalk to the pod. The infection proceeds towards the tip of the pod as dark brown sunken lesion with a diffused yellow halo. The infection also extends to the stalk and reaches the cushion, but does not spread further in the cushion. The infected stalk becomes highly shrunken and can be easily distinguished from healthy stalk. As the infection progresses, the internal tissue of the pod also becomes discoloured. The infection may also start from anywhere on pod surface other than stalk region as dark brown sunken lesion. Such lesions coalesce and form bigger lesions. Microscopic examination of the pinkish slimy mass on the lesions reveals the presence of acervuli with setae and abundant conidia of *C. gloeosporioides*. Ultimately, the pod turns dark brown to black and remains on the tree as mummified fruit (ChandraMohanan and Kaveriappa, 1983a). At this stage, these pods can be easily confused for pods affected by cherelle wilt, which is a physiological phenomenon. The physiological wilt begins as general yellowing of the entire pod (cherelle) followed by browning and blackening of the entire pod. Thus, the physiological wilt of cherelle is distinguishable from cherelle rot. Colletotrichum pod rot is found only on cherelles and young pods with the maximum incidence on cherelles (ChandraMohanan, 1983; ChandraMohanan *et al.*, 1989a). Detailed studies have been conducted on the epidemiology of Colletotrichum diseases of cocoa occurring in India (ChandraMohanan *et al.*, 1989b). The critical period for cherelle rot is February-May, when the susceptible stages of the pods are plenty.

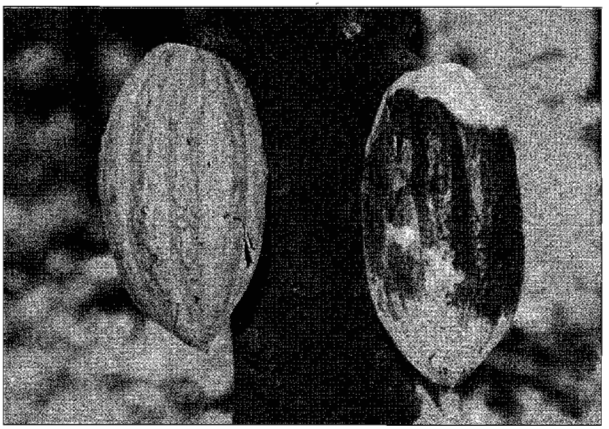

Fig. 1. Black pod infected pod along with a healthy pod

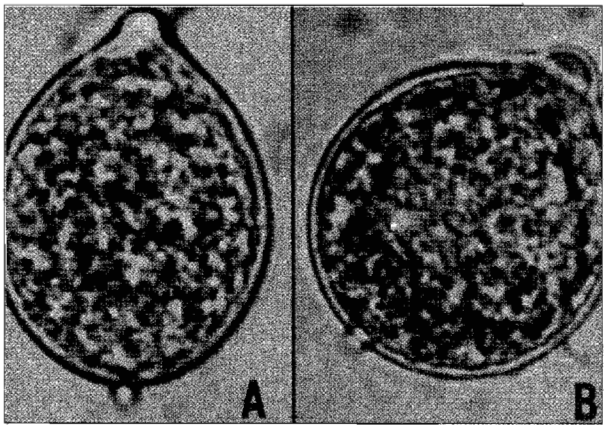

Fig. 2. Sporangia of *Phytophthora palmivora*

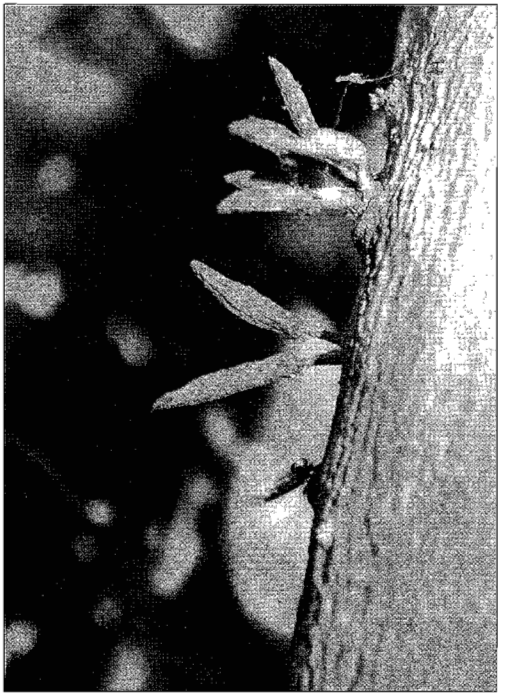

Fig. 3. Cherelle wilt

Various species of *Colletotrichum* infecting cocoa pods have been reported. They are *C. theobromae*, *C. luxificum* and *C. cradwickii* from West Indies, *C. incarnatum* from Cameroon and Sri Lanka (Briton-Jones, 1934), *C. fructitheobromae* from Brazil and *C. theobromicolum* from Congo (Thorold, 1975). *C. gloeosporioides* Penz has been reported as the causal organism of cherelle rot occurring in India. Though different species of *Colletotrichum* has been reported, no effort has been made for a comparative study of isolates of *Colletotrichum* spp. occurring in different cocoa growing countries so as to find out whether they are one and the same species. Detailed studies on *C. gloeosporioides* isolates collected from various localities in India revealed that there is great variability in cultural and morphological characters as well as pathogenecity among the isolates (ChandraMohanan and Kaveriappa, 1984a; ChandraMohanan, *et al.*, 1987). *C. gloeosporioides* isolates also exhibit marked variability in growth response to fungicides and antibiotics (ChandraMohanan, *et al.*, 1991). Genetically, *Glomerella cingulata,* the perfect stage of *C. gloeosporioides* is known to be a variable fungus (Wheeler, 1954).

Bavistin WP (carbendazim 0.05%) and Indofil M-45 (mancozeb) 0.2% are reported to be promising fungicides for the control of *Colletotrichum* infection on cocoa (ChandraMohanan and Kaveriappa, 1984b).

Charcoal pod rot

It is found throughout the year with severity during summer months. Pods of all ages are susceptible. The infection takes place through wounds generally caused by rodents, other pests and insects. The infection appears as dark brown to black spot anywhere on the pod surface and spread rapidly, as a result of which, the pods turn black and remain on the tree as mummified fruits. The infection spreads to the internal tissue and the affected beans turn black in colour. On the surface of the affected pods, spores appear as black powdery mass resembling soot.

The disease is caused by *Lasiodiplodia theobromae* (Pat.) Griffon and Maubl. (*Botryodiplodia theobromae* Pat.). The fungus produces abundant pycnidia on the pod surface. They are black, erumpent and globose. The mature conidia are elongate, pale brown, 2 celled and 20.4-32.4 x 8.7-15.7μ in dimension. Spraying one per cent Bordeaux mixture to the pods, especially during summer months is recommended for the management of this disease. In Kerala out of seven fungicides tried for controlling the disease, Rovral at 0.2% was most effective (Vijayan, and Wilson, 1980). Since *B. theobromae* causes infection through wounds, measures to control insects and rodent pests will also help to reduce the incidence (Nambiar and Nair, 1972).

Monilia pod rot

This disease also called Moniliophthora pod rot or watery pod rot or queredo disease occurs in North-West region of South America (Peru, Columbia, Ecuador, Venezuela), Southern part of Central America (Panama, Costa Rica).

The initial external symptom of the disease is the appearance of spots of mature pod colour on the surface of immature pods. These spots turn brown, enlarge rapidly and cover the entire pod surface. Under favourable climatic condition, the spots become covered with a layer of white mycelium bearing abundant spores. Some pods without any external symptom when opened show the presence of abundant liquid due to tissue degeneration. Beans in infected pods are partially or completely destroyed. The disease is caused by the fungus *Moniliophthora rorei* (Thorold, 1975).

TRUNK AND BRANCH DISEASES

Vascular streak dieback

In the early 1960's, vascular streak dieback (VSD) has been reported as a serious disease of cocoa in Papua New Guinea. About 25-50% yield loss is reported from certain regions of Papua New Guinea due to this disease. The disease has also been reported from many South East Asian countries like Malaysia, Sabah, Sarawak, Philippines, Southern Thailand, India, Hainan Island of China and several provinces of Indonesia.

In India, VSD has been recorded only from Kerala state (Abraham, 1981; ChandraMohanan and Kaveriappa, 1981). Byrne (1976) reported that the yield loss due to VSD was 25-50% in some parts of South East Africa and Papua New Guinea. The first visible symptom of VSD is the yellowing of a single leaf in the second or third flush from the tip of twig with islets of green patches scattered over the yellowish lamina. The infected leaves fall off within a few days and subsequently, leaves above and below it turn yellow and shed resulting in a distinctive situation where the youngest and the oldest leaves on a branch are still present while all the middle ones have fallen. The portion of the bark where leaves have fallen becomes rough due to the swelling of lenticels. Leaf scars resulting from the fall of diseased leaves show blackened vascular tissues when the dry surface is scraped off. As the leaves fall off, the axillary buds sprout, but such shoots so developed soon die after a further growth. Leaves in the latest flush of the diseased seedling or branch often show interveinal necrosis similar to calcium deficiency. Eventually, leaf fall occurs right to the growing tip, which then dies, followed by the rest of the seedling or branch. The fungus may spread internally to other branches or the trunk finally killing the whole tree. If the bark of the infected region is stripped off, the cambium turns rusty brown very rapidly. As a result of the infection, xylem vessels turn brownish and appear as streaking within the vascular tissues. Hence, the disease is known as vascular streak dieback.

The disease can easily be diagnosed in the field by stripping the bark or by splitting the affected stem longitudinally and observing the brownish streaks. If a thin layer of tissue is removed from the leaf scar left by the abscission of infected leaf, dark brown to black dots, which are the discolored vascular traces, can be seen. The discolored vascular traces are also visible when the infected leaves are removed.

VSD is caused by the fungus *Oncobasidium theobromae* Talbot and Keane (Basidiomycotina; Tulasnellales). The sporophore formed on leaf scars, when fertile has a dense, white and velvet appearance. Basidiospores arise from stout sterigmata. They are smooth, hyaline, thin walled, binucleate, multiguttaluate, broad, ellipsoid with one side flattened. They often germinate repetitively when they fall on to their own sporophore.

O. theobromae is a highly specialized, near-obligate pathogen of cocoa. It is the only known wind-borne, leaf penetrating basidiomycete vascular pathogen. Formation of basidia and discharge of basidiospore occur mainly at night after they have been wetted by rain or dew. Sporophores remain fertile for about 10 days on attached branches and for only two days on detached branches. Basidiospores have no dormancy and free water is required for spore germination and infection. When the spores land on the surface of unhardened young cocoa leaves covered with dew, they will germinate and penetrate the epidermal layers to reach the veins. It then moves on into the

xylem and finally reaches the stem xylem. There is an incubation period of three to five months from initial penetration until the first symptom expression.

Infection rate is closely related to the rainfall incidence a few months earlier. The bark surface must be wetted by rain to permit the formation of fruiting bodies and a layer of dew is insufficient. Frequency and duration of wet periods have a greater influence on disease incidence than has total rainfall. Spores are killed by ultraviolet light from the sun.

Since the pathogen is systemic and has a slow rate of natural spread, quarantine measures to restrict the transport of apparently healthy planting material containing the fungus is important in restricting the spread of the disease. It has been shown that when infection passes through approach grafts, the grafts fail. Establishment of cuttings and bud patches taken from infected branches also has not been observed. There is no evidence that the disease is transmitted through seed.

Genetic resistance offers good prospects of controlling VSD in the long run. In Papua New Guinea, the approach to control VSD involves propagation and planting of resistant clones or hybrid seedlings selected from the survivors of the major epidemic in 1960. Cultivars of Upper Amazon and Trinitario origin are, in general, less susceptible than Amelonado or its hybrids.

Cocoa nurseries should not be maintained near diseased trees because young plants are easily affected by the disease (Fig.4). Regular pruning of infected branches is recommended to maintain a very low level of infection. During pruning, the branches should be split open to detect the extend of streaking in the wood. The branches are then to be cut 30 cm below the last detectable streak. Eradicative pruning will be more effective if carried out at least one month prior to the wet season. Removal of prunings from the cocoa field is not necessary, because the fungus cannot survive or produce spores in the dead wood. Such regular pruning helps to remove infection from the plant by reducing internal colonization of the fungus and also prevents spread of the disease by reducing the number of fungal propagules (Dennis and Keane, 1992). Monthly spraying of triazole fungicides (hexaconazole, tebuconazole and triadimenol) has been found to offer good protection against VSD in Papua New Guinea (Holderness, 1990). But it has resulted in the stunting of the plant. Nursery losses from VSD can be controlled by the use of a plastic roof over nursery (Sidhu, 1987) and this has been found to be cheaper and easier than chemical control.

Stem canker

The term canker is generally used for a disease symptom in which there is sharply limited necrosis of the cortical tissue (Ainsworth and Bisby, 1961). But cocoa canker is not a sharply limited necrosis. Though black pod was first distinguished in Guyana and West Indies, canker was first recognized in Sri Lanka (Willis and Green, 1897). Rorer (1910) reported the occurrence of canker in a number of cocoa growing countries from 1897 to 1907, when *P. palmivora* was described and its authentic investigation began. Since then canker disease has been reported from various cocoa growing countries. In India, stem canker was first reported in 1978 in cocoa plants grown as mixed crop in arecanut garden in Karnataka state (ChandraMohanan, 1978).

Stem canker appears at different parts of the tree including jorquette and fan branches. This disease is difficult to detect in the early stages of development. The symptoms on the surface of bark can be detected only by close examination. The size and shape of external lesions as well as symptoms on the external bark vary. The external symptom appears as a greyish brown water

soaked lesion with a broad dark brown to black margin. A reddish brown liquid oozing out from such lesions dries up and forms a rusty deposit.

Based on the studies on the symptoms of the disease occurring in West-Coast of India different kinds of external symptoms, have been reported. The external symptoms appear from December after the rainy season. Dark brown, round to oval discolouration of the bark formed as a result of exudation of reddish brown liquid from the point of infection is the usual symptom. Sometimes the lesions are water soaked and greyish brown. In severe cases, canker lesions coalesce to form larger lesions. Cankers at the collar region are bigger and spread faster. The collar infection appears as dark brown irregular water soaked lesion with reddish brown liquid oozing out. The collar infection then spread to the taproot and main stem. Ultimately, the portions above the infected portion show wilting and finally leading to death. Cankers also develop without any external symptom mainly on seedlings of two or three years and on branches of trees. Such infected seedlings appear weak. Such cankers can be detected only by examining the internal tissue.

When the outer bark of canker infected portion of the stem is removed, the tissues beneath always show a characteristic reddish brown discolouration (Fig.5). Lesions in the internal tissues coalesce leading to extensive rotting. The infection spreads from the cortical tissues to the vascular tissues and reaches the wood. Wood infection appears as greyish brown to black discolouration with black streaks. When canker girdles the stem, dieback occurs. Leaves wilt, turn yellow and fall off. Pods also show wilting. Finally the whole tree dies. Spread of infection in the internal bark is faster than the spread in the surface of bark (Rao and ChandraMohanan, 1993 and 1995).

P. palmivora (A_2 mating type) has been reported as the only species causing stem canker of cocoa in India. The canker often develops from the pods infected by *P. palmivora*. Infection from the pods spreads to the peduncle and then to the cushion and bark causing canker. Hence, such infected pods should be removed and destroyed. Stem canker can be controlled in the initial stages by the excision of diseased bark followed by wound dressing with Bordeaux paste. High yielding cocoa trees and rare germplasm collections with advanced stages of canker disease can be rejuvenated by cutting the whole tree well below the canker lesion and allowing a fresh chupon to develop from the basal portion of the stem.

Chupon blight and twig dieback

Chupon blight and twig dieback are caused by *P. palmivora*. The infection usually initiates in the axils of leaves at the tip of twigs or chupons. It appears as water soaked lesions. Infection also starts anywhere on the leaf blade or petiole and extends backwards into the stem. In any case, the chief characteristic symptom is the appearance of water soaked lesion, which soon turns dark brown to black. The lesions coalesce to form bigger lesions. The lesion on stem spreads longitudinally in all directions and turns dark brown to black and is shrunken. When the lesions girdle the stem, the portion above the point of infection wilts showing twig dieback or chupon blight. Lesions on leaves generally start from the apex or margin of the leaves, more at the apical portion and usually enlarge and coalesce forming large blighted areas. This leads to much defoliation and subsequent dieback (ChandraMohanan *et al.*, 1979).

The disease occurs during south-west monsoon season and becomes severe under conditions of high humidity, improper pruning and heavy overhead shade. This phase of *Phytophthora* infection of cocoa is very important as it plays a major role in the secondary spread of the disease as well as

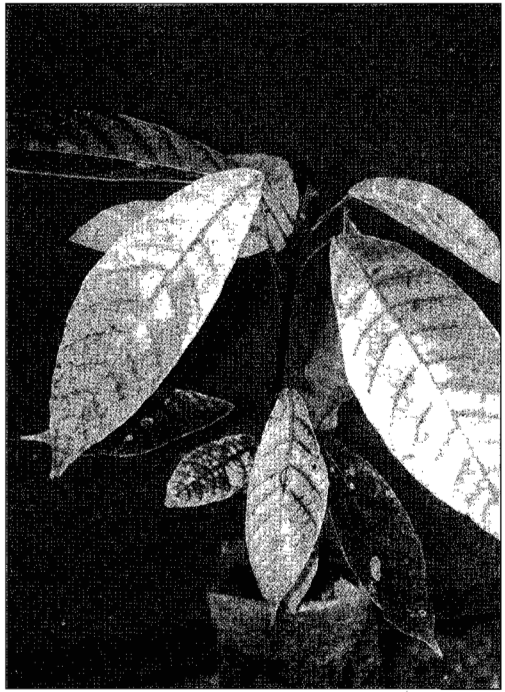

Fig. 4. VSD infected seedling

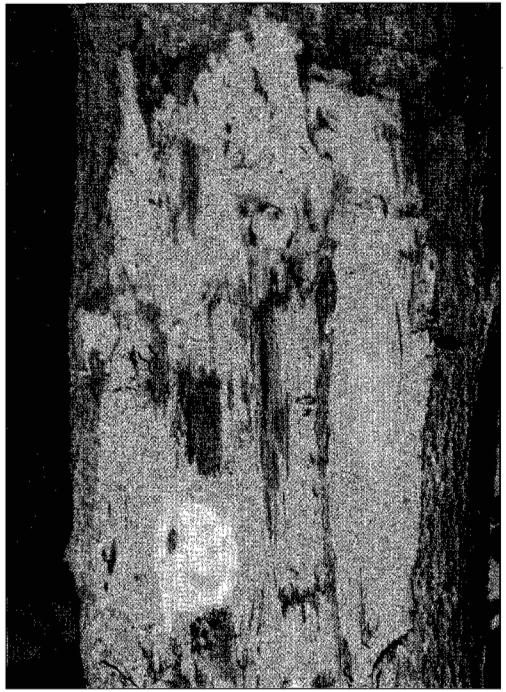

Fig. 5. Stem canker showing lesions

for the high incidence of black pod disease and canker. Removal and destruction of infected twigs and chupons are very important in the effective management of all *Phytophthora* diseases of cocoa. In cases of severe incidence, the plants may be sprayed with one per cent Bordeaux mixture or any other copper fungicide after removing the infected twigs and chupons (ChandraMohanan, 1994).

Pink disease

This disease becomes severe under humid conditions. Fan branches and small twigs are generally infected by the pathogen. It may cause serious damage when major branches are affected. The first indication of the disease is the death of the branch. The disease is characterized by the presence of pinkish powdery encrustations of the fruiting bodies of the fungus. It causes wilting of shoots, shedding of leaves and ultimately drying up of branches.

Pink disease is caused by *Corticium salmonicolor.* The spores are wind borne. Humidity and temperature are critical for disease development. During unfavourable hot periods, the pathogen survives within the pink encrustations or cankers of infected branches. The pathogen has got a wide host range.

The control measures include reducing overhead shade, proper pruning to improve aeration inside the garden, pruning of smaller infected branches and fungicidal treatment. The disease can be checked effectively by pruning the affected branches and swabbing the cut ends with Bordeaux paste. In areas where severe incidence is recorded, the disease incidence can be prevented to a greater extent by spraying one per cent Bordeaux mixture at regular intervals during the rainy season (ChandraMohanan, 1994).

Thread blight

Three types of thread blight viz., white thread blight, horse hair blight and koleroga were reported from different cocoa growing countries. White thread blight caused by *Marasmius scandens* and horse hair blight caused by *Marasmius equicrinis* are the two main types of thread blight in cocoa. White thread blight kills the leaves by spreading a network of white mycelial threads over leaves, petioles and branches. The dead leaves remain suspended by strands of mycelia. Extensive death of young branches and suspended leaves in rows are the common field symptoms. Horse hair blight forms a tangle of thin black threads through the canopy of leaves. Due to this disease, the dehisced leaves along with healthy leaves remain together and form a dense mass preventing the development of new flush. The thread blight spreads from plant to plant as well as to different branches of the same plant through affected plant parts, especially leaves carried by wind (ChandraMohanan and Kaveriappa, 1983b). Thread blight has been found to be more severe under conditions of heavy rainfall and humidity (Briton-Jones, 1934; ChandraMohanan and Kaveriappa, 1981). This disease can be effectively managed by the removal of dead material and by pruning of the affected parts. Shade reduction and structural pruning of the branches may help to reduce the disease incidence to a greater extent.

Leaf blight and shot hole

Foliar infection of cocoa caused by *Colletotrichum* spp. has been recorded in several cocoa growing countries. The disease was reported to have attained epiphytotic proportion in Ghana during 1975 (Dakwa and Danquah, 1978). Foliar infection of cocoa caused by *Colletotrichum theobromicolum* was reported as one of the serious problems of cocoa in Columbia (Sanchez,

1957). Cocoa diseases caused by *C. gloeosporioides* occur in almost all cocoa growing areas in India, but the intensity of the disease varies from garden to garden or locality to locality. Foliar infection caused by *C. gloeosporioides* has been reported as a serious problem in some of the gardens and nurseries (ChandraMohanan and Kaveriappa, 1983c). Leaf blight and shot hole are the major field symptoms caused by *C. gloeosporioides* in India (ChandraMohanan and Kaveriappa, 1983a).

The infection initiates anywhere on the leaf lamina, but more usually from the tip or margins. The symptoms appear as round to slightly irregular chlorotic spots of 2-5 mm diameter, which later turn brown with a clear yellow halo around each spot. Such spots increase in size considerably or coalesce to form large blighted areas with an even margin. Defoliation occurs when such lesions cover a major portion of the leaf. Occasionally acervuli appear as black erumpent, globular structures on dead blighted areas of the leaves. Microscopic examination of the lesions reveals the presence of abundant conidia. Leaf blight is more common on older leaves. Dakwa and Danquah (1978) also found the leaf blight initiating on lower leaves and gradually spreading to upper leaves.

The infection occurs anywhere on the leaf lamina and many spots are found on each leaf. They appear as minute, pinpoint sized, round, sunken, light brown spot with distinct yellow halo. When such a spot attains 4-6 mm diameter, the center of the necrotic spot shrivels and drops off forming a shot hole. The spots then enlarge and coalesce with adjacent spots to form bigger spots occupying a considerable area of the leaf lamina. In advanced stages, the leaves shrivel with a substantial loss in photosynthetic area. In very severe cases, defoliation occurs. Acervuli with setae can be observed on plants of all age groups including seedlings in the nurseries. The infection is usually confined to tender leaves and rarely occurs on older leaves. Shot hole symptoms occur on plants grown under more open conditions.

Defoliation and dieback of cocoa caused by *Calonectria rigidiuscula* has been found to occur in some of the cocoa gardens in India (ChandraMohanan, 1981).

Cushion galls

Cushion gall is a serious malady in several cocoa growing countries. Mainly five kinds of cocoa cushion galls viz., green point gall, flowery gall, knob gall, disc gall and fan gall are recognized (Thorold, 1975). Of these, only fan gall and knob gall are reported from India (ChandraMohanan *et al.*, 1984).

Fan gall

The flower cushion of affected trees produces profusely branched small stem like outgrowths bearing numerous flowers. From a single cushion, 1-10 (usually 5-6) such outgrowths with short internodes are produced. The outgrowths of branches with flowers appear closely packed like a loose gall on a cushion. The length of each such outgrowth is usually 7-9 cm, maximum being 25-30 cm. Occasionally small leaves are produced at the tip of the outgrowths resembling that of a fan branch. Such abnormal flowering is observed on 8% in initial, 2% in the medium and 3% in the advanced stage of severity. Pod setting is not observed on abnormal cushions. However, pod setting is rarely observed on normal cushions of the affected trees. Occurrence of fan galls was reported from Papua New Guinea, and New Britain (Shaw and Burnett, 1969).

Knob gall

Knob galls are observed on 3% of the trees in the affected garden. Affected trees are found to bear 4-12 galls (usually 4-6) on the main trunk below the jorquette. The galls occur on the cushions as hard, woody swellings with a smooth surface and do not bear flowers. As very few such galls are found on each tree, yield is not markedly affected. Similar type of knob galls was reported from New Britain and New Ireland (Shaw and Burnett, 1969).

These two types of galls could not be transmitted to normal flower cushions on gall-free trees. Neither fungi nor bacteria could be isolated from the abnormal galls or cushions. Hence, the etiology of this abnormality remains unknown, and attempts to transmit the disorder were not successful.

Wilt disease

Wilt disease of cocoa also known as Ceratostomella disease or the *Xyleborus- Ceratocystis* complex occurs in Colombia, Costa Rica, Ecuador, Venezuela, Trinidad, Guatemala, Hawaii, Dominican Republic and the Philippines (Entwistle, 1972). Iton (1959, 1960 and 1961) has conducted elaborate studies on the disease and reported, in detail, the association between this disease and *Xyleborus* beetle. Several species of *Xyleborus* have been reported from cocoa plants with Ceratostomella disease. Wilt disease on cocoa have been noticed in Mysore district in India, which has severely affected the gardens. Constant association of *Graphium basitruncatum* has been seen (CPCRI, 2001). Beetles that are associated with the disease have been identified as *Xylesandrus* sp. (CPCRI, 2002).

The major external symptoms of the disease are wilting of the whole tree or part of the tree followed by rapid death of the tree or affected parts. In the initial stages of the disease, the mature leaves change from the normal horizontal position to a pendulous one, similar to that of new flush. Gradually these green leaves develop irregular yellowish or brownish discolouration. The wilted leaves then dry and remain attached to the dead branch for several weeks. The disease is always associated with borer holes on the stem made by *Xyleborus* beetles. The holes are about 1 mm in diameter, with a small amount of wood dust around it. The beetle penetrates the bark and wood more or less at right angles to the axis of the stem. The internal wood tissues surrounding the wound will be discoloured to brownish red or purplish.

Ceratocystis fimbriata Ell. and Hals. (*Ceratostomella fimbriata* (Ell. & Hals.) Elliot) is the causal organism of the disease. The fungus produces large number of spores within the tree, especially in the galleries made by *Xyleborus* beetle. The discoloured wood, the walls of the borer galleries and the frass extruded by the borer contain numerous intracellular chlamydospores of *C. fimbriata.* Chlamydospores are more in artificially inoculated plants. The fungus produces in culture three different types of asexual spores viz., thin-walled endoconidium, thick-walled endoconidium and very thick walled chlamydospores. The sexual spore is the ascospore. The spores are exuded from the tree with the wood dust and are spread by wind and by *Xyleborus* beetles or other insects. Generally, plants under stress are infected. The fungus also infects cocoa trees through wounds made by agricultural implements.

Neither chemical control of the beetle or fungus nor destruction of the infected plants has proved a useful method of control of the disease. The most practical method of preventing the

disease incidence is to minimize wounding during harvesting and pruning. However, sanitation and chemical protection methods are being tried in some of the countries. Resistance to *Ceratostomella* would probably be the best method for effective management of this wilt disease.

Zinc deficiency

Severe incidence of foliar abnormality leading to twig dieback has been reported from several gardens in Kerala, Karnataka, and Tamil Nadu. In most of the cases, chlorosis of leaves is the initial symptom of zinc deficiency. Chlorosis appears in patches and in advanced conditions, the green portion is found only along the sides of the veins, giving a vein banding appearance to the leaves. Thus, the network of vein in each leaf is very distinct. Affected leaves show mottling and crinkling with wavy margin and are thus often malformed. Most of the younger leaves are narrow, much reduced in size and sickle shaped, showing the characteristic little leaf symptom. The sickle leaf symptom is common too; but it does not appear on all plants. Affected plants rarely put forth new flushes and, when they did, the leaves show acute symptoms of zinc deficiency.

Twig symptoms include rosette and dieback. Shortening of internodes causes a rosette type of growth. In severe cases, premature defoliation followed by dieback of the branches is observed. Various combinations of these symptoms are also prevalent.

In certain instances, severe defoliation and dieback cause gradual death of two- to three- year-old cocoa plants. In general, most characteristic symptoms include chlorosis, crinkling of leaves with wavy margin, little leaf, sickle leaf, premature defoliation and die back of twigs (Love, 1961; Wood, 1975).

Jurinak and Thorne (1955) have reported that zinc solubility in soil is minimum within the pH range of 6-8. Schroo (1959) has reported that spraying with 2.5 g zinc sulphate every ten days corrected zinc deficiency within seven months in cocoa plantations in New Guinea. High pH and poor aeration of the soil were attributed as the main causes of the zinc deficiency. Application of zinc sulphate at the rate of 2 kg/ha either to the soil or as a foliar spray corrected zinc deficiency in 2 1/2 year old potted Amazon cocoa seedlings (Ahenkorah, 1969). The results of the field trials conducted in India revealed that foliar spray of 3 g zinc sulphate and 1.5 g lime per litre of water could correct the deficiency to a greater extent (ChandraMohanan *et al.*, 1981).

Cocoa swollen shoot disease

Cocoa swollen shoot disease is still a major limiting factor in cocoa production in Ghana and Nigeria and is one of the most economically important plant disease in the world (Thresh, 1958). The disease is wide spread in Ghana, Ivory cost, Nigeria, Togo and Sierra Leone, SriLanka, Colombia, Trinidad, Venezuela, Indonesia and Sabah.

This disease is caused by a virus known as cocoa swollen shoot virus (CSSV) belonging to badnavirus group. There are 90 strains within CSSV, of these, new jeuben strain (Theobroma virus 1A) which is prevalent in Ghana causes severe disease. CSSV strain 1A produces typical swelling on fan branches, chupons and roots. Young flesh leaves exhibit symptoms of red vein banding followed by chlorosis along side the veins. At a later stage of infection, a fern leaf pattern is produced. Pods become mottled, smoothed than normal and rounded containing only half the normal weight of the beans. Some strains do not produce swelling and most do not produce any pod symptoms. All of them produce leaf symptoms, which vary enabling the distinction of strains.

The disease is mainly spread through mealy bugs. It is also transmitted by grafting but not through pollen or seed. At least 14 mealy bugs species capable of transmitting the disease have been reported (Brunt, 1970). Of these, *Ferrisia virgata*, *Planococcoides njalensis*, *Planococcus kenyae*, *Planococcus citri* are generally most abundant in the field with *P. njalensis* often the most important in transmitting CSSV. There is no effective control measure for managing CSSV infection but its spread can be restricted by destruction of the virus sources. Attempts to control mealy bug vectors by the use of insecticides and biological control using exotic parasites and predators have not met any success.

Legg (1981) has shown that T 85/799 crossed with SCA 6, T 65/238 and PA 7, T 63/967 crossed with T 17/524, T 65/238, IMC 60, T 73/612 and GA 11, T 79/467 crossed with T 17/524, IMC 76, T 65/202 and T 63/ 971 crossed with T 65/238, IMC 60 and IMC 76 were promising in exhibiting tolerance to CSSV. Gamma rays induced mutants from Amelonado, Trinitario and upper Amazon collections were found to be tolerant to CSSV and these were confirmed by ELISA and inoculation with viruliferous *Planococcoides njalensis* nymphs (Ado-Ampomah *et al.,* 1996). Three other viruses, cocoa mottle leaf virus, cocoa necrosis virus and cocoa yellow mosaic virus have also been reported from Nigeria and Ghana.

Verticillium wilt

Sudden death disease or Verticillium wilt has been prevalent in Uganda from 1925. In Brazil, occurrence of the disease was noticed since 1938. The disease is characterized by sudden wilting and death of leaves. The first symptom is the drooping of the leaves without any flaccidity. Subsequently the leaves dry and roll inwards and later fall off. Gradually, the infected small branches break off. In the early stages of disease development, there is also a marked reduction in the root system and wilting of young pods. Necrosis of tap and main lateral roots occurs only after defoliation of the shoot. Discolouration of xylem vessels of the petiole, pedicel, stem and roots are also observed. Severe incidence of the disease, especially following stress condition of drought or water logging can cause death of the tree within one week (Thorold, 1975).

Verticillium dahliae Kleb is the fungus causing the sudden wilting of cocoa plants. The fungus has a wide host range. The spores of the pathogen can remain in the soil for a number of years. From soil, the plant gets infected through roots. Then the pathogen spreads to the xylem vessels to cause wilting. The entry of this pathogen to the plant can be prevented by avoiding root damage during cultural operations.

Witches' broom

Witches' broom has been noticed as a serious problem in several cocoa growing countries like Surinam, Tropical South America namely Bolivia, Columbia, Ecuador, Guyana, Peru, Venezuela and the West- Indies island of Grenada, Tobago and Trinidad (Rudgard, *et al.,* 1993).

The diagnostic symptom of the disease is the production of abnormal shoots or brooms, which are thicker than the normal healthy shoots. The internodes of such brooms are shortened. These brooms produce short lateral shoots with undeveloped leaves. Fan brooms and chupon brooms can be seen on the affected plants. The brooms, which are green initially, turn to dark brown as a result of death of the tissue. Cushion infection leads to hypertrophic growth of flowers and shoots. Small pods on such cushions will die. Cherelles and young pods exhibit malformation. In larger pods, the beans become liquefied or adhere to the pod husk (Rudgard, 1989).

Crinipellis perniciosa (Stahl) Singer, a member of basidiomycetes, is the causal agent of witches' broom. The brooms which are pruned and left on the ground act as source of inoculum (Evans, 1981). Basidiospores are thin walled and short lived. The spores are light and carried by wind. The maximum life expectancy of basidiospores does not exceed 48 hours and the germination of spores on suitable host tissue is rapid being almost complete within four hours after the spores are lodged under high humidity. The infection on expands resulting in a broom. The diseased cushion or infected pod and each broom appears from a separate infection. The fungus does not cause a systemic infection on the tree. It is localized around the point of infection.

Effective control measures have not been possible because of the complex interaction between pathogen, host growth and physiology and agronomic practices (Evans, 1981). However, potential methods for managing disease formulated under the International Witches Broom Project (IWBP) consist of three major strategies viz., phytosanitation, spraying with chemicals and use of host resistance (Rudgard *et al.*, 1993).

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6. PESTS

Mariamma Daniel

INTRODUCTION

The cocoa tree, *Theobroma cacao* Linn. is a small under storey tree native to the South American tropical rainforest of Amazon. This is a shade-loving tree. Cocoa was introduced to all the presently cultivated areas of Asia and West Africa. Since its introduction to countries in Africa and Asia, this plant is liked or disliked by many arthropods, vertebrates etc. Cocoa is cultivated in these areas for periods ranging from few decades to more than a century and some insects and vertebrates of the local fauna have acclimatized to these plants over the years. Some of them became very serious insect pests like the mirid bugs of West Africa and the Southeast Asian pod borer. It is known that following the introduction of a plant to a new area, usually the local insects adapting to it is related to the size of the area planted. This limit is approached asymptotically, the process being comparatively faster. Thereafter, adaptation of additional insect species occurs rather rarely unless the area of planting is noticeably increased (Strong, 1974).

The conditions in which cocoa can be grown in some tropical countries and the relative abundance and distribution of insect pests are suggested or reviewed now and then by different workers (Entwistle, 1972; Leston, 1970; Room and Smith, 1975; Daniel, 1994). The management practices for pests are given based on either years of experience in some localities or on principles of modern pest management that can be followed in cocoa farming, which include Ivory Coast and Malaysia (Petithugenin, 1998), Malaysia (Tay *et al.*, 1992; Wood and Chung, 1992), Sabah (Lim and Ooi, 1992), Papua New Guinea (Moxon, 1992) and Indonesia (Wardojo, 1992). Though many insects and non-insects are known to feed on cocoa, only a small proportion is of economic importance. Among these, many have geographical isolation and thus the number of major pest species in any one area tends to be low in number. For example, though cocoa in West Africa suffers more from pests than elsewhere this situation is caused very largely by two mirids and indirectly by a number of mealybug species that spread the cocoa viruses (Entwistle, 1985). One insect that is of considerable importance is the cocoa pod borer of South East Asia, the gracillariid, *Conopomorpha cramerella* (Snellen)(Ooi *et al.*, 1987).

Yield loss due to pests and diseases in any plantation level crop is a very difficult matter to settle since many biotic and abiotic factors influence this and the influence changes periodically in perennial crops. A cyclical high incidence in the case of some insects like bagworms, some homopterans etc is also a feature in the tropical settings (Bigger *et al.*, 1976; author's observations in cocoa- areca palm intercropping). In a recent paper, Gotsch (1997) has given an expert forecast on cocoa crop protection for the next two decades with the help of the Delphi survey. The discussion concluded that combining various traditional techniques with modern tools of molecular biology might reduce the yield loss due to pests and diseases.

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As in any pest – plant relationships, the economically important insects and non-insects associated with cocoa could be categorized as primary pests, minor pests, some of which acquiring pest status due to different reasons. Among the insect pests, few could cause severe damage during the initial years of the plant and few sucking insects could cause direct loss of the crop by feeding on young and maturing pods. Mirids as a group are the most important and widely present insect pests of cocoa in Africa, Asia etc. The feeding results in severe damage, especially when they attack stem tissue. The feeding lesions can invite the entry of pathogenic fungi to the trees. Leaf cutting ants are one of the main pest groups in New World cocoa. The cocoa pod borer, *C.cramerella* is the major pest in the Philippines, Sabah, and parts of Indonesia other than Malaysia, which was found difficult to manage. The wood boring weevil, *Pantorhytes plutus* is devastating in Papua New Guinea and adjacent islands. The insect also is associated with the spread of the fungus *Phytophthora* causing stem canker. Godyn (1974) has pointed out the pest/disease association as the main reason for the reduction of economic age of cocoa trees in New Britain. No such serious insect damage is reported from India so far. The slow increase in cultivated area and isolated smallholdings may be the reason for this condition of cocoa in this area. Another reason could be the less use of pesticides in most of these areas in general, thereby not affecting the balance of nature in cocoa insects.

Some insects cause serious damage to young cocoa trees in the initial years of its establishment in the filed. The spiny bollworm of cocoa in West Africa and adult chafer beetles in Malaysia are examples of this situation. Cocoa when planted in forest cleared areas or near forests suffer primarily from the attack of some wood boring beetles like the shot hole borer *Xylosandrus compactus* which may have many forest trees as its host plants.

Insects (mealy bugs) are important as vectors of some viruses especially in West African regions. Managing the infestation of mealy bugs is still a problem in most of the tropical belt. Some insects are indirectly associated with the disease spread. Though the direct involvement of scolytid beetles in the transmission is unclear, one scolytid, *Xyleborus ferrugineus*, certainly has an epidemiological role because the huge numbers of *Ceratocystis* spores pushed out of the galleries of beetles borings in diseased wood contribute to disease spread. Insect feeding on pods can cause the entry of wound parasitic fungi.

Minor insects assuming the status of secondary pest was not of common occurrence in cocoa plantations, except during the time of using chlorinated hydrocarbons for the control of ants, which spread the mealy bugs. When dieldrin was used in Ghana to manage mealy bugs by destroying their attendant ants, within a short period, several insect species of normal minor importance rose to high numbers, especially woodborers. In Sabah and Java also the use of pesticides in cocoa, have increased the numbers of *Zeuzera* sp. and leaf-eating bagworms. Though documentation on the exact way these outbreaks occurred are not available, an imbalance by the destruction of natural enemies would have caused this situation. The nature of plant characters also lead to the incidence of some insects in abundance as seen in the case of *Bathycoelia thalassina*, a pod feeder of cocoa in West Africa. When Amazon types and hybrid trees were planted in large areas, the extended cropping pattern provided year round food supply for this bug.

In this chapter the pests of cocoa are dealt with giving more emphasize to the important pests of cocoa from the major cocoa growing countries. The insects that damage cocoa in its different stages of growth are grouped here based on the nature of feeding by them. The most important

information on the association of ants and their role in insect management and the natural enemies documented on cocoa insets are mentioned wherever applicable. The non- insects are detailed as a separate section along with the management aspects.

INSECTS

Sucking Insects

This group damages the flower cushions, flower buds, cherelles, developing fruits, leaves, tender shoots and tissues of stem of cocoa trees.

Mealy bugs (Pseudococcidae)

This cosmopolitan group of insects with exceptional powers of dispersal is often seen colonizing cocoa from the initial years of introduction of cocoa to different countries. Though few species of mealy bugs colonize cocoa trees, two species of *Planococcus* and one species of *Planococcoides* are the most important and most abundant of cocoa insects. They are the cocoa mealy bug, *P.lilacinus*, the citrus mealy bug, *P.citrii* and the West African mealy bug, *Planococcoides njalensis*.

The cocoa mealy bug, *Planococcus lilacinus* (Ckll.) occurs in most of the cocoa growing tracts of South East Asia like India, Sri Lanka and Papua New Guinea. In India it is reported as a serious pest causing damage to cocoa and is present in all cocoa tracts of the country. It occurs consistently on the plant, and is present throughout the year. This colonizes the tender parts of the plant such as the growing tips of the shoots, the terminal buds, the flower cushions, the young cherelles and mature pods. Mealy bug feeding on tender apical shoots results in reduced growth and they become deformed into slender hair like processes giving the appearance of a brush. Colonization of flower cushions results in cushion abortion and continuous attack results in withering and drying up of flower cushions. The feeding on the bark of pods results in irregular cracks and pitting, usually beans are not affected by mealy bug colonization of mature pods. The feeding of this mealy bug induces cherelle wilt. The population peak is in April- May (Nair, 1981).

Citrus mealy bug, *P.citri* (Risso), a cosmopolitan species of the tropics occurs in all cocoa growing tracts. The first report of a cocoa pest in India by Ayyar (1940) is pertaining to this from Nilgris and later by Abraham and Padmanabhan (1967). Abraham and Remamony (1979) reported this from Kerala. This also infests shoot tips, flower stalks, foliage, stem tissues, cherelles and pods. The cherelles are severely attacked and they dry up. Infested mature pods develop irregular sunken necrotic lesions. Population peak occur during July-October as reported by Abraham and Remamony (1979) (Fig.1).

The West African mealy bug, *Planococcoides njalensis* (Laing) occurs throughout West Africa and is the most important mealy bug on cocoa, being the vector of cocoa swollen shoot caused by badnavirus, resulting in heavy crop loss since its discovery in 1934. All past attempts to control this pseudococcid vector with insecticides and natural enemies failed and also the practice of removing infected trees showing visible symptoms achieved limited success (Padi, 1997).

Ants are always found attending to the colonies of mealy bugs. Some construct tents over mealy bug colonies while others make covered nests over colonies with mud particles. Though about seven species of ants are found associated with mealy bug colonies of cocoa in India, only the Asian weaver ant, *Oecophylla smaragdina* (Fab.) and *Technomyrmex* sp are seen attending to

the mealy bugs in southern Karnataka. Colonies of *Technomyrmex* are more prevalent on mealy bug colonies of flower cushions. In Sri Lanka also *O.smaragdina* attends to *P.lilacinus* colonies. The black ant, *Dolichoderus bituberculatus* that is famous in being incompatible with the mirid, *Helopeltis* in Java, also attends to this mealy bug. In West Africa, crematogasterine ants attend to the colonies of *P.njalensis*. It is shown by field studies that the incidence of West African mealy bug is strongly influenced by the nature of ant fauna and the presence of planted shade tree like, *Gliricidia sepium* that provide nesting sites to the associated species of *Crematogaster* (Bigger, 1981). The exact role of attending ants is to be further studied since ants act as predators or protectors of insects.

Indigenous natural enemies, though present in all situations, are not in sufficient numbers to lower the population of mealy bugs. Introduced natural enemies like coccinellid beetles also did not show success. Though many species of parasites and ladybird beetles were released in Ghana between 1951 and 1955, none of these has had any appreciable impact. But many native natural enemies are associated with these mealy bugs and these are documented and studied in some places. In India, the predators observed are the coccinellid beetle, *Scymnus* sp, the caterpillars of the lycaenid moth, *Spalgis epeus* Westwood. Trials with the introduced predatory beetle *Cryptolaemus montrousieri* did not give any positive result (CPCRI, 1986). Ackonor and Mordjifa (1999) have enumerated the natural enemies of *P.njalensis* in Ghana. This included two species of coccinellid predators, *Hyperaspis egregia* Mader and *Scymnus* sp, a cecidomyiid, *Coccodiplosis coffeae* Barnes and six hymenopteran parasitoids. The cecidomyiid was the most common natural enemy, followed by the parasitoid, *Aenasius abengouroui* (Risbec). The author has recently come across a species of cecidomyiid predator on both species of *Planococcus* colonizing cocoa in southern Karnataka. This is also abundant in the field

The control of mealy bugs by contact insecticides is usually difficult because of habits, water repellent nature of their body covering and the protection provided by the ant-constructed nests. The best way to get effective control of mealy bugs is to have spot sprays on the initial foci of infestation so that the population is not allowed to attain very high proportions. Though the control of ants is very difficult, some cultural practices can reduce the colony build up ants. Proper and timely pruning may reduce the colony build up of *O.smaragdina* so that the spread of mealy bug is not accomplished as in unpruned gardens.

Mirids (Miridae)

Mirids, easily recognized as 'capsids' in African cocoa work for more than 75 years, are one of the most important of cocoa insects in many of the cocoa cultivating areas of the world. The most important mirids of cocoa are *Sahlbergella singularis* Hagl.and *Distantiella theobroma* (Dist.), which occur in West and Central Africa. Of these, *S.singularis* is the major pest of cocoa in Nigeria (Nwana and Youdeowei, 1978). In South and Central America, mirids of the genus *Monalonion* are attacking cocoa for over 100 years. The genus *Helopeltis*, first recorded as a pest in Sri Lanka more than a hundred years is also found in Indonesia, Malaysia, and India. *H.theivora* Westwood and *H.antonii* Sign. are reported from Sri Lanka, Malaysia, Indonesia, India, and Taiwan etc. *H.clavifer*, *Pseudodoniella laensis* Miller, *P.typica* and *P.pacifica* occur in Indonesia, Malaysia and Papua New Guinea (Dennis *et al.*, 1995). Adaptation of a mirid species to cocoa is a continuous process and it may not be complete throughout the range of a species. This is seen from the cases from Papua New Guinea mainland and islands. *P. duni* was not seen here until 1949; the species

that is seen in Papua New Guinea mainland is *P.laensis* while *P.pacifica* and *P.typica* are pests in the islands like New Britain and New Ireland. The presence of *H.clavifer* in 1954 nicely exemplifies the adaptation of mirids, which is an ongoing continuous process. Thus *H.clavifer* is a pest on the mainland, but in the islands it does not attack cocoa. *D. theobroma* is present in Sierra Leone but not on cocoa. As Entwistle (1985) points out we have not seen the end of the process of adaptation of unfamiliar mirid species to cocoa.

Life histories of all cocoa mirids are similar. The eggs are laid in the epidermal layer of cherelles and pods, pod stalks, chupons and fan branches and hatch within 10–17 days. There are five nymphal instars, occupying about 18-30 days. The adults are medium sized, very slender and with long legs and antennae in *Monalonion* and *Helopeltis*, but more thickset in other genera (Entwistle and Youdeowei, 1964). The older cherelles and young pods are preferred sites for oviposition as also for feeding by *H.theivora* (Muhamad and Way, 1995).

Mirid feeding results in small water soaked areas that rapidly turn black. These are known as mirid lesions. The lesions appear as circular ones on pods and cherelles (Fig.2) and on stems as oval and elongated. The effects on stem feeding by the genera *Distantiella, Sahlbergella, Psedodoniella* are more severe and long lasting. Soft and hardened tissues of stems are attacked. Feeding on unhardened tissues of stem result in wilting and terminal death (Fig.3). The lesions also serve as entry points of injurious fungi. In West Africa, the wound parasite *Calonectria rigidiuscula* cause extensive die back of branches. In India, die back symptoms are seen only in gardens without overhead shade.

Mirid feeding on pods varies regionally. In West Africa it is of little importance though cherelles may wilt and heavy feeding may result in breakdown of husk and rotting of the bean mass in larger pods. Ojo (1985) in his study in Nigeria on the qualitative damage caused to cocoa pods by *S.singularis* had shown that pod weight and husk weight were significantly reduced when over 25 per cent of the pod surface was covered by lesions caused by mired feeding. There were no significant differences between 0 to 100 per cent surface damage levels in respect of bean weight, pod length and width, total number of beans/pod and number of deformed beans per pod. Though pod feeding causes much of loss, an indirect effect of feeding is the progressive deterioration of the canopy of cocoa stands. Mirid feeding is influenced by the cultural conditions under which cocoa is grown. A capsid blast is seen where there is no overhead shade. When the overhead shade is broken, damage is seen in such gaps. Here groups of cocoa trees may be damaged while trees around may be much less affected. Such pockets of intensive damage are known as 'capsid pockets' in West Africa. A five year study on the chemical control of cocoa mirids of West Africa in relation to their seasonal movement indicated that infestation concentrated in areas with poor canopies during April- July and the spread from these pockets to areas with good canopies, reaching a peak during October- November. Owusu-Manu (1990) reported 93.6 per cent and 3.2 per cent damage to chupons, and fans and pods respectively.

Mirid management is a very tricky matter since mirid population is influenced by many factors like temperature, humidity, water stress, condition of the trees etc. All over the cocoa world, mirid population decline numerically in periods of low humidity but increase to their highest levels with the abatement of the main rains; very heavy rain itself appears to reduce their numbers, though not as greatly as does low humidity (Gibbs *et al.*, 1968; Lavabre *et al.*, 1963). Though in West Africa the main peak of mirid population usually coincide with the main crop it has not been conclusively

Fig.1. Colony of *Planococcus citri* with the attending ant, *Oecophylla smaragdina* on cocoa pod

Fig.3. *Helopeltis* damaged shoot

Fig.2. Feeding lesions of *Helopeltis* on cocoa cherelles

demonstrated that mirids depend on pods for their increase. The peak period varies from year to year. The population *H.theivora* seemed to be dictated by rainfall and numbers of available cocoa pods. There was significant yield decrease with increased mirid population (Muhamad and Fee, 1993).

The chemical control of mirids mostly started with the use of nicotine in West Africa and rotenone in Java. After the discovery of chlorinated hydrocarbons, the use of DDT and HCH initially revolutionized mirid control in West Africa and Java. The first instance of mirid insecticide resistance was apparently of *H.theobroma* to DDT in Java in 1953 but this was not well documented. In Ghana, *D.theobroma* was found to be resistant to gamma-HCH in 1961 and in 1964 in Ivory Coast. Resistance was noticed on *S.singularis* in Nigeria in 1962.The resistance to organochlorines became widespread in major parts of Ghana (Owusu-Manu, 1977). Later carbamates were used, and the carbamate, propoxur was found effective as 225g a.i. per ha; the organophosphates diazinon and quinalphos were also of potential interest when applied in this way.

The insecticidal management of mirids in West Africa and some Asian countries is an ongoing process. Comparison of three methods of treatment with propoxur (Unden at 210 a.i./ha) showed spot treatment as the best control against the mirids, *D.theobroma* and *S.singularis* (Owasu-Manu, 1990). In Nigeria after both laboratory and field trials with diazinon 600EC at three concentrations of 0.125, 0.25 and 0.5% to *S.singularis* it was concluded that the concentrations were all at par in the efficacy when compared to the standard insecticide lindane and dioxacarb. The insecticides were sprayed at monthly intervals from once to five times in the main crop season. The residue analysis of this insecticide in sun dried beans showed that the residues were consistently lower than 0.02mg/kg in 95 per cent of the samples (Idowu, 1997).

Resistance in *H.theivora* to lindane, cypermethrin and deltamethrin was shown by laboratory bioassays in Malaysia (Muhamad and Omar, 1995). Chemical control of *Helopeltis* in Sumatra is evolved as a regular inspection of sample of trees. Twenty per cent trees are sampled for assessing the percentage of trees showing damage. When less than 10 per cent of the trees show damage, spot spraying is advocated, the damaged tree and surrounding trees are treated with gamma-HCH. When more than 10 per cent trees are damaged, blanket spraying of the whole area is recommended. *Helopeltis* attack is strongly associated with gaps in the cocoa canopy and hence the management system includes the repair of such areas by planting seedling cocoa. It also recommends the development of a strong canopy and minimal interference by pruning. The inspection for *Helopeltis* damage has to be carried out every two weeks and the *Helopeltis* census and management system has been effective in controlling and raising yields. (Youdeowei and Toxopeus, 1983).

The use of ants in the management of mirids is gaining importance recently (Way and Khoo, 1991) though practical demonstration of this in tropical situation might be difficult. The black ant, *Dolichoderus bituberculatus* was once used to deter *Helopeltis* in Java and Indonesia (Entwistle, 1985; Graham, 1991). *D.thoracicus* Smitt was used in many trials as a natural biocontrol agent against *H.theivora* in Malaysia. Artificial nest using polyethylene bag filled with cocoa leaves gave the best result per unit investment (Heirbaut and Damme, 1992). Khoo and Ho (1992) had shown that an abundance of *D. thoracicus* clearly had a negative effect on numbers of *H.theivora* with 380 and 2222 per cent more nymphs and adults respectively being recorded in the ant-scarce than in ant abundant plots over the two year period of study. The introduced black ant *D.thoracicus* was used for the natural control of *H.theivora* in Malaysia by attaching leaf pockets containing the

mutualistic pseudococcid, *Cataenococcus hispidus* and the ant. The second method was to isolate the cocoa trees by glue-banding the bottom 30cm of the trunk and pruning the canopy to prevent it from touching other canopies in addition to attaching leaf pockets (Tuck, 1994). In Ghana and Nigeria a lot of attention has been paid to the relationships of the dominant ants and the two most important mirid species. The numbers of *Sahlbergella singularis* are not depressed by ants and may even be slightly increased, perhaps due to ants being inimical to some enemies of mirids. On the other hand, numbers of *D. theobromae* are depressed by the aggressive ant *Oecophylla longinoda*. The extent of protection, which it affords, is determined by its prevalence; it seldom infests more than 20 per cent of trees and usually less. Majer (1975) has emphasized the importance of avoiding the trees with ant colonies so that the range and beneficial effects of the ants could be maximized. Though *Oecophylla* cannot become a primary biological control agent, it should be considered as an important component in integrated control of mirids. In Papua New Guinea, the ant *Anoplolepis longipes* affords protection from several notable pests of cocoa, the mirid *Amblypelta* and *Pantorhytes*, not by predation but by disturbance. *A.longipes* readily colonizes artificial nests e.g. cut lengths of bamboo and can be transported to new areas where its establishment is aided by the planting of *Gliricidia* sepium as a source of food to the ants (Smith and Room, 1978).

Though specific predators are not recorded so far, reduviids, mantids, spiders, and chrysopids are recorded from mirid infesting cocoa farms. But the exact role of these generalist predators in the management of mirids is to be studied. The larvae of the chrysopid, *Ankylopteryx octopunctata* was found to feed on the nymphs of the mirid, *H.antonii* infesting cocoa in south India (Daniel and Saraswathy, 2001).

Mirids are attacked by a number of parasitic insects. In West Africa the eggs are found to be parasitized by three species of minute chalcidoid wasps, *Pediobus, Telenomus* and *Trichogramma*. The nymphs of *Helopeltis* and *Sahlbergella* are killed by parasites of the genus *Euphorus*. Levels of parasitism by *E.sahlbergella* become quite high in Ghana but it is not known if this parasite is ever a limiting factor on mirid numbers (Kumah and Kumar, 1975). The mymarid, *Erythmelus helopeltidis* is reported as an egg parasitioid of *H.theivora theobromae* from Malaysia (Ibrahim, 1989). Mirids are reported as having bacterial (*Sahlbergella*) and fungal (*Monalonion*) diseases but these have not been successfully used for their control. The insect pathogen *Beauveria bassiana* was found infecting the cocoa mired *H. antonii* on cocoa (author's observation) and the *H.theivora theobromae* in Malaysia (Lim *et al.*, 1989).

Other pod feeding bugs

Cocoa pod feeding shield bug, *Bathycoelia thalassina* (H.S.) (Pentatomidae) is a comparatively new pest in West Africa and is at present noticed from Ivory Coast to Cameroon. The eggs are laid in groups on leaves, trunk and branches. The feeding is restricted to pods. These bugs with their long stylets penetrate the husk and the contents of the beans are sucked out so that they become empty and brown. Only a minute lesion is left on the feeding surface. But slicing affected pods will reveal the empty beans and the tracks left through the husk by the stylets of the insects. Young pods become yellow, then black but larger pods stop growing and become yellow, a kind of premature ripening is observed in the case of young pods (Lodos, 1967). The availability of pods throughout the year in some Amazon and hybrid varieties help in the population build up. The field incidence is affected by light intensity within the canopy. A continuous canopy is preferred with a light intensity outside the range of 50-200 lumen, quoted as limiting in Ghana, where it has also been

stated that the outer ten rows of trees carry significantly greater populations (Owusu-Manu, 1975). High population is between August –November, which coincides with the main crop period in Ghana and Nigeria. A loss of 18 per cent has been estimated in Ghana.

The shield bug appears to be having many natural hosts, which are removed by deforestation. *Randia* sp has been suggested as the original host but fruits of other trees like citrus and *Theobroma grandiflorum* are also attacked. The incidence of parasitism and of predation of the shield bug is very high. *Cylindromyia cribrata* (Villen) (Diptera: Tachinidae) is the important parasite in Ghana (Owusu-Manu, 1997). Incidence of parasitism is reported as 10 per cent, the third and fourth instar nymphs are parasitized. But areas under regular application of gamma HCH for mirid control had reduced population of the natural enemies as seen in Ghana and Nigeria (Owusu-Manu, 1975).

A cultural method of management is suggested by removing all the pods once a year when the pods are few in numbers to break the breeding sequence of the insect. Control with acceptable pesticides has proved difficult (Owusu-Manu and Kumar, 1975). Entwistle (1985) suggested that this insect should be managed with less spraying so that the natural predators and parasites can maintain the population.

Coreid bugs are important in cocoa - coconut interplantings since some coreids are pests of coconut also like *Pseudotheraptus*. Two genera are associated with cocoa. They are *Theraptus* and *Pseudotheraptus*. Feeding by *P.devastans* inhibits development of cherelles and causes distortion of old pods. This is more prevalent on hybrid and Amazon cocoa probably because pods are more continuously present throughout the year (Lodos, 1967). Another coreid important in cocoa is *Amblypelta cocophaga* which attack the stem of cocoa in Solomon Islands but in Papua New Guinea *A.theobromae* feeds mainly on cherelles and young pods causing distortion and necrosis (Entwistle, 1985).

Other Homopterans

Many homopterans occur on cocoa but most of them are of minor importance in majority of the cocoa growing countries. The leafhoppers *Empoasca devastans* in Sri Lanka, *Affroccidens* species in Ghana, and *Chinaia rubescence* in Costa Rica cause distortion and premature drop of leaves. In Trinidad, Brazil, Guyana, Costa Rica and Colombia, a membracid, *Horiola picta* feeds on flower cushions, pods and stems and may cause pod wilt (Entwistle, 1985). *Gargara* spp and *Leptocentus* sp are reported from south India as feeding on flower buds, cherelles, pods and tender shoots and they are present throughout the year as a minor pest. The psyllid, *Tyora tessmanni* is important in Africa.

Two species of aphids occur on cocoa. The abundant and cosmopolitan one is the citrus black aphid, *Toxoptera aurantii* B.d.Fos. This aphid colonizes the flower buds, flowers, flush leaves (Fig.4), tender stems and very small cherelles. Leaf crinkling and shedding of flowers are the outcome of infestation. But the role of aphids in flower shedding is not studied in detail. A number of natural enemies feed on the aphids and reduce the population. These include syrphids, cecidomyiids, coccinellids, hemerobiids etc. Daniel and Saraswathy, 2001).

Thrips (Thripidae) usually make their presence felt only when the environmental conditions are different, i.e., when the plants are stressed for water. Out of the few species of thrips that feed on cocoa, the red-banded thrips, *Selenothrips rubrocinctus* (Giard) is the most important and occurs

through out the tropics on cocoa and many other plants. This feeds on the leaves. This is more important in West Indies, Surinam, São Tomé and Ivory Coast (Entwistle, 1985).

Leaf feeding insects

Cocoa trees in all its growing stages exhibit a pattern of leaf production, known as flushing. The new leaves are at first red, and then they turn pink, white and finally green. During the flush, cocoa is particularly susceptible to attack by a wide variety of leaf feeding lepidopteran caterpillars and coleopterans. There are major peaks of flushing in March and October. The shading influences flushing. Trees that are shaded by cover trees flushed significantly less frequently and with lower amplitude than unshaded trees. Flushing is more intense on branches receiving the most sunlight. First major flushing is after the first rains (Majer, 1975).

Seasonality studies of cocoa insects have shown that the flush associated insects exhibit two annual peaks, one with each of the major flushes and no significant increase in numbers of these insects during the minor flushes. Analysis of the coleopteran from the edge samples revealed a species composition more like the major flush fauna with characteristically high numbers of leaf and shoot feeders.

Wherever cocoa is introduced and cultivated in a large scale, a background fauna is available which will take turn to inflict damage on cocoa. Basically three reasons are put forward for any background fauna to becoming a pest; water stress, over isolation and insecticide application. These reasons can make a minor insect becoming serious in some localities for some time, till the reason is present. Shade removal is the factor most conducive to damage by caterpillars. A number of local insects occur in cocoa plantations as background fauna and these may feed on the tender leaves and tender shoots of cocoa sometimes causing appreciable damage to young cocoa plantations. Most of these insects just occur on cocoa without causing any imbalance to the cocoa ecosystem. This process of adaptation to cocoa may be a continuous process and many more insects may be seen on cocoa once the area under cocoa is being increased

Caterpillars

Caterpillars of few lepidopterans infest the cocoa trees. Most of the time the cocoa plants can sustain the levels of defoliation effected by these caterpillars. Since cocoa trees have many flushing seasons, the incidence of feeding by these caterpillars have little effect on the plants. But defoliation can occur in case of feeding by one or two species of bagworms. The feeding by these can result in total defoliation and weakening of the trees as experienced with cocoa planted under coconut.

Bollworm *Earias bipalga* is one of the bollworms of cotton but its caterpillars constituted the most serious insect problem in establishing cocoa in West Africa. Besides feeding on young trees, the larvae feed on the pericarp of unripe pods also. This is a pest of cocoa up to three years old and attack is heavy on unshaded or poorly shaded plants. Destruction of apical buds delays or even prevents jorquette formation. Vertical growth of the trees is also affected as seen in Nigeria (Entwistle, 1964). It is reported that cocoa types in which canopy formation proceeds throughout the year seem least susceptible whereas types with canopy formation is punctuated by periods of inactivity are most susceptible (Entwistle, 1985).

Cocoa armyworm, *Tiracola plagiata* is wide ranging species, but it attacks cocoa in Papua New Guinea. Initially occasional local infestations were known until epidemic populations

developed in some locations. This happened in areas where virgin forest had been clear felled and burnt over. The shade trees like *Leucaena leucocephala* and *Crotalaria anagyroides* are also susceptible to this insect. The insect feeds selectively on apical buds that lead to large-scale destruction of apical dominance. The severely attacked trees may show upward spindly growth (Catley, 1963; Dun, 1967; Laup, 1994). Bud destruction in unshaded young plants with resultant delayed formation of the jorquette is the most notable consequence of attack by cocoa armyworm moth.

Cocoa lymantriids, are the most commonly encountered leaf feeding insects of cocoa in India. The caterpillars of this moth feed on the tender leaves and on the pericarp of cherelles and unripe pods. Three genera of lymantriids, viz., *Lymantria, Euproctis* and *Dasychira* are so far reported on cocoa. The caterpillars of these moths feed on the tender leaves, and on the surface tissues of cherelles and green pods.

L. ampla Walker is the most commonly and abundantly observed leaf-feeding insect of cocoa in India. These are seen more in the field after the monsoon rains. The caterpillars cause severe damage on leaves in young plants. The early instars of this moth feed on leaves or the surface tissues of growing pods during day and night, but later instar caterpillars are nocturnal in habit. During daytime they hide on fallen leaves at the base of the tree or the basal surface of the main stem (Prem Kumar and Nair, 1982). The indigenous natural enemies of this lymantriid include the insect pathogen of the mature larvae, *Paecilomyces fumosoroseus*; a pupal parasite, and a braconid larval parasite *Apanteles* sp (Daniel and Saraswathy, 2001).

Caterpillars of *Euproctis* spp are also defoliators of cocoa. These caterpillars feed on tender leaves, surface of cherelles and green pods. The sporadic high population of *Euproctis* spp can cause severe damage of tender leaves. During a survey it was found that the caterpillars of both these moths together cause about 28% damage to the pods by feeding on the outer tissues. The period of attack is seen from June to July (Prem Kumar and Nair, 1982).

The caterpillars of the leaf webber, *Adoxophyes privatana* Walk. (Tortricidae) web together tender leaves and feed from within, making irregular holes on them. Maximum infestation is recorded during January - March and 20 per cent of shoots are webbed and damaged during heavy infestations.

A number of background fauna switch to cocoa trees now and then but they do not make any serious damage. These include the caterpillars of *D.mendosa*, the geometriids *Hyposidra talaca* Walk., *Pingasa ruginaria* Guen. and *Oenospila quadraria* Guen., the arctiids, *Pericallia ricini* F., *Diacrisia oblique* (Walk.) and *Amsacta gangis* Linn. and the noctuids, *Spodoptera litura* (Fab.) and *Achoea janata* Linn. They usually feed on the leaves.

Beetles and weevils

Grubs of many scarabaeid beetles feed on roots and decaying organic matter in the soil. The adult beetles feed on soft leaf tissues and flowers. Adults can be considered as pests of cocoa. Adults are generally nocturnal but few are diurnal, like *Popillia complanta* Newm.in India, *Rutela lineola* in Surinam and Trinidad and *Pseuudotrochalus concolor* in West Africa. Usually these beetles have long life cycles. Many species attack cocoa in Malaysia like species *of Adoretus, Apogonia, Anomala* and *Chaetadoretus.* (Lever, 1953; O'Connor, 1959). The rose beetle *Adoretus*

versutus Har. is a serious defoliator of cocoa in Fiji and Samoa and Vanuatu (Beaudoin *et al.*, 1995). Young plants in the first one or two years of planting are particularly susceptible to attack by these beetles. In Malaysia, more than 50 per cent reduction in stem girth is reported, with less uniformity in crop stand. More than 30 per cent replanting is also reported (Thong *et al.*, 1977).

Flea beetle, *Monolepta longitarsus* J.G. (Chrysomelidae) is a small reddish beetle feeding on cocoa leaves during the wetter months of the year in India. They cut small circular holes on the leaves. Severe infestation leads to the riddling of tender leaves with holes. The tender shoots also are attacked.

Ash weevils, *Myllocerus viridanus* Fab. and *M.maculosus* Desb. (Curculionidae) are recorded as early as 1967 in the Nilgiris and Yercad regions (Abraham and Padmanabhan, 1967). *M.viridanus* occurs as a major insect in all cocoa growing tracts of Kerala and Tamil Nadu. Adults are seen in large numbers on the underside of leaves and feed on the interveinal tissues leaving the veins intact. The flaccid tender flushes are not preferred for feeding. Population peak is observed in July- September. Infestation is relatively severe on young plants and quite often, the entire foliage of such plants are skeletonised leading to growth retardation. The incidence of ash weevils is more serious in coconut-cocoa plantations.

Leaf cutting ants are reported only from the New World where *Atta* and *Acromyrmex* are very widely distributed in South and Central America. *Atta cephalotes* is the well adapted to forest life and is the main species in cocoa gardens in Brazil. Workers of leaf-cutting ants bite oval pieces from the leaves of many trees including cocoa. Flowers, cherelles and surface of pods may also be used for cultivating the fungus in the subterranean nests. (Cherrett, 1968). The management of this ant using citrus meal impregnated with mirex is safer environmentally (Cherrett, 1969).

Pod feeding insects

Some orders of insects are important as damaging the developing fruits of cocoa in few countries. The most important among them is the South East Asian cocoa moth that has invaded many of the cultivated cocoa tracts in this locality.

Cocoa pod borer, *Conopomorpha cramerella* (Snellen), is the most important cocoa pod borer in many South East Asian cocoa-growing countries. The distribution in South East Asia, damage to cocoa, host plants and biology of this borer is given by Lim (1992).The oviposition pattern of this moth varied with age. Older pods less than seven weeks before ripening were preferred, suggesting some nutritional value or chemical attraction of older pods (Azhar and Long, 1996). A damage relationship was derived relating yield loss in cocoa to the level of attack by *C.cramerella* in Sabah (Day, 1989). It is derived that if 90 per cent of pods are attacked with internal damage, yield loss is estimated at 40 per cent and 5 per cent if less than 60 per cent pods are damaged.

Larval mortality associated with sclerotic layer hardness and thickness is one of the criteria for selection of *C.cramerella* resistant cocoa clones (Azhar and Long, 1996).

Egg parasitism by *Trichogramatoidea bactrae fumata* was found to be independent of pod age and it is not an effective natural enemy. Mass releases of this parasitoid should be intensified during cropping period with less than ten weeks before ripening. An encyrtid prepupal parasitoid of *C.cramerella* was reported from Malaysia (Noyes, 1991). The spread of the cocoa pod borer is found to be through the movement of few adults forming an epicenter. Their offspring are spread

through air currents. Ninety per cent of cocoa pods were infested in epicentre area (Zam and Azhar, 1992). Regular complete harvesting is proposed to achieve economic control if 50 per cent or less of pods are infested (Wood *et al.*, 1992). Entomopathogenic fungi, *Paecilomyces fumosoroseus*, *P.lilacinus* and *Beauveria bassiana* are isolated from pupae of this borer from Malaysia (Lim *et al.*, 1988).

Insecticide management is practiced in all the countries against this using different insecticide. An integrated method of management of this borer is frequent harvesting, destruction of ripe pods and husks in the field and selective spraying of resting sided with deltamethrin, cypermethrin and lindane (Azhar, 1995). Egg parasitoid *T.batrae* also has potential as a biological control agent (Mumford and Ho, 1988). Pheromone traps can also be effectively used to trap and reduce the adult population of this moth (Beevor *et al.*, 1993). Resistance development against synthetic pyrethroids is noticed in Malaysia (Tui, 1996). Daytime resting sites of adults can be effectively used for selective application of insecticides in an IPM package. Adults in this experimental study were found on the underside of branches 45 or less from horizontal, 90 per cent were found in the lower half of the trees (Day *et al.*, 1995).

Stem boring caterpillars and beetles

Like the leaf feeding beetles and weevils, stem boring moths and beetle are also more in forest cleared plantations or plantations near forests in the cocoa growing regions. Borers of both coleopterans and lepidopterans attack cocoa especially the seedlings and trees planted near forest plantations.

The red borer of coffee, *Zeuzera coffeae* Nietn (Cossidae) is a pest in many countries. Caterpillars of this leopard moth bore into young branches and make unramified hollow tunnels inside the stem. The symptoms of attack are a round hole on the stem, drying up of the upper portions above the hole, and excreta and chewed up fibres strewn out on the ground. If the main stems of young plants are attacked, the plants die. When the branches are attacked, only the branches dry up and simple pruning will save the trees.

Many species of cerambycid beetles attack cocoa trees, especially in regions where cocoa is planted in forest- cleared tracts or near forests. The longhorn *Steirastoma breve* is reported only from the New World where it occurs from Argentina to Florida. Within this wide range it is a pest of cocoa in the Guianas, Venezeula, Colombia, Eucador, Trinidad, Grenada, Martinique and Guadeloupe, in the Brazilian Amazon but not in Central America. Attack is mainly on trees six months to five years old (Entwistle, 1985)

The genus *Glenea* is widespread in the Old World tropics, and is reported from Java, Papua New Guinea, New Britain, Malaysia, and India. Several species of this favour dead and dying trees. Attack seems more common in neglected, overgrown plantations. *G.aluensis* that thrives in heavily shaded situations was able to gain a strong hold in the Gazelle Peninsula of New Britain when plantations become overgrown. *G.lefebuei* in the island of New Guinea is not normally a problem in well-maintained plantations. In Java *G.novemguttata* seems to occur especially in plantations bordering on the original forest. Attack on young plantings by *G.ceila* is observed in Sabah (Pang and Pan, 1979). *Glenea* sp is reported from South India as attacking neglected gardens. Attack is seen mostly in lower trunks and the branches are rarely attacked. The grubs tunnel into the trunk and penetrate deeper, making galleries within. The tissues of the bark and wood are

eaten. More than one grub is noticed in a stem. Adults are found inside dried up wood. Girdling of stem and branches is noticed sometimes (Premkumar and Nair, 1982). In the case *G.lefebueri*, the trees become susceptible in the third year and attack is concentrated on the lower trunk (Schreurs, 1965). Galleries of *Glenea* can provide sites for the commencement of *Phytophthora* bark cankers.

The longhorn, *Cerosterna* sp. is a woodborer and has been reported as quite a serious pest in Sabah. The grub bores in the trunk from top to bottom and less frequently, in the main branches. The larvae cut frequent holes to the outside through which frass and mucilage exude. This appears a primary pest. The attack can result in the death of the tree if not treated (Entwistle, 1985). Stem girdler, *Sthenias grisator* Fab. was reported in South India on cocoa (Abraham, 1958).

In the Papua New Guinea regions, weevil borers are economically important pests of cocoa. The genus *Pantorhytes* is restricted to Papua New Guinea, the Bismarck and Solomon Islands. At least six species attack cocoa (Gressitt, 1966; Stibick, 1978). *P.plutus* causes severe infestation in New Britain and New Ireland while *P.biplagiatus* (Guer.) is seen in the Solomon Islands. The eggs are laid in the crevices on the bark and the larvae burrow in the stem or branches to a depth of 1.5cm and feed in tunnels, which are more or less parallel to the surface. Feeding causes cracking of the stem leading to death of the trees. Adults are large and flightless, and may feed on young leaves, on the bark of young shoots and the husk of pods (Entwistle, 1985).

NON –INSECT PESTS

Vertebrate Pests

Of all the fauna that have successfully adapted to cultivated cocoa trees, the vertebrates rank first. These include rats, squirrels, palm civets and birds and they inflict direct loss of the crop by feeding on and damaging the pods (Kamaruddin and Lee, 1981; Bhat *et al.*, 1981). Rats and birds are the main non-insect pests in Trinidad and Tobago (Laurence, 1991). The rodents are considered the key non-insect pests of cocoa in all tropical countries.

Rodents are the major problem in cocoa interplanted with coconut in all the countries since they have the ability to exploit new food sources. Rats and squirrels are the main groups of rodents that damage cocoa in all the cocoa cultivating tracts of the world. These damage the pods and the attack follows a fairly constant pattern. Ripe pods are usually chosen and a large hole is bitten through the pod husk. The beans are then extracted and after the sweet mucilage is eaten, these are discarded. All rodent species while feeding on cocoa pods leave tooth marks on pods. Though the tooth marks made by different rodent species are not distinguishable, the same can be distinguished from the marks on the pods that had been attacked by monkeys, civet cats or birds. Squirrels usually make oval holes on the central or terminal portion of the pods while rats make oval or round holes near the stalk end of the pods for feeding. Squirrels are diurnal and rats are nocturnal in habits. Squirrels damage ripe pods but the rats damage both ripe and immature pods. Among the rodent damaged pods collected from the field during daytime significantly more number of pods had the damage away from the stalk region (96.6%) (Fig.5). Further in these pods oval type of holes (79.8%) was more frequently observed than other types. This result obtained from field studies was on par with that of the damage caused by squirrels in captivity. Among the pods damaged by rodents during night time significantly more number of pods (90.8%) had the damage hole near the stalk portion (Fig.6) and in most of the pods the shape of the hole was round (55.7%)(Bhat, 1980). Similar results were obtained when quantitative analysis for distinguishing

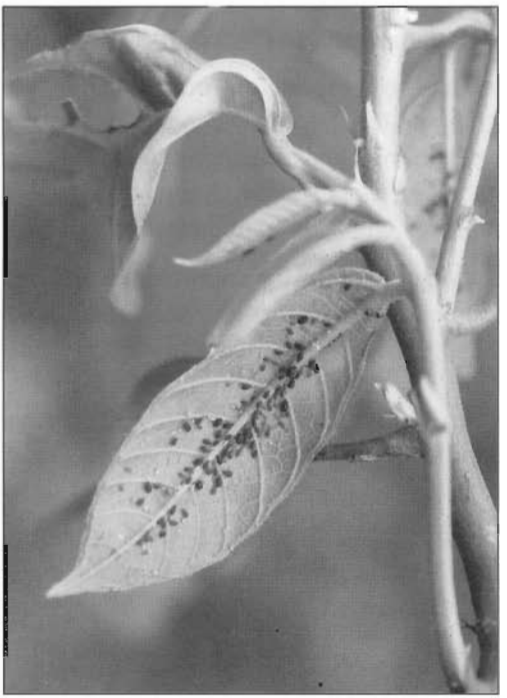

Fig.4. Colony of aphid, *Toxoptera aurantii* on cocoa tender leaf

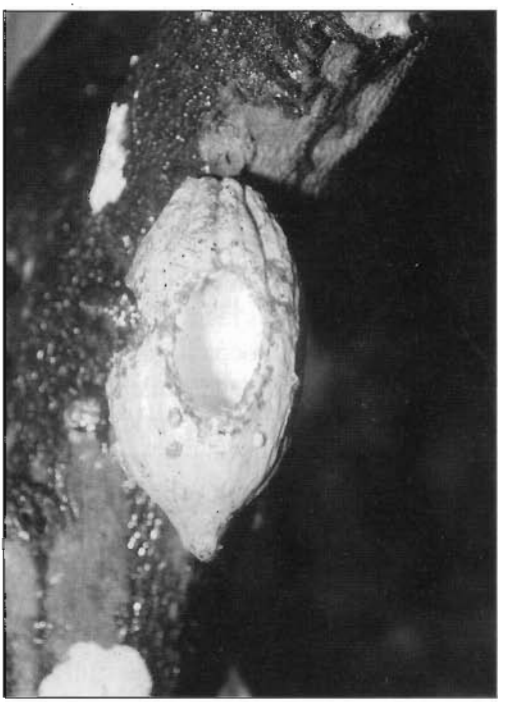

Fig.5. Squirrel damaged pod

Fig.6. Rat damaged pod

wood rat (*R.tiomanicus*) and squirrel (*Callosciurus notatus*) damage to cocoa pods was undertaken in Malaysia. A strong correlation between chip size and hole shape, between chip size and hole position, and between hole shape and position, was obtained. A general guideline for identification of rodent damage in the fields is proposed, the wood rat bores round holes near the stalk and produces smaller chips, whereas squirrels normally bore oval holes away from the stalk and produce larger chips (Noor, 1993).

The population of squirrels was found to be 4-5 numbers per hectare of cocoa garden. The home range of the squirrel is 2 ha. Squirrels are very active during early morning and late evening hours. Rat population is about 25-30 per hectare and home range is 0.5 ha only. The population of *R.rattus* was about seven times that of WesternGhats squirrel, the intensity of squirrel damage to cocoa was nearly three times more than that caused by rats (Bhat and Mathew, 1984).

Many species of rats damage both young and mature pods. Rat damage is reported from most of the tropical countries including the islands. *Rattus tiomanicus* (Miller) and *R.argentiventer* are reported from Peninsular Malaysia. In Vanuatu, the attack by rats is one of the reasons for the low level of yields in the island of Malekula (Jagoret, 1996) and in Fiji; very severe damage was reported (Williams, 1973). The most important rat species observed is the black rat *Rattus rattus* Linn. which is very serious pest of coconuts in all coconut growing areas. The black rat is recorded in India as a major pest occurring in areca –cocoa and coconut-cocoa mixed gardens (Bhat, 1978; Bhat and Sujatha, 1986). Black rats damage cocoa grown as monoculture also since in any South Indian condition the vicinity of preferred nesting hosts like coconut is assured.

Two species of squirrels are reported as pests of cocoa in India. They are the Western Ghats squirrel, *Funambulus tristriatus* Waterhouse; the South Indian palm squirrel, *F.palmarum*. Of these the Western Ghats squirrel is the most serious pest of cocoa in India. Funambulus is reported from Andaman & Nicobar Islands also (Subiah and Mathur, 1991). In Peninsular Malaysia, a survey result showed that in cocoa-coconut smallholdings, the squirrel, *Callosciurus notatus* damages more pods than that by the rats (Idris *et al.*, 1993). In Trinidad, the neotropical red squirrel, *Sciurius granatensis* is identified as the rodent damaging pods in the field. This squirrel was observed to express a significant preference for ripe rather than unripe pods. The extent of damage in pods that were attacked was found to be independent of both ripeness and accession (Warren and Emamdie, 1993). In Bioko Island in Equatorial Guinea, mainly squirrels of the families Sciuridae and Anomaluridae damage the ripening cocoa pods. Average loss of yield was estimated to be 43 per cent. The cocoa plantations are over shaded, and the tall shade trees harbour most of the rodent pests (Smith and Nott, 1988).

Only the cooperative efforts of plantation owners/small farm holdings can achieve management of rodent population. Otherwise the local trials done by individual farm owners have no impact on the population levels of rodents and the damage they inflict on cocoa and other crops. This is more pronounced in the case of rats. Baiting and trapping methods are available. Single dose anticoagulants are available for baiting the rats. In Malaysia, a study on the influence of the ant *Dolichoderus thoracicus* on the incidence of the cocoa pod borer indicated that rat damage was higher in ant –scarce plots throughout the study period. The study area consisted of cocoa intercropped with coconut and the Siam weed *Gliricidia* (See and Khoo, 1996). The number of pods lost to squirrels and civet cats had no effect on the presence or absence of ants, but the looses to either of these mammals were extremely low (Khoo and Ho, 1992). But these observations may

not have much importance to cocoa fields and vertebrate pest damage since these situations are not permanent or cannot be made permanent. The natural predators of rats could be used positively to reduce the population of this rodent. Rat snakes and barn owls should be encouraged to persist in the fields by reinstating their natural habitats. Some initiatives are done in Malaysia by establishing barn owls (*Tyto alba*) in nest boxes of several cocoa, cocoa-coconut areas in UIE estates at Perak, Malaysia. Nest occupancy occurred within two months after establishment. The nests were used for breeding at two cycles per day. Rat carcasses noted in the nests were mainly that of *R.tiomanicus* and field crop losses were low, indicating that at low rat population levels, barn owls could effectively control rats with minimal baiting after about two years (Lee *et al.*, 1999).

Multiple dose anticoagulants like warfarin and fumarin were tried and found effective in controlling rats in cocoa ecosystem. Baiting with rice flour and palm sugar during summer months and added with paraffin wax during rainy season, these poison baits can give good rat control. The second-generation single dose anticoagulants are now available now. Baiting with poisoned wax blocks containing 0.005% brodifacoum around the base of the shade trees was the most efficient method of application against squirrels in the Bioko Island (Smith and Nott, 1988). Bhat and Sujatha (1989) had showed through field trials against the black rat, *R.rattus wroughtoni* that brodifacoum wax cakes could achieve cent percent reduction in damage by two baiting at 10 days intervals. Mathur (1997) had reported a case of damage eradication by tying two cakes of bromadiolone per tree against few rodent species in cocoa intercropped with coconut. It is reported that damage was eradicated after 15 days in cocoa intercropped with coconut by tying two cakes of bromadiolone per tree. Resistance development among rat population to the continuously used rodenticides is common. A case of increased tolerance of *R.tiomanicus* to brodifacoum and bromadiolone is reported from fields in Malaysia (Lee *et al.*, 1990)

Other vertebrate pests

The palm civet, *Paradoxurus hermaphroditus* Pallas (Viverridae) also known as toddy cat, is a nocturnal tree climber. It is present in many cocoa-growing tracts of India, Malaysia. This carnivore damages the pods by biting and breaking the husk of cocoa pods. Abraham and Padmanabhan (1967) reported the damage caused by this to cocoa in south India. Bhat *et al.* (1987) reported 12.8 per cent damage by this to cocoa in Kerala. The palm civet bite and break the husk of cocoa pods. The pieces of broken chunks are 2.0 to 3.0 cm in diameter. There is no distinct pattern for the damage. The terminal half or one side of the pod is broken. While feeding the beans are swallowed and as such no trace of beans is visible directly under the tree. Piles of defaecated beans are seen scattered around the cocoa plantations. Palm civets could be easily controlled by poison baiting with 0.5g of carbofuran granules using ripe bananas as baits. Two such banana fruits have to be tied to the trunk /jorquettes of five to six cocoa trees per hectare.

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7. HARVESTING AND POST HARVEST TECHNOLOGY

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INTRODUCTION

Cocoa produces a large number of flowers during certain periods of the year depending upon the environmental conditions and the type. Of the several thousands of flowers formed, only 1-5% of the flowers are successfully pollinated during the peak flowering season and all those that are set are not carried to maturity. During the lean season, when flowers are fewer, pollination may rise to 40- 50 %. The pollination efficiency is low, but this is compensated by the large number of flowers produced. It is estimated that only one in every 500 flowers matures to a ripe fruit (Purseglove, 1968).

HARVESTING

The pods mature in about 150 to 170 days from the day of pollination. In the cocoa growing regions of India the days for maturity ranges from 135-170. This period varies depending on environmental conditions. A highly significant negative correlation between the number of days from pollination to harvest and the mean temperature during the period of fruit development has been established. According to Alvim *et al.* (1972), N = 2500/ T-9, where N is the number of days from pollination to harvest and T, the mean temperature in ^{0}C.

The stage of maturity of pods is best judged by change of colour of pods. Pods, which are green when immature turn yellow when mature and the reddish pods turn yellow or orange. The change in colour starts from the grooves on the pods and then spreads to the entire surface. Though pods can be harvested as colour changes, the pods may remain on the tree without damage up to a maximum of about one month. The intervals between harvests, therefore can be extended to one month. However, it is safer to harvest at fortnightly intervals. In areas prone to damage by mammalian pests, harvesting intervals may preferably be shorter. When black pod incidence is serious, shorter harvesting intervals are preferred for ensuring field sanitation.

As fruits are borne on the cushions and as damage to flower cushions is to be avoided, harvesting is to be done using a knife. In the case of cocoa, which is pruned regularly and vertical growth controlled, harvesting is convenient. When, growth of cocoa is not controlled, harvesting may have to be done using knives attached to poles, as done in African countries.

Fruit production in cocoa is not uniform and there are often peaks in production. For the Ghanaian cocoa, the peak harvest is in the month of November, the yields being high in October and December. The crop is spread more or less evenly in Malaysian cocoa. Occurrence of peaks in production is often related to environmental conditions and internal physiological factors. When wet and dry seasons alternate, there is often induction of flushing by the onset of the wet season, leading to increase in leaf area and enhanced photosynthetic activity in about a month's time when the leaves harden. Flowering flush commences by this time and peak harvest could be expected after about

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five months. Because of the fruit load, especially towards the later stages of development of pods, further flowering is inhibited and cherelle wilt enhanced. In addition to this, there will be 'crazy' flowering and scattered harvests due to the prevalence of wet and dry periods, in between. Temperature also plays a role by the flowering inhibition in the cool seasons. When temperature remains high and rainfall is well distributed, harvests are more uniform throughout the year as in Malaysian cocoa.

In India also, there are peaks in cropping with the major peak in June-August and another minor peak from November-December (Bopaiah and Shama Bhat, 1989). These are the general trends in the harvesting pattern. But there are obviously location differences, depending mainly on the rainfall pattern of the cocoa growing regions of the Country. At Trichur in Kerala, following the pre-monsoon showers of April-May, there is apparently peak flowering in May which results in the harvest peak in October-November, five months after. Even though flowering continues to be high in subsequent months except July and August, fruit set and development are inhibited by the fruit load. After the harvest of the main crop, there is another bout of successful fruit set and development to result in the peak season during April-May.

POST HARVEST STORAGE AND BREAKING PODS

The harvested pods can be stored for 2-15 days (Fig.1). This enhances pre-fermentation activity inside the pods and helps to facilitate rapid rise in temperature during fermentation. Premalatha & Mohanakumaran (1989a) secured optimum fermentation temperature, a desirable dried bean pH and production of a high proportion of commercially acceptable beans by storing the harvested pods for 2-6 days. However, Dias and Avila (1990) could not find any effect on holding pods for up to 5 days prior to fermentation on duration of fermentation and final acidity. Alamsyah (1991) found high bean pH to >5 and fermentation index to >1 by storage of pods for 3-9 days followed by fermentation for 5 days with turning every 48 h. Use of shallow boxes combined with post harvest pod storage helped to reduce bean acidity (Effendi, 1993). In a trial conducted in 1992 using pods of the Upper Amazon Hybrid, it was observed that storing pods for 15 or 10 days resulted in lower acidity and a stronger chocolate flavour after fermentation for 5 days than storage for 5 days, which produced beans of insufficient acidity (Arikiah *et al.,* 1994). Biehl and Voigt, (1994) recorded correct nib acidification by pulp pre-conditioning, such as by pod storage and bean spreading. The effectiveness of pod storage on reduction of acidity of cured beans has been indicated by Dias and Avila (1993) and Effendi *et al.* (1994).

The harvested pods are broken by hitting against a hard surface and beans are extracted without placenta and kept for fermentation immediately. Only mature, well-developed pods contain good beans. Pods showing symptoms of damage of black pod on the surface need not be discarded if the beans inside are unaffected. The colour of the pulp will be a good indication of suitability, the damaged ones showing discoloration.

PRIMARY PROCESSING

Primary processing denotes production of dry cured beans for the market. This involves fermentation and drying.

Fermentation

Raw cocoa beans are covered with sugary mucilaginous pulp, which are called 'wet beans'. The kernel, which is also called 'nib', is the economically important part. Fresh nib is bitter and is

not suitable for manufacture of different products. When raw, it does not have any flavour, aroma or taste of any of the cocoa products. Chocolate flavour is developed during the two processes viz. fermentation, which is done by the grower and roasting, done by the manufacturer.

All the standard methods of fermentation essentially involve keeping together a mass of reasonable quantity of wet beans for periods ranging from four to six days. In most of these standard methods, there is mixing of the mass of beans usually on alternate days. One of the consequences of fermentation is the loss of most of the pulp around the beans; but more important is the series of biochemical reactions occurring in the beans, which are necessary for inducing the characteristics of the cocoa products.

Biochemical changes occurring during fermentation

The pulp contains about 84.5 % water, 10.0 % glucose and fructose, 2.7 % pentosan, 0.7% sucrose, 0.6% protein, 0.7% acids and 0.8 % inorganic acids (Hardy, 1960). The pulp is sterile initially. But, the presence of sugars and high acidity (pH 3.5) provide excellent conditions for the development of microbial population. A wide range of micro-organisms infect the mass of beans through the activity of fruit flies and contamination from the fermentary. Initially, yeasts proliferate and they convert sugars to alcohol. The cells of the pulp start to break down soon after the fermentation process begins either through an enzyme change or by simple mechanical pressure, and watery contents of the pulp called' sweating' drains out. This continues for 24-36 hours. The sweatings constitute 12-15% of the weight of wet beans. The activity of yeasts leads to the production of CO_2 and at this stage, relatively anaerobic conditions prevail and allow the development of lactic acid bacteria, which assist in the break down of sugars.

The activity of bacteria leads to the production of organic acids. When the sweatings have run off, the conditions become more aerobic and the acidity is reduced by the removal of citric acid. The presence of oxygen allows acetic acid bacteria to take over from the yeasts and convert alcohol to acetic acid. These reactions cause a rise in temperature in the mass of beans. There is a positive correlation between sizes of the relevant microbial populations and the amount of acids produced during fermentation (Samah *et al.,* 1993).

The temperature increases after the first mixing to a peak of about 48 to 50 °C and falls slowly till the next mixing. With the next mixing also, temperature rises again; but often to a lower peak of around 46 to 48°C, which falls again slowly towards the completion of fermentation. The temperature ranges mentioned above should be used only as a guide. Variations are likely depending on the method of fermentation, location of the beans in the ferment and environmental conditions. Yet, the rise in temperature should be taken as indicative of the necessary biochemical reactions and the lack of adequate temperature development, as a symptom of inadequate fermentation.

The pH of the beans and the pulp also varies conspicuously. The fresh cocoa bean pulp is acidic with a pH of around 3.5. The pH of cotyledons is very much higher, around 6.5. After death of the beans, components of pulp diffuse through the testa into the beans and the acids which are synthesized from pulp move into the beans to lower the pH of nibs still further. The pH of nib on the third day will be around 4.8. With further progression in fermentation, pH tends gradually to increase to values around 5.0 by the end of fermentation period. While there is a decrease in pH of the cotyledons, the pH of the pulp increases from the initial level of 3.5 to a final value as that of the nib.

There was no distinct seasonal trend in pH of the pulp and the cotyledons, though the values ranged from 6.4 to 6.9 in the cotyledons and from 3.3 to 4.5 in the pulp. The overall mean pH values were 6.8 and 4.0 for cotyledon and pulp, respectively. The only trend was that low pH values of the cotyledons were often accompanied by relatively low values of pulp also.

The acetic acid diffusing through the testa causes break down of polyphenol and lipid membranes of the vacuoles of the cell and cell contents get mixed. Various enzymatic reactions take place and polyphenols get oxidised. This reaction is partially responsible for the removal of bitter taste from the beans. Herrmann (1995) studied the changes in polyphenols and their oxidative condensation during fermentation. Apart from the purple anthocyanins, the polyphenols in fresh cocoa beans consist mainly of epicatechin, with lower concentrations of catechin and procyanidin. During fermentation, the enzyme polyphenol oxidase produces a strong oxidative condensation, particularly of epicatechins to form the hexamer procyanidin. Bonvehi and Coll (1997) observed that optimally fermented cocoa samples have a maximum total polyphenol content of 58 mg/g, a maximum tannin content of 31 mg/g and a maximum (-)- epicatechin content of 3 mg/g. The parameters are related to the sensory properties of cocoa and can be used to confirm fermentation deficiencies.

The disappearance of phenolic compounds during fermentation reduces bitterness of raw cocoa, while production of volatile compounds arising from the reaction of aminoacids with sugars leads to induction of aroma. The exact nature of compounds responsible for this is not known, although over 300 compounds are considered to have their influence. The most important change which occurs in the cotyledons during fermentation is the appearance of the chocolate flavour precursors. The proteins in the cotyledons undergo hydrolysis, giving rise to amino acids and conversion to insoluble forms by reaction with polyphenols. Biehl *et al.*(1993) recorded a very high proteolytic activity in ripe ungerminated cocoa seeds, which digested the vacuolar storage protein during fermentation. These were suggested to be responsible for the release of hydrophobic amino acids and a large number of oligopeptides essential as cocoa flavour precursors.

Voigt *et al.*(1994) found that free amino acids and oligopeptides are essential aroma precursors. The combined action of two enzymes viz., aspartic endoprotease and carboxypeptidase on cocoa bean protein appeared to be required for the generation of cocoa specific aroma precursors.

The effects of pectinase (polygalacturonase) on natural cocoa fermentation was studied by Bhumibhamon and Jinda (1997). The quality of fermented cocoa beans treated with pectinase was more promising than that of beans not treated with enzyme. The percentage of fully fermented beans increased with increasing duration of the enzyme- soaking period. The percentage of fully fermented beans was 79% and 86% of the total for batches soaked for 3 and 6 h, respectively. No slaty or mouldy beans were observed in these batches, indicating a fermented bean quality equivalent to standard grade 1. The pH values of fully fermented beans were 5.49 and 5.92, which were acceptable in the cocoa market. Pectinase-producing microorganisms, therefore, would have an important role in cocoa fermentation processes.

The enzymes like endoprotease, aminopeptidase, carboxypeptidase, invertase (cotyledon and pulp), polyphenol oxidase (catechol oxidase) and glycosidases are of key importance in flavour precursor formation and in pigment degradation during cocoa fermentation (Hansen *et al.*, 1998). The enzymes exhibited large differences in pH optima and stability during fermentation. Aminopeptidase, invertase (cotyledon and pulp) and polyphenol oxidase were strongly inactivated,

carboxypeptidase was partly inactivated, whereas endoprotease and glycosidases remained active throughout the fermentation. Many enzymes are inactivated during fermentation, so it is generally recognized that the actual period of enzyme action is short. However several key enzymes were not completely inactivated during fermentation.

Beans fermented for 4 days by mix-culture were preferred to those naturally fermented beans were less astringent and acid (Bhumibhamon *et al.*,1997). Beans fermented by mix-culture had theobromine and glucose contents of 13.23-16.76 and 1.05-1.87 mg/g, respectively, a pH of 5.18-5.34, and cocoa butter content of 53.41-58.00%.

Factors Affecting Fermentation

Pod characters

Harvesting at intervals of 1-2 weeks ensures quality. Only healthy ripe pods should be harvested. The frequency of harvesting directly influences quality. Use of over ripe pods may be avoided as these may contain germinated beans, which may allow the entry of moulds and insects. The under ripe pods are also to be avoided as this will affect fermentation due to the low content of sugars. Unripe pods do not ferment properly and temperature of the fermenting mass continues to remain at 35°C after an initial rise to 40°C (Knapp, 1926). The highest concentrations of acetic acid in ripe and unripe beans on the 3rd day of fermentation (157 and 110 mg/10 g, respectively) were recorded by Samah *et al.*(1993). Unripe beans had a lower pH (5.0) than ripe beans (pH 5.6) after 6 days. About 40% of ripe beans achieved a chocolate colour, compared with 27% of unripe beans at the end of the fermentation period. Alamsyah (1991) observed a weak chocolate flavour and low pH of cured cocoa beans from unripe pods. Most pod diseases can lead to complete loss of beans they contain. Even when the beans are not destroyed, it is undesirable to use the beans for fermentation. Criollo gets fermented in a relatively shorter period of 2-3 days while Forastero takes 5-7 days. Hence mixing the beans of these two types is to be avoided.

Quantity of cocoa

The heat generated during fermentation is retained by insulation, but this becomes more difficult to achieve with small quantities. For getting satisfactory fermentation about 100 kg beans are required.

Duration

The duration varies depending on the genetic structure of cocoa mass, the climate, volume and the method adopted. A critical evaluation of the fermentation methods adopted in various countries indicate a wide range of duration of fermentation from 1.5 to 10 days. Yusianto *et al.*(1995) observed that unfermented beans were low in chocolate flavour. Fermentation for 1-2 days was considered insufficient - chocolate flavour had developed but bitterness and astringency were still distinctly present. Fermentation for 3-4 days produced well- fermented beans with adequate chocolate flavour plus strong acid, citrus and brown fruit off-flavours. Fermentation for 5-6 days resulted in over-fermented beans with undesirable (e.g. musty) off-flavours.

Turning

Turning the beans during fermentation ensures uniform fermentation. Variations in the frequency of turning exist in different countries and the preferable interval is once in two days. Dias and

Avila (1993) recorded faster fermentation when turning was done every 24 hours. Frequent mixing (6-h or 12-h intervals) produced a higher number of well-fermented beans than other treatments (Senanayake *et al.*, 1997). When practical aspects of small and large scale fermentation are considered, mixing at 12-h intervals for 6 days is recommended as the most suitable treatment.

Seasonal effects

The climatic conditions during fermentation affects the fermentation. Temperature rises more slowly in wet weather in June- July. Dias and Avila (1993) recorded higher volatile acid contents in May than in June. Fermentation during the dry season was better than that during the wet season (Premalatha & Mohanakumaran, 1989b).

Cocoa Bean Acidity

Cocoa products processed from some samples of cured cocoa beans are found to have detestable acid taste. This is often designated as cocoa bean acidity. It has been found that the beans giving acid taste to the products generally have low pH. The low pH of cocoa beans is also strongly related to titrable acidity.

It is established that the organic acids responsible for cocoa bean acidity are mainly acetic and lactic acids. These are produced from sugars present in the pulp during the fermentation process. Acetic acid produced during fermentation is an essential component of the fermentation process as the acids contribute to bean death, prevent colonisation by putrefactive micro-organisms and create an environment conducive to the formation of flavour and aroma precursors within the bean cotyledons. Yet, excessive quantities of these produce an acid taste in the cocoa products as these are not adequately dispelled in the roasting and conching processes.

The problem of cocoa bean acidity is mostly reported from Malaysian cocoa (Shepherd, 1976). The Ghanaian cocoa is often taken as the standard for comparison as often, best chocolates are produced from Ghanaian cocoa and as acid taste is almost never observed. Bean pH ranges from 5.3 to 5.5 for the Ghanaian cocoa in contrast to the range of 4.4 to 4.7, common Malaysian cocoa. The problem of cocoa bean acidity has been reported in Indian cocoa also, the range in pH being from 4.7 to 6.1 with about 20 to 50 % of the samples with pH values less than 5.0. If a pH of 5 is taken as the limit, there are acidic beans in Indian cocoa also, though the problem of bean acidity appears to be less severe than that of Malaysian cocoa. By improving processing methods like providing gaps in boxes and giving aeration during fermentation, acidity problem could be reduced (Balasimha *et al.*, 1980)

Factors affecting cocoa bean acidity

It was considered for some time that acidity of beans is related to the nature of plant material. Studies on variations in pH of the cotyledons and pulp, however, gave no indications to support this as, in general, the pH values of nearly all types of cocoa were comparable. Further emphasis was placed on the study of factors associated with fermentation and drying. The factors which are considered to be responsible for induction of excessive acidity in cocoa are the following.

Nature of microbial population

During the early stages of fermentation, the conditions are predominantly anaerobic. At the beginning of fermentation, yeasts from natural contamination act on the sugary pulp. With the

drainage of pulp through sweatings, conditions become more and more aerobic and acetic acid/ lactic acid bacteria start predominating. Both the yeasts and the bacteria arise from the natural contamination of the fermenting mass. Depending on the strains of contaminating organisms, there could be differences in the rates of production and degradation of acids. An excessive accumulation of acids may not only allow larger acid concentration in the cotyledons but may also alter further reactions necessary for flavour development in the beans.

Pulp content of beans

The sugar in the pulp being the ultimate precursor of alcohols and finally acids, a larger pulp content means larger production and accumulation of acids. Although the available data do not show any consistent higher pulp content in Malaysian cocoa as compared to the Ghanaian Amelonado beans, partial removal of pulp prior to fermentation has been found to reduce acidity of Malaysian cocoa. Another consequence of larger pulp content could be the delay in the removal of sweatings to the desired levels. This could also mean delay in providing the required degree of aeration.

Sugar content of pulp

The total pulp content remaining the same, a higher sugar content of pulp may mean higher production of acids. Here again, no marked differences in the sugar content of the pulp between Malaysian and Ghanaian beans have been noticed. Also, artificial addition of sugars to Ghanaian Amelonado cocoa did not increase the acidity of fermented and dried beans. As such, the possibility of high sugar content being a major factor in inducing bean acidity appears to be small.

Differences in the methods of fermentation

The bulk of evidences available points out the major role of this factor in inducing bean acidity. In Ghana, the most widely adopted method of fermentation is the heap method in batches of 50 to 450 kg wet beans. In the estates of Malaysia, box method is commonly used and the batch sizes are often well over one tonne. Even though in both the methods, there is mixing of beans alternate days, the extent of bean packing would be more in the box and the ease of drainage of sweatings less. This could logically result in a delay in aeration of the bean mass in the boxes and also a longer period of contact of products of sugar fermentation. Towards the later stages of bean fermentation when acids predominate, this could result in higher diffusion of acids into the beans and resultant modifications of the biochemical reactions in the beans.

Aeration of fermenting mass of beans and flow of sweatings could be improved by partial removal of pulp prior to fermentation. Forcing a stream of air from below the fermenting mass also could achieve this. Both these have been attempted experimentally and these have been found to improve the pH of fermented beans. Quality of the beans based on organoleptic tests also indicated an overall improvement though these beans were still rated inferior to the Ghanaian cocoa. The pH and quality of beans could also be improved by modifying the fermentation boxes using planks with gaps in between at the bottom and sides of the boxes. The flow of sweatings was also found enhanced by the use of such modified boxes. Effendi *et al.* (1994) found that early aeration did not result in off flavours caused by fatty acids and concluded that aeration during fermentation without prior pod storage resulted in insufficient acidity reduction to meet the consumer requirements.

Attempts were also made to reduce the acidity of fermentation fluids in the later stages of fermentation by artificial addition of slaked lime. Presumably because of drastic modifications in the type of reactions, the beans from such a fermentation showed no distinct superiority over those normally fermented in boxes based on taste evaluation, even though the pH of beans did improve. The beans from alkali treatment also had darker and more brittle shells.

Fermentation period

The pH changes during fermentation indicate a continuous decrease in the pH of cotyledons upto the end of fermentation. This is attributable to the continued increase in the production of acids in the fermentation period. Allowing further fermentation enhances the growth of putrefactive bacteria whose activity damages the quality of the beans though the bean pH increases substantially. Reducing the fermentation period and arresting excessive diffusion of acids into the beans could be a logical method of reducing bean acidity. This method, however, has the disadvantage that the necessary reactions in beans would be terminated prior to completion.

Method and duration of drying

Drying of fermented cocoa beans is considered as something more than just driving off moisture. The reactions commenced during fermentation proceeds during the drying process as well. It is also noted that pH of the fermented beans increases during the drying process. One of the reactions leading to an increase in pH during drying must be the loss of volatile acids from the beans. Quick drying leads to increase in acidity of the beans. In fact, the best quality is obtained from sun drying. Even when machine drying is done, the general recommendation is to allow slow drying at temperatures not exceeding 60°C and extend the period of drying to not less than 24 hours. A gentle drying at 40°C led to substantial reduction in acidity (Augier *et al.*, 1998).

Bean Maturation

Bean maturation is described as the process involving loss of acid from cocoa beans by keeping the fermented beans warm, moist and with good air supply. By maintaining this at desirable levels, it had been possible to raise the pH of beans to acceptable levels in the range from 5 to 5.5. Two methods are suggested to reduce the acidity and to improve flavour of box-fermented Malaysian cocoa.

Box maturation

The beans set for fermentation in boxes are to be mixed as usual on the third and fifth days. There may be five extra turns on the sixth and seventh days and the beans may be taken out on the eighth day.

Drier maturation

Beans may be kept to thickness of 25 cm and dried at 50°C. Stacking to depths lower than 25 cm and higher than this resulted in poorer quality presumably because of too fast drying of beans in the former and lack of adequate aeration in the latter.

Maturation of beans may be assessed most effectively by monitoring the pH. However, this method is difficult to be followed, especially at the farm level. There are also other changes in the beans during maturation, one of which is the change of colour of bean surface from light brown to very deep chocolate brown as maturation proceeds. The acid smell also disappears and a distinct

smell reminiscent of hay manifests. This smell is distinct from the odour of putrefaction from over fermentation of beans. In the case of box-maturation, the sudden drop in the temperature also is indicative of maturation. Mature beans are plump.

According to Abeygunasekera and Jansz (1989a), maturation caused a reduction in free amino acids, except for glutamic and aspartic acids. It also increased the content of volatile carbonyls (principally diacetyl, formaldehyde, acetone, acetaldehyde, butyraldehyde (iso- and n-) and valeraldehyde (iso- and n-). There appeared to be a relationship between these two trends, but the appearance of carbonyls is thought to be due not only to the breakdown of amino acids but to other processes including the oxidative degradation of fatty acids.

Holding fermented beans at ambient temperatures with some aeration for 48 h (maturation) increased pH from 4.8 to 5.2 and the content of the main non-volatile carboxylic acids (citric and oxalic acids) did not alter significantly (Abeygunasekera and Jansz, 1989b). There was a loss of sucrose and an increase in glucose, fructose and galactose. The xanthine content declined. Theobromine loss during maturation was about 30%, part of which may have been due to migration of the alkaloid from the cotyledons to the shell. Although the pyrazine content increased, the profile of pyrazines formed during roasting appeared to be unaffected by the maturation process. The anthocyanin content fell by 40-45%.

Dried fermented cocoa beans from different regions of the world recorded an organic acids content in the range 1.3-11.8 g acetic acid/kg, 1.6-9.9 g citric acid/kg, 0.6-11.1 g lactic acid/kg and 2.1-6.5 g oxalic acid/kg. pH values ranged from 4.6 to 5.8 and titrable acidity ranged from 0.08 to 0.31 (equivalents NaOH/kg sample). Cocoa beans from S.E. Asia and the South Pacific were more acidic than W. African beans. Lactic and acetic acids were found to be present in greater concentrations in cocoas from these regions and were considered to be largely responsible for higher acid flavour scores. In contrast, citric and oxalic acids were generally lower in these beans. Flavour evaluation of chocolates made with and without added organic acids indicated that oxalic acid played an important role in chocolate flavour.

Methods of Fermentation

The method of fermentation and its duration will depend largely on the variety of cocoa and the season. Criollo cocoa generally need a shorter period of fermentation as compared to the Forasteros. Season influences the duration of fermentation mainly through its effects on temperature and humidity. At lower temperature and high humidity, fermentation period will be usually longer.

Among the various methods adopted for fermentation in the different producing countries, the heap, tray and box methods are considered as the standard, widely adopted methods.

Heap method

This method is widely practised in West African countries. This essentially involves heaping a mass of not less than 50 kg of wet beans over a layer of banana leaves (Fig.2). The banana leaves are spread over a few sticks to keep them a little raised over the ground level to facilitate flow of sweatings. The leaves are folded and kept over the beans and a few wooden pieces are placed over it to keep the leaves in position. The purpose of keeping the beans covered with the leaves is to conserve the heat produced during the fermenting process. The heaps are dismantled and the beans are mixed the third and fifth days. It needs about six days for the completion of fermentation and the beans can be taken out for drying on the seventh day.

As soon as the beans are heaped, flow of sweatings starts and it continues for the first two days. Colour of the pulp changes on the surface of the mass of beans to a depth of about 10 cm by the third day with the bulk of beans inside retaining the whitish colour. This change of colour indicates the beginning of acetic acid production, which is limited to the surface layers where aeration is adequate. With the mixing of beans on the third and fifth days, beans on the surface whose pulp has almost drained away get mixed with the other pulpy beans. Diffusion of air is thus enhanced and acid fermentation occurs deep in the bean mass also.

Though free movement of air around the ferment is necessary, excessive wind movement may dissipate the heat developed. It is, therefore, safer to arrange the heap in an enclosed room with provision for normal aeration.

The minimum quantity required for effective fermentation is taken as 50 kg. A further increase in the quantity of beans in a heap will be beneficial. However, heaps of more than about 500 kg may be difficult to handle in a lot.

Tray method

This method was developed based on the early observations that when the beans are heaped for fermentation, there is change of colour of the beans upto a depth of about 10 cm when beans are not mixed. This was taken as an indication that there will be adequate aeration of the bean mass upto this depth without mixing and that if the beans are kept only upto this height, mixing can, probably, be avoided. Based on this, beans were filled in trays of 10 cm height holding reasonable quantities of beans and trial -fermented. It was found that when such trays are stacked one over the other, there is adequate development and conservation of heat and that fermentation would be over in a shorter period.

The usual size of wooden trays is 90 x 60 x 13 cm. Battens or reapers are fixed at the bottom of the trays with gaps in between such that the beans do not fall through, but allowing flow of sweatings. The depth of the beans inside should be about 10 cm. The length and width of the trays could be increased to any extent theoretically; but the above standard dimensions will make the size suitable for handling. Each tray of the above size can contain about 45 kg of wet beans. Thus filled, the trays are stacked one over the other. The minimum number of trays required for a stack will be about six. An empty tray is kept at the bottom to allow for drainage of the sweatings. After stacking, the beans of the top-most tray are covered with banana leaves. After 24 hours, the stack of trays is covered with gunny sacking to conserve the heat that develops. There is no need of mixing the beans. Fermentation will be normally completed in four days. On the fifth day, the beans are taken out for drying.

The minimum number of trays required to be stacked is about six; but as many as 12 trays can be used simultaneously. If it is a six-tray stack, the total quantity of wet beans required for effective fermentation will be about 270 kg. When a 12-tray stack is used, the minimum quantity will be about 540 kg.

Box method

This method is suitable for handling large quantities of beans. This is common in Malaysia where cocoa is grown in estate scale. The boxes are made of wood with a standard dimension of 1.2 x 0.95 x 0.75 m. Boxes of this size can hold about one tonne of wet beans. Holes are provided

at the bottom and on the sides of the box to allow flow of the sweatings and to facilitate aeration. The beans are to be mixed on alternate days transferring the beans from one box to another, at the time of mixing. This would necessitate having a minimum of three boxes. These may be arranged in a row in which case the beans are to be transferred from boxes after lifting them. To make transfer of beans convenient, the boxes are sometimes arranged in tiers and shutters provided on one side of the boxes so that the beans falling from the box at the top will run to the lower box on removing the shutters(Fig.3). The beans are mixed on the third and fifth days and are taken out for drying on the seventh day after six days of fermentation.

Though box method of fermentation will be convenient for handling large lots of beans, the quality of box-fermented beans is often rated as inferior to that from heap and tray methods. The factors responsible for lowering the quality are often related to inadequate aeration of the fermenting mass, which results in induction of acidity in the beans. Improving aeration in the boxes by blasting air through the bean mass has been found to reduce acidity. Bean maturation also reduces acidity of the beans.

According to Bhumibhamon *et al.*(1997) the beans fermented in boxes had slightly better cut test values than those in baskets. After 6 days, 54-67% of beans in boxes were fully fermented and 28-45% were 3/4-fermented, compared with 50-56 and 43-49%, respectively, in baskets.

Small Scale Methods of Fermentation

All the standard methods of fermentation need relatively large minimum quantities of wet beans. Even in the heap method, the smallest batch size is 50 kg or the produce from about 500 pods. While these methods suit the conditions in most of the cocoa producing countries, there is difficulty in adopting these under the Indian situation where cocoa holdings are generally very small. One alternative to this is the system of pooled fermentation which is followed in India at present, which involves procurement of cocoa as pods or wet beans and fermentation by the standard methods. Even in this system, there is the difficulty of transporting small quantities of pods or wet beans to the collection points. A more convenient alternative would be to adopt a method of fermentation involving small quantities of beans. Development of a small-scale method is not easily done as the use of a very small quantity of beans will make it difficult to develop adequate temperature of the fermenting mass, which is necessary for proper flavour development. In the standard methods of fermentation, the conditions in the bulk of fermenting mass remain anaerobic in the early part of the fermentation period. This also is difficult to be simulated with very small quantities of beans.

Logically, conservation of temperature could be done by keeping the beans in well-insulated containers with restricted air supply. There is a limit to this restriction in air supply as oxidative reactions must necessarily occur during fermentation. Another alternative would be to do supplemental heating of the fermenting mass from external sources. Though the latter method has been attempted by the use of solar heaters, precise temperature control is required to get desired results. From the point of view of ease of adoption, methods based on restricted aeration and insulated containers would be better.

Attempts were made in India to develop small scale methods of fermentation using bean lots substantially smaller than those required for the standard methods. Some of these methods have been found to be successful, as judged from temperature development of the ferment, pH of the beans and cut test (Kumaran *et al.*,1980 and 1981; Premalatha,1983).

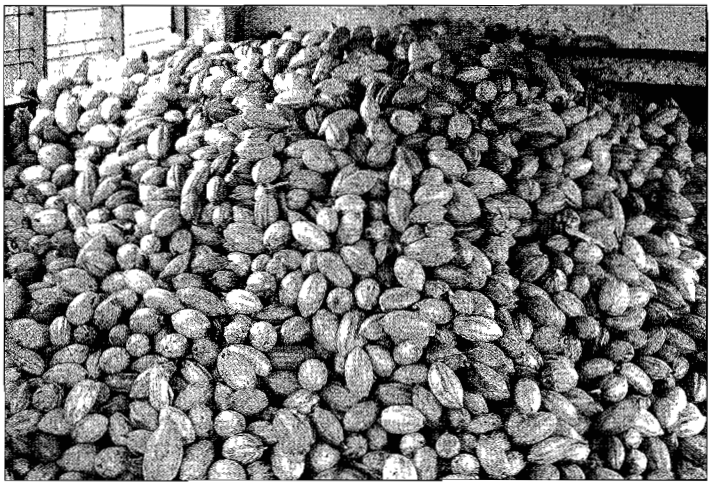

Fig.1. Post harvest pod storage

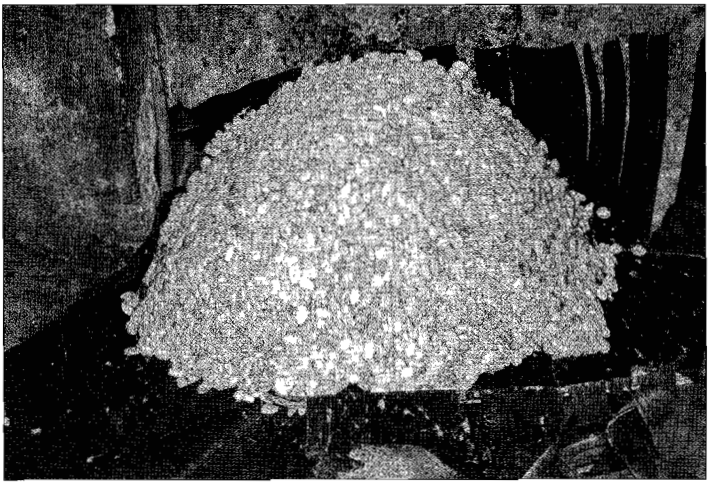

Fig.2. Heap method of fermentation

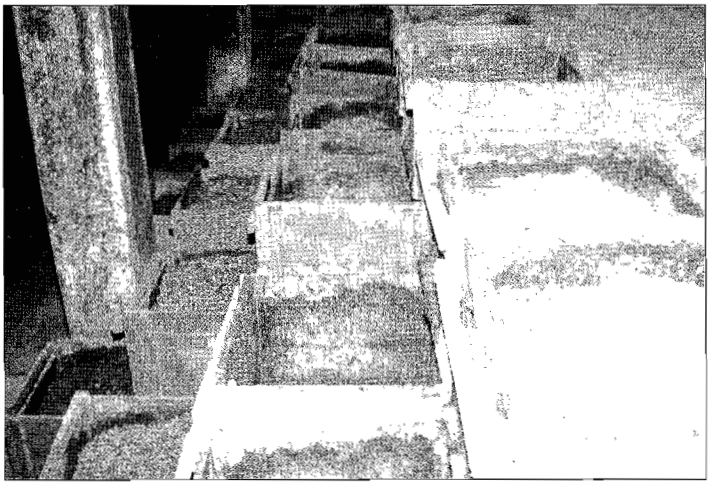

Fig.3. Box method of fermentation

Mini - box Method

Using this method, quantities as small as 2 kg wet beans can be fermented. The box required for this purpose should be made of wood and should be provided with holes of about 1 cm diameter at frequent intervals on the sides and at the bottom (Fig. 4). Wet beans are filled in these boxes and kept covered by a layer of banana leaves. The box is kept raised from the ground level to allow flow of sweating. The unit is kept covered with a double gunny sacking for 24 hours. After third day beans are taken out, mixed and refilled into the box and kept covered. Mixing is repeated on the fifth day and the box is reset. Fermentation will be over by the seventh day.

Mini - basket Method

This is similar to the box method except that closely woven baskets of suitable sizes are used instead of boxes and that a layer of banana leaves is spread before filling the beans in. As in the box method, covering with gunny sacking is done on the second day and mixing is done on the third and fifth days.

The effectiveness of small scale methods of fermentation of cocoa viz. tray, box and basket methods was reported by Kumaran *et al.*(1981). The best method among these is the tray method. Wooden trays of 10 cm deep with slatted split cane bottoms are divided into a number of sections by means of wooden partition that will fit into appropriate grooves at required distances. The capacity of the tray can be adjusted depending upon the availability of beans by keeping wooden plank in appropriate grooves. A convenient tray can be 25 cm width and 60 cm length. Wet beans are filled in the tray and levelled. About 10 kg of wet beans may be required to load one tray fully.

A single tray of beans may not ferment properly and at least four or five trays are needed for successful fermentation. The trays are stacked one above the other in such a manner that the cocoa filled portions are in a single row one above the other. The top tray is covered with plantain leaves. After 24 hours a close fitting gunny sack cover is put over the stack to keep the beans warm. Mixing or stirring of beans is not necessary and fermentation gets completed in 4-5 days, whereas 6-7 days are required for other methods of fermentation.

In the mini- basket method beans weighing 2- 6 kg can be fermented. Bamboo baskets, to hold 2 kg beans may be of 20 cm diameter and 15 cm height. For larger lots, height of the baskets may be increased. These baskets are lined with banana leaves. Wet beans are then filled, compacted and covered with banana leaves. The baskets are placed on a raised platform to allow flow of drippings. After 24 hours, it is covered with gunny sacking. The beans are to be taken out and stirred well after every 48 hours and may be taken out for drying on the seventh day. Premalatha (1983) found that mini-basket lined with banana leaves and mini- box were better suited for fermenting small quantities of cocoa beans.

Yusianto *et al.*(1995) analysed the flavour profile of beans fermented in small scale sweat boxes (40 kg) for 0-6 days with 0-5 turnings. Flavour analysis was carried out by Cadbury Ltd (Bouneville, UK). It was found that unfermented beans were low in chocolate flavour. Fermentation for 1-2 days was considered insufficient wherein chocolate flavour had developed but bitterness and astringency were still distinctly present. Fermentation for 3-4 days produced well- fermented beans with adequate chocolate flavour. Fermentation for 5-6 days resulted in over fermented beans with undesirable musty off- flavours.

Drying

The fermented beans will have a moisture content of about 55 %. Such a high moisture content is unsuitable for storage of the beans as putrefaction may set in. The moisture content has to be brought down to about 6 % for safe storage and transportation. This requires drying of the beans, which should commence immediately on cessation of fermentation. Unless the beans are skin-dry within 24 hours after fermentation, moulds set in and damage the beans. During drying there is biochemical oxidation of excess acetic acid from the beans. This reaction, being enzymatic, can proceed only when the seeds are still moist and when temperatures are below that at which degradation of enzymes occurs.

Sun drying

Sun drying is the simplest and the most popular method in most of the cocoa producing countries. Depending upon the climatic conditions, the beans are exposed to sun for about 12-20 days (Fig.5). This method generally gives good quality beans in traditional areas of cocoa production where the weather is sufficiently sunny. In West Africa, the beans can be simply laid out in the sun, spread in a thin layer on mats raised off the ground or on concrete floors. After two days, the beans are stirred and dried again. In West Indies and South America drying is done on wooden floors, while moveable roofs are used in Trinidad and Brazil. Drying can also be done on moveable trays which can be pushed under a fixed roof. A rocking dryer has been designed by the small farmers of Ivory Coast which consists of a bamboo platform with wooden edges covered with PVC sheeting which can be removed to facilitate mixing. The platform is pivoted about its center so that it can be directed towards the sun.

Artificial drying

Several types of artificial dryers are used and some work on the best drying conditions has been done in different cocoa growing countries. The results reveal that the major conditions recognized are temperature, rate of air- flow, bean depth and extent of bean stirring. Temperature affects the quality of the beans directly by deactivating the enzymes and indirectly by influencing the rate of removal of moisture. Air- flow also affects the rate of drying by affecting the rate of removal of humid air. It also has a bearing on the supply of oxygen for the oxidative degradation of residual acids. Bean depth and stirring decide the uniformity and speed of drying and aeration of the beans. High temperatures, high rates of airflow, lower thickness of beans and frequent stirring logically achieve quicker and more economical drying. However, these result in poor bean quality, the most frequently noted being the induction of acidity. Suitable drying conditions are, thus, a balance between the economy in drying and bean quality.

The maximum permissible temperature for drying is generally taken as about 60 ^{0}C. Variations from this have been reported often to yield beans of comparable quality. These include (i) allowing a higher temperature of about 80 ^{0}C at the final stages following drying at 60 ^{0}C during the initial period when the moisture content is brought down to 25 to 30 % (ii) giving a high temperature of 90 ^{0}C for the initial one to three hours to bring the moisture content to 40 %, followed by drying at a lower temperature of 70 ^{0}C for 8 to 10 hours and (iii) doing a two-stage drying with a resting period in between. Stirring of the beans also has been found necessary both for uniformity of drying and its efficiency. A convenient thickness could be about 12 to 15 cm when mixing is done manually.

Mechanical dryers

Several mechanical driers are used on larger plantations. The major factors influencing the efficiency of these driers include temperature, rate of airflow, bean- depth and extent of bean stirring. They are either movable tray dryers circulating in a tunnel through which hot air is circulated or rotary dryers where hot air passes over beans contained in a moveable cylinder. Yusianto *et. al.*(1995) found conventional high temperature drying to be undesirable as it produced low chocolate flavour and strong off-flavours. Bonaparte *et al.* (1998) recorded open air drying to favour high incidence of external mould than beans from the solar driers, although the differences were minor.

Drying by whatever means, must be thorough, the moisture content being reduced to 6-7 %. Moisture content above 8 % can lead to mould development inside the beans during subsequent storage and transport. While drying in mechanical driers, care must be taken to avoid exposure of beans to smoke and fumes. When the beans are dried properly, they produce a characteristic crackling sound on compressing a fistful of beans in the palm. The more scientific method is to use moisture meter. According to Augier (1998), gentler drying (at 40°C) led to a substantial reduction in acid content.

Adesuyi (1997) assessed the performance of a partially enclosed solar drier and traditional sun drying method for drying cocoa beans. The solar drier attained a significantly higher temperature, lower humidity, faster rate of drying (78 hours compared with 172 hours) and less mouldiness, no germinated beans, and no insect infestation after drying when compared with the traditional sun drying method. The solar drier was significantly more efficient, gave a better quality product and a 38.7% increase in income to the farmer than using traditional sun drying

Cunha *et al.* (1988) designed a platform drier to make artificial drying of cocoa more economical and efficient and to be adaptable for cocoa. The average performance data are as follows: initial load of 3682 kg (205 kg/m^2) fermented cocoa gives 1980 kg (110 kg/m^2) of dried cocoa, drying time of 51.7 h, general efficiency of 17.7% to reduce the mould content from 50.0 to 7.0% wet beans., 30 kg/h of wood used in the furnace and 0.95% breakage of beans in the final weight. The drier construction cost is 52.9% less than the tubular 6 x 6 m drier cost. If it is adapted under an existing sun drying platform, its cost falls to 264 OTN, 64.7% less than the tubular drier.

STORAGE

Dry cocoa beans can be stored for long under suitable conditions. However, the period of safe storage will depend on mainly the relative humidity and temperature of the atmosphere in which the beans are stored. In the temperate climates where humidity also is low the storage life is considered almost infinite. In the tropical regions of high humidity, it will be difficult to store the beans for considerable length of time.

It has been found that the bean moisture content will exceed 8 % when the relative humidity of atmosphere reaches 85 %. This moisture level of 8 % in the beans is critical, as when it is above this level, mould growth sets in. This means that it will be difficult to store cocoa beans without damage in atmospheres whose relative humidity exceeds 85 % for a considerable period of the year unless special precautions are taken to prevent contact of the dry beans with air.

In the cocoa-growing regions of India, the average relative humidity of the atmosphere remains high often exceeding 95 %. Storage of cocoa beans is, thus, difficult in the producing regions of the country in the rainy months. The practice at present followed is to shift the beans to other regions of the country where atmospheric conditions are suitable. Another alternative would be to store the well-dried beans in air-tight containers. Polythene or polythene-lined containers would come in handy for this purpose; but even such containers may not be very suitable for bulk storage of the beans during the continuously humid seasons. Premalatha and Mohanakumaran (1989b) recorded an increase in pH of the beans during the 28-week storage. Bopaiah (1992) studied the deterioration of processed cocoa beans during storage. Moisture content, growth of moulds and insect infestation were recorded at 12-week intervals up to 48 weeks. The microflora associated with processed cocoa beans were studied which affected the quality (Bopaiah *et al.* 1980). The damage due to moulds and insects increased after 36 weeks in storage. Storage of cocoa beans beyond 36 weeks requires redrying and packing to prevent deterioration.

QUALITY REQUIREMENTS

The word 'quality' includes all the important factors of flavour and purity. It also covers the physical characteristics, which have a direct influence on value and acceptability of a lot of cocoa beans. The quality of a sample is primarily judged by the flavour of chocolate made from it. It is also dependent on factors such as bean size, shell percentage, fat content and number of defective beans. Cocoa of good quality will have the inherent flavour of the type of cocoa together with the relevant physical characters and freedom from defects.

Flavour

Flavour is developed during fermentation and roasting. Flavour is assessed by tasting the chocolate made from a sample of beans using small scale methods. This is normally done by a panel of experienced tasters. Samples are evaluated for strength of chocolate flavour, astringency and presence of off- flavours. This method has some drawbacks in that the true flavour cannot be obtained by small scale processing and also the fact the palates of the tasters vary. Even then this is the only acceptable method of assessment of flavour. Davies *et al.*(1991) developed predictive model from the a near – IR (NIR) data on raw beans. In view of the uncertainty inherent in all sensory data, this result is considered to hold great promise for the replacement of difficult and demanding sensory analysis by simple and reliable measurement of NIR absorption for the evaluation of cocoa and other commodities, which are traded for their sensory properties.

The flavour varies with the type of cocoa. Criollo and Trinitario give 'fine' grade. These are highly prized by the manufacturers for making plain chocolate. Criollo gives a mild nutty flavour while Trinitarios have a full chocolate flavour with a some fruitiness or other ancillary flavour. Forastero types like Amelonado, Amazon and hybrids give 'bulk' cocoa, which constitute about 90-95 % of the worlds' supplies. The flavour of bulk cocoas varies from country to country. This variation arises due to the different practices prevalent in these countries on fermentation and drying. Ghanaian and Nigerian cocoas are considered to be of the premier grade in bulk cocoa market. This is due to the strict enforcement of quality standards. The quality of cocoa of Cameroon and Ivory Coast is poor due to lack of strict adherence to quality standards. Brazilian cocoa has the reputation of making off flavours and cocoa from the Dominican Republic has harsh astringent flavour as the beans are under fermented. Malaysian cocoa is considered to be acidic. Both fine and bulk cocoa suffer from several off- flavours, the details of which are furnished below:

Mouldy off – flavour: This arises due to the presence of moulds inside the beans and samples with as little as 4% of internally mouldy beans can impart an off –flavour to the chocolate. This off-flavour cannot be removed by processing. The presence of moulds inside the beans can be revealed by cut test. The moulds inside the beans increase the free fatty acid content of cocoa butter to the levels as high as 20%. If the free fatty acid content of a sample of cocoa beans exceed 1%, the free fatty acid derived from cocoa butter derived from them will exceed 1.75%, a limit which applies in EEC countries. There is also possibility of some moulds giving rise to the presence of mycotoxins (Bopaiah, 1992).

A large number of mould species have been found in cocoa beans. These invade the cocoa beans before harvest, during fermentation or drying and storage. Pods attacked by *Botrydiplodia theobromae* produce high percentage of beans with internal mould. If fermentation is prolonged beyond seven days, the percentage of internally mouldy beans increases considerably. When sun drying is prolonged due to dull weather, moulds get into the beans. When the humidity of the store is high, the beans absorb moisture and turn mouldy. Though moulds can be killed by irradiation (Appiah *et al.* 1982), it is not advisable to use radiation in food industries.

Smoky off- flavour: Contamination by smoke during drying or during storage can cause smoky off-flavours. This off- flavour cannot be removed during chocolate manufacture. The smoky off-flavour is sometimes referred to as 'hammy'. Hammy off- flavours can also arise due to over fermentation. This off-flavour can be detected by crushing bean samples in hand or in a pestle and mortar and then sniffing them. This is a quick test, but it is not as reliable as tasting chocolates made using small- scale methods.

Acidic off-flavour: This is due to the presence of excessive amounts of volatile (acetic acid) and non-volatile (lactic acid) acids. During manufacture, acetic acid is reduced to an acceptable low level, but lactic acid is not removed. The presence of lactic acid in excessive amounts will cause off-flavour. The presence of acetic acid can be readily detected by smelling the beans, but acidity due to lactic acid can only be detected by tasting the chocolate made from them. The non-acid West African beans have a pH of around 5.5. The pH is an indication of the degree of acidity, but not a measure of flavour. The pH of the beans can be manipulated by modifying the curing practices to reach 5.5, but their flavour may or may not be acceptable.

Bitterness and astringency: These arise due to poor fermentation. Though bitterness and astringency form a part of the complex of chocolate flavour, their presence in excess becomes objectionable. This type of off-flavour cannot be removed by normal factory processing. Unfermented or slaty beans have none of the precursors of chocolate flavour and chocolate made from them has a bitter, astringent and thoroughly unpleasant flavour. Fully purple beans or underfermented beans will have some chocolate flavour, but they will be bitter and astringent. Purple colour is due to the presence of unchanged anthocyanins. Anthocyanin is hydrolysed to a colourless leucocyanin during fermentation. A change in flavour is associated with this colour change. Beans with 30 % fully purple beans may impart a harsh and bitter taste to the finished product. The purple beans gradually change to brown during storage (Wickens, 1954). As much as 50% of the anthocyanins can be lost over a period of 4-5 months (Kenten, 1965).

Purity or wholesomeness

It is essential that the cocoa beans delivered to the market are pure. It should not contain any

impurities. In recent years, more importance is given to hygiene and safety at all levels of production and manufacture of food products.

The use of chemical pesticides/ fungicides at different stages of maturity of pods and storage can give rise to toxic residues in the cured beans. Limits have been fixed for the level of these chemicals in cocoa beans in different countries.

During fermentation, drying and storage substantial numbers of bacteria get into the beans. Though bacteria are essential for carrying out the fermentation, the multiplication of different types of bacteria and increase in large numbers can lead to infection by pathogenic bacteria like *Salmonella*. Normal manufacturing process will kill major portion of bacteria.

Several species of insects infest cocoa beans. The most important one which affect the quality of the finished product is tropical warehouse moth (*Ephesia cautella*). The presence of foreign matter may contaminate cocoa, affect flavour or cause damage to the plant and machinery, besides reducing the quantity of edible material.

Consistency

The quality of cocoa cured in a particular site and sent to different places should be consistent. This is essential because the chocolate manufactures aim to produce chocolate of consistent quality. To some extent, consistency of bulk cocoa can be achieved by blending cocoa of the same grade standard.

The average weight of cured dry bean should be at least 1.0 g. Smaller beans have high shell and low fat content. The manufacturers also require beans to be reasonably uniform in size because it is difficult to achieve effective cleaning and uniform roasting. The traditional criterion is that not more than 12 % of the beans should be outside the range $\pm$ one third of the average weight.

The shell should be loose, but strong enough to remain unbroken during normal handling. It should be free from lumps of dried pulp. Main crop of West Africa usually has a shell content of 11-12 %. Shell percentage can be reduced by washing the beans after fermentation, but the shell becomes so brittle that this practice is not advisable.

The cocoa grown under optimum conditions produces beans with 56-58% butter in the dry nib. This is an important factor, which decides the price of cocoa beans. For safe storage, the moisture content of cocoa beans should be around 6-7%. If it is above 8 %, there is risk of mould growth and if it is less than 5%, the shell becomes too brittle and the beans may break.

Cocoa butter characteristics

Good quality cured cocoa beans will contain a free fatty acid content of about 0.5%. The level must be less than 1.0 % as described earlier. Cocoa butter consists of triglycerides i.e. fats, which are made up of glycerol and three fatty acids, of which one is unsaturated. The proportions of fatty acids vary depending upon the growing conditions and this decides the texture of the finished product. Manufacturers prefer cocoa butter that is relatively hard and consistent. Cocoa butter from West African countries gives the desired physical properties.

SECONDARY PROCESSING

Secondary processing denotes the steps involved in conversion of cured beans into different finished products, the main product being chocolate. Chocolate means a homogeneous product

obtained by an adequate process of manufacture from a mixture of one or more of ingredients, namely cocoa beans, cocoa mass, cocoa press cake, cocoa powder, including fat reduced powder with or without addition of sugars, cocoa butter, milk solids including milk fat and non- prohibited flavouring agents.

Secondary processing of cocoa beans is done in specialised factories. Wood (1975), Wood and Lass (1985) and Mossu (1992) described the principles of chocolate manufacture in large factories. The essence of cocoa and chocolate manufacture lies in the development of flavour by roasting the beans followed by extraction of cocoa butter from the nib to produce cocoa powder, and addition of cocoa butter to the nib and sugar to produce chocolate.

Cleaning and sorting

When the beans arrive in the factory, they are cleaned to remove any foreign matter and sorted to separate the small or broken beans by passing them over a continuously vibrating screen. This is well aerated and is filled with powerful magnets. The metallic foreign matter, dusts and broken beans are removed.

Alkalisation

When beans are used for manufacture of cocoa powder the cocoa liquor is generally treated with alkali to improve the colour and to develop the flavour. Alkalised cocoa is known commercially as "Soluble Cocoa". The amount of alkali used for the preparation of soluble cocoa is adjusted to bring about partial rather than complete neutralisation. Saturated solutions of sodium or potassium carbonate or bicarbonates are most generally used while, ammonia, ammonium carbonate, magnesium oxide or carbonate or bi-carbonate or mixtures of certain of the above chemicals are favoured by some manufacturers. Alkali may be introduced prior to roasting or at the nib stage or a chocolate liquor stage. However, it is more economical to mix it with chocolate liquor.

The process of alkalisation involves soaking of nib in warm alkali solution until complete penetration into the nib was achieved. Both the quantity of alkali and its concentration in water used had a profound effect on the colour of the final cocoa. Alkalisation temperature of 80°C to 85°C gave the best flavour. The duration of alkalisation was determined by the time taken for the alkali solution to penetrate the nib. In production experiments this was found to be about an hour which was also the adequate time required for the mixture to reach 80°C (Minifie, 1968).

Liquor alkalisation has been widely practised particularly in Britain, but suspensions or solutions of alkali are used with much less water than with nib alkalisation and as a result sandy – brown cocoa are produced. Nib alkalisation produces a darker cocoa powder than that given by liquor alkalisation.

Roasting

Roasting of cocoa beans, more correctly termed as treatment of cocoa beans in hot air, is one of the most important operations in the processing of cocoa and the degree of treatment required being adjusted to the degree of ripeness of the beans concerned and any other pre-treatment which they may have undergone (Riedel, 1977). The true purpose of roasting is not only restricted to the loosening of the shells, but also to develop positive flavour as well as the removal of excess moisture and other undesirable volatile matter. It enables to bring down moisture content to 1.5-

2%. According to Heinzler and Eichner (1991) amadori compounds, formed by the reaction of reducing sugars (aldoses) and amino acids, occurring in roasted cocoa beans are precursors of the Maillard reaction leading to the formation of aroma compounds.

Different methods of roasting can be employed and they produce different end effects, some of which are more applicable to particular varieties of beans than others. The style of roasting should ensure an absolutely equal treatment of all the beans in the batch. Riedel (1974) suggested that the main objects of roasting are colour development, aroma and flavour development, modification of the structure of the shell so as to permit easier subsequent separation, reduction of moisture content, solubilization of cocoa starch and chemical changes, especially oxidation of some minor constituent of the beans.

Roasting causes some degree of loss of cocoa butter from the nib to the extent of 0.2 to 0.5 % by weight (dry basis) (Riedel, 1974). The loss occurs as a result of migration of fat from the nib into the shell. The higher the temperature, the greater will be the loss. The loss of fat can be appreciably reduced if the beans are cooled immediately after roasting. There is, in any case an overall loss in weight of 5 to 7 % while roasting due to reduction of moisture content. Riedel (1974) also stated that the most favoured temperature for proper roasting of cocoa beans for chocolate making lies between 120°C and 125°C. The optimum temperature is also to some extent dependent on the actual time allowed for roasting. The temperature and time have considerable influence on colour and flavour. Chemical changes take place in the nib at a temperature of about 120°C to 135°C. To obtain the final qualities of flavour, beans should usually be roasted at the lowest practical temperature. A low temperature roast can take up to 60 minutes to complete; a medium roast up to 40 minutes and a high temperature roast from 15 to 25 minutes. The discharged beans must be rapidly cooled to prevent over roasting with attendant discolouration and spoilage of flavour. There is very little loss of volatile acids from the beans during roasting. Up to 10 % of acetic and propionic acids are however released from the shell. Reduction of carbohydrates and amino acids also occur during roasting to the extent of 0.2 % of the dry nib weight. Properly dried beans have a moisture content of 4 to 6 %. During storage, the beans absorb water from the atmosphere and the moisture content can rise to 10 to 20 %. Well- stored beans can show a weight loss during roasting of 4 to 7 %, the greatest part of which is accountable to the removal of moisture.

Roasting can be done using direct or indirect heating, direct heating by gas, direct heating by steam pipes or heating by hot air. One of the most economic roasters is Lehmann Roaster. In this roaster, air is first used for cooling the beans and the beans are then further heated for roasting. The Buhler roaster uses heated air, which blows through the beans as they pass down sloping metal plates. The Nalder & Nalder machine is a steam heated machine, while Barth Sirocco machine uses only heated air for roasting. A continuous roasting machine has been introduced by Probat – Werke, of Emmerich. The roasting is produced by hot air, which is introduced in the appropriate quantity and at the appropriate rate at each stage of the roasting process. Exact control over the moisture content can also be exercised with the help of a special apparatus (Riedel, 1974).

Kibbling and winnowing

The shell is separated from the cotyledon by a process called 'kibbling'. The purpose of winnowing is to separate the shell and germ and to split the cocoa into its natural segments (cocoa nibs). Roasted cocoa beans can contain between 10 % and 15 % shell depending on the source and

about 1 % germ. The presence of significant amount of shell in chocolate will affect both colour and flavour and in addition reduces the effectiveness of refining. The separation of shell and germ can be carried out separately or together, depending on the choice of commercial plant. Cocoa beans are first cracked by passing through rollers or rotating cones. An air current is then used to blow away the lighter shell. The velocity of this air stream is critical, it should be sufficient to remove the undesirable shell but not too high to blow off the costly nib and must be varied to suit the changing size of cocoa bean from differing sources.

Discharged cocoa shell may contain as much as 20 to 25 % of cocoa fat. Yields of between 80 to 86 % are normally achieved by winnowing. The shell butter content of commercial shell is variable and fluctuates according to the amount of fat transferred from the nibs through roasting and the efficiency of the winnowing machine in separating nibs from shell. Cocoa shell butter is a deep yellow solid, and melts to a dark brown liquid. On account of its high acid value shell butter is not acceptable as human food.

Ademosun (1993) described a medium-scale cocoa dehulling and winnowing machine. The machine is rugged and easy to operate and maintain. The only adjustment required on the machine is the roller clearance. The quantity of cocoa nibs dehulled increases rapidly as the roller clearance decreases from 14 to 8 mm. The dehulling efficiency of the machine is 98.36% and the winnowing efficiency is approximately 95.5%.

Blending and Grinding

The cotyledons (called the 'nibs' at this stage) are ground to get 'mass' or 'liquor'. Cocoa mass contains about 55-58 % fat, which is also called 'cocoa butter'. This butter has the characteristic of "melting at body temperature". The cocoa nibs are finely ground at a relatively high temperature. Normally cocoa is subjected to a pre-grinding stage followed by fine grinding (Bauermeister, 1978). The particle size of the finished product has pronounced effect on its suitability as an ingredient of different food products (Minifie, 1968). During this operation heat is generated by friction, which melts the cocoa butter. Normal grinding is by means of either cylinder rollers of 3 or 4 stages or a ball mill. The ball mill gives better over all performance as regards to fineness of grinding and is simple to maintain (Bauermeister, 1978).

The other methods adopted by roll grinding which, uses a series of hollow water-cooled steel rolls or by a combination of steel and stone rolls operating at different speeds (Minifie, 1968). Each mill had a fixed and rotating steel disc and the gap between them was adjustable to give the required output and fineness. Daffey (1976) reported a Bauermister mill type referred as "Beater Blade Mill". This grinding mill is guaranteed for 600 hours, which is equivalent to 600 tonnes of product. Also it has the advantage of the ease of accessibility for cleaning and adjustments.

Extraction of the butter from the cocoa mass

Cocoa butter is extracted from mass or liquor with the help of a hydraulic press (Carver *et al.*, 1970). Horizontal pump-filled presses seems to work best when liquor is fed at temperature of about 93°C. In some of the installations, temperature is as high as 104°C to 113°C. Holding the liquor at these temperatures for a long time can affect the flavour and perhaps the colour of the final powder. Welch (1975) has also reported that liquor for pressing is normally heated just prior to pressing from 98 to 110°C and for fast pressing will ideally contain 1-1½ % moisture.

Brederode (1974) explains an automated system in which the roasted nibs are ground and during the process temperature develops to 100°C. Fat in the nib (55%) melts and the resultant liquor is pumped into a battery of horizontal pot presses, which are hydraulically operated at a pressure of 390 kg/ cm^2. The press cake that is obtained will have a fat content of 10-24% according to pressure and time.

A cocoa butter extractor for small scale use has been devised by Ganesan (1982; Fig.6), which utilized the pressure developed by hydraulic jack for extraction of the butter. The equipment could extract 44.8 % of the butter by applying a pressure of 248.72 kg / cm^2 at 70 °C. Broadbent *et al.* (1997) used a Brazilian-made, small-scale, portable expeller for extracting cocoa butter.

The cocoa butter obtained by employing any one of the above methods is filtered, if necessary, is neutralized and refined, deodourized and tempered. It is then moulded and cooled. At this stage it is hard in consistency, waxy, slightly shiny, pale yellow in colour and oily to touch. It melts at a temperature close to 35°C giving a clear liquid.

Making cocoa powder

The cake left behind at the bottom of the presses after the extraction of butter, contains a further 20% butter. This cake is milled and sieved. There are two types of cocoa powder: high fat powders containing 20-25% fat and low fat powders containing 10-13% fat. High fat powder is used in drinks while low fat powder is used in cakes, biscuits, ice creams and other chocolate flavoured products. In Thailand, high fat powder is used for the manufacture of cigarettes.

Production of Chocolates

Chocolate is produced by mixing sugar with nib or mass to which cocoa butter is added to enable the chocolate to be moulded. The proportion of mass sugar and cocoa butter varies with manufacturer and it remains to be a trade secret. The mixture of mass and sugar is ground at elevated temperatures to such a degree that the chocolate is very smooth. The mixture is then refined. This gives an absolutely homogenous mixture and a very fine grain size. It is carried out in cylindrical grinders which are placed on top of the other and which are adjusted to operate at increasingly closer spacings, rotating at different speeds of around 200 revs/minute. The mass then becomes dry and flaky. It is kneaded again in a blender and at this stage cocoa butter is added along with flavouring agents, if necessary. This mixture is then subjected to a process of mixing is called 'conching'. It is carried out in large vats- the conches. The original conche was a shell shaped tank and hence the name. In this conche, a roller is pushed to and fro on a granite bed for several hours or even days at temperatures ranging from 60-80°C. The time spent in conches determines the texture of the chocolate. Most of the cocoa butter and lecithin needed is added at the final stage of conching. Conching removes volatile acids contained in the beans and makes the chocolate homogeneous. After this the beans are tempered by reducing the temperature to 28-30°C in automatic tempering vats. The tempered chocolate passes into a weighing hopper which distributes it into moulds, tapping which causes the moulds to be continually shaken in order to distribute the mass evenly without air bubbles, refrigeration at 7°C and finally removing the chocolate from the moulds. This is done by turning out the moulds on to a felt conveyor belt, which receives the chocolate. The chocolates are wrapped in attractive packages. These operations are fully automated.

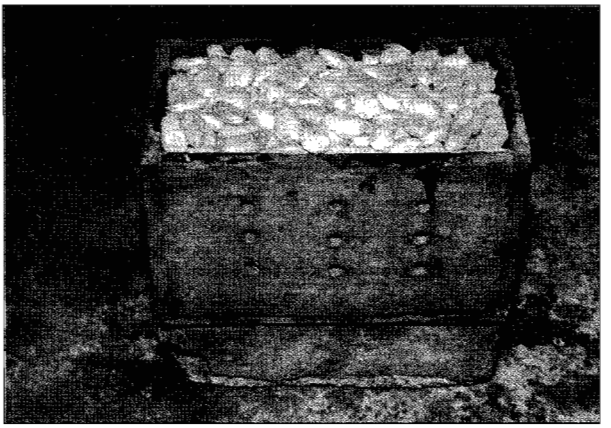

Fig.4. Mini-box fermentation

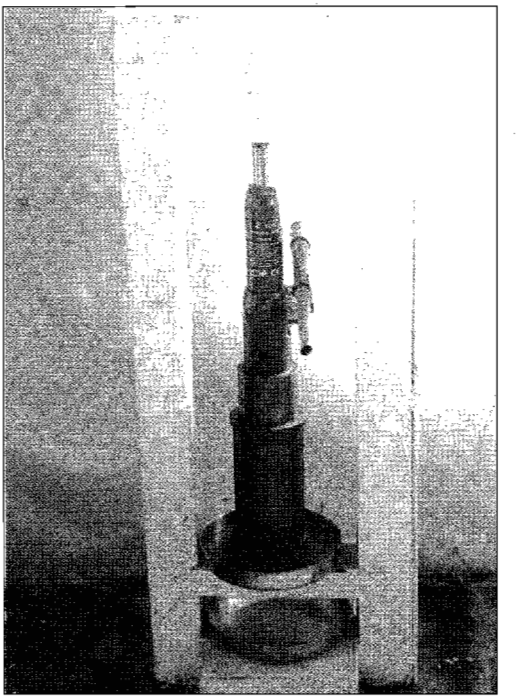

Fig.6. Cocoa butter extractor developed at KAU

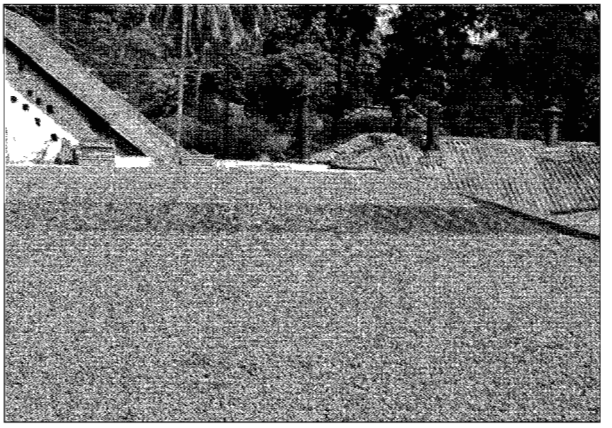

Fig.5. Drying of cocoa beans on ground

Milk Chocolates are prepared by adding milk or milk powder at the first stage of mixing mass with sugar. The milk is condensed with sugar and mass is then added. The mixture is dried under vacuum. This product is called 'crumb' and this is ground and conched with additional cocoa butter as described above. A typical crumb contains 13.5% liquor, 53.5% sugar and 32% milk solids. Various forms of milk chocolates have been developed which, differ in quantitities of these ingredients (Chmiel *et al.*, 1993; Hachiya *et al.*, 1994; Marsoner, 1995; Meister & Piek, 1990; Moor *et al.*, 1990; Zumbe and Bade, 1992). Apart from these, several cocoa based products like drinking chocolate, enrobing chocolate, chocolate flavoured milk etc. are used (Frassino *et al.*, 1998; Olenev and Tvorogova, 1988; Salama, 1994).

NUTRITIONAL VALUE OF CHOCOLATES

The chocolate based products have high energy value in relation to their volume. They contain a proportion of carbohydrate and protein together with vitamin B complex. Milk chocolate also contains milk protein, calcium and other minerals The plain chocolate contains 64.8% carbohydrate, 29.2% fat, 4.7% protein, sodium 11 mg/ 100g, K 300 mg/ 100g, Ca 38 mg/ 100g, Mg 100 mg/ 100g, P 140 mg/ 100g etc. A 100 g bar has 500 calories. It contains theobromine and caffeine, which are responsible for stimulatory effect. The chocolates have a restorative, energy producing and tonic effects on the body. Some studies indicate that the plain chocolate has a cholesterol content of 1 mg/ 100g and therefore plays a negligible role in cholesterol intake. However chocolate is not advocated for diabetic patients.

Digestibility studies of cocoa butter by Shahkhalili *et al.* (2000) showed that cocoa butter, consumed as black chocolate within a normal mixed diet, has a high digestibility and a digestible energy value of 37 kJ/g in man. However, the digestibility (Mitchell *et al.*, 1989) and absorbability (Chen *et al.*, 1989) of cocoa butter were significantly less.

BY-PRODUCTS

Processing of cocoa both at primary and secondary levels leave a large quantity of waste materials. The disposal of these is one of the problems in major cocoa growing tracts. Research on utilization of these indicate that several useful byproducts can be produced from cocoa wastes. The important waste materials are pod husk, sweatings, germ and shell.

Pod husk

About 70-75% of the pod is constituted by pod husk. This is generally discarded after collection of beans. The pod husk contains crude protein (5.69-9.69%), fatty substances (0.03-0.15%), glucose (1.16-3.92%), sucrose (0.02-0.16%), pectin (5.30-7.06%), nitrogen free extract (44.21-51.27%), crude fibre (33.19-39.45 %), theobromine (0.20-0.21%) and ash (8.83-10.18%) (Nambuthiri and Shivashankar, 1985).

Use as animal feed

The protein and fibre resemble hay. The pod husk contains less theobromine than cocoa shell and so makes it less dangerous as a feed stuff. Incorporation of a 20 % pod husk in cattle feed has shown beneficial effect (Sampath *et al.*,1990). According to Donkoh *et al.*(1991) cocoa pod husk (CPH) contained crude protein 76.6, ether extract 43.7, crude fibre 325, ash 101, acid detergent fibre 414, neutral detergent fibre 522 and hemicellulose 108 g/kg DM. Metabolizable energy content

was 4.72 MJ/kg. In broiler chickens, 1 week old, CPH 200 g increased feed intake by nearly 60%, reduced growth and reduced feed conversion efficiency. Evaluation of cocoa husk, cocoa shell, cocoa cake and cocoa dust in poultry and livestock feeds by Abiola and Tewe (1991) showed that all by products had nutritive value. However, cocoa husk was considered to be more useful than the others in animal feed because of its high content of minerals, low level of theobromine and its availability in large quantities on cocoa farms and plantations. Ridzwan *et al.*(1993) reported that in white rabbits, there was no significant difference in final body weight, weight gain and feed conversion efficiency among rabbits given cocoa-pod husks. There was a slight decrease in energy digestibility when crude fibre content increased, especially for the diet containing cocoa-pod husks 300 g/kg. In lambs, 15-30% CPH in meal increased the mean daily gain in body weight (Antongiovanni *et al.*,1993). 10 and 20% CHM in laying hen diets had no significant effect on egg production (%), egg weight and feed efficiency (Sobamiwa, 1998)

In *O. niloticus* fingerlings reared in a recirculation system, Falaye and Jauncey (!999) determined the acceptability, digestibility and nutrient utilization of feeds containing cocoa husk. Three semipurified isonitrogenous diets formulated to contain cocoa husk 0, 100 or 200 g/kg were fed to satiation 3 times daily. Although feeds containing cocoa husk were acceptable to the fish, as indicated by their voracious consumption and positive weight gains, there were reductions in gross feed conversion efficiency with cocoa husk feeds.

As manure

The nitrogen and phosphorus content of the pod husk is comparable to farm yard manure from animals. The potash content is very high (2.85 to 5.27% K_2O). Adu-Dapaah *et al.*(1994) obtained higher shoot and root dry matter yields in maize with increasing application of cocoa pod ash. Application of 140 kg cocoa pod ash/ha (equivalent to 56 kg K_2O/ha) produced the same dry matter and shoot K yields as 56 kg K_2O/ha as muriate of potash. The optimum rate of application of cocoa pod ash was 280 kg/ha (112 kg K_2O/ha).

Other uses

The high fibre content of pod husk suggests its use in paper manufacture, but its low fibre length of 0.3 – 0.5 mm rules out this possibility. Pod husk as a source for the production of furfural (9%) is not comparable in yield with (9%) materials like oat hull, corn cob and cotton seed. Hence production of fufural from pod husk is not commercially viable. The dry pod husk contains 5.3-7.08% pectin. This is high when compared to established raw materials like orange pulp, lemon pulp and apple pomace. The quality of endocarp pectin is superior to that of pectin from sweatings.

Mucilage

The concentration of alcohol in the sweatings is about 2-3% and of acetic acid 2.5%. The sweatings contain water 79.2-84.2%, dry substances 15.2-20.8%, Citric acid 0.77-1.52%, glucose 11.60-15.32%, sucrose 0.11-0.92%, pectin 0.90-1.19%, proteins 0.56-0.69%, salts (K, Na, Ca, Mg) 0.41-0.54% with a p^H of 3.2-3.5. Sweatings can be used for making jelly or jam. The pectin from sweatings show slow setting characteristic.

Shell

The availability of bean shell is of the order of 11-12 % of the dry beans. It contains 2.8% starch, 6.0 % pectin, 18.6% fibre, theobromine 1.3%, caffeine 0.1%, total nitrogen 2.8%, fat 3.4%,

total ash 8.1%, tannins 3.3%, vitamin D 300 IU etc. The yield of furfural is about 5-6%. Though there is possibility of extracting protein, tannin and red colour from shells, this is not economically viable. The scope for use as animal feed is limited due to high theobromine content. Chase (1989) recorded available milk fat contents 3.17, 3.27, 3.60 and 3.69% for the rations containing 0, 3, 6, or 9% cocoa shell meal (CSM). Yeong *et al.* (1989) found that in broiler chicks, feed containing 0, 5, 10, 15 and 20% cocoa bean shell (CBS) in the starter and finishing period or in the finishing period alone of 4 and 4 weeks, respectively decreased in feed intake and body weight gain with increased dietary CBS. Mortality increased with the increased dietary CBS. At 20% CBS, mortality was 70 and 83.7% for chickens and ducks, respectively. Mortality was due to 1.99% of theobromine in CBS, which caused intestinal lesion in the distal part of the digestive tract. Mortality and adverse effects were less serious if the feeding of CBS-based diets were started only in the finishing period.

A daily intake of theobromine of more than 0.025 g kg of body weight has adverse effects. Deaths are reported in horses at a daily rate of 0.027 g per kg of body weight. While small quantities of theobromine are tolerable to ruminants, they are dangerous to pigs and poultry. As fertilizer, shells act as humus forming base. They do not decompose readily. This can be overcome by heaping for one season. Theobromine is extracted commercially and methylated to form caffeine, which has greater demand than theobromine. As fuel, the calorific value of shell is about 7400-8600 B.T.U. which is a little higher than that of wood.

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8. DEVELOPMENT AND MARKETING

P.P. Balasubramanian

INTRODUCTION

Cocoa (*Theobroma cacao* L.) a native of Amazon base of South America got its entry into India in the early half of the 20th century. Administratively it is conferred plantation status like coffee, tea and rubber but is seldom recognised as a plantation crop under the Indian Agrarian Administrative Sector. It is also one of the supporter of Agro-based industry in India. Cocoa beans is the primary raw material for confectioneries, beverages, chocolates and other edible products. The commercial sector of cocoa in India hardly takes place in a major way in the international export trade. Majority of the processed cocoa products are consumed within India. The tropical diversified congenial climate available in India provides immense scope for its cultivation.

Cocoa is hardly grown as a mono crop. Its imminent capacity to share the alley spaces of tall growing coconut and arecanut palms and its combining ability with the microclimatic conditions available in such perennial gardens helps its cultivation in utilising such areas without exacting for an independent growing climate of its own. In any groves of tall growing palms where 40-50% sunlight penetration is possible, cocoa stands first to absorb such solar energy, remaining symbiotic to the main crop and generating additional income as well, besides helping the amelioration of the soil conditions making beneficial not only for its own growth but also for the benefit of the main crop under which it takes its shelter. When development of cocoa in such conditions is considered, its integration with other perennial coconut and arecanut groves also becomes important. Therefore the integrated development of cocoa, in other words is an integrated management of coconut and arecanut along with cocoa.

PRODUCTION

The major area of cocoa production is West Africa where, about 60 per cent of the world's cocoa is grown. The four major African producers are the Ivory Coast, Ghana, Nigeria and Cameroon. Out side of West Africa, other major producers of cocoa are Indonesia, Malaysia, Brazil, The Dominican Republic and Ecuador. Ivory coast is the largest producer of cocoa in the world followed by Indonesia and Ghana, accounting for a total production of nearly 2 million MT (ICCO, 1998; Fig.1).

From 1980-81 to 1990-91, cocoa production in Ivory Coast increased by 95% and in 1996-97 reached 11,25,000 tonnes. High and consistent prices paid to farmers in the early years helped to lay the foundation for the increase in production. Prices were guaranteed for farmers despite the falling world prices. Ivory coast is a low cost producer with reasonable production yields. Indonesia has outstripped all other countries in terms of production growth. In 1981-82 it had produced 16,000 tonnes and in 1996-97 production rose to 3,20,000 tonnes. The growth has been assisted by a free economy combined with cheap government land grants. Almost 90% of production in the

Cocoa, 2002 (Ed. Balasimha, D.), CPCRI, Kasaragod 671 124

world comes from smallholdings under 5 hectares. The United States Department of Agriculture (USDA) forecast world cocoa production in 2002 at 2.89 million tonnes (Lattre *et al.*, 1998). The trend in world cocoa area and production is given in Figs. 2 and 3.

CONSUMPTION

Netherlands and U.S.A. are the major consumers of cocoa and cocoa products. Other consuming countries are Ivory Coast, Germany, Brazil, UK and France (Fig.4). Chocolate has reached most regions of the world but the level of consumption varies widely. The developed nations generally have high levels of chocolate consumption in comparison with the developing nations. Nearly two-third of cocoa product imports are consumed by Western Europe and North America. Demand in emerging economies, however, is growing. In China, imports rose to 9,000 tonnes in the year 2000, an increase of more than 90 per cent over the previous year, Other Asian markets also appear to have good growth potential (ICCO, 1999).

Chocolate is now the biggest sector of the $30bn European confectionery market, Valued at $5,323.4m in 1996. The UK had the highest chocolate sales in Europe, followed by Germany at $4,266.6m and France with $2,122.1m. At an expenditure of more than $90 per head per year UK spends more than twice the European average of $48.08. Other big spenders are the Irish and the Swedish. European chocolate consumption per person per year, showed that the Swiss were the highest consumers at 10.18 kg per person, followed by Belgium and Germany. The lowest consumers were Portugal at 1.93 kg and Greece at 2.84 kg (Rothwell, 1998).In China, 34,000 tonnes of chocolate are consumed each year. Average consumption of confectionery is 0.55 kg per head. The volume of confectionery sales is forecast to grow at a rate of 12.7% per annum up to the year 2001, compared with United States market growth of 1.2% and the Britain at 1.5%.

The estimates for 2000-2001 show that world cocoa consumption was around 0.525 kg per head. There are, however, wide variations in consumption levels between the regions. Europeans consume on average around 1.73 kg per head, Americans 1.3 kg Asians 0.093 kg and Africans 0.146 kg (Taylor, 2000).

INDIAN SCENARIO

The area under cocoa prior to 1980 was 22,600 ha with an estimated production of 3200 MT of dry beans. Kerala was the major State holding 18,000 ha with 1500 MT of production. Karnataka was the only other state where cocoa cultivation was existing and the area was 4300 ha with a production of 1700 MT. Not much change took place in increasing the area but on the contrary a declining trend was observed in these two States and by 1996-97 the area under these two States were of the order of 10,240 ha and 1,160 ha respectively. The production in these two States was of the order of 5750 MT and 650 MT respectively in 1996-97. From 1997-98 onwards the non-traditional tracts of Karnataka and other States like Andhra Pradesh and Tamil Nadu started developing cocoa. As on day, with the implementation of 8th Five Year Plan programmes through distribution of high yielding varieties in the form of clones and hybrid seedlings, the area under Karnataka increased to 4400 ha. Andhra Pradesh and Tamil Nadu, which are new entrants from later part of 80's, have an area of 2744 and 92 ha respectively. Kerala further dwindled down in its area to the level of 8949 ha. The productivity of cocoa on an average stagnates at 500 kg of dry beans per ha. The details of area and production of cocoa as on 2001-2002 are given in Table 1.

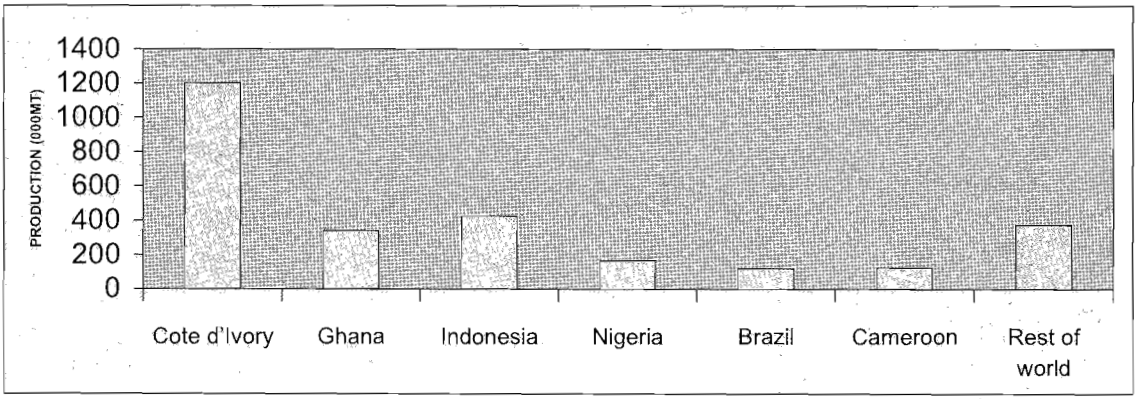

Fig. 1. Global cocoa production

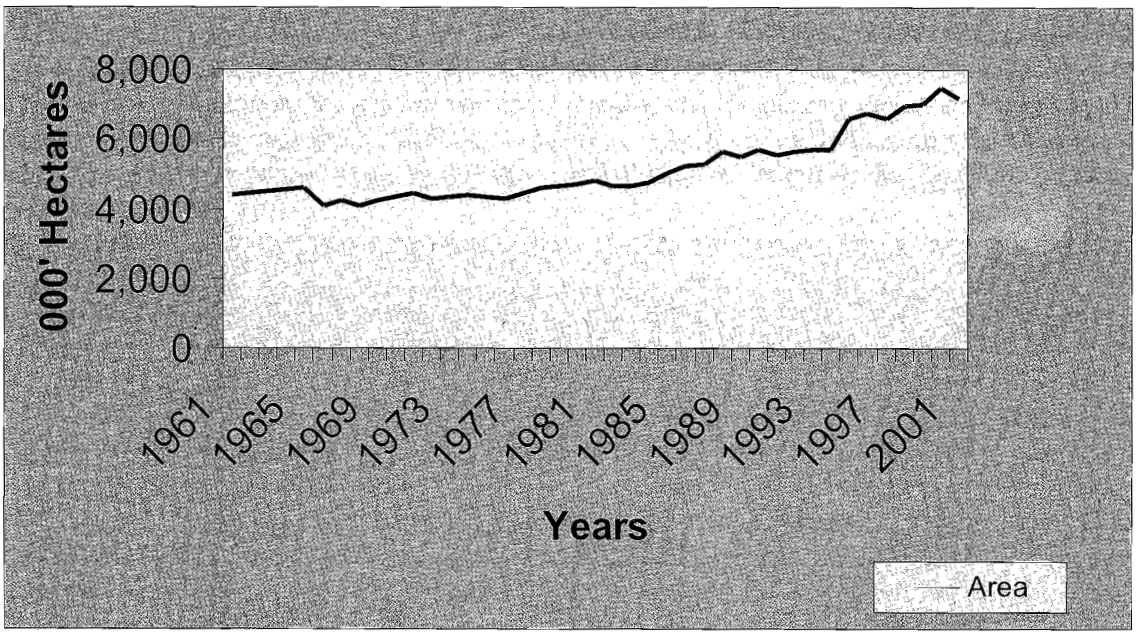

Fig.2. World cocoa area (*Source: FAO Statistics 2002)*

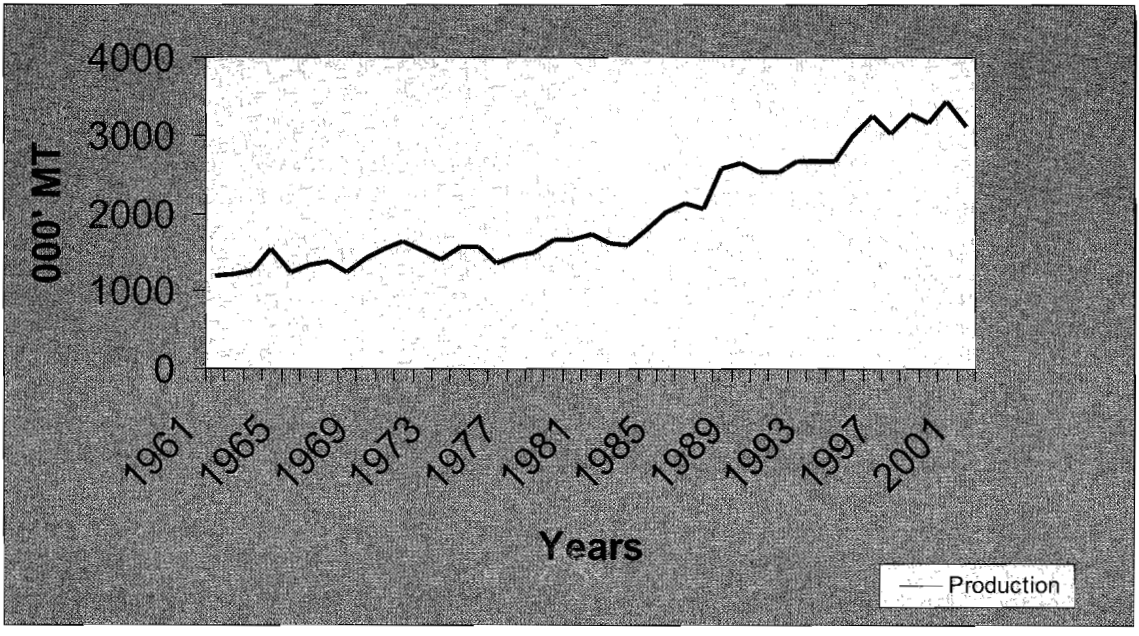

Fig.3. World Cocoa Production (*Source: FAO Statistics 2002)*

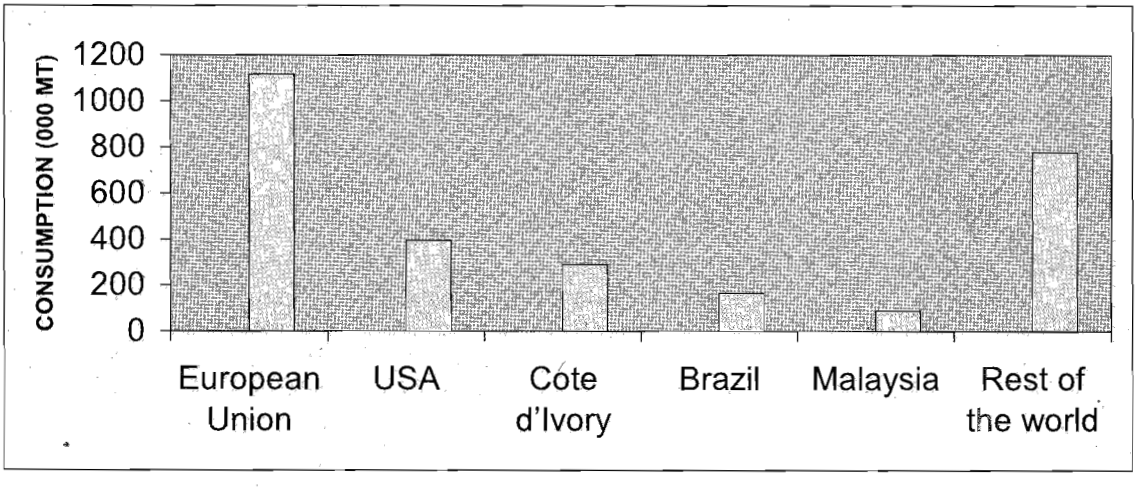

Fig.4. Global consumption of cocoa

Table 1. Area and production of cocoa in India (2001-02)

State	Area (ha)	Production (MT)
Kerala	8949	4874
Karnataka	4406	1870
Andhra Pradesh	2744	890
Tamil Nadu	92	50
Total	16185	7650

The Indian chocolate market was about 20,000 tonnes in volume and US $125m in value in 1998 and is growing at about 15 per cent per year. Per capita chocolate consumption is very low, which is about 200g per person and it is mainly consumed in urban areas. In the middle and higher income groups 70 per cent of children, 43 per cent of young adults and 16 per cent of adults consume chocolate. In 1996-97 Cadbury had 62 per cent of the Indian chocolate market with 11,500 tonnes, Nestle 25 per cent at 4,500 tonnes, Lotus 9 per cent at 1,800 tonnes and Amul 4 per cent at 700 tonnes. Cadbury increased its market share in 1998 to 70 per cent (Agarwal, 2000).

In India a trend of increasing consumption of chocolates and other cocoa-based products has emerged, especially among the middle class. The growth of the chocolate market has in the past been restricted by the low purchasing power of a large section of the population. Also, until recently, chocolates and other cocoa-based snack foods were considered to be expensive and looked upon as food of elitist consumption. After India adopted the process of economic liberalization in July 1991, major changes occurred in the food habits of the people. This followed the marked rise in gross domestic product (GDP) growth, which put a lot more purchasing power in the hands of the middle-class population. Studies have revealed that demand for and consumption of snack food is more income elastic than price elastic. A study projected sales of the Indian chocolate industry to rise from $125m at present to $175m by the year 2000 and to $450m by the year 2005 (Agarwal and Mehta, 1999).

MARKETING

The world cocoa market is characterized by a cycle of brief boom periods of shortages and rising prices, followed by much longer periods of excess supply and falling prices. Consumers respond more rapidly to price alterations than do producers. These cycles of price boom and price fall are sufficiently persistent to affect the steady growth of cocoa production and consumption (LaFleur, 1984). In the 1990s, the world cocoa market has become increasingly sophisticated and has seen a number of changes. These include the bulk delivery of terminal market cocoa, recent changes in the area of quality assessment, and the move towards harmonization of physical contract terms within the European Union. Trading techniques worldwide have continued to improve in line with improvements in communications and, despite current low prices, cocoa is still the seventh largest food commodity exported in the world (Dand, 1999).

The potential for growth in consumption of chocolate products in India is very high. Cocoa bean production also has great potential for increase. It is estimated that 50% of the current crop is lost through pests and diseases. If this damage were controlled production would be instantly increased, and growing cocoa become much more profitable, giving an incentive to more farmers to take up cultivation (Krisnaswamy, 1995)

Kerala was the leading state in India promoting cocoa cultivation. Massive area coverage was possible through distribution of cocoa seedlings. There was an attractive price for cocoa pods and beans prevalent till 1980's. This favorable situation coupled with planting material distribution could bring about an enviable coverage under cocoa cultivation recording 29,000 ha of cocoa by 1980-81 (Velappan, 1992). Being a crop subjected to the monopolistic exploitation of the available industrial units, however paved ways for fall in price in 1981-82 and 1982-83. Inadequate marketing network and the fall in price since 1982-83 developed a sense of insecurity among the plantation communities, which detrimentally affected its expansion, besides attributing to neglectful approach by the plantation community. Throughout 1980's, wet beans price of cocoa remained below Rs.10/- per kg. Only from the beginning of 1990's, the price gradually increased offering a price varying from Rs.12/- to Rs.17/- per kg which could help in resetting the cocoa cultivation and industrial consumption back on its tract, as we find it now. Average price of cocoa fetched by an Indian farmer is around Rs.17/- per kg of wet beans at present.

In the 1990s, the cocoa market has become increasingly sophisticated and has seen a number of changes (Dand, 1999). These include the bulk delivery of terminal market cocoa, recent changes in the area of quality assessment, and the move towards harmonization of physical contract terms within the countries. Trading techniques worldwide have continued to improve. The domestic prices of cocoa beans are comparable to international prices (Table 2).

Table 2. Price behaviour of cocoa beans (Rs/kg)

Year	Domestic	International
1996	48.95	48.40
1997	56.30	49.20
1998	60.00	55.70
1999	74.00	65.60
2000	64.00	38.80
2001	54.00	44.63

EFFORTS OF COCOA DEVELOPMENT IN THE PLAN PERIODS

A Central Sector Scheme providing training to farmers and laying out field demonstrations on scientific methods of cultivation and on farm processing of cocoa beans was implemented in the 5th Plan and the same was continued in the subsequent two Plan periods (6th Plan & 7th Plan). During the 8th Five Year Plan steps were taken to generate good quality planting materials, to rejuvenate unproductive trees and to support irrigation and marketing network besides measures for transfer of technology through demonstration and farmers training programmes.

Eventhough a good beginning in this regard was made during 8th Plan period, establishment of clonal seed gardens, demonstration plots and production and distribution of hybrid seedlings and grafts production, oriented programmes with a project approach and integrated measures were highly lacking. The infrastructural development also was very much limited particularly towards the generation of high yielding clones and hybrid seedlings. Even though research institutes were assisted towards development of clonal seed gardens, there was not proper linkage with area coverage.

Infrastructure for generation of planting materials has been supported only to Research Institutes which has been quite inadequate to the quantum requirement to the planting material when compared to the production target to be achieved. Strengthening this area with establishment of Regional Nurseries has become a thrust area in this regard.

Experience over the years had shown that cocoa comes up very well in the traditional areas in the country (Kerala and Karnataka) as an inter crop of coconut and arecanut especially when cultivated with irrigation. Results of experiments conducted at CPCRI and KAU has also shown that if properly managed with fertilizers and irrigation, the yield of the main crop (coconut and arecanut) also tends to increase. The experience in the farmers field also had been similar in the early years and it was considered that this crop combination is compatible and symbiotic. The large return of organic residues by cocoa and the substantial build up of the organic matter content of the soil were the reasons for the benefits obtained from coconut and arecanut. To increase production, the unthrifty nature of existing cocoa gardens do pose a serious problem. Rejuvenation by top working method standardised by the research has been found beneficial. However, adoption of such practices is possible only in Kerala and Karnataka. Due to its high location specific nature, adoption of such practices in large scale is rather difficult. Therefore, emphasishave to be again on new area development.

The productivity of the existing gardens are not highly encouraging, as such productivity level is only just 30% of the potential exploitable by way of using high yielding clones. The genetic inferiority of the existing plantations is one of the factor for low productivity. Sufficient contribution of the research by way of evolution of good selection and hybrids are now available. Clonal multiplicationof these varieties have a potential productivity of 3 kg of cocoa per tree. Basic infrastructure build up by way of regional nurseries is therefore the foremost approach in the 9th Five Year Plan. Technological development in cocoa by way of proper nutrition, clonal multiplication and pest and disease management are of recent origin and transfer of these technolgies among the plantation community is an essential part of propagating economic level of cocoa plantation management. Besides adequate publicity on these aspects as one of the measures of transfer of technology, development of model cocoa clonal gardens also envisaged in the 9th Five Year Plan. In order to strengthen the present marketing systems in cocoa adequate infrastructure for the formation of marketing systems is envisaged in the 9th Plan. Integration of production technologies has the salient approach of 9th Five Year Plan.

There is great potential for producing cocoa in irrigated coconut and arecanut gardens because of its need for partial shade. States like Kerala, Karnataka, Goa, some parts of Maharashtra, Pondicherry, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal will therefore offer considerable scope for its development as these areas are coastal belts where coconut is grown under irrigated conditions. Of the 15.00 lakh ha of coconut gardens in India, the coconut areas in Karnataka, Pondicherry, Tamil Nadu and Andhra Pradesh are mostly irrigated in nature. In respect of other states, nearly 30-40% are under irrigation. Therefore not less than 3.00 lakh ha will definitely be suitable for growing Cocoa as an inter-crop.

FUTURE STRATEGY

Cocoa is generally taken up as an inter-crop or more precisely a companion crop under irrigated coconut and arecanut gardens. To some extent it is grown under rainfed conditions in some parts

of Kerala. The production of cocoa beans hardly meets 30% of the demand projected by the processing industry in India. As assessed, the demand of cocoa beans is 30,000 MT by 2005 AD. To step up the production to the projections of the industry, at least 23,000 MT are to be produced within a span of 10 years. In other words, if only a 20% annual growth rate is achieved, attaining 30,000 MT by 2005 is possible. In order to achieve this production level 20,000 ha at least will have to be brought under cocoa during the 9th Five Year Plan. In order to attain self sufficiency, increasing the area by inter-cropping cocoa in the available irrigated coconut/arecanut gardens both in traditional and non-traditional areas is the only way to increase production of cocoa beans. Therefore inter-cropping cocoa in 15,000 ha of irrigated coconut and arecanut garden with F1 hybrid seedlings/grafts have been suggested in the 10th Plan. To increase the production, the unthrifty nature of existing gardens is to be replanted/rejuvenated by top working method standardized by the research. Infrastructural support by way of establishment of Regional Nurseries and transfer of technology through demonstration, farmers training and plant protection campaigns are also envisaged in 10th Five Year Plan.

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