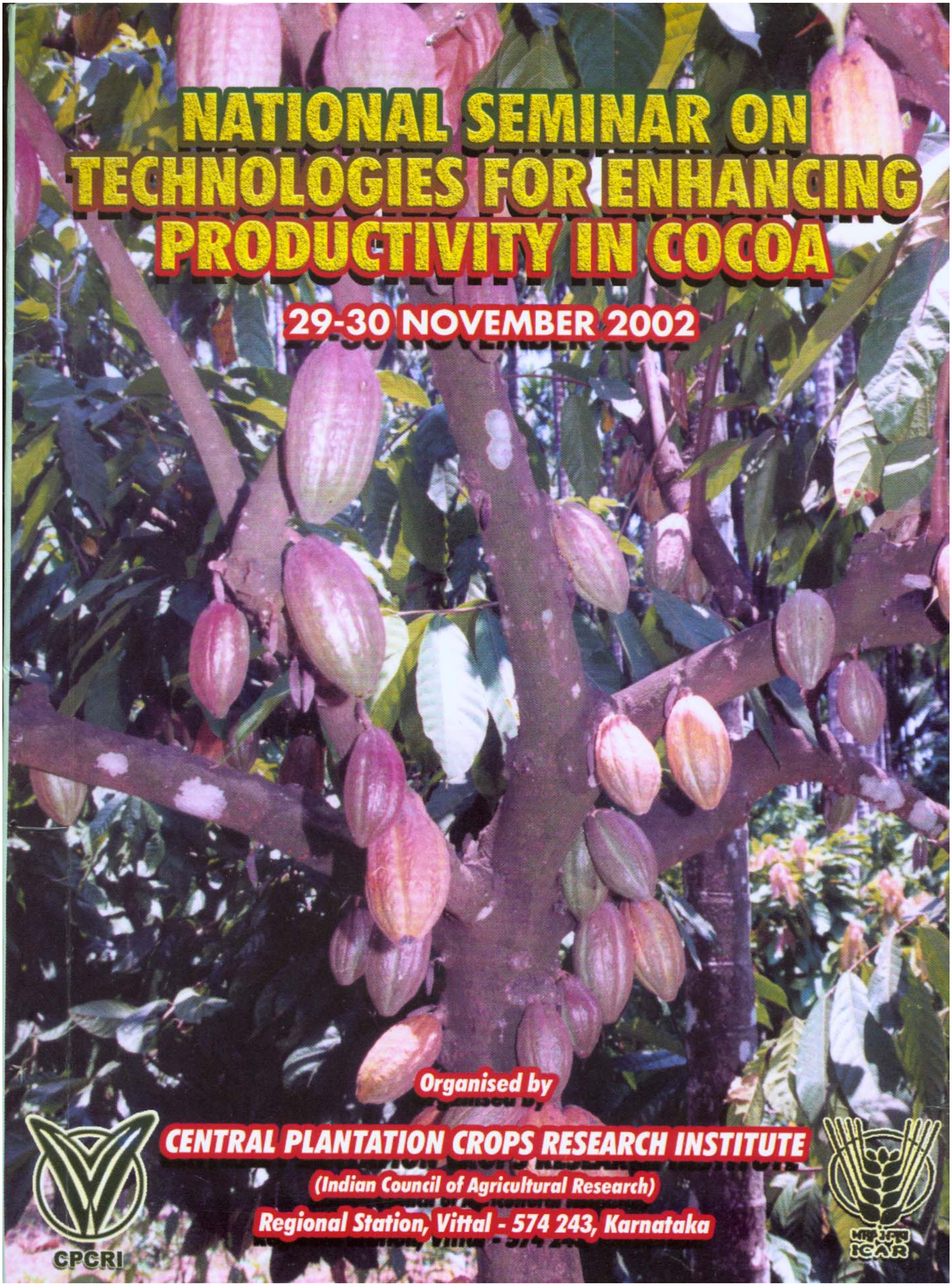

# NATIONAL SEMINAR ON TECHNOLOGIES FOR ENHANCING PRODUCTIVITY IN COCOA

## 29-30 NOVEMBER 2002


Organised by

CENTRAL PLANTATION CROPS RESEARCH INSTITUTE

(Indian Council of Agricultural Research)

Regional Station, Vittal - 574 243, Karnataka

# NATIONAL SEMINAR ON TECHNOLOGIES FOR ENHANCING PRODUCTIVITY IN COCOA

29-30 November 2002

## EXTENDED SUMMARIES

**Editors :**
**Ravi Bhat**
**D. Balasimha**
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***Organised by***

CPCRI

**Central Plantation Crops Research Institute**
**(*Indian Council of Agricultural Research*)**
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# FOREWORD

Cocoa (*Theobroma cacao* L.), a native of Amazon river basin, was introduced in India in the early part of 20th century. It is a shade loving crop traditionally grown under forest cover. The major cocoa cultivating countries of the world are Ghana, Ivory Coast, Indonesia, Brazil, and Nigeria. Contribution to the world cocoa production from Asian countries is about 18 per cent. Though India's contribution to world cocoa production is negligible, the cocoa growing condition in South India as a component crop along with palms, makes it an important crop in forthcoming years. The commercial cultivation of the crop started in India in the 1960's and at present it is cultivated in 14,200 hactares with a production of 6,000 tonnes and a productivity of 480 kg/ha.

According to the Cocoa Development Council, the demand for cocoa beans by 2003 is about 18,000 to 20,000 tonnes and this is going to increase over the years. This needs improvement in cocoa production by 15-20 per cent. Cocoa can be grown in the interspaces of major cultivated palms. It can give additional income of more than Rs. 50,000/ha without adversely affecting the yield of main crop. So time has come to exploit the potentialities of cocoa production in India by increasing the area under cocoa.

Central Plantation Crops Research Institute's Regional Station at Vittal, started systematic research on cocoa since 1970 and has given initiation for increasing cocoa production in India. The Institute has standardized the cultivation technologies and has identified high yielding clones. The Institute has a germplasm collection 137 accessions, which supports the breeding programme. The Institute is instrumental in popularizing cocoa among the farmers.

The National Seminar on Technologies for Enhancing Productivity in Cocoa being organized by Central Plantation Crops Research, Regional Station, Vittal is timely since cocoa cultivation is being extended to newer areas. This seminar reviews the work done on cocoa for the last 30 years in different parts of the country. I hope the seminar will be a stepping stone for increasing the cocoa production in the country. I am happy to know that an interface programme with farmers is also arranged to understand the problems of farmers, which can help in restructuring the research programmes on cocoa.

I hope the deliberations during different sessions by the research workers, development agencies and the farmers will lead to concrete conclusions for increasing cocoa production in the country.

I wish the seminar all the success.

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# PREFACE

Cocoa (*Theobroma* cacao L.), a beverage crop came into India in the first half of the 20th Century. But commercial cultivation was started only in the 1960s. It is being grown as an intercrop in arecanut and coconut gardens in Karnataka, Kerala, Tamila Nadu and Andhra Pradesh. The cocoa area is being extended to Maharashtra also. Presently cocoa is being grown in an area of 14200 ha in India. The production level of 6000 tonnes is not sufficient to meet the existing demand of cocoa industries. The demand for cocoa is increasing day-by-day. So it is essential that the potentiality of cocoa production have to be exploited in the country especially as under storey crop in arecanut and coconut gardens.

Central Plantation Crops Research Institute, Regional Station, Vittal earlier known as Central Arecanut Research Station established during 1956, pioneered in introducing cocoa as a commercial crop in the arecanut and coconut gardens. Systematic research on cocoa was started during 1970s at this Station. The cultivation practices like spacing, fertilizer levels, irrigation management and pruning have been standardized over the years. Many of the high yielding lines and hybrids have been identified. Later on the research was also initiated at Kerala Agricultural University. Lot of work has been done over the last 4 decades. But looking to the present day demand for cocoa, there is a need to strengthen the research on cocoa. This needs reviewing the work done on different aspects of cocoa for last 4 decades. In this connection the institute is organizing a National Seminar on Technologies for Enhancing the Productivity in Cocoa for the first time, which can help in giving new outlook to the cocoa research and development in the country.

People from all the cocoa growing areas of the country are attending the seminar. Apart from research workers, people from developmental agencies, industry and growers are also participating in the Seminar. The seminar is divided into five sessions *viz.*, Crop Improvement, Production Technologies, Plant Protection, Post Harvest Technology and Technology Dissemination, Development and Marketing for better discussion on different topics. In all 31 papers will be presented in the seminar, which includes lead papers, oral, and poster presentations.

The extended summaries submitted by authors have been included in the proceedings.

Editors

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# TECHNOLOGIES FOR INCREASING PRODUCTIVITY IN COCOA

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## Introduction

Cocoa is a crop of recent introduction to India. It is the third important beverage crop next to coffee and tea and primarily an important item of confectionery industries. The cocoa of commerce is the cured dry beans, which contains 57% fat, 7 % protein, 7 % carbohydrate and 1.7 % theobromine. It is one of the most compatible crops in the interspaces of coconut and arecanut plantations. After a severe set-back till 2001, the crop is now getting wide acceptability among the growers due to price hike reaching an all time high of Rs 27/- per kg of wet beans. Based on reports, it is most likely that this trend will continue during 2003 also. The soil and climatic conditions prevailing in Kerala are suited for the cultivation of cocoa except that irrigation is required in areas prone to prolonged drought and fertilizer application is necessary, as the soils are poor in fertility. The important problems faced by the cocoa growers in the country are high cost of production, low productivity from existing plantations, inefficient procurement system by the companies, lack of technical know-how on secondary processing, damage to pods caused by squirrels & rats and incidence of Vascular Streak Die Back disease.

## Cocoa growing countries of the world

It is a native of Amazon river basin, which later spread to all over the tropical regions of the world in the 18th and 19th centuries. Commercial cultivation was commenced in Ghana in 1879. 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 producer of cocoa in the world. As on today, about 68% of the total world production of cocoa beans come from these African countries into which this crop was introduced relatively very late. At present, bulk of world production comes from the developing countries of the world. However, bulk of the cocoa is consumed in the developed countries.

The world production of dry cocoa beans had been around 1.5 million tonnes in the 1970's and in the range from 1.5 to 2.5 million tonnes in the 80's. It remained at around 2.5 million tonnes during 1990's up to 1993-94. The present production (2000-01) is 2.819 million tonnes. Based on 2000-01 statistics, the major producing countries are Ivory Coast, Ghana, Indonesia, Brazil, and Nigeria, their contribution being 82.0 % of the world total (Fig.1). The African countries produced 68 % and the Central and South American countries, 14% of the total. The Asian countries produced the remaining 18%. The contribution of India is negligible (0.21%).

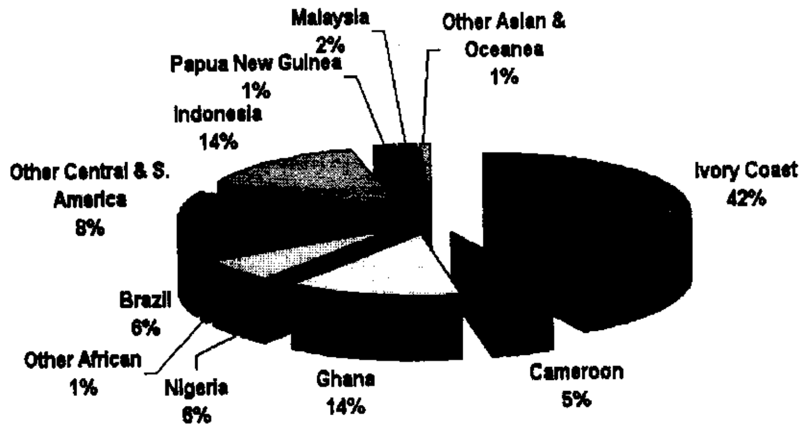


Fig. 1. Cocoa growing countries of the world

**Status of cocoa in India**

Cocoa was introduced into 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 were damaged by pests and diseases. Some plants 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 introduction was made as pods mainly from Malaysia. These were then followed by introductions from African countries.

In India, cocoa cultivation on commercial scale started with meager acreage in the states of Kerala, Karnataka and Tamil Nadu in the 1960's. Further expansion was sluggish up to the 1970's; but by the middle of 1970's, consequent on the impressive rise in the price of raw beans in Indian and international markets, there was boost in the acceptance of cocoa as a crop. An added advantage of this crop was that it could be successfully cultivated as a mixed crop in coconut plantations. Because successful cultivation of cocoa required irrigation, coconut gardens were brought under irrigation. This benefited coconut also. Starting from a few hundred hectares during 1960's, the area under the crop increased to 1927 hectares by 1970-71 and to 29,000 hectares by 1980-81. From this peak in area, there was a drastic decline to about 22,500 hectares by 1982-83 and then a steady decrease to 9,700 hectares by 1994-95. The present area under cocoa in India is 11,300 ha. The area under cocoa in Kerala and Karnatake are presented in Fig.2. The decline in price of the produce was the reason for such a lack of interest in this crop and the consequent decrease in area.

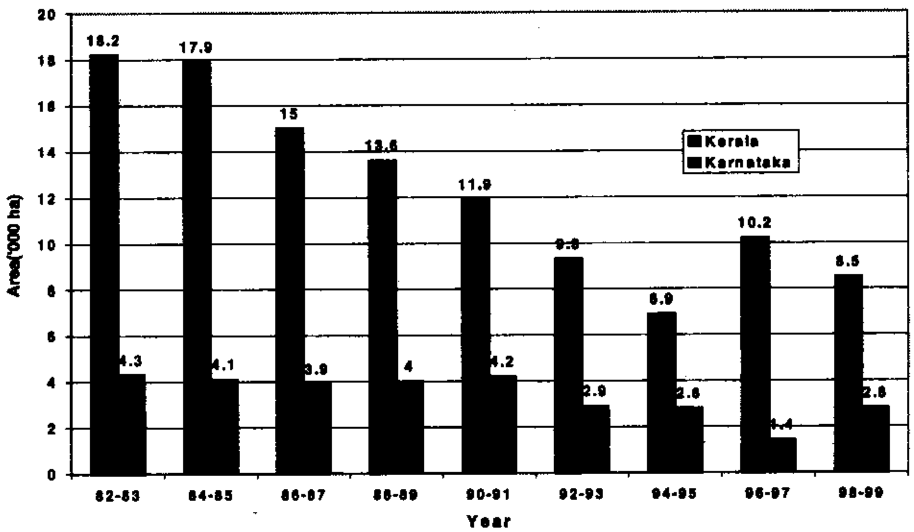


Fig. 2 Area under cocoa in India

Production, on the contrary, registered a steady increase over the years to reach a peak of 7715 tonnes of dry beans by 1985-86, after which it decreased to the lowest level of 5800 tonnes by 1995-96. There was a marginal increase to 7000 tonnes by 1996-97. The production of cocoa from Kerala and Karnataka are given in Fig.3. At the present average productivity of 30 pods per plant annually; the production would have been around 14,500 tonnes if the area of 29,000 hectares of 1970-71 existed. The current area under the crop also is a meager fraction of the area under coconut and arecanut in the country. The potential for area expansion is immense as a mixed crop of these two main crops.

The requirement of cocoa beans to feed cocoa based industries in India is around 16,000 tonnes. The consumption of cocoa products is reported to increase at the rate 12-15% per year. Based on an estimate, it is indicated that the requirement of cocoa in India by the end of 2005 would be around 30,000 tonnes. Hence there is scope for expansion of area under cultivation. Cocoa products are being exported from India and India gains a foreign exchange of nearly Rs. 10.00 crores every year.

Among the states, Kerala accounts for about 82 per cent of the area and production in the country, nearly all of the remaining area and production being contributed by Karnataka. Cultivation is extended to some pockets of Tamil Nadu and Andhra Pradesh in recent years.

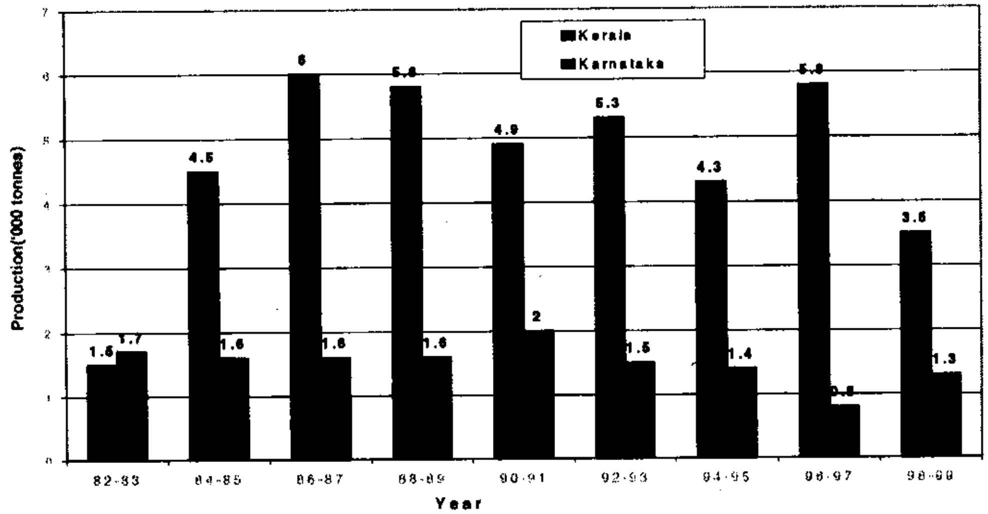


Figure 3 Production of cocoa in India

**Cocoa research in India**

Research on cocoa in India was initiated by the research-cum demonstration unit of the Cadbury India Ltd. established at Chundale in Kerala in 1965. There were some valuable contributions of this cocoa research unit. These were on management aspects especially shade regulation, planting density, pruning, some aspects of propagation, fermentation and drying of cocoa beans. The research activity was taken over by the Central Plantation Crops Research Institute in early 1960's. In Kerala Agricultural University, cocoa research was initiated since 1970s.

**Achievements**

**a. Crop improvement**

At CPCRI and KAU, crop improvement had its mandate of introduction, selection, hybridization and evaluation of cocoa. The biggest assembly of germplasm in India is being maintained at the Kerala Agricultural University with 540 accessions. Breeding programme at Kerala Agricultural University is one of the strongest in the world and the approximate number of experimental hand pollinations made every year is about 10,000. Thousands of hybrids were produced out of which many are undergoing evaluation in the field. In the early years, yield improvement was the only breeding objective. But since 1996, tolerance to VSD was added as yet another objective.

The main achievements of these two institutes are furnished below:

- The germplasm collection consisting of 540 diverse types (imported & local) are being maintained at Kerala Agricultural University. This is the largest assembly of germplasm of cocoa in India. At CPCRI, 137 diverse types are being maintained.
- Morphological characterisation of the germplasm was undertaken.
- The Kerala Agricultural University released seven high yielding and vascular streak die back resistant clones for cultivation in all cocoa growing regions of the country.
- From CPCRI, four hybrids with higher yield were recommended for cultivation in Kerala.
- Thousands of hybrids derived from hand pollination are being evaluated for yield and other desirable traits in the field at Kerala Agricultural University. At CPCRI also, a number of hybrids are being evaluated.
- Breeding for evolution of drought tolerant varieties has been taken up at CPCRI. Nine F1 hybrids after screening for drought tolerance were planted in the field. Seedling screening and field evaluation showed two hybrids to be drought tolerant.
- Thousands of VSD tolerant hybrids derived from hand pollination and survived in the nursery after screening are being studied for yield characters at the Kerala Agricultural University.
- Hundreds of selected clones are being evaluated in comparative yield trials at the Kerala Agricultural University.
- Inbreds are being produced every year and inbreeding reached up to $S_4$ generation in one genotype at Kerala Agricultural University.
- Four scion orchards with selected clones are being maintained at the Kerala Agricultural University.
- One polyclonal and one biclonal seed garden each have been established at the Kerala Agricultural University and the CPCRI.

**b. Crop management**

- Conducted long term experiments on manurial trials and fertilizer needs have been recommended.
- Standardized the vegetative propagation technique of cocoa by patch budding
- Studied the effects of different levels of illumination on growth and yield. The results indicated that the plants raised under open conditions recorded five times increase in yield and the result was consistent.
- Irrigation under conditions prevailing in Thrissur district with prolonged dry weather significantly increased yield.
- The training & pruning techniques were standardized.
- Top working, a novel technique for rejuvenating old and unproductive plantations, was standardized.
- Leaf litter addition through recycling of organic wastes in cocoa was studied.
- Effect of weather on cocoa and improvement of bean size through seasonal crop orientation was studied.

- Soil nutrient dynamics in cocoa was studied.
- Growth and yield analysis of top worked cocoa plants was conducted.
- Root level interaction in coconut - cocoa system was studied.
- Nitrate reductase activity was worked out.
- Studies were conducted on weed management in cocoa nursery.

**c. Crop protection**

- Etiology and control of seedling blight of cocoa were investigated.
- Studied Vascular streak dieback of cocoa and its management.
- Survey was conducted for important cocoa diseases in Kerala. During the survey, a number of diseases were found to occur in cocoa with varying intensities. The diseases noticed were Vascular streak die back, *Phytophthora* pod rot, *Colletotrichum* pod rot, Seedling blight, *Phytophthora* canker, Pink disease, White thread blight, Horse hair blight, Leaf blight, Chupon blight, twig die back and *Lasiodiploidia* pod rot.
- Infestation reactions and management of *Helopeltis theivora* in cocoa clones were studied. The most important observation was that the mammalian pests were the most serious and difficult to control. The only effective method of bringing down damage by these pests was the use of integrated methods of checking the population build up. These included use of traps and poison baits. Experimental observations over these years showed that the degree of damage could range from as low as 5 to 100% depending upon the control measures adopted.

**Improved production technology for enhancing yield**

***1. Use only quality planting materials***

Research findings indicted that when seedlings are used for planting, select only vigorous and healthy seedlings produced from polyclonal seed garden or selected mother plants as described earlier. When budded plants are used, select two or more clones for planting as the use of a single clone can lead to no production due to the existence of self- incompatibility in cocoa.

***2. Select the suitable site*:**

Shade levels under coconut canopy are highly variable depending mainly the spacing of coconut, extent of canopy development and age of palms. It is estimated that light infiltration through coconut canopy ranges from about 30 to 80 per cent depending upon these factors. Based on this, it is desirable that a coconut plantation that will let in more light through the canopy may be chosen for raising cocoa. If the light infiltration is over 50 per cent, it may be beneficial to provide additional shade using temporary shade plants like banana.

***3. Give optimum spacing***

The coconut plantations in India are not space planted and while laying out cocoa in such plantations, rooting patterns of the component crops may be reckoned as the guide. It is found that in coconut, 75 per cent of the live roots are concentrated in an area roughly two meters around the base. The feeding roots of cocoa extend to 120-150 cm, and hence the distance between cocoa and coconut may have to be 3.2 - 3.5 m to avoid any serious overlapping of active root zones. Thus in coconut gardens, plant to plant distance between cocoa and coconut may be 3.2 - 3.5 m. and that between cocoa plants, 3 m. At this spacing, the average number of cocoa plants in a hectare of coconut may be taken to be 500. In coconut plantations spaced at 7.5 m x 7.5 m, and cocoa planted at a spacing of 3m x3m, the effective spacing of cocoa plants would be 3 m x 7.5 m. At this spacing, a total of 614 plants can be accommodated in a hectare.

When cocoa is planted in arecanut gardens spaced at 2.7 m x 2.7m, spacing for cocoa is also to be 2.7 m x 2.7 m. This type of planting results in crowding of cocoa canopy. Therefore, it is desirable to plant one row of cocoa in between two rows of arecanut. The net spacing for cocoa would then, be 5.4 x 2.7 m and the population in a hectare would be 686.

***4. Take pits of optimum size***

In soils of low fertility and in gravelly lateritic zones, digging pits of 50 $cm^3$ and filling with a mixture of surface soil and organic manures become necessary. In soils of good structure and depth, there is no significant advantage out of making big planting pits.

***5. Take up planting at the right season and use correct method***

Cocoa seedlings or budded plants can be planted at any time of the year provided soil moisture conditions are favourable. Under Indian conditions, the best time for field planting is by the onset of pre- monsoon showers in May - June. Though early planting would necessitate watering before the onset of monsoons, this will be beneficial for better establishment.

Planting is to be done on soil surface rather than in deep pits as practised in many other plantation crops. This is due to the fact that the feeding roots of cocoa are confined to the surface irrespective of the zone at which seedlings are initially planted.

Budded plants are to be planted after removing the poly bag. Care should be taken to see that the bud union is above the ground level.

***6. Give post planting care***

Immediately after planting, basins may be mulched with organic materials. Shoots which emerge from the lower portions of the bud patch are to be removed periodically to ensure healthy growth of scion shoot. In summer, provide mulch materials with chopped banana sheath, coconut husk, cocoa husk etc. to conserve moisture when shade is not optimum.

***7. Control weeds***

During the first three to four years of planting, it is essential to keep the field free from weeds. When canopy is fully formed, shade intensity will be so high that practically no weed growth occurs below it.

***8. Manipulate shape of clonal plants***

Budded plants from fan shoots have diffuse branching system and bushy growth habit. If a better shape of the plant is desired, appropriate formation pruning may be necessary. This would involve identification of a chupon arising from a fan shoot, allowing it to grow and removing the original, lower fan-like shoots in stages. This, however, has to be done slowly as an early drastic pruning will inhibit growth.

*9. Provide optimum shade*

Cocoa, in its original habitat is an understorey tree in the shade of tall trees. Therefore cocoa has been cultivated under shade. However, cocoa behaves as a sun plant in its yield response, there being impressive increases in yield with increasing illumination. In a trial laid out at Vellanikkara involving shade manipulation; there was consistent and steady improvement of yield of cocoa with increasing levels of illumination. The extent of yield increase in the open as compared to the intense shade level ranged from 2.4 times to 7.8 times. However, shade is a must for initial establishment of the crop.

*10. Adopt judicious pruning*

Cultivation of the crop under mixed cropping situations necessitates pruning. The results of studies at Kerala Agricultural University, Vellanikkara showed that there was more or less consistent superiority of the unpruned control in terms of yield. It is desirable to restrict the growth to one tier at a convenient height (1-1.5 m). When jorquetting takes place at lower levels, this may be raised by nipping off all fan branches and allowing one chupon to develop and grow further to jorquette at the desired height. After this is achieved, further vertical growth is arrested through periodical removal of chupons. A second tier may be allowed when the first tier is damaged. Drooping fan shoots are to be cut and removed once a year when the crop load is low (December - January). Pruning and shaping of grown up plants may be done gradually without much shock to the bearing plant.

*11. Supply the required nutrients*

The fertilizer recommendation for cocoa under average management after reaching steady bearing is 100:40:140 g of N, $P_2O_5$, and $K_2O$ per plant for an year and for cocoa producing over 60 pods per year, double this dose is recommended.

Plants showing zinc deficiency symptoms (narrowing of leaves, sickle leaf formation, green vein banding and chlorosis in interveinal areas) may be sprayed with 0.5 -1 % zinc sulphate three times a year. Organic manures are beneficial for depleted soils in India in the early years. In adult plantations, organic manuring may not be essential.

Fertilizer application for rainfed cocoa is recommended in two splits, the first coinciding with the rains in May- June and the second by the close of rain by September- October. For irrigated cocoa, fertilizers may be applied in equal splits during May-June, September- October, December and February.

The best method is to rake in and mix fertilizers with soil in shallow basins of around 150 cm. radius for grown up plants. Basin size may be 25 cm during the first year and the radius is gradually increased to 150 cm by the third year.

*12. Provide irrigation in areas prone to drought*

Under conditions of well-distributed rainfall, cocoa grows up well as a rainfed crop and irrigation is not necessary. However, in cocoa growing belt of India, rainfall is not well distributed with rainfree periods extending from 4 to 6 months. This necessitates irrigation in summer months once in 5 days.

*13. Adopt top working to rejuvenate old and genetically poor plants*

This technique is useful to rejuvenate old and unproductive cocoa plants and also to convert genetically poor yielders to high yielders. This technique consists of snapping back the desired trees below the jorquette after cutting half way. A number of chupons would arise below the point of snapping. Patch budding is done on three to four vigourous 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. The top worked trees grow much faster and give prolific yield one year after the operation.

***14. Control pests effectively***

Cocoa is affected by over 1,500 insects in different cocoa growing countries of the world. In India, cocoa is a crop of recent introduction and as such the number of pests actually involved are comparatively less.

Among the major pests infesting cocoa, the major ones are red borer, tea mosquito, rats, squirrels, grey weevil, mealy bugs, cock chaffer beetles, citrus aphid etc. The incidence of red borer, the larvae of which bores into the stem can be controlled by spraying carbaryl 0.1% on the stems. Pruning and burning of infected parts are to be done as soon as symptoms are noticed.

Spraying Endosulfan 0.05 % can control the tea mosquito, which causes deformation of pods and blackening.

The mealy bugs occur in groups on the tender shoots, flower stalks, foliage and on the developing pods. These can be controlled effectively by spot application of quinalphos @ 0.025 % or Phosalone 0.05 %. These insecticides may be applied only after collecting the pods, which are ready for harvesting.

Adults and nymphs of red branded thrips appear in colonies on the under surface of leaves and also on pods and feed on the fluid exuding from the scraped tissues. Infested leaves turn pale green to pale brown and dry up later. The pest can be controlled by the application of 0.05 % suspension of quinalphos, phosalone or fenthion. Striped squirrels, rats and civet cats are the non- insect pests of cocoa. Damage is very serious in isolated cocoa gardens. They cut irregular holes on the walls of the maturing pods and completely extract the contents. Continuous trapping using attractants and poison baiting will be effective to check the population. As these damage ripe fruits only, the damage can be reduced by harvesting regularly and not allowing the ripe pods to remain on the trees for long periods.

***15. Manage diseases effectively***

Vascular Streak Die back (*Oncobasidium theobromae*) is the most serious disease. This disease may occur on the main stem of a seedling or on a branch of an older tree. The first symptom is the yellowing of one leaf usually the second or third behind the growing tip with the development of green spots or islets scattered over the yellow background. 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 oldest leaves on a branch are still present while all the middle ones have fallen. Leaf scars of fallen diseased leaves and adjacent bark are sometimes covered by a white, loosely adherent fruiting body of the fungus. If the diseased stem is split longitudinally, xylem will appear as discoloured brown streaks. The disease is more serious in Kottayam district of Kerala at present but has spread to all the cocoa growing regions of the state.

Regular pruning of infected branches is recommended to maintain a low level of infection in grown-up trees. Eradicative pruning will be more effective, if carried out one month prior to the wet season. Removal of prunings from the field is not necessary, as the fungus cannot survive on dead wood. Use of tolerant clones is recommended to check the spread of the disease.

Black pod disease (*Phytophthora palmivora*) is very severe in rainy seasons. Pods of all age groups are susceptible to the disease. The colour of the affected pod becomes dark brown or black. For controlling this disease, infected pods are to be removed as and when they appear on the tree. Provision of good drainage and aeration in the garden are important during the monsoon period. Spray with 1 % Bordeaux mixture with adhesive (Rosin washing soda preparation) before the onset of monsoon immediately after removing the infected pods.

Charcoal pod rot (*Lasidiplodia theobromae*) occurs mainly during dry season. Symptoms initially appear as pale yellow spots on pods, which enlarge into larger lesions having chocolate brown colour. In most cases, the complete pod becomes black in colour and exhibits a sooty covering all over consisting of the spores of the fungus. Infected pods become mummified and remain attached to the plant. The disease is also found to affect young twigs causing die back. Since the disease mainly affects wounded pods and pods of plants under stress, better management practices will reduce the incidence of the disease. Use of Rovral (Iprochone) at 2000 ppm at monthly intervals for six weeks during the dry season is the suggested control measure. Since the fungus is a wound pathogen, spraying of 1 per cent Bordeaux mixture along with an insecticide will also be useful.

Colletotrichum pod rot (*Colletotrichum gloeosporioides*) is common during January - May months. In severe cases of infection, the whole pod surfaces are infected, pod shrinks, and remains on the tree in a mummified form. The symptoms are different from cherelle wilt in that in this case, the characteristic dark brown lesions with yellow halo develop in the early stages of the disease. Carbendazim and Mancozeb are promising fungicides for the control of this disease. All dried and infected pods are to be removed and spraying with 1% Bordeaux mixture or 0.2 % Captafol before the onset of monsoons will be effective.

Cherelle wilt is a physiological disorder characterised by drying and wilting of young pods. Wilted pods remain attached to the tree. The major cause of this disease is considered to be physiological involving competition for carbohydrates and mineral nutrients. The competition for carbohydrates occurs when the tree is loaded with a large number of pods.

***16. Harvest at the right stage of maturity'***

It takes about 150 -170 days from pollination for attaining harvest stage. The stage of maturity of pods is the best judged by change of colour of pods. Though pods can be harvested just by the appearance of colour change, they remain without damage upto a maximum of about one month on the tree. It is however, safer to harvest at fortnightly intervals. When instances of mammalian damage to pods and black pod incidence are noticed, the harvesting intervals may be shorter. Harvesting may be done with a sharp knife without damaging the cushions. In Kerala the peak harvesting periods are October- December and April - June.

**Future thrust**

Cocoa is highly compatible with coconut and arecanut. With the present average productivity of 30 pods/ tree/year, the returns per hectare will be around Rs. 40,000/- per year. The cost of production to realise the average yield is about Rs. 15,000/ ha. The hybrids and clone have high yield potential of about 60 pods/ tree / year. The average productivity and returns can be increased to a significant level by simply using good quality planting materials. As control of diseases through the use of fungicides is not advisable, more thrust should be given for evolution of disease resistant genotypes with high yield potential. Survey of pests and diseases has to be continued to monitor the occurrence of new diseases and to check whether these turn out to be serious.

Cocoa is the only crop subjected to the monopolistic exploitation of different industrial units. Inadequate marketing network and fall in price since 1982 developed a sense of insecurity among the planting communities, which detrimentally affected its expansion, besides attributing to neglectful approach by the growers. The present system of procurement of cocoa from the farmers is quite inadequate leading to heavy losses. In the present context of globalization, the companies are free to import the raw material from the other countries and it seems that they prefer to have imported cocoa rather than the domestic produce. There is very high disparity between the prices of cocoa realized by the grower and finished product sold by the manufacturers. Research on small scale processing at primary and secondary levels has to be initiated so that the dependence of the growers on industries for the disposal of their produce is avoided.

SPECIAL ARTICLE

# COCOA DEVELOPMENT PROGRAMME IN KARNATAKA

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## Introduction

Cocoa (*Theobroma cacao* L.); Family Sterculaceae has its origin in the tropical areas of South and Central America. It was introduced to India, in the early half of the last century. However, The commercial cultivation of cocoa in India and Karnataka commenced from the nineteen sixties. Cocoa is mostly grown as a companion crops interspersed within the irrigated coconut and areca gardens. Although, cocoa comes under the definition of plantation crops, pure plantations of cocoa as such are rare.

Cocoa, an evergreen tree produces ripe pods having beans covered with mucilaginous tissues. The harvest of cocoa pods is spread over several months but peak harvesting is normally done during the months of July-August and November-December. Cocoa beans are largely used in the confectionery industry for which the demand is on the rise. It is a good balanced health drink and owing to its rich fat content, cocoa has gained importance in the field of navigation and army expeditions.

The total world production of cocoa has been 27.18 lakh MT and the world consumption of cocoa has been 27.59 lakh tones. As cocoa is a tropical crop, the tropical and sub tropical regions of India are suitable for growing cocoa. The cocoa growing states in India are Kerala, Karnataka, Goa, Maharashtra, Andhra Pradesh, Tamil Nadu, Pondicherry, Orissa and West Bengal.

Cocoa was introduced in the southern parts of India, mainly Kerala and Karnataka during 1965. In the late eighties, there was a major expansion of area under cocoa in the southern states of Kerala, Karnataka and Tamil Nadu, where cocoa is grown as a mixed crop along with arecanut and coconut. Cocoa is cultivated in an area of 14,200 ha with an annual production of 6,000 MT and productivity of 480 kg/ha (1998-99).

## Cocoa cultivation in Karnataka

In Karnataka, cocoa is traditionally grown in Dakshina Kannada, Uttara Kannada, Chickamagalur and Shimoga districts. The area under cocoa in Karnataka was about 2000 ha a few years back. Of late, there has been an increase in area under cocoa with the total area of about 2800 ha. Initially, when cocoa was introduced in Dakshina Kannada district during 1965, it was accepted well by the farmers. However, after 1990, the crop lost its importance among the farmers as they could realize higher returns per acre from areca cultivation.

The almost stagnated growth of cocoa production at around 6,000 tons per year in India leaves a supply gap of 6,000 tons at present, in the country. Narrowing the gap between demand and supply remains the distant dream, as 18,000 to 20,000 tons are required by the year 2003 considering 15 to 20 per cent of market growth as projected by Cocoa Development Council.

Karnataka can contribute significantly to the production of cocoa in the country if proper developmental measures are taken. The potential areas of maidan districts of Karnataka such as Mysore, Mandya, Hassan, Tumkur, Bangalore, Kolar, Chitradurga, Chamarajanagar and Davanagere where coconut is extensively grown under protective irrigation can be exploited. Cocoa can be successfully grown as a mixed crop in the coconut gardens in these districts. At present about 2500 acres are under cocoa in maidan districts. These plantations are about two to three years old. The prospect of cocoa development in non-traditional areas is of immense importance to the farmer, to the cocoa industry and also to the country because of the impact of the crop on the foreign exchange.

Looking at the potentiality of the districts like Mysore, Bangalore, Mandya, Tumkur, Hassan, Chitradurga, Kolar, Chamarajanagar and Davanagere for cocoa cultivation, Karnataka can emerge significantly as one of the top cocoa producers in the country, even if we harness at least 20 per cent of the total available area from the these districts.

The setback of cocoa production in Karnataka mainly in Dakshina Kannada district has been largely due to the following reasons:

- Higher returns per acre from areca cultivation in early 1980s
- Fear of root competition between cocoa and areca nut

Owing to the above reasons, the area of cocoa under arecanut has decreased in the district and consequently there is reduction in production from 1,200 tons to 600 tons. As there is a negative approach among the growers in Dakshina Kannada, the expansion of area under cocoa has not improved. The cultivation of cocoa has made an impact in non-traditional areas of maidan districts of Karnataka viz., Mysore and Mandy in recent years, where early bearing and yield are noticed. The major thrust was given by the Department of Horticulture, Government of Karnataka in association with M/s Cadbury India Limited. Consequently, extensive areas have been covered under cocoa in these areas.

**Cocoa Development Programmes**

In recent years, the Department of Horticulture, Government of Karnataka with the assistance of Cadbury India Limited under the Central Sector Scheme have motivated the farmers in Mysore and Mandya districts to take up cocoa cultivation in the existing coconut gardens through establishment of demonstration plots, field visits, free supply of seedlings, other inputs and timely extension service. Ms/ Nestle India Ltd is also involved in the expansion of area under cocoa in the district of Hassan on the same lines. The progress made with respect to the development of cocoa in the state during the last five years is detailed in Annexure-I.

For the year 2002-03, an outlay of Rs.50.00 lakhs has been allocated for the area expansion programme of cocoa under the Central Sector Scheme for the Integrated Development of Cocoa in Tumkur, Chitradurga, Bangalore, Davanagere, Mysore, Hassan, Kodagu, Mandya, Chamarajanagar and Bellary districts.

Although the potential area is available, there is need to prepare ground work through extension and to extend subsidy for cultivation of cocoa to cover up extensive areas within the next five years as the first stage of development. There is scope for expansion of area under cocoa in the irrigated coconut gardens in the non-traditional cocoa growing districts as detailed below.

**Scope for further expansion of area under cocoa in Karnataka (in irrigated coconut gardens)**

| Sl.No. | District | Hectare |
|---|---|---|
| 1. | Mysore | 10,291 |
| 2. | Mandya | 15,530 |
| 3. | Hassan | 6,732 |
| 4. | Tumkur | 10,183 |
| 5. | Bangalore | 8,174 |
| 6. | Chitradurga | 6,000 |

**Future strategies to enhance the production**

- Expansion of cocoa to non-traditional areas
- Narrowing down the gap between the yield obtained in farmers field and the yield realized in experimental farms
- Supply of superior planting materials and replacing seedlings by grafts
- Transfer of proven technologies through field demonstration
- To identify and propagate varieties which produce quality standard beans for export market
- Development of eco-friendly organic farming technologies for producing organic chocolates.
- Evolving resistant/tolerant strains of cocoa against diseases like wilt, black pod, canker etc.
- By-product utilization is another measure to enhance the net income of the farmers

**Advantages of cocoa as a mixed crop in coconut gardens**

An additional income of Rs.15,000-20,000 per acre can be realized by growing cocoa as a mixed crop in coconut gardens. The other advantages include manure to the soil (750 kg/ha) through foliage drop, control of weeds, conservation of soil moisture, income throughout the year, no root competition with coconut and cocoa pod husk as good cattle feed.

**Conclusion**

With India contributing only 0.2% to the world consumption of cocoa, there is further scope for increasing the production of cocoa in the country. Karnataka too can contribute significantly to the production of cocoa. Looking at the potentiality of the area available under coconut in non-traditional areas of Karnataka and the catalytic role played by the confectionery industry, the prospect for cocoa development looks very bright with the necessary impetus from the Government.

**Reference**

Vikraman Nair, R., Mallika, V.K., Prasannakumari Amma, S., Abraham Koshy and Balasubramanian, P.P. 2000. *Cocoa Cultivation – Science and Techniques*. KAU.

Annexure-I

Programme and progress under Central Sector Scheme for Developemtn of Cocoa for the last five years in Karnataka (Rs. in Lakhs)

| Sl. No | Scheme/Sub component | 1997-98 | | | | 1998-99 | | | | 1999-2000 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Programme | | Progress | | Programme | | Progress | | Programme | | Progress | |
| | | (Fin) | (Phy) | (Fin) | (Phy) | (Fin) | (Phy) | (Fin) | (Phy) | (Fin) | (Phy) | (Fin) | (Phy) |
| 1 | Production/procurement of quality planting materials (Cocoa clonal plants) | 9.16 | 0.498 grafts | 9.16 | 0.498 grafts | 26.665 | 138635 | 25. 511 | 238635 No. of grafts | 13.70 | 0.40 grafts | 3.389 | 0.38 grafts |
| | | | 0.6066 seedlings | | 0.6066 seed | | | | | | 3.38 F1 hybrids | | 5.524 F1 hybrids |
| | | | 1 scion garden | | 1 scion garden | | | | | | | | |
| 2. | A. Establishment of cocoa demonstration plots (New 1 year)<br>B. Maintenance of demonstration plots (II year) | 2.69 | 393 No of plots | 2.739 | 233 No of plots | 1.05 | 350 No of plots | 1.035 | 285 No. of plots | 0.75 | 106 No of plots | 0.75 | 106 No. of plots |
| 3. | Rejuvenation of unproductive cocoa gardens | 0.30 | 40 Nos. of gardens | 0.716 | 40 No. of gardens | | | | | | | | |
| 4. | Providing irrigation facilities | 3.20 | 5 Nos | 0.20 | 5 Nos | | | | | | | | |
| 5. | Training | | | | | 0.25 | 250 Nos | 0.20 | 200 Nos | 0.25 | 125 Nos | 0.25 | 125 Nos |
| 6. | Contingency | | | | | 0.335 | | 0.835 | | | | | |
| 7. | Area expansion programme | | | | | | | | | | | | |
| | Total | 12.85 | | 12.84 | | 28.80 | | 28.58 | | 14.70 | | 14.38 | |

Contd...........

| Sl. No | Scheme/Sub component | 2000-01 | | | | 2001-02 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Programme | | Progress | | Programme | | Progress | |
| | | (Fin) | (Phy) | (Fin) | (Phy) | (Fin) | (Phy) | (Fin) | (Phy) |
| 1 | Production/procurement of quality planting materials (Cocoa clonal plants) | | | | | | | | |
| 2. | A. Establishment of cocoa demonstration plots (New 1 year)<br><br>B. Maintenance of demonstration plots (II year) | | | | | | | | |
| 3. | Rejuvenation of unproductive cocoa gardens | | | | | | | | |
| 4. | Providing irrigation facilities | | | | | | | | |
| 5. | Training | | | | | | | | |
| 6. | Contingency | | | | | | | | |
| 7. | Area expansion programme | 7.00 | 341.008 ha | 6.997 | 342.00 | 15.79 | 900 ha | 15.31 | 809 ha |
| | Total | 7.00 | | 6.997 | | 15.79 | | 15.31 | |

## SESSION – I

## CROP IMPROVEMENT

**CHAIRMAN: DR. N. M. NAYAR**

**RAPPORTEUR: DR. ANITHA KARUN**
**DR. SAMSUDEEN**

# CROP IMPROVEMENT IN COCOA (*THEOBROMA CACAO* L.)

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Cocoa (*Theobroma cacao* L.) is an economically important tropical tree, the seeds of which are used to produce cocoa and chocolate. It is a native species of tropical humid forests on the lower eastern equatorial slopes of the Andes, in South America (Cheesman, 1944). It spread to all over the tropical regions of the world in the 18$^{th}$ and 19$^{th}$ centuries. Commercial cultivation was commenced in Ghana in 1879. From Ghana, it spread to other African countries; the most important of which are Ivory Coast, Nigeria and Cameroon, which account for about 68% of the total world production. Cocoa was introduced in India in the early 20th century; but its cultivation was limited to a few Government farms. Cocoa cultivation resumed in a big way in the 1960's with pods of Forastero type.

## Genetic structure

*Theobroma cacao* L. includes a large number of highly variable populations, which cross with each other. There are self compatible and self- incompatible types in the population. There are two major groups of cocoa viz., Criollos and Forasteros. The genetic variability within a Forastero population has been studied by many. Variability in yield expressed as dry weight or wet weight of beans, pod value, pod characters, number and weight of seeds was very high. Certain Upper Amazon populations such as LCTEEN and IMC are very variable

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

The IBPGR 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, which forms 70% of it, 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. 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.

**Priorities in breeding**

The objectives of breeding will reflect regional priorities for yield, other desirable characters and disease resistance depending upon the environmental conditions. In all cocoa growing countries, yield improvement was the primary objective. With the spread of diseases like witches' broom, cocoa swollen shoot virus,vascular streak dieback, black pod etc., which are difficult to be managed with chemicals, more thrust is now being bestowed for evolving disease tolerant types. The other objectives include retention of traditional flavour, adaptation to local environment, early and sustained bearing, tree shape and size, pod size and bean characters

**Methods of breeding**

***Introduction***

The basic step in any breeding programme is the introduction of new genetic material. The introduced types are evaluated in the field for yield, pod and bean characters, incompatibility reaction, reaction to pests and diseases and adaptation to the environment. The superior types emerging from this can be utilized for commercial planting or may be included in the breeding programme.

***Selection***

Selection is one of the oldest breeding methods and is the basis of all other crop improvement programmes. 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.

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. Selection of superior plants from the populations is based on certain criteria. 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.

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 Pounds' seedling collection showed exceptional vigour, precocity and high yield in Ghana. These observations and similar ones in Trinidad were attributed to hybrid vigour. These led to seeking heterosis through crossing between divergent parents.

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.

The seedlings selected based on vigour/ disease tolerance are field planted. On attainment of steady yield, the hybrids are evaluated for their performance. 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 were carried forward to the progeny trials. The highest yielding hybrids with other desirable attributes are multiplied and released as new clones. The Kerala Agricultural University has been successful in releasing three hybrids (CCRP 8-10), with high yield and tolerance to VSD.

*Selection of parents, testing GCA and SCA*: 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.

***Hand pollination***

In artificial pollination, a flower bud that will open the following day, recognized 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. 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, fertilization 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. The pods are collected at maturity, beans are extracted and sown in the nursery.

***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. 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 up to 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 vigourous 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 from each progeny 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 even in the seedling stage.

**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), (PP), Moniliasis pod rot (MO), cocoa swollen shoot virus (CSSV) and vascular streak dieback (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. The important diseases on which breeding work has been carried in different countries include black pod disease, witches broomdicsease, cocoa swollen shoot virus, vascular streak dieback, Moniliasis pod rot and *Ceratocystis* wilt.

**Cocoa breeding in 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 1960'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 was planted 1970 with 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 67, LANDAS 358 etc. Nineteen superior types were identified from the germplasm and among these the type Amelonodo x Na 32 was found to be the best. 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 progeny trials during 1981, 1983 and 1987. 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 Jarangau 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.

Work was also done at Vittal in breeding for drought tolerance. The germplasm as screened for physiological parameters like chlorophyll stability index, proline accumulation under stress and seed germination under low osmotic potential and 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, NC 31, NC39 and NC42.

***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. The approximate number of experimental hand pollinations made every year is about 10,000. Thousands of hybrids were produced out of which many are undergoing evaluation in the field. In the early years, yield improvement was the only breeding objective. But since 1994, tolerance to VSD was added as yet another objective.

The germplasm 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 being evaluated for yield, pod and bean characters, and self- incompatibility. The superior types are being utilized in breeding programme.

Selection of superior plants was continued from 1987 from germplasm collection and hybrids produced from time to time and four comparative yield trials involving 134 genotypes were established. Based on performance and tolerance to VSD, seven clones (CCRP 1 to 7) were recommended for cultivation in India.

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. 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. Hence it necessitates testing of clones/ hybrids for cross incompatibility before they are released for cultivation.

The production of homozygous plants for utilization in the breeding 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.

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 (Mallika *et al.*, 2000).

In order to produce good quality hybrid seeds, a biclonal seed garden with six self-incompatible 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. Then parents of each hybrid are interplanted to allow maximum cross-pollination. Hybrid pods can be collected from 1243 plants. The pods from this garden can produce around 5-lakh-hybrid seedling per year.

Cocoa breeding aimed at selecting superior types invariably leads to a narrowing of the genetic base. This in turn can lead to increased vulnerability of the crop to pests and diseases. The approach must be to produce as many diverse hybrids / clones as possible and recommend the superior 10 or more for cultivation as clonal mix. This is also necessary in view of the self and cross incompatibility exhibited by the crop. The commercial varieties may be tested for cross compatibility relations among them and only compatible clusters are to be distributed for commercial cultivation. A general outline of cocoa breeding method for adoption in India has been suggested by the Kerala Agricultural University.

**Future breeding strategies in cocoa**

Though a lot of work is done on improvement of the crop since 60-70 years, 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 is not feasible by conventional methods. 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 is shown to be mainly due to additive gene effects and maximum gene dispersion over sub-populations will increase the chances of detecting transgressive hybrids.

Clonal selection after recombination would be better for short term progress, where clones are accepted commercially. By concentrating on development and utilization of technologies, there is need to develop stable, long- term conventional breeding work. 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. Considerations should be given to redesigning the tree architecture to improve photosynthetic efficiency and harvest index.

In most of the breeding programmes, importance should be given to flavour aspects. Assessment of flavour is not very easy in cocoa. However, certain simple procedures for assessment of flavour have been developed recently. The current achievements in molecular genetics seem to have an impact on crop improvement of cocoa in the coming years. The progress in the development of new technologies in plant breeding has been tremendous during the past 15 years. These techniques can make a useful contribution if the traditional breeding base is strong enough to support their integration.

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# OPTIMISING DNA AMPLIFICATION PARAMETERS FOR RAPD ANALYSIS IN COCOA (*Theobroma cacao L.*)*

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Conventionally Cocoa (*Theobroma cacao L.*) accessions have been characterized by morphological and agronomic traits. But these are subject to environmental and physiological influences. Also descriptors of this kind only afford limited information of the relatedness of accessions. Therefore, interest is directed on the use of molecular marker techniques. Such genetic markers are believed to be unaffected by external parameters and also provide a measure of genetic relatedness. The development of a PCR-based arbitrarily primed genetic assay called RAPD (Random Amplified Polymorphic DNA, (Williams *et al.*, 1990) or AP-PCR (Arbitrarily Primed PCR, Welsh and McClelland, 1990) has greatly changed the prospects for application of molecular markers to study populations and to accelerate breeding. Of the several molecular markers used, RAPD is the simplest and particularly popular in the characterization of plant genetic resources. The present investigation was carried out to standardize the optimum PCR parameters for template DNA amplification for RAPD analysis.

## DNA Extraction

Total genomic DNA extraction was standardized using just mature green leaves by modified CTAB protocol. DNA concentration was measured by running the aliquots (5μl) on 0.8% agarose gel and taking the absorbance at 260 nm in UV Spectrophotometer

## Amplification

Protocol for the polymerase chain reaction was optimized by varying the concentration of template DNA, $Mg^{++}$salt, Taq DNA polymerase, dNTP concentration, primer concentration and annealing temperature. PCR was carried out in DNA Thermal cycler (Eppendorf mastercycler gradient, Germany) with 25μL reaction mixture. PCR chemicals including Taq polymerase were procured from Bangalore Genei and primers were obtained from Operon Technologies, Alameda, USA. Reaction products were mixed with loading dye (0.25% bromophenol blue and 40% sucrose w/v) and spun briefly before loading onto gel. The amplification products were separated on 1.2% agarose gel at 80 V followed by staining with ethidium bromide. Molecular weight of bands was estimated by 100 bp and 500bp ladder (Bangalore Genei).

## Standardization of template DNA

DNA concentration is the first and most important parameter to be optimized as it influences the reproducibility of RAPD patterns (Williams *et al.*, 1993). Varying

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the concentration of template DNA from 20 to 50 ng revealed that 30 ng DNA gave maximum number of reproducible bands and thus considered ideal for RAPD analysis. Template DNA from 20-50 ng in 25 µL reaction mixture gave good amplification. However at 20 ng and 50 ng DNA template concentration, some bands were missing compared to other concentrations. 30 ng templates DNA gave uniform bright bands. Hence 30 ng was taken as optimum for PCR amplification (Fig1.).

**Standardization of $MgCl_2$**

$MgCl_2$ is an important variable that affects intensity of bands. In addition to Mg++ ions bound by the template DNA, the nucleotides (dNTPs) and the primers, Taq DNA polymerase also requires free $Mg2^+$ ions. Their concentration has an influence on primer annealing, the melting temperature of the PCR product and product specificity. A titration of different concentrations of $MgCl_2$ from 0, 0.5 mM, 1.0 mM, 1.5 mM, 2.0 mM, 2.5 mM, 3.0 mM and 3.5 mM in 25 µL reaction mixture showed that 1.0 mM and 1.5 mM was optimum for PCR. This is in addition to the 0.6mM of $MgCl_2$ present in the PCR assay buffer. An excessively high concentration lead to a reduction in stringency, i.e. reaction specificity.

**Standardization of dNTPs and Taq Polymerase**

A final concentration of 0.4 µM of dNTP and 0.9 U of Taq polymerase in the reaction mix were found to be optimum for RAPD analysis. Taq Polymerase is active over a broad range of temperatures, primer extension will occur at the specific temperatures of annealing.

**Standardization of primer concentration**

The primer is an oligonucleotide of 10 bp length. The primer concentration from 0, 0.2 µM, 0.4 µM, 0.6 µM, 0.8 µM and 1 µM showed that 0.8 µM was optimum for amplification of Cocoa DNA. Primers from kit OPC were used for standardizing primer concentration. The G+C composition of primers varied from 60-70%. GC content of a primer is the best indicator of whether it will result in amplification (Fritsch *et al*, 1993). The higher the G:C content, the higher the likelihood of amplification. The primer sequences that resulted in good polymorphic bands are recorded in the Table 1. The choice of primer and nucleotide concentration has significant influence on PCR. A high primer concentration increases the probability of spurious priming and leads to the generation of nonspecific products.

**Standardization of Annealing temperature**

Gradient of annealing temperature from 35°C to 55°C in the thermal profile showed that 45°C was optimum for obtaining reproducible RAPD patterns. The PCR thermal profile is as follows. Initial denaturation at 94°C for 2 min followed by 45 cycles of denaturation at 94°C for 1 min, primer annealing at 45°C for 1 min and elongation at 72°C for 1 min with a final extension at 72°C for 5 min.

Annealing temperature along with $MgCl_2$ influences relative intensities of amplified bands. In fact, high-temperature annealing should result in enhanced specificity, because the hybridization of the primer to the template DNA occurs under more stringent conditions. If the temperature is too low, non-specific priming will occur. Very long annealing times normally do not improve yield, but rather produce an increase in spurious priming and, thus, greater amounts of nonspecific PCR products.

**Primer Survey**

Initially 40 primers from primer kits OPB and OPC were screened using three accessions namely Jarangau Red Axil, Na –33 and EET-272 in order to identify the suitable ones for analysis. Most of the primers we tested produced good number of amplified fragments that were detected by gel electrophoresis and staining with ethidium bromide. Some primers produced polymorphisms detected by amplification of DNA fragments that varied in size depending on the accession used. Out of 40 primers screened, 8 primers (B4, B8, B16, B17, B18, B19, C3 and C20) did not produce any amplification. This may be due to the lack of homology between the primer sequence and the genome sequence of accessions. Ten primers viz., B5, B11, B7, B9, B14, B15, B2 and B20, C15 and C16 resulted in inconsistent or sub optimal products while C1, C14, C17 and C19 gave very similar amplified products (monomorphic bands). Hence these were discarded. Eighteen primers were found to be polymorphic between the accessions tested. Table 2 shows the nucleotide sequences of the 10 primers used for RAPD analysis to distinguish cocoa accessions.

PCR was carried out using standardized PCR parameters for different cocoa accessions resulted in good amplification. Hence 30 ng template DNA, 1.0 mM $MgCl_2$, 0.4 µM of dNTP and 0.04 U of Taq polymerase and 0.8 µM primer concentration were found optimum for carrying out RAPD analysis in cocoa

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**Table1. Standard RAPD protocol for DNA amplification**

| Concentration | Volume (µL) | Final concentration |
|---|---|---|
| Double distilled water | 10.17 | |
| PCR Buffer 10X | 2.50 | 1x |
| $MgCl_2$ 25 mM | 1.00 | 1mM |
| DNTP, 10 mM | 4.00 | 400µM |
| Primer, 5µM | 4.00 | 0.8 µM |
| Taq DNA Polymerase 3U/ µL | 0.33 | 0.9 U |
| Template DNA, 10ng/ µL | 3.00 | 30 ng/ µL |

**Table 1a.Thermal profile for DNA amplification**

| | | | |
|---|---|---|---|
| Initial denaturation | 94°C | 2 min | |
| Denaturation | 94°C | 1 min | |
| Primer annealing | 45°C | 1 min | 45 cycles |
| Polymerization | 72°C | 1 min | |
| Final extension | 72°C | 5 min | |

Fig.1.Optimisation of DNA template concentration.

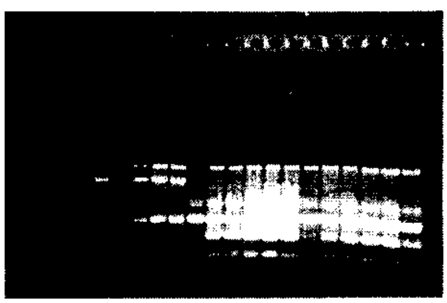

**Table 2.Primers and their sequences used in RAPD analysis of cocoa accessions.**

| Primer | Primer Nucleotide Sequence |
|---|---|
| OPB-1 | 5'GTTTCGCTCC3' |
| OPB-6 | 5'TGCTCTGCCC3' |
| OPB-10 | 5'CTGCTGGGAC3' |
| OPB-12 | 5'CCTTGACGCA3' |
| OPC-2 | 5'GTGAGGCGTC3' |
| OPC-5 | 5'GATGACCGCC3' |
| OPC-7 | 5'GTCCCGACGA3' |
| OPC-10 | 5'TGTCTGGGTG3' |
| OPC-12 | 5'TGTCATCCCC3' |
| OPC-13 | 5'AAGCCTCGTC3' |
| OPC-18 | 5'TGAGTGGGTG3' |
| OPC-9 | 5'CTCACCGTCC3' |
| OPC-19 | 5'GTTGCCAGCC3' |

# PLANTLET REGENERATION FROM SOMATIC EMBRYOS IN COCOA (*Theobroma cacao* L.)

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Somatic embryogenesis could be exploited for rapid clonal propagation of superior genotypes. In cocoa, somatic embryogenesis has been obtained from immature zygotic embryos. Although regeneration from embryogenic tissues does not vegetatively propagate the maternal clone, it would be of use in multiplying the progeny of selected crosses. An understanding of the process of embryogenesis from zygotic embryos could also provide a basis for attempts to achieve embryogenesis from maternal tissues.

The study was conducted at plant tissue culture laboratory, College of Horticulture, Vellanikkara. Embryoids were cultured on liquid M. S. medium (Murashige and Skoog 1962), full or half strength and Woody Plant Medium (WPM) (Lloyd and McCown, 1980) with 3 to 5 percent sucrose, in order to standardize the media for germination. To enhance plantlet regeneration from embryoids, treatments like rinsing and desiccation of embryoids for varying times were done. As the development of embryoids into shoot was in a slow pace a trial was conducted for enhancing shoot regeneration. Treatments like removal of cotyledons and use of different growth supplements were tried for inducing shoot growth. Effects of coconut water (CW), GA and NAA were tested alone or in combination, with basal media MS and WPM. Micrografting was attempted to recover plantlets from embryoids by grafting the germinating embryoids to in-vitro as well as ex-vitro seedlings. For in-vitro grafting a wedge shaped inscision was made on shoot portion at 5 cm height in stocks raised in-vitro. Radicle end of embryoids was also cut to fit in to the wedge and tied firmly in position using a copper wire. For ex-vitro grafting, stocks were raised in polythene bags in nursery and 3-4 weeks old stocks were topped retaining 4 to 5 cm stem above cotyledones. Method of grafting was the same as in in-vitro. High humidity was maintained by covering the grafts with polythene bags. Grafted embryoids were hardened by gradually exposing the plants. After four weeks plantlets were completly exposed.

Cocoa embryoids are reported to have some inhibitors preventing their germination. Hence they are properly washed and dried before transfer to the germination media. Rinsing embryoids for three minutes with double distilled water followed by a desiccation for three minutes was found to enhance the plantlet regeneration.

Size of the embryoids also influenced the germination. Large sized embryoids of more than 4mm, when cultured in half MS medium with 5 percent sucrose showed maximum germination. When these embryoids were cultured on medium with 4 or 3 percent sucrose, a gradual reduction in germination was noted (Table 1). Embryoids of small size did not germinate in all the treatments tried. Rate of conversion of embryoids to plantlet was second in case of embryoids of size 2 to 4 mm. They exhibited proper

[+] College of Horticulture, Vellanikkara rooting and feeble shoot growth. Shoot and root development did not occur simultaneously. Roots were almost dead by the time of development of shoot. Hence plantlet regeneration was found to be difficult.

In most treatments using growth supplements in both MS and WPM as basal media embryoids remained green without any further growth. Only in MS and ½ MS with NAA 0.2 + GA 1.0 mgl $^{-1}$ + CW 15 percent shoot growth with feeble leaves were noticed. When embryoids were cultured in1/2 MS medium containing 5 percent sucrose, rarely normal shoot growth was obtained. However, none of these plantlets attained proper size for planting out.

Adu-Ampomah *et al.*, (1988) reported continuous production of an endogenous factor especially in the somatic embryo cotyledon, which promoted callus formation. Exogenous application of hormones amplified this effect. So they suggested the germination of embryoids in hormone free liquid medium after removal of cotyledons and sub culturing to a medium with GA and NAA for differentiation in to plantlet.

Present study on germination of embryoids confirmed the presence of inhibitor. Germination was maximum in liquid medium containing half strength MS salts and 5 percent sucrose after washing and desiccation for 3 minutes each. Washing of the embryoids and renewal of the liquid medium might have reduced the inhibitor present and desiccation induced a stress condition. Both these were useful for regeneration of embryoids. Rooting, hardening and planting out were crucial steps in micropropagation during which a sizable number of tissue culture derived plants are lost. This aspect of micropropagation becomes much more critical in case of minute plantlets recovered from somatic embryoids. By adopting the technique of micrografting such plantlets could be saved and they could be directly transferred to the field with in a short span.

Aguilar *et.al.*, (1992) observed that the embryoids without cotyledon showed better plantlet recovery by micrografting and they needed ten months for complete plantlet regeneration. In our studies successful grafts were obtained from germinating embryoids devoid of cotyledon and having at least a single hardened leaflet. Successful grafts could be made ready for field planting within two months. The expenses on micropropagation could also be very much reduced by micrografting on ex-vitro seedlings. Rooting was not required; hardening turned out to be very simple and the minute shoot of the embryoids produced leaves as big as those of normal seedlings within a period of two months. The presence of an already established stock converts the minute shoot to a normal plantlet within a short span.

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**Table. 1. Effect of different media on the germination of somatic embryos of cocoa.**

| Treatment (liquid medium) | Percentage of germination of size of embryoids | | | |
|---|---|---|---|---|
| | >1mm | 1-2mm | 2-4mm | >4mm |
| ½MS+3%S | 0.0 | 0.2 | 0.5 | 12.3 |
| ½MS+4%S | 0.0 | 0.1 | 7.8 | 26.2 |
| ½ MS+5%S | 0.0 | 1.3 | 27.3 | 83.5 |
| ½ PM+5%S | 0.0 | 0.3 | 7.4 | 31.2 |
| MS+5%S | 0.0 | 0.0 | 0.0 | 0.0 |

# SELECTION INDICES IN COCOA

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Cocoa, *Theobroma cacao* L., of the family Sterculiaceae, is the only economically important species among the twenty-two that constitute the genus *Theobroma*. The main impediment to cocoa crop improvement is the unreliability of identification of superior genotypes in the early years. Experimental evidences point out that a minimum period of eight years is required for accurately predicting yield potential of cocoa genotype. More frequent application of a quantitative genetic approach to cocoa would thus seem desirable to permit the preparation of a breeding index, the objective being simultaneous improvement of the different characters chosen as selection criteria.

A set of twelve clonal cross-combinations maintained in a randomized blocks design with 3 replications (4 trees/replication) at Cadbury KAU Co-operative Cocoa Research Project (CCRP) farm of college of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur, served as the base material for the present study. Observations on seventeen growth and yield attributes along with yield over thirteen years from planting were recorded. Selection indices were worked out using discriminant function technique according to Smith (1936) based on traits, which showed high heritability and genetic correlation with yield. Out of 17 yield attributes recorded, only ten attributes, which exhibited significant genotypic correlation with yield, were chosen fro index formulation. Further choice of the attributes included in the index construction was based on the absolute values of their heritability and genotypic correlation coefficients with yield ($r_g$). The direct effects of the respective traits were also considered.

Discriminant functions involving all ten yield attributes that exhibited significant correlation with yield recorded a relative selection efficiency over direct selection for yield at 5 per cent selection intensity RE (%) of 158.18 and predicted Genetic advance (GA) estimate of 2.47. The corresponding estimates in the selection index based on eight yield attributes that obtained the first eight ranks on the basis of absolute ranking were found to equal 157.17 and 2.45 respectively.

The selection indices constructed for all possible combinations of the five predictor variables *viz*., dry weight/bean, pod weight, bean thickness, bean length, and efficiency index, selected based on the absolute ranking method recorded an RE of 151.83 and a corresponding genetic advance (GA) of 2.37. The RE and GA of the index formulated with dry weight/bean, bean thickness, bean length and efficiency index were 150.35 and 2.34 respectively.

Results on formulation of suitable selection criteria for yield in cocoa with different combination of traits (i) pod weight (ii) bean thickness (iii) bean length (iv) dry weight/bean and (v) efficiency index revealed that, straight selection for yield was more efficient than indirect selection based on different traits taken individually. The exception being the selection index based on bean thickness, which proved to be slightly more efficient (RE=101.09 per cent) over straight selection for yield.

Considering two traits at a time, the combination of dry weight/bean and efficiency index recorded the highest efficiency. Among the three-factor combination, the index involving bean length, bean thickness and efficiency index showed maximum efficiency. In four-trait combination, the index involving dry weight/bean in addition to the above three traits *viz.*, bean length, efficiency index and bean thickness, recorded the highest efficiency while the index formulated over all five traits recorded maximum efficiency in the present study.

Though the relative efficiency exhibited an increasing trend with addition of traits, the increase was at a declining rate. The inclusion of as many as ten traits would be cumbersome and is not desirable. In view of the magnitude of improvement in bean yield with each additional trait, the index involving four traits *i.e.*, dry weight/bean, bean length, bean thickness and efficiency index was considered efficient compared to the five trait based index (involving pod weight in addition to the four traits mentioned above).

Importance of selection indices for identification of superior genotypes has been discussed by several workers in cross-pollinated species *viz.*, cocoa (Cilas, 1991), arecanut (Ramachander and Bavappa, 1972), coffee (Srinivasan, 1982) and coconut (Balakrishnan *et al.*, 1993).

In the ranking of cross-combinations in the Sr. II hybrids $H_4$ (M 16.9 x GII 19.5) and $H_3$ (M 16.9 x GII 20.4) secured first and second ranks based on index worth computed using five and four traits based discriminant functions. This ranking of cross-combination confounded the ranking of theses genotypes based on direct selection for yield.

Cocoa being a perennial crop, selection of superior genotypes based on yield would require compilation of yield data for several successive years beyond the eighth year of planting when crop is considered to reach a steady state of bearing. Consequently, results from a planned study to identify superior genotypes would require a minimum period of eight years. In this context, selection index formulated with four traits *viz.*, dry weight/bean, bean length, bean thickness and efficiency index identified to be efficient, would prove immensely useful in selecting desirable genotypes based on their genetic worth. It would benefit future breeding programmes as a pointer towards superior genotypes in the early years of bearing *i.e.*, two to two and a half years from planting, negating the long wait of a minimum of eight years as stated earlier.

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# ESTIMATION OF GENETIC PARAMETERS FROM SPECIFIC CROSSES OF COCOA (*THEOBROMA CACAO* L.)

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A review of the crop improvement programmes in cocoa on a global basis suggest that after an initial phase of spectacular improvement, the progress of cocoa breeding tended to be slow (Warren, 1992). One of the main reasons for the slow progress is that the selection of parents and breeding plans were not backed by genetic studies. In the Kerala Agricultural University crop improvement of cocoa through hybridization and selection was initiated from 1984 onwards. A lot of work has been done on selection of parents, hybridization and evaluation of the progenies. During 1994, the progenies of twenty five specific crosses derived from ten better combiners viz. G I 5.9 (a clone from Scavina entry), G II 19.5 (a local selection), G VI 24 (clone of NC-40), G VI- 51 (IMC 67), G VI 59 (ICS 6), G VI 60 (Na 33), G VI 64 (C 3) and M 9.16 and M 13.12 (clones from local population at Mannuthy) were field planted in RBD with three replications and with six plants/ treatment. As an assessment of the genetic parameters it was considered essential to continue breeding studies in the right direction in this institution, the present investigation was undertaken for the period from 1994-1999.

The plants started bearing in 1997. Pods from bearing cocoa trees were harvested at an interval of 15-20 days during 1998-99 and observations on pod yield were recorded. Observations on number of mature pods including damaged pods, pod length (cm), pod width (cm), pod weight (g), pericarp thickness (mm), number of beans per pod, wet bean weight per pod (g), bean length (mm), bean width (mm), bean thickness (mm) and dry weight per bean (g) were recorded. The data on plant height (2YAP), girth, $HD^2$ (height x stem diameter$^2$) (6 MAS) were also collected. The mean values computed for each character per tree were processed to assess genetic variability, heritability and heterosis. The genetic variability, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability, genetic advance, genetic gain and heterosis were estimated using standard procedures.

The analysis of variance revealed significant difference for all the characters except pod weight and plant height (2YAP). The extent of genetic variability was higher for yield, number of pods / tree and $HD^2$, and moderate for all other characters except pod weight and plant height. PCV was greater than GCV for all the traits. This evidently suggests the larger involvement of the environmental and genotype x environment interaction effects on trait expression. Among the fifteen characters, $HD^2$ recorded the highest PCV of 70.53 and GCV of 62.14.

The GCV together with heritability estimates can be employed to predict the extent of advance expected out of selection and it is not possible to assess the heritable variation with the help of GCV alone. The heritability estimates indicated that the values were moderate for number of beans/ pod and bean width. All the other characters recorded low heritability values. Height, bean thickness and bean length recorded negative values. Yield recorded a low heritability with a moderate genetic gain. Low heritability along with low genetic gain observed in the present study indicated the major role played by the non- additive genes and influence of environment. The study indicated that the poor specific combining ability of parents used in the study, though they were good combiners.

The impact of yield improvement through heterosis in cocoa has been demonstrated by Pound (1932) and Posnette, (1951). The heterosis for important characters revealed that among the 25 cross combinations, the number of hybrids which expressed significant positive relative heterosis estimates varied from 11 to 18. For number of pods per tree, yield and pericarp thickness heterotic vigour was observed in 24, 23 and 22 hybrids respectively.

The number of hybrids, which showed significant positive values for heterobeltiosis, was found in the range of four to nine. However for yield and number of pods per tree hybrids that expressed heterosis equalled 23 and 20 respectively.

The standard heterosis estimates in the hybrids for various traits ranged from one to twelve. For yield and number of pods per tree heterotic expression was observed in 21 hybrids whereas for bean width heterotic vigour was found in 15 hybrids.

The data indicated that $H_{23}$ (G VI-59 x G VI-64) was the best cross combination. This exhibited very high heterotic performance for yield, number of pods per tree and wet bean weight per pod. This implies that the specific combining ability of the parents was good due to better complementation of desirable genes. $H_{16}$ (G II-19.5 x G VI-64) and $H_5$ (M-13.12 x G VI-24) were found to be the next best cross combinations with high heterosis for yield and number of pods per tree. The data suggested that the parents of the hybrids $H_{23}$, $H_{16}$, and $H_5$ could be successfully used for raising biclonal seed gardens.

The results revealed that the hybrids varied significantly with respect to most of the characters studied viz. yield, pod length, pod width, wet weight of beans, dry weight per bean, number of beans per pod, bean size, pod number, pericarp thickness, seedling vigour and girth of the tree. The estimates of PCV were higher than GCV for all the traits studied indicating the involvement of non-additive genes and influence of environment on trait expression. $HD^2$ (6MAS), number of pods per tree, yield, dry weight per bean and wet weight per pod showed higher GCV when compared to other traits.

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# STABILITY OF POD YIELD IN COCOA (*Theobroma cacao L.*) UNDER KANNARA CONDITIONS

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Cocoa (*Theobroma cacao L.*) is an important beverage crop grown in the interspaces of coconut and arecanut plantations (Bhat and Bavappa, 1972). Even though it has been introduced in 1960's for commercial cultivation the yield potential is not yet tapped in India. There has been a continuous effort in introducing different germplasm through many sources and select good lines with higher yields (Bhat *et al.*, 1998). The investigation on genetic parameters of yield and yield determining characters in cocoa is a topic of recent concern. The study of genotype - environment interaction is an important biometrical aspect not only from genetical and evolutionary point of view but is also considered to be very relevant to production problems in general and the plant breeding potential in particular (Breese, 1969). With this background, the current investigation is aimed at assessing the nature and extent of genotype x environment interaction exhibited by 47 cocoa accessions over five seasons.

The experimental material consisted of 47 promising accessions collected from Nigeria, Ghana, Malaysia, Kew Gardens (England) and India immediately planted during, 1990 (24 accessions) and 1991 (23 accessions) under two separate experiments. They were planted as an intercrop in coconut garden at a distance of 2.7 x 5.4 m in alluvial soil at CPCRI, Research Centre, Kannara, Thrissur Dt., Kerala. The experiments were laid out in a Randomized Blocks Design with the 47 accessions replicated twice. Six trees of each accessions represented single replication. The yield in number of pods per tree and pod weight per tree was recorded for each year from 1997 to 2001. The data were subjected to stability analysis according to the model proposed by Eberhart and Russel (1966).

Among the forty-seven accessions the better performing clones under each experiments are tabulated. From the data in Table 1, it is revealed that the yield difference among accessions was statistically significant during all the 5 years. This suggested that the performance of the accessions was influenced by the environmental conditions prevailing during different seasons of growth. This showed that the environmental conditions during different years were not similar. Among the 24 accessions grouped under experiment I, the clone Amelonado x Na-32 ranked first during three seasons, second during two seasons. Variation in ranking was noticed in terms of number of pods and pod weight in all the accessions. Amelonado x Na-32 recorded maximum number of pods (60.43 pods/tree) and pod weight (18.63 kg/tree) with regression coefficients of 1.31 and 1.24 respectively followed by Jarangau Red Axil (JRA) recorded 52.89 pods/tree and pod weight of 15.21 kg/tree. SCA-6, SIAL-93, L-364 performed better with significant mean yield per tree (47.85, 44.96, 44.66 pods/tree respectively).

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Among the 23 accessions evaluated under experiment III, NC-12 recorded a best yield of 52.52 pods/tree weighing 14.69 kg/tree with the regression coefficients 1.25 and 1.73 respectively. The next best yield was observed in V-1 with 31.65 pods/tree and pod weight of 7.88 kg/tree followed by NC-63, V-7 and NC-46 with a pod yield of 28.63, 28.30, 27.35 pods/tree respectively. Overall evaluation of the performance of forty-seven cocoa accessions indicated that the clones Amelonado x Na-32, Jarangau Red Axil, NC-12, SCA-6 and SIAL-93 were superior than others with increasing yield trend over five years.

The pooled analysis of variance for number of pods and pod weight is given in Table 2. The highly significant mean squares due to varieties revealed the presence of genetic variability in the population under consideration. The mean squares due to Environment + (Genotype x Environment) were also significant. This suggested that the genotypes interacted considerably with environmental conditions prevailing during various seasons. The components indicated that the interaction was largely contributed by significant mean squares due to Environment (linear) and Genotype x Environment (linear). The variance due to pooled deviation was significant showed less predictability of performance.

The estimates of three stability parameters namely mean performance of each accession, regression coefficient (bi) and deviations from regression ($S^{-2}$ di) for number of pods and pod weight of promising accessions are given in Table 3. Presence of linear component of Environment and Genotype x Environment was noticed in all accessions. It is important to note that for a complex character like yield such a linear response is not only predictable but also inherited (Bains and Gupta, 1972).

The highest yield performance, a significant regression coefficient (Preferably closer to unity) and non-significant mean square deviations are the requirements of an ideally adopted genotype (Eberhart and Russel, 1966). The clones Amelonado x Na-32, Jarangau Red Axil, NC-12, SCA-6 and SIAL-93 fulfilled these requirements, which are the stable ones with high mean values hence, may be rated as the best types. Thus, based on these studies they may be considered as the better-adopted accessions under Kannara conditions.

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**Table 1. Pod yield performance of cocoa accessions over 5 years**

| EXPERIMENT I | | NO. OF PODS | | | | | WEIGHT OF PODS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sl. No. | Clones | 1997 | 1998 | 1999 | 2000 | 2001 | 1997 | 1998 | 1999 | 2000 | 2001 |
| 1 | JRA | 24.85 | 45.70 | 71.60 | 51.95 | 87.50 | 9.82 | 11.15 | 25.12 | 21.38 | 27.42 |
| 2 | AxNa-32 | 24.40 | 60.50 | 83.25 | 75.75 | 83.90 | 6.50 | 15.40 | 27.00 | 18.00 | 28.08 |
| 3 | AxNa-33 | 20.55 | 10.90 | 28.30 | 32.75 | 37.50 | 5.18 | 2.55 | 9.00 | 11.68 | 22.67 |
| 4 | AxPa-7 | 10.90 | 5.00 | 9.15 | 15.90 | 36.35 | 2.88 | 1.90 | 3.17 | 8.85 | 14.00 |
| 5 | Pa-7xNa-32 | 14.60 | 28.10 | 21.35 | 32.75 | 37.00 | 5.78 | 6.38 | 7.38 | 14.07 | 12.57 |
| 6 | L-356 | 11.30 | 11.20 | 79.30 | 40.65 | 64.50 | 4.10 | 3.45 | 24.58 | 14.27 | 27.02 |
| 7 | L-357 | 11.00 | 37.30 | 60.70 | 41.45 | 35.50 | 2.85 | 8.20 | 18.30 | 17.92 | 17.00 |
| 8 | L-358 | 21.95 | 11.35 | 34.80 | 74.90 | 41.75 | 6.07 | 3.08 | 11.12 | 16.88 | 13.12 |
| 9 | L-361 | 23.25 | 17.35 | 19.60 | 27.50 | 36.25 | 6.18 | 4.35 | 6.60 | 17.00 | 12.25 |
| 10 | L-364 | 23.60 | 27.15 | 73.50 | 51.55 | 47.50 | 4.50 | 8.57 | 19.35 | 17.58 | 19.38 |
| 11 | L-365 | 3.95 | 7.05 | 46.50 | 32.80 | 57.85 | 4.38 | 2.25 | 12.88 | 12.05 | 22.50 |
| 12 | I.C.S-6 | 14.90 | 33.00 | 52.70 | 33.60 | 72.65 | 3.65 | 7.07 | 15.60 | 12.38 | 24.75 |
| 13 | I.M.C-10 | 18.85 | 16.75 | 40.45 | 49.75 | 56.00 | 5.30 | 3.88 | 10.70 | 18.50 | 16.75 |
| 14 | I.M.C.67 | 6.70 | 11.85 | 73.40 | 54.60 | 69.40 | 1.88 | 4.45 | 22.08 | 18.27 | 18.60 |
| 15 | EET-272 | 20.65 | 54.80 | 40.85 | 42.30 | 43.00 | 6.00 | 14.40 | 13.00 | 10.18 | 15.25 |
| 16 | Na-31 | 2.25 | 1.30 | 3.90 | 20.60 | 17.95 | 0.55 | 0.32 | 1.10 | 5.55 | 5.68 |
| 17 | Na-33 | 3.80 | 4.65 | 7.35 | 14.40 | 40.05 | 0.85 | 1.92 | 1.55 | 11.25 | 11.75 |
| 18 | Na-242 | 10.45 | 20.05 | 7.00 | 45.65 | 53.50 | 3.00 | 7.03 | 22.88 | 15.50 | 20.05 |
| 19 | S.C.A-6 | 21.10 | 16.65 | 37.50 | 41.55 | 84.50 | 8.27 | 4.18 | 12.80 | 15.81 | 23.20 |
| 20 | S.C.A-12 | 5.90 | 24.50 | 29.10 | 28.60 | 50.40 | 1.65 | 5.60 | 8.90 | 9.85 | 23.45 |
| 21 | SIAL-93 | 12.50 | 26.50 | 30.50 | 32.15 | 123.15 | 4.03 | 6.62 | 10.07 | 11.38 | 43.62 |
| 22 | I.C.S-95 | 17.50 | 23.80 | 38.55 | 37.95 | 40.00 | 6.07 | 11.10 | 15.07 | 17.05 | 18.50 |
| 23 | I.C.S-96 | 1.30 | 1.75 | 10.75 | 5.90 | 8.80 | 0.28 | 0.47 | 3.35 | 1.12 | 2.35 |
| 24 | I-14 | 2.75 | 5.60 | 32.55 | 51.65 | 77.50 | 0.77 | 1.40 | 9.62 | 16.62 | 25.67 |
| **SEd** | | **3.26** | **7.22** | **13.42** | **10.71** | **17.13** | **1.09** | **2.03** | **4.27** | **4.01** | **5.99** |
| **CD at 5% level** | | **6.74** | **14.79** | **27.77** | **22.16** | **35.44** | **2.26** | **4.20** | **8.83** | **8.30** | **12.39** |

**Table 2. Analysis of variance for pod yield and pod weight in cocoa accessions tested over 5 years**

| Source of variation | Degrees of freedom | | Mean sum of squares | | | |
|---|---|---|---|---|---|---|
| | Experiments | | Pod No. | | Pod Weight | |
| | I | II | I | II | I | II |
| Genotypes | 23 | 22 | 903.48* | 507.77* | 83.17* | 40.08* |
| Environment + (Genotype x Environment) | 96 | 92 | 483.38* | 259.63* | 61.20* | 22.16* |
| Environment (linear) | 1 | 1 | 25030.69* | 9600.27* | 3781.84* | 2039.4* |
| Genotype x Environment (linear) | 23 | 22 | 338.64* | 267.03* | 34.70* | 111.6* |
| Pooled deviation | 72 | 69 | 188.68 | 121.89 | 17.99 | 18.92 |
| Pooled error | 115 | 110 | 3.11 | 0.77 | 8.10 | 0.19 |

*Significant against pooled deviation at 5 % level.

**Table 3. Mean yield (pods/tree), pod weight and estimates of stability parameters for cocoa accessions tested in 5 years.**

| Clones | Pod No. | | | Pod Weight | | |
|---|---|---|---|---|---|---|
| | Pods/Tree | Regression Coefficient (bi) | Deviation mean square ($S^{-2}$ di) | Weight/Tree | Regression Coefficient (bi) | Deviation mean square ($S^{-2}$ di) |
| **Experiment I** | | | | | | |
| A x Na 32 | 60.43 | 1.31 | 249.99 | 18.63 | 1.24 | 22.93 |
| IRA | 52.89 | 1.45 | 195.35 | 15.21 | 1.30 | 12.95 |
| SCA 6 | 47.85 | 1.54 | 306.91 | 13.29 | 1.13 | 4.70 |
| SIAL 93 | 44.96 | 1.64 | 383.44 | 15.14 | 2.16 | 99.01 |
| **Experiment II** | | | | | | |
| NC 12 | 52.52 | 1.25 | 58.25 | 14.69 | 1.73 | 56.24 |
| V 1 | 31.65 | 2.56 | 34.32 | 7.88 | 2.21 | 5.33 |
| NC 63 | 28.63 | 1.01 | 18.90 | 9.45 | 1.15 | 4.09 |
| V 7 | 28.30 | 1.76 | 122.04 | 7.65 | 1.67 | 7.77 |

# CROSS -COMPATIBILITY RELATIONSHIP WITHIN SELECTED CLONES OF COCOA

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Self incompatibility is a mechanism which ensures obligate out breeding. Incompatibility in cocoa is unique in that the site of incompatibility is the embryosac (Cope, 1962). After incompatible pollination, the pollen tube grows faster and delivers the gametes into the embryo sac in a normal fashion. The embryo sac is in no way abnormal and the rejection is due to the failure of male nuclei to unite with the egg. This incompatibility is referred to as "prefertilization inhibition in the ovule" and it is genetically controlled. Fusion or non-fusion is controlled by a series of alleles operating at a single locus (S), showing dominance or independence relationships (Purseglove, 1968). In incompatible matings, the flowers drop 2 to 4 days after pollination. If a population of cocoa is examined for self-incompatiblity reactions, it could be observed that majority of the plants belong to self incompatible group (CCRP, 2000-01). Cross incompatible types frequently occur between two individuals with different genotypes and it occurs only in diploid gametophytic systems when individuals share the same S genotype (Richard, 1986).

In hybridization programme, the first step is selection of parents with high yield, desirable pod and bean characters, disease resistance and incompatibility reaction. Based on superiority in yield, the selected types will be selfed to assess the self incompatiblity. Only self incompatible types are utilized as parents in crossing programmes. Hybridization in cocoa is less tedious due to the existence of morphological barriers to self pollination and existence of self- incompatibility. These adaptations enable production of hybrids without emasculation and this technique is widely used in establishment of clonal gardens. Genetic superiority of the seedlings can be ensured if vigourous hybrids arising from diverse parents are used. However, many genetically superior plants cannot be fully exploited in breeding or cannot be distributed to growers due to the existence of cross incompatibility. In many breeding trials, crosses in a full diallele fashion could not be produced due to this problem. In order to know the cross compatibility relations in selected 16 exotic clones of cocoa in the germplasm, a crossing programme was chalked out during 1999-2000.

The Kerala Agricultural University maintains a germplasm of cocoa, which includes many renowned clones of the world and locally selected materials. From among the clones, which had attained stable, yield, 16 self incompatible clones with high yield, and desirable pod and bean characters were selected for crossing programme. The clones selected for the study were GVI 172 (AMAZ-6-3), GVI 182 (IMC-20), GVI 183 (LAF 1), GVI 184 (LCT EEN 167), GVI 185 (LCT EEN- 162-1010), GVI 186 (MAN 15-2), GVI 187 (MAN 15-60), GVI 189 (PA 56), GVI 191 (TJ-1), GVI 193 (UF 667), GVI 198 (Local), GVI 204 (LCT EEN 163A), GVI 235 (Local), GVI 254 (Local), GVI 258 (Local) and GVI 264 (Local). During the flowering season from September to March, crossing was attempted in all possible combinations excepting reciprocals. Out of 128 crosses envisaged, only 120 crosses could be effected due to the scarcity of flowers/ overlapping of flowering intensity in some of the clones. The pod set in each cross, number of pods harvested and number of beans were recorded. Out of 120 crosses made, 23 were cross incompatible. In the case of thirteen crosses, the number of flowers available was too small to arrive at a conclusion and confirming their position of cross compatibilty

The results showed that the compatibility reaction between the clones varied widely. The study helped to group the clones into compatible and incompatible clusters.

The cross compatible clusters were

| | |
|---|---|
| 1. GVI 172(AMAZ-6-3) | GVI 185 (LCT EEN- 162-1010), GVI 189 (PA 56), GVI 254 (Local), GVI 258 (Local), GVI 264 (Local) |
| 2. GVI 182 (IMC-20) | GVI 184 (LCT EEN 167), GVI 185 (LCT EEN- 162-1010), GVI 186 (MAN 15-2), GVI 189 (PA 56), GVI 193 (UF 667), GVI 198 (Local), GVI 204 (LCT EEN-163A), GVI 235 (Local), GVI 254 (Local), GVI 258 (Local) , GVI 264 (Local) |
| 3. GVI 183 (LAF 1) | GVI 185 (LCT EEN- 162-1010) |
| 4. GVI 184 (LCT EEN 167) | GVI 185 (LCT EEN- 162-1010), GVI 193 (UF 667) |
| 5. GVI 185 (LCT EEN- 162-1010) | GVI 186 (MAN 15-2), GVI 187 (MAN 15-60), GVI 189 (PA 56), GVI 191 (TJ-1), GVI 193 (UF 667), GVI 198 (Local), GVI 204 (LCT EEN-163A), GVI 235 (Local), GVI 254 (Local), GVI 264 (Local) |
| 6. GVI 186 (MAN 15-2) | GVI 187 (MAN 15-60), GVI 189 (PA 56), GVI 191 (TJ-1), GVI 193 (UF 667), GVI 204 (LCT EEN-163A) |
| 7. GVI 187 (MAN 15-60) | GVI 204 (LCT EEN-163A), GVI 254 (Local), GVI 258 (Local) |
| 8. GVI 189 (PA 56) | GVI 191 (TJ-1), GVI 193 (UF 667), GVI 204 (LCT EEN-163A), GVI 254 (Local), GVI 264 (Local) |
| 9. GVI 191 (TJ-1) | GVI 204 (LCT EEN-163A), GVI 235 (Local) |
| 10. GVI 193 (UF 667) | GVI 204 (LCT EEN-163A), GVI 254 (Local), GVI 258 (Local), GVI 264 (Local) |
| 11. GVI 198 (Local), | GVI 254 (Local), GVI 258 (Local), GVI 264 (Local) |
| 12. GVI 204 (LCT EEN-163A) | GVI 254 (Local), GVI 258 (Local), GVI 264 (Local) |
| 13. GVI 235 (Local) | GVI 254 (Local) |
| 14. GVI 254 (Local) | GVI 264 (Local) |

The cross incompatible clusters identified were

| | |
|---|---|
| 1. GVI 172(AMAZ-6-3) | GVI 204 (LCT EEN-163A), GVI 235 (Local) |
| 2. GVI 182 (IMC-20), | GVI 191 (TJ-1), GVI 193 (UF 667) |
| 3. GVI 183 (LAF 1) | GVI 191 (TJ-1), GVI 193 (UF 667), GVI 204 (LCT EEN-163A), |
| 4. GVI 184 (LCT EEN 167) | GVI 186 (MAN 15-2), GVI 187 (MAN 15-60), |

| | |
|---|---|
| | GVI 189 (PA 56) |
| 5. GVI 185 (LCT EEN- 162-1010) | GVI 258 (Local) |
| 6. GVI 186 (MAN 15-2) | GVI 198 (Local), GVI 258 (Local) |
| 7. GVI 187 (MAN 15-60) | GVI 187 (MAN 15-60), GVI 191 (TJ-1), GVI 235 (Local), GVI 264 (Local) |
| 8. GVI 189 (PA 56) | GVI 258 (Local) |
| 9. GVI 191 (TJ-1) | GVI 198 (Local), GVI 254 (Local) |
| 10. GVI 254 (Local) | GVI 258 (Local), GVI 264 (Local) |

The clones GVI 182 (IMC-20) and GVI 185 (LCT EEN- 162-1010) were compatible with ten clones each. GVI 182 (IMC-20) was incompatible with two clones GVI 191 (TJ-1) and GVI 193 (UF 667). GVI 185 (LCT EEN- 162-1010) was incompatible with only one clone, GVI 158 (local). Cross incompatibility indirectly measures the degree of closeness between the genotypes. When the parents used in crossing happen to be genetically similar, incompatibility mechanism operates and there is no fruit set. The study indicated that among the genotypes used, GVI 182 (IMC-20) and GVI 185 (LCT EEN- 162-1010) were more genetically diverse when compared to other clones. These when crossed with ten other clones, produced pods.

The cross incompatible clusters might have been derived from a very few genotypes. The results could be of use to cocoa breeders when the above clones are selected as parents.

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# STANDARDIZATION OF MEDIA FOR SOMATIC EMBRYOGENESIS IN COCOA (*Theobroma cacao* L.)

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Cocoa (Theobroma *cacao* L.) belongs to the family Sterculiaceae and is the most important beverage crop of the world after tea and coffee. The development of technique for somatic embryogenesis and *in vitro* plant regeneration of cocoa would enhance rapid propagation of desirable genotypes and might lead to the exploitation of the likely somaclonal variation.

The work was carried out at plant Tissue culture Laboratory, College of Horticulture, Vellanikkara. To standardize the basal media for somatic embryogenesis in cocoa, M.S.medium (Murashige and Skoog 1962), $B_5$ medium (Gamberg and Shyluk, 1981) and Woody plant medium (WPM) (Lloyd and Mc Cown 1980) were used along with NAA 1.8 + Thiamin 1.0 + Casein hydrolysate (CH) 200mgl$^{-1}$ + coconut water (CW) 10% + Sucrose 4%. In order to standardize the growth regulator and media supplements, a trial was conducted using growth regulators ABA, NAA and 2,4-D at four different levels with and without 10 percent coconut water and 10mll$^{-1}$ of amino acid stock (lysine 40, tryptophan 20, leucine 40, arginine 40 and glycine 200ml l$^{-1}$) in MS medium. Embryogenic response of cocoa was studied in medium containing complex organic supplements like CH and CW at different levels and combinations. Here the basal medium was MS + NAA 1.8 + Thiamine 1.0 mgl$^{-1}$ + Sucrose 4%. In all the studies explant used was immature cotyledon.

Effect of different basal media for induction of embryogenesis from immature cotyledon explants of cocoa showed that in MS medium percentage of embryogenisis in both Amelonado and Criollo genotypes were high (Table1). Also it was showed that genotype Criollo had greater response to embryogenic pattern of development in this media. Basal medium WPM also had positive influence on embryogenesis. Here genotypic difference was not observed. Using $B_5$ as basal medium Amelonado was responding at a rate of 38.9 percent, but response of Criollo was found to be very poor (3.4%). Embryogenesis in plants have been observed in a range of media starting from relatively low salt containing White's medium to more concentrated MS medium. The present study revealed that embryogenic response in cocoa is more pronounced in high salt containing medium like MS.

In the media proposed by Adu–Ampomah *et.al.*, (1988) for somatic embryogenesis from immature cotyledon explants of Amelonado types of cocoa, embryogenic response was 62.5 percent with an intensity of 14.5 numbers and 15.8 percent of normal embryoids of size more than 4 mm. In the present study on the elimination of complex organic nutrients resulted in low frequency and intensity of embryogenesis (Table 2). When one of these was removed a reduction in embryogenic response was observed and the effect was more when CW removed. However, elimination of CH and addition of CW at 15 percent resulted in increase in frequency, intensity as well as percentage of larger sized embryos. Hence the medium found to be

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[+] College of Horticulture, Vellanikkara the best to promote embryogenesis in cocoa was MS + NAA 1.8 + Thiamine 1mgl$^{-1}$ + CW 15% + Sucrose 4%.

Study on the effect of growth regulators on somatic embryogenesis from immature cotyledon explants of genotype Amelonado showed low embryogenic response at lower level of NAA. However, the response was on par at 1 and 2mgl$^{-1}$ (60.8 - 70.37 % and 5.1 - 6.8 numbers). By the addition of 10 percent CW, frequency was similar, but intensity was higher. Better response to 2,4-D was observed at 1.5 and 2 mgl$^{-1}$ (Table 3) frequency of embryogenesis was enhanced when 10 percent CW was added to the medium. Size of the embryoids induced by 2,4-D was less. Among the four levels of ABA tested, 2.0 mgl$^{-1}$ was the most effective (42.6 and 4.2 nos.). A proportionate increase in size of the embryoids was observed with increase in levels of ABA. About 60% of the embryos formed were of more than 4 mm size at 2.0 mgl$^{-1}$ of ABA.

Of the two auxins tried, NAA at 1-2 mgl$^{-1}$ was found to be superior in inducing somatic embryogenesis in cocoa. Adu-Ampomah *et.al.*, (1988) also reported cocoa somatic embryogenesis in presence of NAA in the media. Somatic embryos induced by 2,4-D were sub-optimal for regeneration to plantlet. Coconut water favored somatic embryogenesis in cocoa as evidenced from present studies. Growth inhibitor Absessic acid at 2.0 mgl$^{-1}$ produced embryoids with maximum size and minimum abnormalities.

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## Table 1. Effect of basal media in somatic embryogenesis of cocoa.

Addition to basal medium – NAA 1.8 + Thiamine 1.0 + CH 200 mgl$^{-1}$ + CW 10% + Sucrose 4%.

| | | Percentage of cultures showing | | |
|---|---|---|---|---|
| Basal medium | Genotype | Expansion of cotyledon | Callusing | Calllus & embryoids. |
| B5 | Amelonado | 14.3 | 46.7 | 38.9 |
| | Criollo | 12.5 | 84.1 | 3.4 |
| WPM | Amelonado | 23.7 | 38.1 | 38.1 |
| | Criollo | 8.3 | 48.8 | 42.8 |
| MS | Amelonado | 11.9 | 22.6 | 65.5 |
| | Criollo | 10.7 | 11.3 | 79.8 |

**Table 2. Response of immature cocoa cotyledon to complex organic nutrients for embryogenesis.**

Genotype: Amelonado Basal medium. MS + NAA 1.8 + Thiamine 1.0 mgl$^{-1}$+ Sucrose 4%.

| Addition to basal medium | * Frequency of embryogenesis | **Intensity | Percentage of normal embryoids of classes (mm) | | | |
|---|---|---|---|---|---|---|
| | | | < 1 | 1-2 | 2-4 | > 4 |
| Nil | 58.2 | 6.2 | 34.5 | 32.4 | 26.1 | 7.0 |
| CH 200 mgl$^{-1}$ + CW-10% | 62.5 | 14.5 | 11.3 | 32.7 | 40.2 | 15.8 |
| CH-200 mgl$^{-1}$ | 59.8 | 7.4 | 7.3 | 40.8 | 38.4 | 13.5 |
| CW-10% | 60.2 | 10.2 | 14.8 | 59.8 | 18.5 | 6.9 |
| CW-15% | 72.5 | 18.3 | 11.3 | 25.8 | 32.5 | 20.4 |

*Percentage of cultures showing embryogenesis
**Number of embryoids formed per explant.

**Table 3. Effect of media Supplements on induction of embryoids .**

Genotype -Amelonado Basal medium –MS + Amino acid stock 10 mll$^{-1}$ + Sucrose 4%.

| | With CW. | | | | | | Without coconut water | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Growth regulator mgl$^{-1}$ | Frequency | intensity | Percentage of normal embryoids ( mm). | | | | Frequency | Intensity | Percentage of normal embryoids (mm). | | | |
| | | | >1 | 1-2 | 2-4 | < 4 | | | >1 | 1-2 | 2-4 | < 4 |
| NAA 0.5 | 8.2 | 1.1 | | | 100 | | 56.4 | 3.1 | 40.6 | 59.4 | | |
| 1.0 | 60.8 | 5.2 | 27.2 | 28.5 | 35.3 | 9.0 | 54.1 | 9.3 | 58.9 | 42.1 | | |
| 1.5 | 68.1 | 6.8 | 31.8 | 27.1 | 35.4 | 5.6 | 55.2 | 6.9 | 28.1 | 50.2 | 13.6 | 7.1 |
| 2.0 | 70.3 | 5.1 | 34.7 | 26.1 | 32.4 | 6.9 | 56.6 | 11.2 | 18.5 | 59.8 | 13.9 | 6.9 |
| 2,4-D.5 | 7.4 | 1.2 | | 100.0 | | | 40.1 | 3.2 | 17.5 | 82.5 | | |
| 1.0 | 21.2 | 5.4 | 55.3 | 44.7 | | | 41.9 | 4.4 | 33.2 | 66.8 | | |
| 1.5 | 41.2 | 10.3 | 29.4 | 70.6 | | | 40.2 | 2.3 | 50.2 | 49.8 | | |
| 2.0 | 33.4 | 5.5 | 23.2 | 76.8 | | | 41.4 | 3.0 | 60.4 | 39.6 | | |
| ABA.5 | 26.4 | 7.1 | 20.2 | 79.8 | | | 26.2 | 4.2 | 42.2 | 41.8 | 16.0 | |
| 1.0 | 23.1 | 4.3 | | 81.7 | 18.3 | | 41.6 | 1.9 | | 37.4 | 62.6 | |
| 1.5 | 30.9 | 4.4 | | 23.6 | 62.2 | 14.6 | 43.9 | 3.1 | | 49.6 | 50.4 | |
| 2.0 | 42.6 | 4.2 | | 20.4 | 19.2 | 60.4 | 42.8 | 4.3 | | 42.9 | 57.1 | |

# AN OVERVIEW OF INBREEDING IN COCOA

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Development of inbred lines and their use in production of hybrids is one of the accepted methods for exploiting hybrid vigour in cross pollinated crops. The existence of self- incompatibility in majority of the plants in a population makes development of pure-lines almost impossible. Though the frequency of occurrence of self-compatible types in a population is limited, there are certain high yielding self-compatible trees, which could be selfed to produce inbred lines in cocoa. With the objective of producing fully homozygous plants and ultimately securing maximum hybrid vigour by crossing between two unrelated inbreds, inbreeding programme was undertaken at Cadbury- KAU Co-operative Cocoa Research Project, Kerala Agricultural University, Vellanikkara from 1988 onwards.

Hand pollinations for selfing were done in four high yielding self compatible genotypes (GI 3.16, G II 7.4, M12.21 and M18.7) during 1988 and two genotypes (GII 7.2 and GIV 35.7) during 1992. Seeds from the pods, which developed after selfing, were sown in the nursery along with seeds from hybrids and open pollinated plants. Observations on height (H) and girth (D) at four, five and six months after sowing were recorded. The $HD^2$ values were worked out. From the selfed seedlings, twenty vigourous seedlings were selected and field planted from each genotype. These trees on flowering were again selfed to produce the next generation ($S_2$). Sowing inbred pods, selection of vigourous seedlings, field planting, selfing etc. were continued up to four generations in GII 7.4, three generations in G I 3.16, two generations in GII 7.2 and M 18.7 and one generation in M 12.21. Since all $S_1$ plants under M12.21 were self incompatible, $S_2$ could not be produced. Similarly, GII 7.2 $S_2$ being self incompatible, further generations could not be produced. Many more genotypes were included since 1992 and selfing was continued. At present there are 37 genotypes in $S_1$ generation, 8 genotypes in $S_2$ generation, 4 genotypes in $S_3$ generation and one genotype in $S_4$ generation.

Observations on girth and yield (5YAP) of the six genotypes mentioned above as well those of all field established inbreds planted during 1992 were recorded. The yield and girth of hybrids and open pollinated seedlings of the same age were observed. The jorquetting heights of the inbreds were recorded in 1999-00. In order to have a comparison of pod characters in both inbreds and hybrids, characters viz. pod length, width, weight, wet bean weight, bean number, length, width and single bean dry weight of the hybrids and inbreds planted during 1994 were recorded. Assessment of inbreeding depression in relation to $S_0$ and immediately preceding generation for the four above mentioned genotypes was done for yield, girth, jorquetting height, pod weight and single bean dry weight.

The inbred seedlings showed some abnormalities in the nursery stage. A general reduction in size and vigour was noticed among the seedlings. The genotypes differed considerably in their response to inbreeding. In some genotypes, a large proportion of inbreds showed lethal characteristics. These seedlings were very small with weak stem and small leaves. Such plants could not be maintained and were lost in the nursery. The results indicated that the inbreds were less vigorous when compared to hybrids and open pollinated seedlings of the same age. During the seedling stage, the difference in vigour was marked. Observations on $HD^2$ values of seedlings recorded four, five and six months after sowing indicated that the extent of inbreeding depression varied with genotype. In $S_1$ of G1 3.16 the $HD^2$ value recorded at 6 MAS were only 9.6 while that in $S_1$ M 18.7 was 26.8. The respective value for hybrids was 47.0 and OP 29.9 (CCRP, 1988-89).

Another peculiar morphological abnormality noted among inbreds was the forking of the main stem. In many $S_2$ and $S_3$ plants, the main stem forked into two after field planting. In $S_4$, this phenomenon was more common producing three to four chupons even in the seedling stage. Upon field planting, one of the most vigorous chupons overgrew masking the growth of others. The weaker chupons perished in due course (CCRP, 1999-00).

The inbreds started bearing after fifth year only as against the hybrids, which started bearing from the second year. There was marked difference in the field performance of the inbreds when compared with hybrids. The yield and girth of the inbreds planted during 1992 in the fifth year were 10.5 pods/tree/year and 27.6 cm respectively while that of hybrids was 34.5 pods/ tree/ year and 27.7 cm respectively.

The results on inbreeding depression indicated that the degree of depression varied with the genotype. In yield, the genotypes GI 3.16 and GII 7.2 showed low level of depression in early generations of selfing. GII 7.4 showed high depression in the early generations. Those genotypes with low degree of depression may require only a few generations of selfing to attain homozygosity. For girth and jorquetting height, all the genotypes recorded higher values in the early generations of selfing. In later generations all the genotypes except G I 3.16 were inferior to parental generations. The $S_4$ generation of GII 7.4 and $S_3$ of GIV 35.7 recorded high degree of inbreeding depression as compared to parental generation for jorquetting height. Such a phenomenon of dwarfing among inbreds was also observed in the later generations of other genotypes in the field. The increased vigour in $S_1$ and $S_2$ generations can be attributed to the fact that rigorous selection was exercised in the nursery.

The genotype GIV 35.7 expressed high inbreeding depression for pod weight in $S_1$ and $S_2$ generation when compared to $S_0$. Pod size of inbreds was smaller which also led to low bean weight, bean number, size and dry bean weight. Pods of some plants also exhibited irregular shape, dark green colour and rough mesocarp. The beans and placenta of ripe pods of some trees were adhering firmly so that the beans could not be extracted. Cherelle wilt and incidence of vascular streak die back were very severe in inbreds.

The self incompatible selfed progenies were utilized in hybridization programme with the objective of producing hybrids with some uniformity. $S_1 \times S_1$ hybrids from three genotypes could be field planted in 1995 and their performance was comparable with other hybrids of the same age. $S_2 \times S_2$ cross of the genotype GII 7.2 x GI 3.16 was field planted in June 2002.

**Acknowledgement**
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# AN INSIGHT INTO THE PRESELECTION METHOD IN COCOA

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Hybridization involving cross compatible parents produces a large number of hybrid seedlings. However, all these seedlings cannot be field planted due to constraints in space and money. As in any other perennial crop, preselection parameters with positive correlation have been worked out in cocoa by Glendinning (1966), Ngachou and Lotode (1971), Enriquez (1981) and Paulin *et. al.* (1993). At Kerala Agricultural University, the preselection method of using $HD^2$ has been utilized in hybridization programmes since 1984 (CCRP, 1988). The effectiveness of the said method was tested in hybrids on attaining steady yield and the results indicated the absence of significant association between $HD^2$ values of the seedlings at four, five and six months after sowing and yield (Francies, 1998; Sridevi, 1999 and Varghese, 1999). These studies indicated the need for searching early growth parameters right from germination and working out correlation with final vigour. In this background, the present study was therefore undertaken in the Cadbury- KAU Co-operative Cocoa Research Project, College of Horticulture, and Vellanikkara for the period from August 1999 to August 2000.

Twenty pods each were collected from five self- incompatible clones planted in biclonal gardens viz., G I 5.9, G II 19.5, G II 20.4, G VI 56 and M 13.12 during August 1999. Beans were sown under uniform conditions in the nursery. Observations on sprouting were recorded and the seedlings were grouped into four sets depending upon the speed of germination as Set I, Set II, Set III and Set IV (Seedlings emerging on 15, 17, 19, and 23 DAS, respectively). Number of seedlings/ treatment was 100. The seedlings were individually labelled. The seedlings were maintained under uniform level of management for 375 days. Observations were recorded on height (H), girth (D) at fortnightly intervals during the first three months and later on at monthly intervals for a period of one year. The mean height, diameter and $HD^2$ were worked out. The correlation coefficients for height (H), girth (D) and $HD^2$ were computed between the seedlings at different growth intervals with final vigour after 375 days and these were tested for significance.

The results of correlation coefficient analysis suggested that the speed of germination in general had no significant association with the final seedling vigour. The hybrid seedlings derived from the four clones showed wide variation with respect to correlation and seedling vigour.

In GI 5.9, height of the seedlings under the Set I recorded significant correlation during early intervals with final vigour. However, diameter and $HD^2$ differed in that it recorded positive correlation at 75 to 90 DAS and 75 to 135 DAS respectively. Under Sets II, and IV the seedlings recorded negative correlation between early intervals and final vigour. The studies thus indicated that in this clone, though the height of seedlings germinated at 15 DAS exhibited positive correlation between early intervals and final vigour, the other observations were not positive.

The results in clone G II 19.5 suggested that the seedlings under Set III only showed positive correlation between early growth intervals and final vigour. This clone recorded negative correlation during early intervals for diameter and $HD^2$ with the final values.

GII 20.4 behaved in very different way in that the early observations did not carry a positive association with the final value. In G VI 56, the seedlings under Set I registered positive relationship for girth from 105 DAS to 165 DAS with final vigour. The seedlings under Set IV showed negative values for height at 45 to 60 DAS with final value. However, girth showed a positive association from 45 to 90 DAS with final value. The $HD^2$ values were positive only between 60 to 375 and 75 to 375 DAS. In clone M 13.12 the values were significant only towards the latter part of the experiment.

The results in general suggested that the seedling vigour at early stages were not at all correlated with final vigour. It is observed that the late germinated seedlings could make up the difference in vigour during the course of growth. This was contradictory to the observations made by other workers. It is clear that the method adopted in Kerala Agricultural University (Enriquez, 1981) was quite inefficient and a large number of valuable types might have been lost during the seedling screening procedure. The results point out the immediate need to search alternative methods of preselection. The recent innovations in biotechnology may be explored to develop a viable preselection method in cocoa.

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## SESSION – II

## PRODUCTION TECHNOLOGIES

**CHAIRMAN: DR.V.RAJAGOPAL**

**RAPPORTEUR: DR. S. E. APSHARA**

# MANAGEMENT OF COCOA

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In India, commercial cultivation of the crop was started in the 1970's. During the initial years, many of the management practices adopted in major producing countries had to be adopted in India also. However, differences in agroecological and cropping situations demanded standardization of agrotechniques exclusively for our country. Therefore, studies have been undertaken in India on different aspects of management. The research findings are explained in this paper.

## Climate

For ensuring best growth of cocoa, proper distribution of rainfall is considered more important than the total amount. In most of the major South American, African and Southeast Asian cocoa-producing countries, distribution is more or less even with minor peaks. It is so well distributed that around 10 cm of rain is received almost every month. The pattern in the cocoa belt of India is totally different with the bulk of the rain received in two or three months. It remains rain-free for as long as four months in the southern districts of Kerala and as much as six months towards the northern parts of the state and the southern part of Karnataka. Such a rainfall distribution indicates the necessity of providing irrigation for cocoa in India. It is to be noted that cocoa is not an irrigated crop in any of the main producing countries. An ancillary conclusion to be drawn is that cocoa production in India will be more expensive because of the necessity of this management practice. The bulk of cocoa in India is raised as a mixed crop of coconut or arecanut and providing irrigation becomes relevant in such a system especially in coconut gardens most of which are not irrigated.

## Soil

In the cocoa growing regions of India, soil texture is often coarser and gravelly with low moisture retention capacity and poor fertility as compared to those of other countries. One of the important consequences of these is the low moisture retention in our soils, which again indicates the essentiality of providing irrigation. Soil fertility of coarser textured soils also must be expected to be poorer which would make manuring and fertiliser application necessary. Most of the cocoa soils of major producing countries are derived from freshly cleared forest vegetation thus making them fertile especially with respect to organic matter and nitrogen contents. For the mixed cropping situation in India where the soils are heavily depleted due to long periods of continuous cultivation, manuring and nutrient supplementation through fertilisers are essential components of crop management. A comparison will indicate that the average nitrogen content of Ghanaian soil put to cocoa cultivation is nearly five times that of Kerala soil.

**Propagation**

*Seed propagation*: The variability in the seedling progeny limits the desirability of the use of seedlings as planting material. The results of the studies indicate that when parents with better combining ability are chosen, the chances of recovery of heterotic hybrids are high in cocoa. The Kerala Agricultural University has established poly and biclonal seed gardens using better combiners for seed pod collection and distribution among the growers. If seed pods cannot be procured from such seed gardens mother plants are to be selected based on yield, pod and bean characters.

Seeds of cocoa are non-dormant and lose viability within seven days. Better germination in the nursery could be attained when the seeds were sown shallow with hilum end down or in a flat position. Peeling the seed coat, though enhances the speed of germination, the extent of additional advantage seems to be only marginal. Though the seeds will germinate at any time of the year, seeds may be preferably sown by December-January so that 4-6 month old seedlings become available for planting by May-June.

Studies conducted by Gopinathan (1981) indicated that cocoa seedlings must be shaded and well watered for better germination. The optimum shade level was 50-55 per cent. It was indicated that irrigation at 75 per cent available moisture was the best. It was seen that cocoa seedlings couldn't be grown without any shade irrespective of frequency of irrigation. Except NAR and LAR, all the growth characters were increasing with increase in shade level upto 50-55 per cent and increase in frequency of irrigation. The highest total uptake of nutrients was noticed in the plants shaded up to 50-55 per cent level.

Seedlings are transplanted after four to six months. Only vigorous seedlings are to be used and based on height and stem girth, about 25 per cent poor seedlings may be rejected. When seedlings are grown under heavy shade, hardening for ten days by exposing to higher illumination may be necessary before transplanting.

*Vegetative propagation*: In view of the high variability exhibited by seedling progenies, vegetative propagation is preferred for large scale planting. Though vegetative propagation of cocoa by budding, rooting of cuttings and grafting are feasible, the widely accepted method in India is budding.

The Kerala Agricultural University has released ten improved cocoa clones, which are self incompatible and tolerant to Vascular Streak Dieback. The standardization of a viable vegetative propagation method enables large-scale production of these high yielding clones for distribution among the growers. The method standardized in Cadbury–KAU Co-operative Cocoa Research Project, Vellanikkara is described hereunder.

The bud wood is to be selected from high yielding, disease resistant elite plants. Scions are preferably precured by cutting off laminae of all the leaves of the selected scion shoot to a distance of about 30 cm from the tip. After ten days when the petioles have fallen off, these scion shoots are cut and used for budding immediately. Bud wood can be stored by dipping in benzyl chloride followed by washing in water and then sealing the cut ends using molten wax. Bud wood is then wrapped in moist cotton wool and in turn in wet tissue paper or blotting paper and packed in boxes with wet packing material. The packet is then covered using polythene sheets. Storage life of the bud wood can be extended up to ten days by this method.

As far as possible, bud wood is to be collected from chupons as those produced from fans may develop into bushy plants with spreading habit.

Rootstock, six to twelve months old may be selected in such a way that scion and rootstock are of the same thickness. Among the different successful methods, T, inverted T, patch, and modified Forkert methods, patch budding is adopted in Kerala Agricultural University. This method consists in 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.

**Selection of planting materials**

When seedlings are used for planting, select only vigorous and healthy seedlings produced from polyclonal seed garden or selected mother plants. When budded plants are used, select two or more clones for planting as the use of a single clone can lead to no production due to the existence of self incompatibility in cocoa.

**Spacing**

The spacing adopted for cocoa in the major producing countries had been highly variable. 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. On the other extreme, a relatively wide spacing of 5 m x 5 m is adopted in Sri Lanka. Experimental evidences indicate that, a close spacing of 2.7 m x 2.7 m was found better up to the eighth year of planting whereas beyond the eighth year, a spacing of 4 m x 4 m proved to be superior. The extent of yield difference between these two spacings tended to narrow down with advancing age.

The ultimate spacing and population level to be followed should be decided taking into account the factors contributing to the extent of canopy development, the variety used and the type of management. For the African situation where the less vigorous Amelonado is predominantly cultivated, which has a long pre-bearing period, and where practically no costly input is used, a closer planting may be beneficial. This will also mean a better crop in the early bearing period. For the Amazonian type which is dominant in India and where fertiliser application and irrigation are given on per plant basis, close planting will increase the cost of production which may not commensurate the extra yield of the early years. Taking these into consideration and based on the extent of canopy development observed under Indian situation, a spacing in the range of 3 to 4.5 metres between the plants is recommended. For arriving at the spacing of cocoa under coconut, further considerations on the root spread of the associated crops will also be necessary. Among the other cocoa producing countries like the Philippines, Papua New Guinea and Malaysia where cocoa is cultivated along with coconut, the spacing followed in Malaysia is rather close one, there being two rows of cocoa in between the rows of coconut at a plant-to-plant distance of around 2 m. The coconuts are spaced 8 to 10 m and the cocoa population in a hectare would be about 1000. The general recommendation for our situation could be that for coconut planted at the normal spacing of 7.5 m x 7.5 m or less, there may be a row of cocoa in between two rows of coconut and that when coconut spacing is distinctly more, it may be possible to accommodate two rows of cocoa in between coconut rows.

If a spacing of 3 m between cocoa plants is taken as the standard and cocoa is planted as a single row in between coconut trees spaced at 7.5 m x 7.5 m, the effective spacing between cocoa plants would be 3 m x 7.5 m. At this spacing, a total of 444 plants can be accommodated in a hectare of coconut plantation. One more cocoa plant each can logically come in between columns of coconut trees and the total number thus total number of cocoa plants could be 614 in a hectare.

Root activity studies on rain fed 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 90 per cent of the root activity.

The conclusion, thus, would be that the plant-to-plant distance between coconut and cocoa may be 3.2 to 3.5 m and that between cocoa plants, 3 m. At this spacing, the average number of cocoa plants in a hectare of coconut may be taken to be 500.

Other than in coconut plantations, cocoa is planted in India in the interspaces of arecanut. Arecanut is usually planted at a spacing of 2.7 m x 2.7 m and the usually adopted spacing of cocoa also is the same, with the cocoa population being the same as that of arecanut. The general experience is that such spacing results in crowding of cocoa canopy. The recommendation is a row of cocoa to be planted in between two rows of arecanut. The net spacing for cocoa then would be 5.4 m x 2.7 m and the population in a hectare, 686.

**Planting**

Each country has its own favoured method of planting. In Sao Tome 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. Experimental results generally indicate lack of any significant advantage out of making planting pits if soils are naturally deep enough and are fertile. However, if soils are gravelly or if hard pans occur within the depth of penetration of roots, such a practice may be advantageous. Again, if the soils are naturally of low fertility especially on the surface, there may be advantage arising out of incorporation of manures that usually accompanies filling of planting pits. The general recommendation given for the Indian situations where soils are of low fertility and where gravelly laterite zones occur at varying depths in the soil is to dig pits of 50 cm length, width and depth, fill them with a mixture of surface soil and organic manures, and to plant the seedlings at the surface level. This recommendation of the size of planting pit is to be taken only as a general guideline and the final decision is to be taken considering the two advantages of breaking any hard soil layer and of the improved fertility in the root zone.

A point to be noted is that cocoa seedlings are to be planted on the soil surface rather than planting in pits as practiced in many other plantation crops. This is necessary because the feeding roots of cocoa get concentrated on the surface irrespective of the zone at which seedlings are initially planted.

**Shade**

The shade levels at which cocoa was cultivated had been highly variable. A survey of the farmers' farms has indicated that most of the cocoa received about 40 per cent incident light, the range being 30 to 80 per cent. The results of a number of shade trials taken up since the 1950's in cocoa producing countries have shown that the shade requirement of young cocoa plants is as much as 75 per cent which can be gradually brought down to about 25 per cent when cocoa comes to production. Such variations in shade levels are provided in the sole crop situations in the other countries by providing different types of shade plants and by their selective thinning. The studies conducted by Nair *et al.* (1996) at the Kerala Agricultural University on the response of cocoa to shade 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. However, shading may be necessary in the early years using temporary shade plants.

In one of the suggested shade regulation methods in other countries, there would be two types of shade plants; permanent shade trees planted or left without removal while clearing the forest for cocoa cultivation at a relatively wide spacing of about 13 to 15 metres and temporary shade plants. These temporary shade plants may be at the same spacing as cocoa, alternating with it. The common temporary shade plants in African countries are banana, tree cassava or cera rubber (*Manihot glazeovii*) and cocoyams (*Colocasia esculenta*). These shade plants are gradually removed as cocoa grows and canopy develops. The permanent shade tree commonly used for planting in Ghana is *Terminalia ivorensis*. The other shade trees that may be used are Gliricidia (*Gliricidia maculata*) planted at about 3 m x 5 m., dadap (*Erythrina lithosperma*) and *Leucaena leucocephala*. With both permanent and temporary shade plants, the shade level will be high resulting in best vegetative growth of young cocoa. When temporary shade plants are removed as cocoa comes to bearing stage, illumination level would be higher, stimulating production.

The shade levels under coconut canopy are highly variable depending mainly on the spacing given to coconut, the extent of canopy development and the age of palms. If a choice is possible, a coconut plantation that will let in more light through the canopy may be chosen for raising cocoa. However, if the light infiltration is more than 50 per cent, it may be beneficial to provide additional shade for young cocoa. Banana planted at the same spacing as cocoa may be a suitable temporary shade plant. Banana may be removed as cocoa canopy closes and the plants start bearing.

**Manures and fertilisers**

The presence of shade trees, the dense canopy development of cocoa and the large turn over to the soil of cocoa litter prevent any substantial loss of soil by erosion and depletion of nutrients. In a study at the Central Plantation Crops Research Institute at Kasaragod, India, the amount of organic material returned to the soil as cocoa litter was estimated as 818 and 1985 kg/ha/year (on dry weight basis) in the single and double hedge systems of planting of cocoa. The quantities of fertiliser nutrients contained in organic material from double hedge planting were estimated as 50 kg N, 11 kg $P_2O_5$ and 35 kg $K_2O$ per hectare. Sreekala (1997) studied the organic recycling through cocoa litter. The total annual litter fall was 5.3 t/ha in the shaded field and 8.2 t/ha in the open. In both, litter fall was maximum during December-January with the peak occurring in the first fortnight of January. Litter fall was lower in the wetter months of the year. Nutrient return through litter fall was high in the open (109.7, 6.8, 104.2, 103.7 and 57.4 Kg N, P, K, Ca and Mg respectively). Under shade, nutrient return worked out to 66.9, 5.0, 59.7, 84.9 and 40.3 Kg N, P, K, Ca and Mg, respectively.

In India, with coconut as the main crop, the extent of depletion of nutrients from soils is very high. Coconut returns practically nothing to the soil by way of crop residues as all the plant parts are economically important and are removed. Cultivation of short duration inter-tilled intercrops like tapioca has further led to the loss of soil nutrients, especially as these intercrops are not often manured and fertilised adequately. Therefore for cocoa in India, fertiliser application is a must. The recommendation has been based on crop removal. This may be worked out based on the quantities of fertiliser nutrients removed by way of pods assuming that the remaining residues from the crop go back to the soil.

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 fertiliser 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. For cocoa under better management where the average annual yield is over 60 pods, double this dose is tentatively recommended.

**Method and time of application of fertilisers**

Fertilisers may preferably be applied in shallow basins of 120 to 150 cm radius and raked in without serious damage to the roots. The general recommendation in most producing countries is to broadcast fertilisers in the entire field without any soil tillage. This may be suitable when soil surface is wet and there is chance of immediate dissolution of fertilizers. An immediate mixing of fertilisers with soil under less moisture condition will reduce chances of volatile loss of nitrogen especially when urea is used as the nitrogenous source.

For timing of application of fertilisers, the stages of crop activity and the seasons of moisture availability may have to be considered. Taking these into account, fertiliser application of rainfed cocoa may be done in two splits, the first coinciding with the pre- monsoon rains during May-June and the second by the close of the monsoons, by September-October. For the irrigated cocoa whose crop activity will extend to summer seasons also, fertilisers may be applied in four equal splits during May-June, September-October, December and February. Such four-split application has been found beneficial for coconut also.

For young cocoa in the field, the dose of fertilisers may be one-third the annual dose for adult plant for the first year and two-third for the second year. As cocoa under good management will start giving reasonable yield from the third year, it may be logical to supply full dose of fertilisers from then.

The suitable practice of fertiliser application for cocoa in India would appear to be to rake in and mix the fertilisers with soil in shallow basins of about 150 cm radius around grown-up plants. The basin size will have to be smaller for cocoa in the early years of establishment.

Application of organic manures for adult cocoa may not be essential, as there is a large return of organic debris to the soil by cocoa plants. However, for young cocoa, organic manures will be useful. These may be applied in the planting pits when seedlings are field planted and to the shallow basins afterwards. Experience had been that organic manuring is immensely beneficial for young cocoa plants in the depleted soils of India.

**Micronutrient needs**

Zinc deficiency symptoms were reported in cocoa by Nair *et al.* (1980). A few seedlings showing similar symptoms were collected and were supplied with zinc sulphate at 1.0 and 1.5 per cent through foliar spray. The plants receiving the spray recovered. However, there was no significant advantage due to supplementation of this nutrient to cocoa plants (Nair *et al.*, 1994a).

**Pruning**

Cocoa grows naturally in tiers. There will usually be only one chupon growth in a seedling. Under good management and when adequately shaded, most of the plants jorquette at a height of 1 to 1.5 m. The number of fans arising at the jorquette will be in the range from three to five, the most common being five.

Pruning is intended to restrict the growth of the trees to a convenient height, to have the first tier developed at the desired height and to remove the excessive and inconvenient development of branches. A trial was conducted in Vellanikkara to assess the extent of pruning required for the crop and the results have been reported by Nair *et. al.*,(1994a). The results showed that there was more or less consistent superiority of the unpruned control in terms of yield. However, the superiority of unpruned plants is to be taken only as the early trend and once canopy shaping is achieved, the differences tended to narrow down. In this trial, the significantly higher yield of un-pruned control plants observed during the fourth and fifth years ceased to be statistically significant during the subsequent years though the trend of superiority of control continued with decreasing magnitude with advancing age.

It is, thus, only for convenience that cocoa is pruned. Among all the major cocoa - producing countries, the only country in which cocoa is regularly pruned is Brazil. Pruning is not a part of management of cocoa in any of the African countries.

Having the first tier developed at heights lower than 1 to 1.5 m will make the cultivation operations difficult. Therefore, the first tier should develop at heights not less than 1-1.5 m. If plants jorquette at lower heights, the stem with the developing fans may be nipped off just below the jorquette. New chupons will arise on the main stem. One healthy chupon shoot may be allowed to grow up and jorquette. All the other chupon shoots may be removed. This process of nipping chupon shoots may be continued till the desired height is attained. Generally for plants under heavy shade, jorquetting is higher. Restrictions on growth like limitations in availability of mineral nutrients and water tend to lower jorquette height. Some plants do not jorquette at normal height. They tend to grow very tall before the fans develop. There is no known method by which jorquetting height could be lowered in such cases. However, such plants are rare in a population. It is advisable to have only one main chupon stem.

Vertical growth is to be limited to a single tier. However, a second tier may be allowed to develop if the first tier is damaged. Arresting further vertical growth would require continuous removal of chupons that develop from below the jorquette. This will have to be a continuous process as the normal tendency is for the plants to put out new chupon growth. Normally, chupons arise from chupon stems only and fan laterals, from fans. Rarely, chupons arise from fans also especially when cocoa is pruned by removing new chupon branches. When chupons arise from fans, they do so generally from the fan branch portions around the jorquette. These are also to be removed at the early stages

Many fan branches tend to droop down at the ends and often reach ground level. These drooping branches may be cut off at a suitable distance from the jorquette. This operation may be done once a year preferably when the crop load is low. December-January and July-August may be convenient under the Indian situation, as cocoa will be nearly pod-free during this period. Removal of part of the foliage may also help to reduce transpiration in the summer season.

While the above recommendations may apply in the case of cocoa that is developing, any pruning and shaping of grown-up cocoa plants may be done gradually without much of shock to the bearing plant. For example, if raising of the first tier of a bearing plant is desired, it may be allowed to form a second tier from a chupon that arises naturally and after the second tier is fully developed, the fans of the first tier may be removed in phases. The suitable period for this operation for Indian cocoa may be in December-January. Similarly, if the second tier that is already developed is proposed to be removed, it may also be done in phases, removing the fans one by one.

**Post planting care**

Immediately after planting, basins may be mulched with organic materials. Shoots that emerge from the lower portions of the bud patch are to be removed periodically to ensure healthy growth of scion shoot. In summer, provide mulch materials with chopped banana sheath, coconut husk, cocoa husk etc. to conserve moisture when shade is not optimum.

**Weed control**

During the first three to four years of planting, it is essential to keep the field free from weeds. When canopy is fully formed, shade intensity will be so high that practically no weed growth occurs below it.

**Shaping of clonal plants derived from fan shoots**

Budded plants from fan shoots have diffuse branching system and bushy growth habit, If a better shape of the plant is desired, appropriate formation pruning may be necessary. This would involve identification of a chupon arising from a fan shoot, allowing it to grow and removing the original, lower fan-like shoots in stages. This, however, has to be done slowly as an early drastic pruning will inhibit growth.

**Top working**

Top working is useful to rejuvenate old and unproductive cocoa plants and also to convert genetically poor yielders to high yielders. This technique was standardised at the Cadbury–KAU Co-operative Cocoa Research Project, Vellanikkara (Nair *et. al.*, 1994b). This 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 premonsoon showers.

The top worked trees start yielding heavily from the second year onwards. About 50 per cent improved yield is 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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# PHYSIOLOGY OF COCOA

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Cocoa was introduced to Southern India during the present century mainly as an intercrop of coconut and arecanut gardens since the microclimate was found to be suitable for their growth. Among plantation crops, in cocoa the physiology has been 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 under-storey 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 (Balasimha, 1987).

The microclimate existing in coconut and arecanut gardens and which transmit approximately 30 to 50 per cent of light is very conducive to cocoa growth as they are shade tolerant. The light penetration from an arecanut canopy and yield were optimum in 1:1 ratio of arecanut and cocoa combination at 3.3 x 3.3 m spacing. However, in the existing arecanut gardens with 2.7 x 2.7 m spacing, a planting of 2.7 x 5.4 m for cocoa is good due to least self-shading. The leaf morphology and photosynthetic rates attain optimum levels under these conditions.

The cocoa tree needs a high and well-distributed rainfall, possibly with a short dry spell to stimulate flowering. The climatic conditions are different in regions of Southern India; with well-distributed rainfall in Southern Kerala compared with long dry spells during summer months in Northern Kerala and coastal Karnataka. Wind is another important yield determining factor, the duration and intensity varying in different cocoa producing areas. However, in India the palms under which cocoa is cultivated, themselves offer some protection to the intercrops, the damage caused is minimal or non-existent.

Photosynthetic efficiency is a primary determinant of cocoa productivity and saturating levels are attained at around 1/5th of total light intensity (about 400μ mol $m^2s^1$). Thus, the light levels under these palms are more than adequate for cocoa trees. The net photosynthetic rate (Pn) ranges from 1.6 to 7.0-μ-mol $CO_2$ $m^2s^1$ in cocoa leaves depending on season and accession (Balasimha *et al.*, 1991).

The increments in growth parameters at pre-bearing age will influence the yields. Thus, it is very important to plant vigorous seedlings for better establishment and yield potential at maturity. Progenies, which are more vigorous, have capacity for high yield and the less vigorous seedlings are generally late bearers and tend to be unproductive. Once the stem area is fixed, it is difficult to enhance further the productivity of cocoa and only possibility then would be to increase the number of fruit bearing branches, which has shown strong positive correlation with yield. There were also significant correlations of yield with biomass and harvest index. The high yielding accessions viz., Amel x Na 33, Landas 364 and Landas 357 had higher biomass, harvest index and canopy Pn. Thus, the increased biomass production and efficient partitioning towards the sink (harvest index) would increase yield.

The growth and yield is influenced by a number of environmental factors, particularly rainfall, temperature and water stress. Cocoa is a very sensitive plantation crop to drought. Water stress affects the most important physiological determinants of yield-canopy architecture, photosynthesis and partitioning of assimilates. The drought intensity is more pronounced in northern regions of Kerala and coastal Karnataka (dry spell extending upto 3-6 months). The plants are subjected to severe stress in the rainfed coconut gardens. However, the situation is better in arecanut gardens, which are irrigated. But non-availability of water towards end of summer exposes the plants to stress (Balasimha, 1999).

Due to this reason, efforts have been made to identify drought tolerant characteristics in cocoa accessions. Research conducted for the last decade has shown that thick leaf, higher epicuticular wax content and efficient stomatal closure under drought to reduce transpirational water loss is responsible for better drought adaptation (Balasimha *et al.*, 1988). Such increases in stomatal resistance did not affect Pn significantly and it was found that the water use efficiency was enhanced in tolerant accession types. It has been possible to identify drought tolerant accessions viz., NC 23 (P3 x P), NC 29(P6 x P4) and NC 42 (T 86/2), which are introductions from Nigeria. These are being used as parents along with high yield trees in breeding programme. Under situations where the dry periods are shorter, it is possible to introduce drought tolerant genotypes identified at this Regional Station. However, since this drought adaptive strategy may fail in such areas of longer periods of dry season, it is necessary also to have a proper scheduling of irrigations. Studies to find out threshold levels of soil moisture for cocoa productivity and water economy through drip irrigation has been initiated. Water relations, soil moisture profiles and photosynthetic characters were determined in relation to drip irrigation in cocoa, which showed stress effects at I1 (10l/day) level. Optimum responses were noticed in I2 (20l/ day) level.

Cocoa plant requires fairly large canopy and leaf area to sustain high productivity because of its very low Pn and net assimilation rate. When cultivated as intercrop under palms, a maximum of two-storey canopy architecture may be maintained. The plants require minimum of pruning, which is restricted to removing the highly shaded and non-fruiting branches. The main stem may be kept to 1-1.5m height before allowing the first jorquette. Thus it is clear that canopy area is an important determinant of yield rather than leaf Pn. The canopy- Pn i.e., leaf area x Pn is determining factor for cocoa productivity. Pruning is essential for maintenance of optimum canopy shape. Maximum yields were obtained in large canopy (16-20 $m^2$) in a spacing of 2.7x5.4m. The average land equivalent ratio (LER) for different treatments ranged from 0.82 to 1.74 that showed the advantage of mixed cropping of areca and cocoa.

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# SOIL SOLARIZATION AND BIOFERTILIZERS ON THE GROWTH OF COCOA SEEDLINGS.

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Cocoa is propagated through seedlings and budded plants. Budded plants are preferred for new planting mainly to avoid the variability exhibited by seedling progenies. Nevertheless, to prepare budded plants seedlings, as rootstocks, have to be prepared in large numbers. The nursery must be planned in such a way as to get the maximum number of healthy seedlings that attain buddable girth in the shortest time. Solarization, a method of heating the moist soil by covering with transparent polythene sheets, was found to be of immense advantage in preventing the occurrence of soil borne diseases and germination of weeds, and improving the performance of many crops (Yaduraju, 1993). *Azospirillum* and Arbuscular mycorrhizal fungi (AM fungi) are well accepted as efficient biofertilizers for the early growth and vigour of seedlings of many crops (Nair and Peethambaran, 2000). The present experiment was undertaken with the objective of testing the feasibility of producing healthy cocoa seedlings in the shortest period by the solarization of nursery potting mixture and application of biofertilizers involving *Azospirillum* and AM fungi.

The experiment was conducted at the cocoa nursery area of Cadbury- KAU Co-operative Cocoa Research Project attached to the College of Horticulture, Kerala Agricultural University, Thrissur during 2000-2001. It was laid out in 5 X 4 factorial in Completely Randomised Design (CRD). Solarization at different intervals (0, 15, 30 and 45 days) and fumigation with Dazomet were compared together with four levels of biofertilizers (*Azospirillum*, AM fungi, *Azospirillum* plus AM fungi and no biofertilizer). The prepared potting mixture was spread as low raised beds in an open area where bright sunshine is available, moistened and covered tightly with polythene sheets. The polythene sheets were removed after the expiry of the prescribed periods. For planting cocoa seeds, polythene bags were filled with this solarized potting mixture or fumigated potting mixture according to the treatments. Azospirillum was applied at the rate of 10g per polythene bag after the germination of seeds. For AM fungi, after three-fourth filling of polythene bags with potting mixture, the maize roots on which AM was multiplied along with rhizosphere soil was applied at 50g per bag. Observations on growth parameters (height of the plants, collar girth, number of leaves, leaf area per and dry matter production per plant) were taken from five tagged plants in each treatment at monthly intervals for three months after sowing. The number of seedlings that reached budding stage (pencil thickness) was selected from each treatment at biweekly intervals after about three and half months, and their numbers noted.

The results showed that there were improvements in all the growth parameters of cocoa seedlings, i.e.; plant height, collar girth, number of leaves per plant, leaf area per plant and total dry weight per plant due to solarization for 30 and 45 days and fumigation with Dazomet when compared to non-solarized plots. Responses to biofertilizer application were also significant. All the biofertilizer-applied plots had improved growth characters. Some interaction between solarization and biofertilizer was also noticed, especially with respect to collar girth and number of leaves. Collar girth is an important parameter, as it is the major character on which budding stage is determined. Solarization for 45 days with *Azospirillum* or with *Azospirillum* plus AM fungi was found to be superior to other combinations.

Earliness in reaching budding stage is an indication of efficient nursery management. Attempt to select seedlings that reached buddable stage was first done after 107 days of sowing. This continued upto 38 days and stopped when more than 90 percent of the seedlings were selected, and when no further selection was possible due to poor growth. The treatments 30 and 45-day solarization and fumigation showed the highest early removal of seedlings for budding. A progressive total of 98.0 per cent, 98.5 per cent and 97.5 percent of seedlings respectively could be selected for budding by 144 days in these treatments, whereas only 60.5 percent could be taken for budding from non-solarized plots by this time.

The weed free conditions from germination onwards created a competition free environment, which is conducive for early vigorous growth of seedlings in all the above promising treatments. The increased collar girth observed at 30, 60, 90 days after sowing is a clear indication of vigorous growth of seedlings for early budding. Biofertilizers also showed earliness for budding. The effects of biofertilizers were more apparent at the first removal of seedlings for budding. The overall growth improvement due to solarization and biofertilizer application helped in attaining early budding stage of seedlings. As pointed out by Yaduraju (1993), growth responses following soil solarization is likely to result from reductions of major factors limiting plant growth such as fungal or bacterial pathogens, soil borne insects, weed growth, together with an increase in the availability of mineral nutrients. Favourable growth of biofertilizer-applied plants over control could be attributed to many reasons, viz. increased nutrient uptake, hormonal effect of IAA, gibberellins and cytokinins released by micro-organisms or indirectly affecting the balance between harmful and beneficial organisms in the rhizosphere or by production of antibiotics and quinines which are known to give protection to plants against plant pathogens (Sivaprasad *et al*, 1984; and Cuenca, *et al*, 1990).

The results suggest that soil solarization in combination with biofertilzer application can be one of the non-chemical means to improve the overall growth of cocoa seedlings, and thereby early root stock production in cocoa nursery.

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# MIXED CROPPING OF COCOA IN COCONUT IN POLLACHI TRACT OF TAMIL NADU

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Coconut is being grown in area of 45000 hectares in Pollachi Taluk of Tamil Nadu. The farmers started growing various inter/mixed crops in recent times due to the reduction in income from mono crop of coconut because of various problems. Cocoa has been found to be good companion crop in irrigated coconut gardens because of need for partial shade (Vikraman Nair *et al.*, 2000). Cocoa as a mixed crop yielded 300 kgs of dried beans of cocoa under Kerala conditions (Nelliat, 1979). Cultivation details were collected from farmers' fields of Pollachi Taluk of Tamil Nadu to study the performance of cocoa as mixed crop in coconut.

The study was conducted from the selected farmers' fields of Pollachi region where the coconut cocoa mixed cropping was started 3 years ago. The details on area under coconut, age of the coconut crop, area under cocoa and age, soil type, method of planting, spacing adoptt !, method of irrigation, type of fertilizers applied, and method of processing were collected from 10 farmers' field and compiled and presented in this paper.

The results of the study revealed that the farmers have started growing cocoa after the reduction of income from coconut due to various problems. The soil type of most of the fields was red sandy loam. Most of the farmers who are growing cocoa as mixed crop have planted approximately in 25% of the total area of coconut. The age of coconut varied between 20-35 years in most of the gardens. The age of the cocoa crop varies from 1-3 years. Cocoa is being grown as single hedge system with spacing of 9 feet between plants in between two rows of coconut. In few gardens the cocoa was planted only in the bunds as mixed crop. In one of the gardens 5 cocoa seedlings were planted in between 4 palms *i.e.* 1 seedling in the center and 4 seedlings in the coconut rows in each direction. The cocoa population varied from 225 to 675 plants/ha in different method of planting. The height of cocoa varies from 2-5 feet in different gardens. Fertilizers like DAP and urea were applied to the cocoa separately in few farmers' holdings and organic manures alone applied in few other farms. Flood or basin or drip irrigation system is adopted depending upon availability of water. Separate drip lines or basins were provided for coconut and cocoa. Drought condition affected the growth of cocoa in few gardens. The crop is already started yielding in few farmers' fields and a dried beans yield of 0.5 kg/plant was recorded during third year. Thomas (1978) reported that an average yield of 1 kg dried beans was recorded in the farmers' field under Kerala conditions. The pods are dried in basket method and the produce is sold afterwards. The farmers prefer cocoa because of the current price prevailing in the market.

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# TOP WORKED COCOA TREES: AN APPRAISAL OF FIELD PERFORMANCE

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Top working, a method of rejuvenating old and unproductive cocoa trees has proved to be successful in cocoa. The studies carried out at Kerala Agricultural University, during 1988-89 led to the standardization of a procedure for top working in cocoa (Nair *et al.*, 1996). Growth and yield analysis of these trees in the initial years of top working were reported by Jose *et al.* (1998). The present study relates to the field performance of 447 top worked trees, originally planted in 1980 and top worked in 1994.

In order to study the influence of source of scion on the performance of top worked trees, fifteen high yielding clones were selected from the germplasm and designated as M 9.16, M16.9, G I 5.9, G I 10.3, G I 15.5, G II 19.5, G II 20.4, G IV 18.5, G IV 35.7, S 44.1, G VI 51, G VI 54, G VI 55, G VI 64 and G VI 68. The trial was laid out in RBD with four replications with a minimum of six plants per plot. The data on the yield of pods from these plants were collected and analysed for seven years from 1995-96 to 2001-02. The yield was estimated in terms of pod yield per tree per year. Though the trees produced pods on both trunks (belonging to the original tree), the pods borne on the canopy portion alone were recorded and those borne on the trunk were not counted. The tree stature (habit) was also observed.

The observations on tree stature indicated that the number of scion shoots successfully established at the time of budding is important in determining the vegetative growth and yield of trees. As in jorquetting, it is preferable to have four to five shoots emerging from all sides of the stem. When shoots are confined to only one side of the stem, gradual die back was observed on the other side followed by termite attack. Continued connection with a live growing tissue keeps the trunk healthy on all sides. When only one or two unhealthy scion shoot survived, gradual die back of the canopy was observed. In general, the performance of trees is very good when three or more chupon shoots are established on all sides of the trunk.

The data on number of pods/ tree/ year (excluding pods produced on the trunk) indicated that the mean yield of pods over seven years ranged from 21.6 to 45.6. The data also showed that yield had stabilized in second to third year after top working. The mean yield over the seven years was 29.4 pods/ tree/ year (excluding trunk yield). If the yield from trunk were also considered, higher values would have been obtained.

In order to study the influence of source of scion on the performance of top worked trees, clone-wise mean values were worked out. The results indicated that there is difference in yield by using diverse genotypes. Genotypic differences were observed in determining the pod morphology and number of pods. Among the fifteen clones tried, G IV 35.7 continued to give consistently superior yield. During 2001-2002, the mean pod yield in trees of this clone was 56.5. In general, the mean yield of pods over the seven years ranged from 21.6 to 45.6, maximum being in G IV 35.7 and minimum in M 9.16. The data for seven years indicated that the next superior clone is G I 5.9

followed by S 44.1, G II 20.4, G IV 18.5 and G II 19.5. Most of these clones are the released ones from Kerala Agricultural University. The superiority of these clones is confirmed by top working also.

A comparison of the yield of top worked trees with those of budded plants of the same age showed that there is impressive improvement in pod yield in the initial years. It was of the order of 1122.7 % (Budded 2.2 / top worked 26.9) in the third year. Although the difference in yield tended to decline in the subsequent years, the advantage obtained was substantial. The data for 2001-2002 showed that the mean yield of top worked plants was 32.7 (excluding pods from trunk portion) while that of budded plants was 19.51 with a percentage increase of 67.4.

The results suggested that when yield declines, due to use of poor genetic stock or due to old age, top working holds better promise than replanting. This enables the farmer to get income right from the second year.

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# ORGANIC FARMING IMPROVES COCOA YIELD

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The Varanashi Farms (VF) in Adyanadka of Dakshina Kannada district is around 20 ha in extent growing a variety of annual and perennial crops such as rice, banana, pepper, vanilla, arecanut, coconut, cashew, cocoa etc. Prior to 1981, VF received organic manures such as fresh green leaves, FYM etc. Chemical manures were sparingly used. The crop yields, including that of cocoa were low during the period.

However, after 1981, the enthusiasm of the first author after his post-graduation in Agriculture, led to the use of fertilisers and other chemicals for about ten years. Application of these was done to cocoa as per the package of practices, at times the fertilisers, mostly replacing organic manures. Such attempts improved the cocoa yields to some extent.

The organic farming wave influenced the Varanashis to go for organic from 1991. The information from TNAU, Coimbatore and elsewhere was handily utilised for compost preparation from coir pith, an otherwise problematic waste and pollutant. For about five years, Varanashi Co-compost (coir pith compost) was applied to cocoa at the rate of 12 kg per plant, completely dispensing with the use of chemical fertilisers. (Moorthy, 1993)

Further efforts to compost different raw materials using appropriate additives led to the development of a new and simple compost technology called the VRF Method of Composting. The substrates mixed with appropriate additives are spread layer by layer over a thin 10 cm high shallow mud-bunded tank having plastic underlining beneath. A composite culture of useful microbes called Varanashi Composter containing bio-control agents, P-solubilizers and and N-fixers is added at 1-2 kg per tonne of the materials. When the heap is about one metre high, the sides and top are also covered with plastic sheet. Depending on the raw material, the compost could be used after four to six months. (Moorthy *et al.*, 1997).

Balanced compost prepared by the above method using coffee cherry husk, coir pith and poultry manure was applied to cocoa crop in later years i.e. from 1997 onwards (Moorthy *et al*, 1996).

The yield data of cocoa crop during the high chemical input period and the organic period are given in Table-1.

It is clear that over years, that there is a substantial increase in yield in the crop after the introduction of organic farming. The yield of fresh cocoa pods increased from an average of 4.1 kg to 7.43 kg per plant during organic period showing an increase of 78.8 per cent.

The soil fertility of cocoa plots in VF before and after the introduction of organic farming practices is furnished in Table-2.

It is clear that switching over to organic farming has improved the fertility status of the soil with respect to organic carbon, available phosphorus and potash levels.

A spectacular increase in cocoa crop yield is noticed due to change over to organic farming. Besides, the soil fertility is also improved, these confirming the sustainability achieved as a result of adopting organic farming.

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**Table-1. Yield increase in cocoa due to organic farming**

(fresh pod, kg/plant)

| Year | Yield | Year | Yield |
|---|---|---|---|
| **High chemical input phase** | | **Organic period** | |
| 1989 | 3.94 | 1992 | 8.08 |
| 1990 | 3.73 | 1993 | 8.53 |
| 1991 | 4.63 | 1994 | 7.22 |
| | | 1995 | 7.70 |
| | | 1996 | 6.72 |
| | | 1997 | 6.27 |
| **Mean** | **4.10** | **Mean** | **7.43** |
| | | **% Increase** | **78.8** |

**Table-2. Soil analytical data from areca-cocoa mixed garden**

| Period | | pH | EC (mmho/cm) | O.C. (%) | Available $P_2O_5$ | Available $K_2O$ |
|---|---|---|---|---|---|---|
| | | | | | ← kg/ac | → |
| | | | 1. *Diaramoole* plot | | | |
| BF | | 5.4 | <0.2 | >1.26 | 14.5 | 54 |
| AF | A | 6.1 | - | 3.4 | 73.6 | 155 |
| | B | 6.0 | - | 1.3 | Tr. | 61 |
| | | | 2. *Hesarugade* plot | | | |
| BF | | 5.3 | <0.2 | 1.1 | 11.6 | 48 |
| AF | A | 6.3 | - | 1.7 | 61.0 | 533 |
| | B | 5.7 | - | 2.8 | 29.9 | 321 |
| | | | 3.*Moolethota* plot | | | |
| BF | | 5.2 | <0.2 | >1.26 | 27 | 52 |
| AF | A | 5.8 | 0.2 | 1.5 | 111 | 179 |
| | B | 5.4 | 0.2 | 1.6 | 28 | 155 |

Note : A : Soil layer 0-20 cm; B: Soil layer 20-40 cm; Tr. : Traces
BF : Before introducing organic farming (i.e. April 1991); AF: After introducing organic farming (i.e. May 2001)

# PHYSIOLOGICAL PARAMETERS AND YIELD IN COCOA HYBRIDS

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Cocoa plants are sensitive to drought and yields are affected as drought periods of 3-6 months are encountered in southern India. Efforts made to identify drought tolerance characteristics among cocoa have resulted in identification of five tolerant ones (Balasimha *et al.*, 1988). In an earlier study nine hybrids from crosses of three tolerant and four high yielding accessions showed that some of them showed positive physiological traits of drought tolerance (Balasimha *et al.*, 1999). In this study eighteen hybrids developed in a crossing programme with tolerant and high yielding trees are reported.

Crossing high yielding and drought tolerant trees were done to evolve hybrid lines. Three tolerant trees viz., NC 42/94, NC 23/43, NC 29/66 and five high yielding trees viz., I-56, III-105, III-35, II-67 and I-14 have been used. The seedlings were raised in polybags. After six months the seedlings were planted in the field at CPCRI Research Centre, Kidu. The trial was laid out in RBD with three replications and 6 plants per plot. Growth measurements were taken periodically. The stomatal resistance, water potential and other biochemical parameters were measured as described earlier (Balasimha *et al.*, 1988, 1999). Pod yields were monitored periodically.

Eighteen hybrids were screened for drought tolerance using some physiological and biochemical parameters. The physiological parameters showed significant variations in stress and non-stress conditions. Water potential decreased during stress (Table 1). The stomatal resistance showed significant variations and increased considerably during stress (Table 2). The stomatal closure under drought has been shown to be an important adaptive feature in cocoa (Balasimha *et al.*, 1999; Joly and Hahn, 1989). Chlorophyll fluorescence indices in these hybrids were measured. The Fo and Fv/Fm ratios showed significant differences (Table 3). It has been shown that these parameters are useful indices for screening for drought tolerance.

The study on hybrids showed differences in some of these characters during early years. Hybrids that maintain higher leaf water potential and stomatal resistance can be considered as drought tolerant. The pod yields were recorded and showed significant variations among the hybrids (Table 4). High pod yields were recorded in hybrids III-35x23/43, III-35x29/66, III-105x42/94 and 42/94xIII-35. The hybrid 42/94xIII-35 also showed higher water potential under stress condition. Higher leaf turgor resulting from efficient stomatal regulation is an important character for identifying tolerant cocoa types. Some of the hybrids with high yields and positive drought tolerant traits are useful materials for growing under water-limited conditions.

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Table 1. Leaf water potential in cocoa hybrids (bars)

| Treatment | Non-stress | Stressed |
|---|---|---|
| I-56 X 23/43 | -6.60 | -14.96 |
| I-56 X 29/66 | -6.63 | -13.93 |
| I-56 X 42/94 | -7.70 | -14.70 |
| III-35 X 23/43 | -7.23 | -13.93 |
| III-35 X 29/66 | -6.86 | -13.96 |
| III-35 X 42/94 | -6.60 | -15.03 |
| III-105 X 23/43 | -8.00 | -14.16 |
| III-105 X 29/66 | -6.93 | -15.03 |
| III-105 X 42/94 | -6.63 | -13.23 |
| 23/43 X 1-56 | -7.66 | -11.40 |
| 23/43 X III-35 | -6.76 | -12.60 |
| 23/43 X III-105 | -7.03 | -11.13 |
| 29/66 X I-56 | -5.50 | -11.66 |
| 29/66 X III-35 | -7.46 | -12.30 |
| 29/66 X III-105 | -6.10 | -12.66 |
| 42/94 X I-56 | -6.13 | -12.23 |
| 42/94 X III-35 | -6.93 | -11.76 |
| 42/94 X III-105 | -6.90 | -12.33 |
| Mean | -6.87 | -13.17 |
| CD (P=0.05): Treatment | 1.12 | |
| Season | 0.46 | |
| Interaction | 1.95 | |

Table 2. Leaf stomatal resistance (s/cm) in cocoa hybrids

| Treatment | Non-stress | Stressed |
|---|---|---|
| I-56 X 23/43 | 2.19 | 2.34 |
| I-56 X 29/66 | 2.09 | 2.29 |
| I-56 X 42/94 | 1.91 | 4.38 |
| III-35 X 23/43 | 1.67 | 3.37 |
| III-35 X 29/66 | 1.40 | 2.65 |
| III-35 X 42/94 | 1.71 | 1.81 |
| III-105 X 23/43 | 1.95 | 2.52 |
| III-105 X 29/66 | 2.11 | 1.95 |
| III-105 X 42/94 | 1.17 | 2.34 |
| 23/43 X 1-56 | 1.55 | 2.50 |
| 23/43 X III-35 | 2.74 | 2.94 |
| 23/43 X III-105 | 2.33 | 2.92 |
| 29/66 X I-56 | 2.43 | 2.56 |
| 29/66 X III-35 | 1.68 | 2.54 |
| 29/66 X III-105 | 2.00 | 2.46 |
| 42/94 X I-56 | 1.91 | 2.10 |
| 42/94 X III-35 | 1.58 | 1.93 |
| 42/94 X III-105 | 1.22 | 1.81 |
| Mean | 1.86 | 2.40 |
| CD (P=0.05) | | 0.30 |

Table 3. Chlorophyll fluorescence parameters in hybrids (units)

| Treatment | F0 | | Fm | | Fv | | Fv/Fm | |
|---|---|---|---|---|---|---|---|---|
| | NS | S | NS | S | NS | S | NS | S |
| I-56 X 23/43 | 580 | 1016 | 2895 | 2807 | 2334 | 2119 | 0.799 | 0.553 |
| I-56 X 29/66 | 547 | 1098 | 2868 | 2540 | 2337 | 1452 | 0.808 | 0.629 |
| I-56 X 42/94 | 563 | 794 | 2986 | 2225 | 2556 | 1520 | 0.811 | 0.623 |
| III-35 X 23/43 | 592 | 997 | 3120 | 2592 | 1999 | 2157 | 0.771 | 0.270 |
| III-35 X 29/66 | 623 | 747 | 3212 | 3143 | 1977 | 2464 | 0.758 | 0.751 |
| III-35 X 42/94 | 642 | 873 | 2660 | 2604 | 2233 | 1787 | 0.793 | 0.663 |
| III-105 X 23/43 | 551 | 805 | 2748 | 2712 | 2161 | 1852 | 0.795 | 0.663 |
| III-105 X 29/66 | 627 | 752 | 2721 | 2231 | 2128 | 1478 | 0.778 | 0.666 |
| III-105 X 42/94 | 545 | 723 | 2610 | 2528 | 1983 | 1887 | 0.782 | 0.759 |
| 23/43 X 1-56 | 596 | 805 | 2621 | 3178 | 2042 | 2370 | 0.779 | 0.723 |
| 23/43 X III-35 | 676 | 797 | 2862 | 2751 | 2186 | 1947 | 0.762 | 0.795 |
| 23/43 X III-105 | 654 | 785 | 3001 | 2645 | 2347 | 1841 | 0.782 | 0.719 |
| 29/66 X I-56 | 606 | 699 | 2572 | 2704 | 2967 | 2007 | 0.764 | 0.710 |
| 29/66 X III-35 | 614 | 667 | 2916 | 2167 | 2245 | 2033 | 0.776 | 0.783 |
| 29/66 X III-105 | 649 | 780 | 2547 | 3085 | 1913 | 2192 | 0.744 | 0.751 |
| 42/94 X I-56 | 627 | 648 | 2921 | 3016 | 2293 | 2390 | 0.779 | 0.769 |
| 42/94 X III-35 | 637 | 709 | 2807 | 2852 | 2170 | 2143 | 0.796 | 0.742 |
| 42/94 X III-105 | 657 | 639 | 2549 | 2689 | 1892 | 1948 | 0.742 | 0.725 |
| Mean | 610 | 801 | | | | | 0.779 | 0.702 |
| CD(P=0.05%) | | | | | | | | |
| Treatment | 110 | | | | | | 0.048 | |
| Season | 45 | | | | | | 0.015 | |
| Interaction | 191 | | | | | | 0.066 | |

Table 4. Yield performance of cocoa hybrids

| Treatment | No.of pods/tree/year |
|---|---|
| I-56 X 23/43 | 30.6 |
| I-56 X 29/66 | 27.9 |
| I-56 X 42/94 | 35.4 |
| III-35 X 23/43 | 39.4 |
| III-35 X 29/66 | 34.7 |
| III-35 X 42/94 | 38.6 |
| III-105 X 23/43 | 30.8 |
| III-105 X 29/66 | 23.2 |
| III-105 X 42/94 | 37.9 |
| 23/43 X 1-56 | 32.0 |
| 23/43 X III-35 | 33.4 |
| 23/43 X III-105 | 32.5 |
| 29/66 X I-56 | 23.8 |
| 29/66 X III-35 | 29.0 |
| 29/66 X III-105 | 15.0 |
| 42/94 X I-56 | 33.8 |
| 42/94 X III-35 | 36.5 |
| 42/94 X III-105 | 29.6 |
| Mean | 31.4 |
| CD (P=0.05) | |

# SESSION – III

# PLANT PROTECTION

**CHAIRMAN: DR. ROHINI IYER**

**RAPPORTEUR: DR. P. RAJAN**

# IMPORTANT COCOA DISEASES IN INDIA AND THEIR MANAGEMENT

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With the expansion of area under cocoa and with the increase in age of the plantations, pests and diseases are becoming more and more important. Among the nursery diseases, seedling blight caused by *Phytophthora palmivora* has been recorded as a serious problem during rainy season in most of the cocoa growing areas in India. When the seedlings are very young during rainy season the disease becomes very serious and warrants control measures (ChandraMohanan, 1994; ChandraMohanan and Kaveriappa, 1981).

Phytophthora pod rot is the most important disease of cocoa in all cocoa growing countries. In India too, black pod disease caused by *P. palmivora* is the most important disease owing to the extent of damage and nature of disease (ChandraMohanan and Chowdappa, 1999). The disease can be effectively controlled by integrated disease management. Periodic removal and destruction of infected pods will help to reduce the disease incidence to a great extent by reducing the source of inoculum for secondary spread. Cultural practices like proper pruning and regulating the overhead shade to reduce high humidity and to improve aeration have been recommended for better control of the disease. Spraying of Bordeaux mixture one per cent at 15 days interval starting from the onset of monsoon along with periodic removal of infected pods is very effective in managing the disease in severely affected gardens.

Cherelle rot caused by *Colletotrichum gloeosporioides* is a very serious problem on young pods in India (ChandraMohanan and Kaveriappa, 1983). The disease incidence is more during Jan- May or when young pods, the susceptible stages, are plenty in the garden. The intensity of the disease varies from garden to garden. Carbendazim and mancozeb are reported to be promising fungicides for the control of the disease.

Charcoal pod rot caused by *Botryodiplodia theobromae* occurs throughout the year in the cocoa gardens in India. *B. theobromae* is a weak pathogen causing infection through wounds. This disease has not been so far reported as a serious problem.

Among the diseases affecting trunk and branches, stem canker caused by *P. palmivora* is the most important disease (Thorold, 1975). The incidence of the disease is increasing year after year. When the main trunk is affected, the whole tree is killed. Thus, the disease is very important from the economic point of view. Management of other Phytophthora diseases like black pod, chupon blight and twig dieback is very important in reducing stem canker incidence.

In India, Vascular streak dieback (VSD) has been so far reported only from Kerala state. It is a destructive disease of cocoa. VSD can be easily diagnosed in the field based on the characteristic symptom of the disease. Since the pathogen is systemic and has a slow rate of spread, quarantine measures to restrict the transport of apparently healthy planting material containing the fungus are important in restricting the spread of the disease. Propiconazole has been reported as an effective fungicide in checking the disease.

Pink disease (*Corticium salmonicolor*), white thread blight (*Marasmius scandens*), horse hair blight (*Marasmius equicrinis*), chupon blight and twig dieback (*P. palmivora*) and foliar diseases like leaf blight and shot hole (*C. gloeosporioides*) are some of the diseases of, at present, minor importance reported from India.

Severe incidence of zinc deficiency leading to foliar abnormality and twig dieback has been observed in several gardens. Foliar spray of a mixture of 0.3% zinc sulphate and 0.15% (w/v) lime has been reported to be an effective and quick method of correcting zinc deficiency in cocoa.

Diseases such as swollen shoot (virus disease) and witches' broom, Monilia pod rot and green point gall which are all of fungal etiology are known to occur in severe form in other countries. However, these diseases have not been so far recorded from India.

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# PEST MANAGEMENT OF COCOA

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Cocoa, *Theobroma cocoa* Linn. a native of the tropical Amazon rain forests is cultivated in the southern states of India for about 40 years. This tree is now grown in Kerala, Karnataka and Tamil Nadu mostly as a component of mixed cropping with palms like areca (*Areca catechu* Linn.) and coconut (*Cocos nucifera* Linn.). Relatively smaller cocoa plantations are in existence in some parts of South India, mostly as forest cleared ones. Whether cocoa is grown in cultivated environments or in forest plantations, by virtue of its canopy, a special climate is prevalent in cocoa plantations. This environment is conducive to the build up of different insects and diseases and to some specific insect-plant relationships.

Area under cocoa in India is about 16,000 ha and the size of holdings varies from 50 trees of homestead plantings to bigger plantations. Cocoa is not under the attack of any insect species that warrants regular insecticide application. Since the cocoa plantations/plots are in fragmented/isolated strips, the impact of local insect fauna on this plant is yet to be realized. Another reason for this situation is the slow increase in area under this plant. The acclimatization process of local fauna is an ongoing process because of this slow increase in cultivated area. We already know the share of some local insects, which have adapted to this tree in some states for the last 35 years. This will be a continuing process since cocoa is finding its place into non-traditional areas of the country.

About 1500 insects are recorded on cocoa from all over the cocoa growing tracts of the world. The insect fauna noticed on cocoa in India is numbering to only 60 species. Few of the sucking insects like mealy bugs, mirids, and some other hemipterans can cause direct loss of the crop by feeding on young and developing cocoa pods. None of the major insect pests of areca palms and coconut palms are found to inhabit the cocoa trees or feed on them. The only exceptions are the bagworms and the vertebrate pests. The scenario of the insect and non-insect pests of cocoa are given below on the basis of damage caused on different plant parts.

## Sucking insects

The insects in this category suck sap from all parts of the plant and from tissues of all ages. Mealy bugs, mirids, aphids, cow bugs and few other homopterans are the main insect groups that damage the plant parts by sucking. The most prominent damage is on flower cushions, cherelles and tender shoots, which wilt due to this.

***Mealy bugs*:** Mealy bugs (Pseudococcidae) flourish in dry weather with low humidity. Mealy bug feeding can cause morphological changes in young seedlings by feeding on stem apices that can alter the normal tree architecture.

Two species of pseudococcids are important in India, colonizing this plant from the initial years of introduction, viz. the cocoa mealy bug, *Planococcus lilacinus* (Ckll.) and the citrus mealy bug, *P. citri* (Risso). These are present in all cocoa tracts of the country. It has a wide range of host plants. *P. lilacinus* is reported as a serious pest from India in the seventies. This occurs consistently on the plant and is present throughout the year. *P.citri* is present in all cocoa growing tracts.

Mealy bugs colonize the tender parts of the plant like the growing stems of seedlings/young grafts, flower cushions, unripe pods (cherelles), apical regions of all types of branches and the growing mature pods. Apical bud destruction results in reduced growth and the apical shoots deform into slender hair like structures. This can delay the formation of jorquette and a typical canopy. Damage on flower cushions results in total suppression of flower production and these wither and dry up. Feeding on cherelles is usually restricted to the pedicels and this results in the weakening of cherelles, which ultimately wither away. A cluster of wilted cherelles is a pointer to the presence of mealy bugs. Mealy bugs usually colonize the bark surface of growing pods. Though minute cracks, pitting, and discolouration are observed on the pod surface, large pods seldom show any adverse effects of mealy bug colonization.

Mealy bugs are present on cocoa trees through out the year. Population of *P.lilacinus* is lowest in June, July and August and a peak is reached in April and May. Population peak of *P.citri* occurs during July-October.

***Mirids* :** Mirids (Miridae) are important pests of cocoa in most of the cocoa cultivating tracts of the world. The generic composition of these mirids in different parts of the world indicates that these are area specific in its distribution. In West and North Africa the genera are *Sahlbergella* and *Distantiella*. These mirids are not seen in Asian countries. The important mirid in the Asian region is the genus *Helopeltis* and it is distributed in Sri Lanka, Indonesia, Malaysia, and India. *H.antonii* infests a wide variety of plants of economic importance in India like cashew, cocoa, guava etc Adaptation of *Helopeltis* to cocoa was seen in many places after the large scale planting of cocoa in Dakshina Kannada district of Karnataka and many parts of Kerala and Tamil Nadu. In some cases it was *H.theivora* infesting tea plants that shifted to cocoa, planted adjacent to tea plantations. The incidence of *Helopeltis* on cocoa was seen in the 1980s in many areas of Dakshina Kannada though from the early seventies cashew, its primary host was infested in these areas.

The nymphs and adults of *H. antonii* and *H.theivora* feed on the tender shoots, young shoots, cherelles and pods of cocoa trees. Characteristic circular water soaked lesions develop on cherelle and pod surface, which blacken after few hours of feeding. Tender shoots with linear lesions wilt and dry up in course of time. The heavily damaged cherelles wilt and dry up. Severe infestation may lead to deformations of pods, including the corky bean tissues. Die back of heavily infested trees was observed in parts of Sullia and Subramonia areas of Dakshina Kannada district.

***Tree hoppers*** (Membracidae): The incidence of treehoppers is seen in a cyclical nature on cocoa. Two membracids, *viz*; *Gargara mixta* and *Gargara* sp. infest cocoa in parts of South India. These cow bugs are also widely distributed with many host plants. The nymphs and adults of these bugs feed on the tender shoots and on cherelles. Another genus *Leptocentrus* is also seen feeding on cocoa. Both these are attended by the ant *Oecophylla smaragdina* Fab.

***Aphids:*** Citrus black aphid, *Toxoptera aurantii* B.de.F. (Aphididae): This dark brown to black aphid colonizes the tender leaves, shoots, flower cushions, flower buds and small cherelles. Severe feeding results in crinkling of leaves and shedding of flower

buds. On flowers, they colonize the flower stalks. Aphid colonies are found through out the year on cocoa plants, but highest infestation is noticed from July to January months.
***Thrips***: Two species of thrips are found infesting cocoa.Red-banded thrips, *Selenothrips rubrocinctus* (Giard) has adapted from cashew. These thrips colonize the mature leaves and an unidentified species colonize both tender leaves and surface of pods. Infested leaves turn brown and dry up and on pods scabby patches develop. The infestation of this species can be very severe during drought periods.

**Leaf feeding insects**

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.

Three genera of lymantriid are so far reported on cocoa. These are *Lymantria ampla* Walker, *Euproctis guttata* Walk. and *E.subnotata* Walk. and *Dasychira mendosa* Hb. The caterpillars of these moths feed on the tender leaves, and on the surface tissues of cherelles and green pods. *L. ampla* is the most commonly and abundantly observed leaf-feeding insect of cocoa. These are seen more in the field after the monsoon rains. The caterpillars cause severe damage on leaves in young plants.

Caterpillars of the yellow shaded moths *Euproctis* spp feed on tender leaves and cherelles and surface of green pods. The sporadic high population of *Euproctis* spp can cause severe damage of tender leaves. Hairy and brightly coloured caterpillars of *D.mendosa* feed on tender leaves, flower buds and bark surface of tender pods.
***Loopers*** (Geometridae): Three species of geometrids are recorded from South India. These are sporadic in nature and cause extensive defoliation of nursery seedlings and young trees. The genera are *Hyposidra talaca* Walk., *Pingasa ruginaria* Guen. and *Oenospila quadraria* Guen.

Many of the common caterpillars infesting local host plants also feed on cocoa, but these usually do not make any serious damage. These include the caterpillars of the arctiids, *Pericallia ricini* F., *Diacrisia oblique* (Walk.) and *Amsacta gangis* Linn. and the noctuids, *Spodoptera litura* (Fab.) and *Achoea janata* Linn. The caterpillars of these damage the seedlings also especially in nurseries.

The leaf webber, *Adoxophyes privatana* Walk. (Tortricidae) The caterpillars of this moth 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.

***Beetles and weevils:*** Few species of leaf feeding beetles and weevils are found to damage the leaves of cocoa especially during the rainy season.

*Popillia complanata* Newm. (Scarabaeidae): Adult beetles damage the leaves severely and they prefer tender leaves. Adult beetles are very active, swift fliers and feed on leaves dwelling on the underside of leaves. Initial feeding results in small circular holes that coalesce later and the leaf is heavily damaged by irregular perforations. The midrib region is not eaten. The incidence is more during August-September (Prem Kumar, 1976).

*Flea beetle, Monolepta longitarsus* J.G. (Chrysomelidae): A small reddish beetle feeding on cocoa leaves. They cut small circular holes on the leaves. With the slightest disturbance they jump to the soil. 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): Recorded as early as 1967 in the Nilgiris and Yercad regions by Abraham and Padmanabhan. *M. viridanus* occur 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.

**Stem boring caterpillars and beetles**

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): 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 of 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.

**Management of insect pests**

The management of insect pests of cocoa is at present not a serious problem in most of the cocoa growing tracts of the country. Because of the diversity of the habitat, none of the cocoa insects assume serious proportions, which warrant regular insecticide application. Most of the insect problems could be managed with minimum interference. But very few species can be a problem in some environments.

Mealy bugs can be a problem in the initial years of the plants and also in gardens with some of the native ant species like the weaver ant *O. smaragdina* and the mud nest building black ant, *Technomyrmex* sp. The former ant species can be considered as both an enemy and predator but the latter species is always inimical to cocoa production since it is always associated with mealy bug colonies. As a general rule management of ants of any kind is not a practical one. Habitat management is the only solution in this case like proper pruning of cocoa trees. Mealy bug colonies could be reduced by spot application of insecticides like dimethoate on plants with initial infestation in a farm. Management of these mealy bugs by insecticides can be done as spot sprays whenever the incidence is over 15 per cent. Spot spray with 0.05% dimethoate or monocrotophos is effective in maintaining the population at a low level.

Stem boring beetles and weevils also require the attention of farm workers. The affected branches and young plants must be checked for the insects and proper remedial measures are to be adopted. The seasonal and localized incidences of bagworms also require the attention of farm workers. When bagworms are in abundance, these could be hand picked and killed.

**Native natural enemies in cocoa orchards**

Since cocoa is not under regular sprayings of any kind of pesticides in most of the cocoa tracts of south India, it must be implied that the native natural enemies are exerting a good control of the insect fauna of the trees. The observations carried out at the cocoa farms of the institute have given some idea of the natural enemies of some of the insects. The native natural enemies include predators, parasites, insect pathogens and generalist predators like spiders, reduviids, some coccinellids etc.

A number of predators are observed on the mealy bugs. These include a coccinellid, *Pullus* sp. and a lycaenid, *Spalgis epeus* Westwood. Recent studies have shown the presence of a parasite and a cecidomyiid predator.

The citrus black aphid, *T.aurantii* is controlled in the field by the action of a number of predaceous insects like syrphids, hemerobiid, a chrysopid, a cecidomyiid and an endoparasitic cecidomyiid. Among these, the two species of syrphids *viz*; *Dideopsis aegrotus* (Fab.) and *Paragus yerburiensis* Stuck. and an unidentified cecidomyiid are the key predators of this aphid. The population of predaceous cecidomyiid was abundant on aphid colonies from June to September and the syrphids were present through out the year with a peak from September to January. The chrysopid, *Ankylopteryx octopunctata* is a general predator feeding also on other cocoa insects like the nymphs of *Helopeltis* spp. treehoppers etc.

**Role of ants in cocoa farms**

A mosaic of ants is a regular phenomenon in any tropical locations and a number of ants are found in cocoa farms also. A systematic study on the species composition of ants is lacking from this cocoa- areca and cocoa- coconut ecosystems. Out of these five genera of ants are important and they dwell both on the trees and on the ground. They could be mainly classified as the scavengers, predators or trophobionts. Out of these, the trophobionts are important economically because the populations of many homopterans flourish well on cocoa when attended by these ants.

*Oecophylla smaragdina* Fab. These arborecolous ants are associated with honeydew producing homopterans like mealy bugs and membracids, but they are never found attending to aphid colonies. This ant can attack and prey on a variety of insects but this aids in the spread of mealy bug colonies. The ant may protect the mealy bugs from some predators, since it has the nature of attacking other insects within their foraging territories.

The crazy ant, *Anoplolepis longipes* is not a predatory ant, but it drives away other ants, especially *O.smaragdina* which shows hostility. It can tolerate other insects including ants, which are not hostile. This ant attends mainly to treehoppers, mealy bugs and rarely on aphid colonies.

*Technomyrmex* sp. This carton nest-building ant is constantly associated with mealy bug colonies.

**Vertebrate pests**

Some vertebrates had successfully adapted to cocoa trees wherever the tree is introduced and cultivated. These include rats, squirrels, palm civets and birds and they inflict direct loss of the crop by feeding on and damaging the pods.

***Rodents*** : Rats and squirrels. These animals 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 extracted and after the sweet mucilage is eaten these are discarded. Three rodent species are the most important vertebrate pests of cocoa. They are the Western Ghats squirrel, ***Funambulus tristriatus*** Waterhouse; the South Indian palm squirrel, ***F.palmarum*** Linn. and the black rat, ***Rattus rattus*** Linn. Of these the Western Ghats squirrel and black rat are the major pests occurring in areca-cocoa and coconut-cocoa mixed gardens and pure gardens of cocoa. The squirrel is the most serious pest of cocoa in India.

All rodent species while feeding on cocoa pods leave tooth marks on pods. The tooth marks on pods that had been damaged by rats could not be distinguished from those of squirrels. The tooth marks on pods by one of the rodent species could be distinguished from the marks on pods damaged by either monkeys or civet cats. 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.

***Management***: 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 especially rats. Baiting and trapping methods are available. Single dose anticoagulants are available for baiting the rats.

**Other vertebrate pests**

The palm civet, *Paradoxurus hermaphroditus* Pallas (Carnivora). Known otherwise as the toddy cat, this nocturnal climber damages the pods by biting and breaking the husk of cocoa pods. The broken pieces are 2.0to3.0cm in diameter. The terminal half or one side of the pod is broken. 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 treated banana fruits have to be tied to the trunk /jorquettes of five to six cocoa trees per hectare.

**Conclusions**

Cocoa farms in India are small in size and mostly not continuous. A stage of monoculture is not yet the fashion. Some degree of diversity exists in most of the cocoa plantations. This may be reason for the low damage level by insects in cocoa farms. Even the ground flora is congenial for the perpetual existence of parasites and predators. This diversity has to be maintained and if possible increased so that we can have cocoa plantations with minimum interference of external factors. The background fauna that shifts now and then to cocoa trees are not very serious in most of the cases. The only exceptions will be the case of some bagworms in some localities that can defoliate the trees fully if not properly controlled.

Cocoa is a shade-loving plant and a degree of moisture is a must for the good growth and fruit setting of these plants. This tree cannot sustain water stress. This condition can invite the incidence of thrips to a very high level, which should be avoided for the good maintenance of the plantations.

Cocoa when grown as a component of mixed cropping with areca palms or coconut palms is not damaged by any of the major insect pests of palms. Locations where the root grubs of areca palms are prevalent and if they are not controlled by taking proper integrated management practices, the same grubs can feed on the roots of cocoa trees also and damage them seriously. The incidence of root grub is location specific and care should be taken to avoid the damage on cocoa trees.

Cocoa when being extended to newer areas is to be closely looked for any incidence/adaptation of fauna, which can cause serious damage. Systematic surveys are required for noting these changes. These surveys will give us an idea about the acclimatization of local fauna to cocoa in new geographical areas or different cropping areas.

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# VARIATION IN SYMPTOMS OF VASCULAR STEAK DIE BACK OF COCOA IN KERALA

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In India, cocoa (*Theobromae cacao.* L.) is mainly cultivated in Kerala. Diseases affecting this crop act as important factor responsible for low yield. Among these diseases, Vascular Streak Dieback (VSD) has now become a devastating one. The disease was first reported from Papua New Guinea and it was shown by Keane *et al.* (1972) and Prior (1978) to be caused by a new genus and species of fungus, *Oncobasidium theobromae* (Talbot and Keane, 1971). In India, the disease was first recorded by Abraham (1981) and Chandramohanan and Kaveriappa (1982) in Kottayam district. Abraham and Ravi (1991) after a detailed disease survey reported that the disease was prevalent in almost all districts of Kerala except Thrissur and Palakkad. Now it is prevelant through out the cocoa growing tracts of Kerala (KAU, 1993). As this disease is widespread and resulting in severe crop loss and also of the fact that there are reports of occurrence of variation in disease symptoms (Zainal Abidin *et al,* 1981; Varghese *et al.,* 1983, Wood and Lass, 1985), a detailed investigation was carried out on the symptomatology of VSD in Kerala.

This study was taken up under the Cadbury-KAU Co-operative Cocoa Research Project, College of Horticulture, Vellanikkara. The symptomatology of the disease was studied from the naturally infected seedlings and grown up plants due to the near obligate nature of the pathogen. The study was conducted by frequent visits to the cocoa nurseries and gardens of farmers' fields of different cocoa growing tracts of Kerala from the onset of South West monsoon till the end of North East monsoon for a period of three seasons.

During the study, the characteristic symptoms of the disease described by Kaene *et al.* (1972) from Papua New Guinea, like yellowing of one or two leaves in the second or third flush from the tip with distinct green spots on yellow back ground, defoliation of yellowed leaves with healthy leaves at the tip and lower portion remaining intact, lenticel enlargement, axillary bud proliferation, three distinctive marks on fallen leaf scars, presence of white sporophores on leaf scars, discoloration of xylem vessels, intervenal chlorosis of new flushes of diseased plants and finally dieback symptom were seen. In addition to that, during the course of study, some variations in symptom expression were noticed. The variations in symptoms noticed are:

1. The initial diagnostic symptom in seedling was the necrosis of the stipules of the terminal bud without any other symptoms.
2. The leaves arising out of such buds would be smaller in size and chlorotic.
3. In the infected seedling, the area adjacent to the midrib and veins remained green while other portions were yellow.
4. On mature leaves of seedlings/ twigs, first symptom was the development of pale green colour of the leaf lamina with intermingled normal green areas starting from the proximal end of the leaves.

5. Leaves with such initial symptoms were seen either on the middle or tip of th twigs.
6. Sometimes only proximal end of the infected leaves showed yellowing wit green islets and the end remained green.
7. The leaves with the disease symptom did not usually fall off but remaine attached to the twigs with yellow region turning to dark brown and green islet remaining as such.
8. Severe marginal necrosis of the leaves of the infected twig, resemblin potassium deficiency was also observed.
9. Lenticel enlargement was not always observed as the usual early symptom.
10. In mild infection, the growth of twigs and axillary buds was noticed but witl marked reduction in the internodal length and leaf size.
11. Chlorosis of entire leaves of infected small twigs.

These types of symptoms of VSD were not recorded from the earlier studies Thus, the study revealed that there were variations in symptom expression in Kerala and a better understanding of these variations in symptoms will be useful in prope diagnosis of the disease. The variation in symptom expression noticed during the study may be due to the presence of different isolate of the pathogen or due to climatic factors. Variation in symptoms of VSD occurring in Malaysia was reported earlier (Varghese *et al.*, 1981). Zainal Abidin *et al.* (1981) suggested the existence of a separate isolate of the pathogen in Malaysia. Further studies are necessary to confirm whether the symptom variation in Kerala is due to difference in pathogen or due to any other factors.

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# EFFECTIVENESS OF CERTAIN CONTROL METHODS AGAINST RATS AND SQUIRRELS INFESTING COCOA*

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The role of rodents as pest of cocoa, *Theobroma cacao* Linn. is well documented in several cocoa growing countries of the world (Entwistle, 1972). In south India, the black rat, *Rattus rattus wroughtoni* Hinton and the Western Ghats squirrel, *Funambulus tristriatus* Waterhouse are considered the major rodent pests of this crop. The damage caused by these reached as high as 50% in certain cocoa growing areas of south India (Bhat *et al.*, 1981). The effectiveness of certain methods of control such as poison baiting and trapping is reported in this paper.

The effectiveness of three different methods of control, *viz*; poison baiting with slow poison such as warfarin; poison baiting with acute poison such as zinc phosphide and trapping with single catch 'live' traps was studied in three separate cocoa- arecanut mixed gardens located in and around Vittal, D.K. Each plot consisted of about one hectare in area. The pre-control observations on the intensity of damage were carried out daily for three days by counting the number of pods damaged by rats and squirrels separately based on their feeding patterns (Bhat, 1980). In each garden 20 traps / bait points were selected at random, and the control operations were carried out in the following manner.

In the first plot, poison baiting was carried out with warfarin (0.025%) bait blocks. The baits were prepared by mixing paraffin wax, rice powder and jaggery (Bhat, 1982). One bait block of about 25g in size was tied on the jorquett of the marked tree and poison baiting continued for eight days by replenishing the bait wherever found missing / completely consumed. In the second plot, poison baiting was carried out with ripe jackfruits impregnated with 2% zinc phosphide. The poison baiting was carried out for two days after pre- baiting for three days with plain baits. In the third plot, traps were baited with ripe jackfruits, which were found better than other baits in attracting squirrels, set for five consecutive days. The traps were observed daily, trapped animals removed and reset again. The baits were changed every day with fresh ones.

Post control observations on the intensity of damage were also made for three consecutive days immediately after the control operations. However, in the first garden where warfarin was used, the observations were carried out only after 10 days of control operation as the rodents generally die after 7 – 8 days of consumption of slow poisons.

The results of this study (Table 1) showed that squirrels were best controlled by trapping, whereas rats were successfully controlled by all the three methods. Trapping reduced squirrel damage by cent percent, whereas the reduction with poison

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baiting with zinc phosphide and warfarin was only 17.6% and 31.0%, respectively. Trapping was very effective in the control of squirrels in other countries also (Han and Bose, 1980).

**Table 1. Effectiveness of different methods of control against rats and squirrels in cocoa**

| Method of Control | Target animal | No. of pods damaged during different periods | | | | | | | | % reduction |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Before control operation | | | | After control operation | | | | |
| | | 1st day | 2nd day | 3rd day | Total | 1st day | 2nd day | 3rd day | Total | |
| Warfarin (garden-1) | Rat | 5 | 15 | 6 | **26** | 1 | 0 | 0 | **1** | **96.2** |
| | Squirrel | 9 | 8 | 12 | **29** | 6 | 5 | 9 | **20** | **31.0** |
| Zinc phosphide (garden-2) | Rat | 13 | 15 | 8 | **36** | 0 | 0 | 0 | **0** | **100.0** |
| | Squirrel | 7 | 5 | 5 | **17** | 4 | 6 | 4 | **14** | **17.6** |
| Trapping* (garden-3) | Rat | 4 | 4 | 3 | **11** | 0 | 0 | 0 | **0** | **100.0** |
| | Squirrel | 8 | 8 | 11 | **27** | 0 | 0 | 0 | **0** | **100.0** |

*Rodents trapped: 23 rats ; 7 squirrels

It was also noticed that the squirrels developed bait-shyness towards acute poisons on the very first day of poison baiting, whereas the rats developed bait-shyness after the second day of poison baiting. This was the main reason for the poor performance of zinc phosphide baiting against squirrels. Wax- bound warfarin baits were found less attractive for squirrels and they did not accept the baits, which led to a low success of warfarin baiting against these animals. However, rats accepted the poison baits readily which resulted in good control.

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# FIELD EVALUATION OF VSD TOLERANT HYBRIDS IN THE EARLY YEARS OF BEARING

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Vascular Streak Die back (VSD) caused by *Oncobasidium theobromae* is the most serious disease of cocoa in Kerala. Severe incidence of the disease was noticed in Kottayam district in the early 1990's and now it has spread to all cocoa growing tracts in the state. *Oncobasidium theobromae* is a unique fungal pathogen which is near obligate, wind borne, leaf penetrating and xylem infecting. Fungicidal control has little value in checking the incidence and severity of the disease (Abraham *et al.*, 2000). The main approach to control the disease involves propagation and planting of resistant clones and hybrid seedlings. Keane and Prior (1992) showed that the resistance to VSD is polygenically controlled and is highly heritable and hybrid progenies of resistant parents are likely to be resistant. Based on this, elaborate hand pollination programme was undertaken for four consecutive years starting from 1995-1996 at the Cadbury – KAU cocoa Research Project, Kerala Agricultural University. The parents selected mainly involved clones SCA 6 and SCA 12 with reported tolerance along with other tolerant genotypes in the germplasm. These were crossed with other superior clones and hybrids. Using 137 such parents, 238 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.

The 917 hybrid seedlings field established in 1998 and 1999 were regularly observed for their growth and tolerance to VSD. Observations were recorded on height, girth and spread of the plants along with pod yield in bearing hybrids. In addition to pod yield, pod characters like pod weight, length, width, pericarp thickness, wet bean weight and bean characters like number, length, width and thickness of bean and peeled bean oven dry weight were recorded.

VSD screening in hybrids was done using a 0-9 scale (Abraham, *et al.*, 2000). The data for the year 2001-02 showed that most of the screened hybrids continued to exhibit tolerance in the field. When the nearby plots with cocoa plants were almost fully infected with VSD, most of these hybrids were free of any symptoms. A score on the symptoms revealed that out of the population of 917 plants, only 62 plants showed symptoms, that too on a mild scale (0.00-3.00). Out of these, 6.3 % belonged to scale 1 and only 0.40 %, to scale 3.00. A high level of resistance to VSD is reported in clones like SCA 6 and SCA 12 from Papua New Guinea. According to Vossen (1997) the resistance to this disease is inherited in an additive manner and heritability is high. In Papua New Guinea and Sabah, the most promising cocoa genotypes maintained their level of resistance for more than 30 years and there is no indication of break- down of resistance.

Many of these hybrids started bearing in the third year of field planting indicating their vigour and precocity. The vegetative growth parameters like height, girth and spread recorded in the early years also revealed that these hybrids are as vigourous or even better than plants from other crosses. In this population, 359 plants have already started bearing and their yield, pod and bean characters are comparable with superior hybrids from other trials.

Yield data for 2001-2002 showed that 1.67 % of bearing hybrids produced a pod yield of more than 20 pods/ tree/year in the fourth year of growth in the field and 18.39% had 10-20 pods/ tree/year. Encouraging results were also obtained in the study of pod and bean characters of these hybrids. Out of 279 plants observed, 103 had acceptable values with pod weight > 300g, wet bean weight/ pod > 80 g and peeled bean oven dry weight of > 0.80 g. These values in young hybrids are also likely to be improved in subsequent years (Mallika *et al.* 1996). Eventhough SCA 6, a clone characterized by small bean size was used as one of the parents in many crosses, early observation shows that many plants show heterosis in these characters.

The above study shows that VSD is one of the diseases, which can be tackled easily through resistance breeding. There is ample scope for multiplication and distribution of high yielding VSD tolerant hybrids within the next few years from this project.

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# NATURAL ENEMIES OF THE CITRUS BLACK APHID *Toxoptera aurantii* (B.d.Fonsc.) COLONIZING COCOA IN KARNATAKA - A STUDY*.

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Among the many insects, which infest cocoa tree, *Theobroma cacao* Linn. in India, the citrus black aphid, *Toxoptera aurantii* (Boyer de Fonsc.) (Hemiptera: Aphididae) is one of the three abundant insects seen, the other being the lymantriid caterpillars and mealy bugs. This aphid colonizes the tender shoots and leaves, flower cushions and developing cherelles. Few species of ants are found attending to this aphid. Cocoa, an introduced tree to India and grown in large scale for the last 35 years, is not usually sprayed with insecticides for the control of any insects. But, most of the insects are in a balanced state, and one of the reasons for this condition is the influence of natural enemies on these insects. With this background, studies were initiated to document the different natural enemies that are associated with the various insects of cocoa. This paper gives an account of the native natural enemies of this aphid in Dakshina Kannada district of Karnataka.

Surveys and field observations were carried out periodically in the cocoa plots of the institute and from some private cocoa plantations in Dakshina Kannada district to see the native natural enemies associated with this aphid of cocoa. The weather parameters of the locality during the survey years ranged in the following fashion. The maximum temperature varied from 28.3°C in July to 36°C in April and the minimum temperature ranged between 16.1°C in January to 25.6°C in May. The premonsoon showers were received in April and May. The months of June, July and August received the highest rainfalls with a range of 693- 1417mm with the least in June and highest in July. Relative humidity (RH) ranged between 89.5 to 97%. Plant parts colonized by aphids like leaves, shoot tips, flower buds and cherelles were collected at random from the different cocoa plots during different seasons. These samples were brought to the laboratory to catalogue and document the natural enemies present on the aphid colonies. The immature stages of different natural enemies were reared in the laboratory and the taxonomic determination of different groups was got done through the services of Commonwealth Agricultural Bureau. Observations on the field biology of some predators were also done.

The population of the aphid *T. aurantii* started building up on cocoa trees in June along with the onset of southwest monsoon rains, though it is present on the trees throughout the year. The population is more on tender cocoa leaves after the summer months i.e. from June to January. The aphids colonize the tender leaves (coloured green and red), tender shoot tips, flower cushions, flower buds, flowers and just formed cherelles. The colonization and feeding result in crinkling and shriveling of tender leaves, shedding of flowers and flower buds. The colonization of aphids is one of the reasons for the shedding of flowers in cocoa.

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* CPCRI contribution No. 1166

A number of natural enemies are always found associated with this aphid population. The natural enemies collected so far from this aphid are given in Table 1. These included predators, parasitic flies and insect pathogen. These predators were abundant in the field when the population of aphids was more.

**Syrphids** (Diptera: Syrphidae): Two genera of syrphids are found to be key predators of *T.aurantii.* They are *Dideopsis aegrotus* (Fab.) and *Paragnus yerburiensis* Stuckenberg. These hover flies are closely associated with the aphids for its reproduction and survival in the particular ecosystem. Syrphid flies were encountered in the field from August, with a peak from September to December and occurs up to end of summer months on the very low population of aphids on each leaf. The presence of these syrphids in these months is a limiting factor of the aphid population when other predators are less. The larvae of these hover flies exert a good control of the aphids, aphid colonies in tender shoots are totally removed by these aphids, only the presence of aphid skins can tell the existence of these aphids

The eggs of these are found laid very close to aphid colonies on leaves and flower buds. The emerging larvae have very easy access to prey material. The maggots have very soft bodies with a broader portion at the posterior end, and tapering anterior portion. The maggots feed on different stages of this aphid and the larval period is completed in 6-7 days. The puparium is attached to leaves. The adults emerge in 7-8 days. The adult flies can be found flying near aphid colonies and near flowers in the field.

**Cecidomyiids** (Diptera: Cecidomyiidae): Commonly known as the aphid midges, these are described from different parts of the world feeding on many aphid species. A species of cecidomyiid was first collected from *T.aurantii* colonies in June 1992. The population appeared on aphid colonies after the premonsoon showers in June and it was abundant from June to September, then started declining but found up to January. The maggots of this predator was highest in the field in the month of July when the number of eggs of the of this predator ranged from 1- 90 on aphid-colonized leaves. The number of maggots ranged from 1- 85 depending on the size of the aphid colony. At the fag end of its incidence the midges are found to lay more eggs even on very thinly populated aphid colonies. This cecidomyiid appears to be a species of *Aphidoletes* but the identity has to be confirmed.

**Coccinellids** (Coleoptera: Coccinellidae): Only one species of ladybird beetle is so far recorded from this aphid in this region. The two-spotted adult and the flat grubs feed on all stages of the aphids. This predator is seen in low population throughout the year. This is identified as *Pseudaspidimerus* sp.

**Lacewings** (Neuroptera): Members of two families of neuropterans, *viz;* Chrysopidae and Hemerobiidae are found associated with this aphid.

The hemerobiid, commonly known as brown lacewings is a more specific predator of aphids and it feeds on all species of aphids seen in areca-cocoa gardens including the aphids infesting weed plants inside the plantations. This hemerobiid is among the most abundant predator found from September to January. The eggs are laid on leaves near aphid colonies and the larvae are smooth without any bristles. This is identified as *Micromus* sp. The chrysopids (green lcewings) are generalist predators in areca –cocoa system. The larvae feed on the young ones of many insects colonizing areca palms and cocoa like aphids, nymphs of the mirid, *Helopeltis* spp, crawlers of armoured scale insects and phytophagous mites.The adult of this chrysopid are found flying inside cocoa plots during sunny hours. The eggs are laid on separate stalks attached to leaves, in batches. The larvae have bristles; they cover the back of their body with debris of empty skins of insects and other materials. They make a rounded, silk cocoon. This is identified as *Ankylopteryx octopunctata* (Fab.).

**Parasitic cecidomyiid** (Cecidomyiidae): An endoparasitic cecidomyiid also was found to exist on this aphid. Eggs of this fly are laid attached to the body of the aphids and the maggots enter the body of the aphid and grow inside. Such aphids could be identified by the altered size and shape of the abdomen. The maggot pupates inside the body of the mummified aphid. This endoparasitic fly is to be identified.

**Insect Pathogen:** An epizootic of a fungal disease was noticed on this aphid in some years. The pathogen was found to cause total suppression of aphid colonies on leaves and the disease could eliminate whole colonies of the aphids. This insect pathogen was identified as *Verticillium* sp.

This initial study shows that the aphid population is regulated in the field by biological factors like the action of natural enemies like predators, parasite and insect pathogen along with the usual abiotic factors.

**Table.1. Natural enemies collected from *Toxoptera aurantii* colonizing cocoa trees.**

| Sl.No. | Natural enemy | Family/Order | Stage feeding on aphids | Season of incidence |
|---|---|---|---|---|
| 1. | *Aphidoletes* sp | Cecidomyidae/Diptera | Maggots | June- January |
| 2. | To be identified | ,, ,, | ,, | ,, |
| 3. | *Dideopsis aegrotus* | Syrphidae/Diptera | Maggots | September-May |
| 4. | *Paragus yerburiensis* | Syrphidae/Diptera | Maggots | ,, |
| 5. | *Pseudaspidimerus* sp | Coccinellidae/Coleoptera | Adults & grubs | Throughout the year |
| 6. | *Micromus* sp | Hemerobiidae/Neuroptera | Adults and larvae | September - January |
| 7. | *Ankylopteryx octopunctata* | Chrysopidae/Neuroptera | Larvae | Throughout the year |
| 8. | *Verticillium* sp | Deuteromycota | Insect pathogen | Epizootic level in some years |

# MYCORRHIZAL ASSOCIATION OF COCOA IN RELATION TO WILT DISEASE IN HUNSUR DISTRICT*

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Root and root zone soil samples of cacao (*Theobroma cacao* L.) from seven different plots in wilt affected area were collected from Hunsur District of Karnataka. Vesicular Arbuscular Mycorrhizal fungi help to increase the productivity of the host through the transfer of nutrients from the soil to the root system. The vesicles, which are sac like structures, store phosphorus as phospholipids and also enhance the supply of phosphorus, zinc, copper, sulphur and manganese (Singh *et al.,* 1995). Aonla, ber and pomegranate plants have shown improvements in biomass production with inoculation of AM fungi (Rao, 2002).

Vesicular Arbuscular Mycorrhizal fungi are symbionts in association with majority of plants and are well known for their role in conforming disease resistance against soil borne diseases. The prevention of disease are (a) by the blocking of the entry points together with suberization around the entry points, (b) by elaborating enzymes, which aid in protection, (c) by competing for nutrients in the rhizosphere, (d) by alleviating stress of the host. Histochemical studies suggest the higher amounts of phenols and lipids found in mycorrhizal plants are due to the contribution of the AM fungal structures. The lipids synthesized by the fungus appear to serve a role of a growth sink of energy for the host. As a component of rhizosphere the Vesicular Arbuscular fungi help the host plant in the uptake of nutrients, particularly phosphorus, which helps to enhance the root growth and the consequent vegetative growth of plant.

In the present investigation, soil and root samples were collected from the rhizosphere of cocoa, grown in seven plots in Hunsur District of Karnataka State. Standard methods were followed for AM fungal propagule estimation, percentage of root colonization and identification of AM fungi. Roots from each sample were cut approximately into one centimeter segments, cleared by boiling in 10% KOH for 30 minutes and stained with 0.1% trypan blue in lactoglycerine or 0.4% acid fuchsin. The presence or absence of hyphae, arbuscules and vesicles or spores was recorded in 100 root segments of 1 cm length and the percentage of infection calculated for each plant.

From the soil samples, the occurrence of spore types were also recorded after extraction by the wet sieving and decanting method of Gerdemann and Nicholson (1963). The incidence of mycorrhizal infection and the number of spores present in the rhizosphere of each plant are given in Table 1.

Occurrence of higher colonization by mycorrhiza was observed in the rhizospheere of healthy cocoa plants. The present study was conducted in 7 different plots, which were surveyed for wilt disease. Colonization of AM fungi varied in different plant roots and spore counts ranged between 250 to 450 spores/100 g of soil. A total of 5 AM fungal species were found associated with cocoa roots.

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* CPCRI contribution no. 1163.

Mycorrhization improved the growth and development of the cocoa plants indifferent conditions. The rate of mycorrhization was higher in healthy plants that were present among diseased ones in the plots. The presence of greater number of mycorrhizal roots seen in the healthy plants suggest that they might have exerted a beneficial protection against the disease. AM spore density was higher in the top soil (0-25 cm). In cocoa, the feeder roots are more abundant in the surface soil. The different species of AM fungi identified were *Glomus mossae, G. fasciculatum, G. macrocarpum, Gigaspora calospora* and *Scutellospora* sp. The presence of more colonization was noted in the healthy plants (Table 2). It is very interesting to see the absence of living spores within the rhizosphere of dead plants. The diseased plants had the minimum number of spores in their root zone. Greater colonization was more in the roots of healthy plants occurring in the diseased tract.

Further it is necessary to extend this study to other regions where cocoa plantations have been initiated to understand whether greater mycorrhization observed in the healthy plants occurring in the disease tract is a cause or effect.

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**Table 1. Average colonization within the collected samples.**

| Sl. No. | Plot selected | Samples collected from crops with cocoa | Percentage of infection | No. of spores in rhizosphere soil calculated for 100g |
|---|---|---|---|---|
| 1. | Hunsur – a | Cocoa coconut (6 samples) | 76 | 1486 |
| 2. | Hunsur – b | Cocoa coconut (6 samples) | 74 | 1327 |
| 3. | Hunsur – c | Cocoa coconut (7 samples) | 70 | 1370 |
| 4. | Hunsur – d | Cocoa coconut + banana (5 samples) | 75 | 740 |
| 5. | Hunsur – e | Cocoa coconut (5 samples) | 78 | 857 |
| 6. | Hunsur – f | Cocoa coconut (5 samples) | 72 | 826 |
| 7. | Hunsur – g | Cocoa coconut + arecanut (6 samples) | 71 | 1160 |

**Table 2. Incidence of mycorrhization in dead, diseased and healthy plants.**

| Sl. No. | Plot selected | Total selected plants for root and soil collection | Fungal presence in roots of diseased plants | No. of spores calculated for 100g soil | Fungal presence in roots of healthy plants | No. of spores calculated for 100g soil |
|---|---|---|---|---|---|---|
| 1. | Hunsur – a | Cocoa coconut (6 samples) | Present 2 | 360 2 | Present 3 | 1126 3 |
| 2. | Hunsur – b | Cocoa coconut (6 samples) | Present 2 | 334 2 | Present 2 | 994 2 |
| 3. | Hunsur – c | Cocoa coconut (7 samples) | Present 3 | 236 3 | Present 3 | 1134 3 |
| 4. | Hunsur – d | Cocoa coconut + banana (5 samples) | Present 2 | 323 2 | Present 1 | 416 1 |
| 5. | Hunsur – e | Cocoa coconut (5 samples) | Present 1 | 230 1 | Present 2 | 626 2 |
| 6. | Hunsur – f | Cocoa coconut (5 samples) | Present 2 | 234 2 | Present 2 | 594 2 |
| 7. | Hunsur – g | Cocoa coconut + arecanut (6 samples) | Present 2 | 324 2 | Present 2 | 837 2 |

## SESSION – IV

## POST HARVEST TECHNOLOGY

**CHAIRMAN: DR. K. U. K. NAMPOOTHIRI**

**RAPPORTEUR: MR. K. MADHAVAN**

# HARVEST AND POST HARVEST TECHNOLOGY

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Cocoa is the only source of chocolate. Chocolate is sold in a highly competitive market. Quality of the finished product is dependent on factors like the type or variety grown, agrotechniques adopted, environmental conditions during the development of the pod and the processing technology. This indicates that good quality cocoa can be produced if care is bestowed in cultivation, processing and drying techniques. It is therefore important on the part of everybody involved in production and processing to do everything possible to maintain and improve standards of quality. Growing cocoa by providing the optimum conditions and harvesting at the right stage of maturity at farmer's level and adoption of the right methods for processing at manufacturer's level are very critical for ensuring quality. Faulty processing can lead to deterioration of quality of even the best quality beans. However, post harvest losses are comparatively less in cocoa as quantity of cocoa processed at farmers' level is negligible.

## Harvest

The pods mature in about 150 to 170 days from the day of pollination. This period varies depending on environmental conditions. 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. From tall trees, harvesting may be done using knives attached to poles.

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 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 April-May in locations with SW monsoon starting in May and ending by November. There is another minor peak in the months of October and November. But there are obviously location differences, depending mainly on the rainfall pattern of the cocoa growing regions of the Country.

**Post harvest storage and breaking pods**

The harvested pods can be stored for 2-15 days. This enhances pre-fermentation activity inside the pods, facilitates rapid rise in temperature during fermentation leading to desirable dried bean pH and production of a high proportion of commercially acceptable beans. It ensures correct nib acidification by pulp pre-conditioning. Post harvest storage of unbroken pods is impracticable on large- scale production because of the amount of extra handling involved, and in areas where cocoa pod borer is prevalent.

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**

***Fermentation***

Raw cocoa beans are covered with sugary mucilaginous pulp and the beans with the pulp around 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. 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.

The acetic acid diffusing through the testa causes break down of poly phenol and lipid membranes of the vacuoles of the cell and cell contents get mixed. Various enzymatic reactions take place and polyphenols get oxidized. This reaction is partially responsible for the removal of bitter taste from the beans.

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 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).

*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. Problem of cocoa bean acidity has been reported often from Malaysian cocoa.

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. 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.

**Methods of fermentation**

The method of fermentation and its duration will depend largely on the variety of cocoa and the season. 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. 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.

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*: 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, at the same time allow for free flow of sweatings. Allowing for the space required for the reapers, net 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 .95 x .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 alternate daily 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. The beans are mixed thus alternate daily, 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. A further discussion of the causes for and amelioration of bean acidity appears in the portion on cocoa bean acidity.

**Small scale methods of fermentation**

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. 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.

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 (mini- box, mini basket, tray and heap) 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).

**Drying**

The fermented beans will have 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. It takes 10 to 15 days for dryng.

The methods used to dry cocoa can be divided into two main types- sun drying and artificial drying. The dried beans are bagged in jute bags with capacity of 62.5 kg, after removing flat and broken beans.

**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. As in the case of other plant products, cocoa beans also attain equilibrium moisture content in a given atmosphere either by gaining or losing moisture.

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.

**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. The different aspects of quality like flavour, purity and consistency are discussed.

**Secondary processing**

Secondary processing of cocoa beans is done in specialised factories. Wood (1975), Wood and Lass (1987) 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. The major steps involved are cleaning, alkalization, roasting, kibbling and winnowing. After this the beans are blended and grinding done.

Cocoa butter is extracted from mass or liquor with the help of a hydraulic press. Another method of fat removal is solvent extraction. The powder and butter that is obtained by solvent extraction will contain solvents, which may cause undesirable flavour changes as in the case of screw pressing.

A cocoa butter extractor for small scale use has been devised by Ganesan (1982), 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 $70^0$C.

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 $35^0$C giving a clear liquid.

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 Chocolate**

A large number of grossly unidentified compounds are considered to be involved in inducing the characteristic chocolate taste and aroma of cocoa products. The relative abundance of these is expected to vary, depending on each step in the process of manufacture. Precise standardisation of conditions is, therefore, required to make cocoa product of standard and reproducible quality. These are also considered to be responsible for the large brand-related variation in the taste of cocoa products.

In simple terms, 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$^0$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 reducing the temperature to 28-30$^0$C in automatic tempering vats.

Dressing includes moulding, where 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$^0$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.

The milk chocolates are made by adding milk or milk powder at the first stage of mixing mass with sugar. The milk can be condensed with sugar, mass is then added and the mixture is dried under vacuum. This product is called 'crumb' and this ground and conched with additional cocoa butter as described above. A typical crumb contains 13.5% liquor, 53.5% sugar and 32% milk solids.

A number of products are now available in the market like drinking chocolate, enrobing chocolate, chocolate flavoured milk etc.

**By-products**

***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 & Shivshankar, 1987). The pod husk contains less theobromine than cocoa shell and can be used as cattle feed. Incorporation of a 20 % pod husk in cattle feed has shown beneficial effect (Sampath *et* *al.* 1990). In lambs, 15-30% CPH in meal increased the mean daily gain in body weight (Antongiovanni *et al.*, 1993). It can also be used as manure since 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% $K_2O$). So it is more appropriate as a fertilizer since cocoa has requires high K. 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. 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 pH 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.

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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# COCOA AND COCOA BASED PRODUCTS

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## Introduction

The cocoa tree, *Theobroma cacao* is indigenous to South America and it is believed that the Amazon and ornico valleys were the first homes of these trees. It is an exotic tropical tree producing cocoa beans, which is the principal raw material, used in making cocoa powder and chocolates. The cocoa bean played an important role in the "Aztecs" traditions and legends and perhaps no other food has an equally romantic history. They believed the plant to be of divine origin. Columbus first bought cocoa beans to Europe but only as curiosities, and his fellow countryman Don Cortes was the first to recognize its commercial value as a drink.

The original Cocoa products were not sweetened and much impetus was given to their use when Spanish nuns of Guanaca developed formulas for sweetening them. Spain was the first country in Europe to manufacture chocolate and was a leader in the industry for many years. About the year 1606, the use of cocoa beans was introduced into Italy, from where it is passed across the border to Austria and France, and eventually to London whereby about 1700 it had become an exceedingly fashionable beverage. The foundation for the modern milk chocolate industry was laid on 1876 by Daniel Peter of Vevy, Switzerland who developed a method of blending milk with sugar and cocoa

## World Cocoa Production

The main producers of cocoa are Ivory Coast, Ghana, Nigeria, Brazil, Ecuador, Indonesia, and Malaysia. World production of cocoa beans in 1998/99 was estimated at 2887000 tonnes, representing an increase of 118000 tonnes (4.4%) from the level of 2690000 tonnes recorded in the 1997/98 season. It has further increased to 3066000 tonnes in the year 1999/2000 (6.2%) and declined in 2000/01 by 260000 tonnes (-8.5%).

## Cocoa Production in India

India is a small producer of cocoa beans and the cultivation of which started long years back. The variety of cocoa planted by Britishers was "Criollo" variety. Cultivation on commercial scale with forastero variety started in 1970. Now nearly about 24000 hectares of land is under cocoa cultivation. Most of the output comes from Kerala, Karnataka and parts of Tamilnadu and Andra Pradesh. India produces about 20,000 tonnes of cocoa beans annually.

## Processing of Cocoa

After the pods are cut from the trees the beans with the adhering pulp are removed and transferred to heaps, boxes or baskets for fermentation to take place and finally dried to a safer moisture level. The correct fermentation and drying of cocoa is of vital importance and no subsequent processing of the bean will correct bad practice at this stage.

The original products prepared from whole nibs or beans and sugar was extremely rich drink because of the high fat content. In 1828 Van Houten of Holland introduced his press which expressed some of its cocoa butter and this ultimately led to the manufacture of cocoa powder. As a result of the manufacture of cocoa powder by pressing, quantities of cocoa butter became available and this natural fat had unique solidifying properties, which enabled moulded tablets of chocolate to be prepared. With the invention of fondant crème it became possible to coat fondant crème centre with chocolate.

Many different sorts of products can be derived from cocoa. The husks of cocoa pods and the pulp, or sweatings, surrounding the beans can be used to derive some products such as

1. Animal feed from cocoa husk.
2. Potash from cocoa pod husk.
3. Production of soft drinks and alcohol from the fresh cocoa pulp juice (sweatings)
4. Cocoa juice extracted from the pulp is a good source of pectin for the processing of jams and marmalades.

Once the beans have been fermented and dried they can be processed to produce a variety of products. These products include;

1. Cocoa Butter: is used in the manufacture of chocolate. It is also widely used in cosmetic products such as moisturizing creams and soaps.
2. Cocoa Powder: is used as an ingredient in many food stuffs. For eg: chocolate flavoured drinks, desserts, chocolate spreads, cakes and biscuits.
3. Cocoa Mass/Liquor: used as an ingredient to produce chocolates.

The processing of cocoa beans involves cleaning, roasting, alkalization of cocoa nib and grinding to obtain cocoa mass. Then the mass is subjected to press yielding cocoa powder and cocoa butter. The yield of cocoa mass varies from 79-82%.

Roasting develops flavour and aroma, reduces the moisture content and renders the shell in a loose condition so that it can be readily removed in the process of winnowing.

At the same time as Van Houten introduced hydraulic pressing, the process of alkalization was developed and this helped to improve colour and flavour of cocoa. The process involves treatment of cocoa nib/liquor with solutions of alkali usually in the form of potassium or sodium carbonate to neutralize the free acids.

**Nutritional value of cocoa powder**

The fat content of cocoa powder varies between 10% and 24%. Cocoa powder contains proteins in small and varying levels but the protein is low in digestibility. Cocoa powder has a high proportion of dietary fibre upto 30% and variety of minerals of which potassium and sodium are of primary importance. Cocoa butter of powder provides good amount of vitamin E. The following table gives the nutritional value of cocoa powder.

| Constituents | Gram per 100g |
|---|---|
| Fat | 11.0 |
| Moisture | 4.0 |
| Total N | 4.25 |
| Crude protein | 21.5 |
| Theobromine | 4.5 |
| Dietary fibre | 34 |
| Potassium | 2 |
| Sodium | 0.01 |
| Vitamin E | 30 mg per kg |
| K. calories (per 100g) | 205 |

**Cocoa Products Market**

World cocoa bean production is about 2.8 m.tonnes. A rough estimate indicates that after processing one-third of production remains as cocoa liquor and the rest is pressed to make cocoa butter and cocoa powder. The majority of the cocoa butter is used in chocolate production with cocoa liquor. Therefore roughly two-thirds of bean production is used to make chocolate and one-third to cocoa powder. About 25% of the world cocoa powder production is used in the manufacture of compound chocolate and confectionary, 25% is used in the production of bakery products and biscuits, a further 25% is used in instant drinks and 20% is used in the dairy and ice-cream industries.

**Cocoa based products**

***A. Chocolates***

Chocolate is made to many different recipes and contains extra ingredients in addition to cocoa products. Therefore the nutritional value will vary with the ingredients. For example, dark chocolate has a high proportion of cocoa solids and will therefore retain more of the nutritional value of cocoa than milk chocolate, which has a lower proportion of cocoa solids. But in milk chocolate, milk provides a rich source of proteins, which the body can use, and so its protein value is higher than that of dark chocolate.

**Nutritional value of Chocolates:**

| | Dark Chocolate | Milk Chocolate |
|---|---|---|
| Weight g | 40 | 40 |
| Calories | 200 | 210 |
| Calories from fat | 100 | 120 |
| Total fat g | 11 | 13 |
| Saturated fat g | 7 | 7 |
| Protein | 1 | 3 |

The essential raw materials for chocolate manufacture are; Cocoa liquor, cocoa butter, refined sugar, milk powder, butter oil, lecithin and flavour.

*Process*: There are three basic operations involved in chocolate manufacture, they are;

1. Preliminary mixing
2. Refining
3. Conching

The mixing is a method of bringing the ingredients together in the correct proportions and presenting a mixture, which can be used without any difficulty in the refining stage. Refining process is to have a precise control over particle size of the chocolate. Conching is very significant process for the development of flavour and texture of the chocolate.

B. ***Count Line Products***

Milk chocolate is usually used to provide eating sensation to countline products containing multi component products. It can make up 35-50% of the products by weight. The products of this category are multi component and complex in their makeup and vary depending on the flavour and texture of the product. These include sugar confectionary centres like nougat, marsh mallows, cereals or biscuit centres covered in chocolate.

***C. Panned Products***

Milk or dark chocolate is used to a great extent in the manufacture of sugar coated chocolate. The process involves panning where the chocolate lentils are engrossed in stages with sugar syrup under controlled conditions of temperature and humidity. They are finally coloured and polished.

D. ***Instantized Cocoa***

Cocoa powder along with sugar is instatised with suitable wetting agents and stabilizers with some added flavour. The process involves agglomeration of particles of cocoa and sugar by means of steam and then dried. The mixture is now instantized for quick dispersion of particle in hot or cold liquids.

# QUALITY CHARACTERISTICS OF COCOA INCORPORATED FROZEN FOOD

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Cocoa, not only is one of the principle ingredients used in the confectionery but its widely enjoyed flavour properties make it a favourite material of bakers, ice cream producers and other food manufacturer. It may be used in many forms such as beverage, syrup, flavouring, coating or a confectionery items. Chocolate (cocoa) continue to be the No.1 flavour in any of our life times and many manufacturers use chocolate ice cream (cocoa) as base. Flavour and colour intensity can meet consumers expections, therefore cocoa powder is used in the ice cream to give desired chocolate flavour and colour. The use of cocoa powder making it denser and richer and give to smooth texture. Present investigation was under taken prepare chocolate ice cream and compared with control.

The ingredients used for preparing instant ice cream mix as per standard procedure, (Goyal *et al.*, 1987) are skim milk powder, sugar, corn flour, stabilizer, emulsifier and cocoa powder. The instant ice cream mix was prepared from the weighed quantum of corn starch (10g) mixed with the addition of cocoa powder (3g). Then the stabilizer (0.6g), emulsifier (0.6g) and powder sugar (78.8g) were added little by little followed by skim milk powder (10g) and the mix was folded gently with the help of ladle. A control instant ice cream mix was prepared without the addition of cocoa powder. The instant ice cream mixes were packed in different packaging materials such as MPP and MPP stored in plastic bottles. The storage behaviour of the instant ice cream mix was observed by storing at room temperature.

For 100g instant ice cream mix, 500 ml fresh milk, 60g fresh cream and 15g liquid glucose were added while processing ice cream and the procedure adopted is presented in the Fig. 1.

The chemical changes such as moisture, acidity, reducing and total sugars, protein, ash and minerals (calcium, iron and phosphorus) (Ranganna, 1995). TSS and pH (Saini *et al.*, 2001) and fat (Sadasivam and Manickam, 1996) were determined periodically over a period of 180 days. Microbial load of the samples were enumerated by the method described by Istavankis (1984).

The quality characteristics of the ice cream prepared from instant ice cream mix was analysed for quantity obtained, volume, freezing temperature, freezing time, surface, texture, crystal formation, melting time and viscosity as described by Arbuckle (1977). The ice cream prepared from instant ice cream mixes were subjected to sensory evaluation as stated by Arbuckle (1977).

Neither the storage period nor the packaging materials influenced the changes in quality characteristics of instant ice cream mixes both control and treated samples. Whereas the chemical composition showed a slight variations during the study period.

### Chemical changes of instant ice cream mix during storage

The changes in the chemical composition was noted in the instant ice cream mixes as the storage period increased (Table. 1).

A gradual increase in the moisture content was observed throughout the study period. The initial moisture content of the samples (10.11 – 10.13%) had changed to 10.41 and 10.37 in $F_1$ and 10.46 and 10.42 in $F_2$ packed in MPP ($P_1$) and MPP stored in plastic bottles ($P_2$) respectively at the end of 180 days of storage.

The freshly processed instant ice cream mixes contained 0.36 ($F_1$) and 0.40 ($F_2$) of acidity and changed to 0.42 and 0.41 in $F_1$ and 0.48 and 0.49 per cent in $F_2$ packed in $P_1$ and $P_2$ respectively after storage. The pH of ice cream mixes was found to be reduced during storage in both the samples ($F_1$ and $F_2$). Whereas the TSS of the instant ice cream mixes (46 and 48°Bx) did not show any change during storage.

An increasing trend in reducing sugar was noted throughout the study period in both $F_1$ and $F_2$ samples packed in $P_1$ and $P_2$. The initial value of reducing sugar (3.53 – 3.48%) had increased to 4.64 - 4.47 ($F_1$) and 4.57 – 4.42 ($F_2$) packed in $P_1$ and $P_2$ respectively after storage.

The freshly prepared instant ice cream mix contained 37.20 ($F_1$) and 38.90 ($F_2$) of total sugar, which reduced to 35.24 and 35.96 in $F_1$ and 36.94 and 36.90 per cent in $F_2$ packed in $P_1$ and $P_2$ respectively at the end of storage period.

Initially the control and the treated samples had more or less similar protein content. At the end of storage it had decreased to 4.66 – 4.77 and 4.75 – 4.86 per cent in $F_1$ and $F_2$ respectively.

The fat, ash calcium, iron and phosphorus content of the control and treated samples were 0.62 and 0.66g, 3.0 and 3.5g, and 147.46 and 158.16, 0.49 and 0.68 and 136.00 and 140.10 mg respectively per 100g. Neither the packaging nor the storage period showed any variation during storage. The nutrient content such as protein, calcium, iron and phosphorus were found to be higher in cocoa incorporated ice cream than control.

### Microbial load

The bacterial and fungal count of freshly processed instant ice cream mixes ($F_1$ and $F_2$) were 1.0 x $10^{-3}$ and 1.0 x $10^{-3}$ cfu per g respectively. At the end of storage period, the bacterial and fungal population were increased to 1.3 – 2.0 x $10^{-3}$ and 1 – 2 x $10^{-3}$ cfu per g packed in different packaging materials ($P_1$ and $P_2$).

### Quality characteristics of ice cream prepared from instant ice cream mixes

The quality and sensory characteristics of the ice cream was observed and the data obtained are given in the Table 2. The ice cream samples ($F_1$ and $F_2$) were frozen at – 20°C for 4 hours. The weight of the ice cream prepared from 100g of instant ice cream mix with the addition of milk, liquid glucose, fresh cream with and without the addition of cocoa powder were 465 ($F_1$) and 483 g ($F_2$) and it could be served as 9 and 10 cups containing 50g each respectively. The volume of ice cream obtained before and after freezing was 495 and 513 ml and 529.65 and 547.65ml for $F_1$ and $F_2$ respectively. Very smooth texture was observed in the cocoa incorporated ice cream than in control. The melt down rate and melting time of cocoa incorporated ice cream was gradual and 945 sec, whereas the control showed slightly fast and 920 sec respectively. The high viscosity of the product gave a smooth texture, gradual melt down rate and longer melting time to the cocoa incorporated ice cream.

The sensory attributes such as appearance, colour, flavour and taste of the cocoa incorporated ice cream were highly acceptable by the consumer. The richness in colour and flavour of the cocoa added ice cream had secured the highest score value (5.0) for each sensory attribute than control (3.7 – 4.4).

An increasing trend in moisture, acidity and reducing sugar and a decreasing trend in pH, total sugar and protein during storage was observed in the samples. The storage period did not influence the fat, ash and mineral content of the mixes. The nutrient content of cocoa incorporated instant ice cream mix was slightly higher than the control. The quality and sensory characteristics of the cocoa incorporated ice cream was highly acceptable by the consumer.

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**Fig – 1. Preparation of Ice cream from instant ice cream mix**

Boiling the fresh mix

↓

Adding instant ice cream mix and liquid glucose

↓

Mixing continuously (2 min)

↓

Cooling the content (RT)

↓

Adding fresh cream (60g) and mixing again

↓

Whipping for 3 min (mixie)

↓

Pouring in an ice cream tray

↓

Freezing for 4 hours (-20°C)

↓

Stroing at – 20°C

**Table 1 Chemical changes of instant ice cream mix during storage**

| Sl. No. | Chemical constituents | Moisture % | Acidity (g%) | pH | Reducing sugar (g%) | Total Sugar (g%) | Protein (g) |
|---|---|---|---|---|---|---|---|
| 1 | **0 day** | | | | | | |
| | $P_1 F_1$ | 10.11 | 0.36 | 4.83 | 3.53 | 37.20 | 4.90 |
| | $P_2 F_1$ | 10.11 | 0.36 | 4.83 | 3.53 | 37.20 | 4.90 |
| | $P_1 F_2$ | 10.13 | 0.40 | 4.87 | 3.48 | 38.90 | 5.01 |
| | $P_2 F_2$ | 10.13 | 0.40 | 4.87 | 3.48 | 38.90 | 5.01 |
| 2. | **60 days** | | | | | | |
| | $P_1 F_1$ | 10.15 | 0.38 | 4.81 | 3.93 | 36.74 | 4.81 |
| | $P_2 F_1$ | 10.13 | 0.38 | 4.82 | 3.84 | 36.96 | 4.89 |
| | $P_1 F_2$ | 10.18 | 0.43 | 4.84 | 3.84 | 38.44 | 4.92 |
| | $P_2 F_2$ | 10.16 | 0.42 | 4.86 | 3.79 | 37.66 | 5.00 |
| 3. | **120 days** | | | | | | |
| | $P_1 F_1$ | 10.37 | 0.41 | 4.76 | 4.31 | 36.09 | 4.75 |
| | $P_2 F_1$ | 10.33 | 0.39 | 4.80 | 4.16 | 36.51 | 4.81 |
| | $P_1 F_2$ | 10.40 | 0.46 | 4.79 | 4.22 | 37.79 | 4.86 |
| | $P_2 F_2$ | 10.36 | 0.46 | 4.81 | 4.00 | 37.45 | 4.92 |
| 4. | **180 days** | | | | | | |
| | $P_1 F_1$ | 10.41 | 0.42 | 4.73 | 4.64 | 35.24 | 4.66 |
| | $P_2 F_1$ | 10.37 | 0.41 | 4.75 | 4.47 | 35.96 | 4.75 |
| | $P_1 F_2$ | 10.46 | 0.48 | 4.74 | 4.57 | 36.94 | 4.77 |
| | $P_2 F_2$ | 10.42 | 0.49 | 4.78 | 4.42 | 36.90 | 4.86 |

$P_1$ - MPP
$P_2$ - MPP stored in plastic bottles
$F_1$ - Control
$F_2$ - Cocoa incorporate

**Table 2. Quality characteristics of ice cream prepared from instant ice cream mix**

| Sl.No. | Characteristics | Control ($F_1$) | Cocoa incorporated ($F_2$) |
|---|---|---|---|
| 1. | Quantity (g) | 465 | 483 |
| 2. | Volume (ml)<br>Before freezing<br>After freezing | <br>495<br>529.65 | <br>513<br>547.65 |
| 3. | Cups obtained<br>(50g / each) (No.s) | 9 | 10 |
| 4. | Texture | Smooth | Very smooth |
| 5. | Melting quality | Slightly fast | Gradual |
| 6. | Melting time (sec) | 920 | 945 |
| 7. | Viscosity (sec/10 ml) | 30 | 42 |
| 8. | Appearance | Good (4.4) | Very attractive (5.0) |
| 9. | Colour | White (4.3) | Light Brown (5.0) |
| 10. | Flavour | Starchy flavour (mild) (3.9) | Strong cocoa flavour (5.0) |
| 11. | Taste | Good (3.7) | Very good (5.0) |
| 12. | Over all acceptability | Good (4.6) | Very good (5.0) |
| 13. | Cost per serving | 2.47 | 2.47 |

* The values in the parenthesis indicates the score values

## SESSION – V

## TECHNOLOGY DISSEMINATION, DEVELOPMENT AND MARKETING

**CHAIRMAN: SRI B. NAGARAJ SHETTY**

**RAPPORTEUR: DR. C. V. SAIRAM**
**DR. S. KALAVATHI**

# COCOA DEVELOPMENT IN INDIA

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Cocoa, as a most beneficial perennial inter crop among the coconut groves in India, has a prominent role to play in Indian agrarian, industrial and commercial sector. Considering the production of cocoa world over, in spite of huge exploitable potential available in India, its cultivation, promotion and administrative outlook do not support its growth in the country. As a most sturdy tropical evergreen crop, the Indian conditions provide immense scope for cocoa to develop as one of the pioneering commercial produce of the country.

The crop has been found well adaptive as a companion crop with irrigated coconut and arecanut gardens because of its need for partial shade. Other than the traditional cocoa growing states of Kerala and Karnataka, Coastal belts where coconut is grown under irrigated conditions viz., the States of Goa, Maharashtra, Pondichery, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal offer considerable scope for its development.

## Infrastructure

Promotional activity on agriculture, particularly perennial agriculture, seldom stands aloof from the angles of research, development, input support, infrastructure facilities, organized marketing, processing and export activity. Indian agriculture has made tremendous growth in the post independent era and the growth of horticulture sector in particular has made commendable performance in the recent past as far as cocoa promotion is considered, owing to its industrial and commercial value the research sector have played a prominent role.

## Research

The research efforts have resulted in selection and hybridization whereby 11 high yielding varieties have been recommended for large scale planting. These varieties have the capacity to produce upto 4 kg dry beans per plant as against 1 kg potentiality being obtained from the existing plantations.

The Research Institutes and the agencies assisted in the 8$^{th}$ Plan for planting material generation have provided the nucleus planting material (clones of high yielding varieties of cocoa) to the identified agencies for establishment of regional nurseries in 9$^{th}$ Plan. The regional nurseries established in the first two years will generate F1 hybrid seedlings from the nucleus seed material obtainable from the research/development agencies identified for such support in the 8$^{th}$ Plan. From 3$^{rd}$ year onwards the regional nursery will supply clones of high yielding varieties developed from their clonal mother plants grown under each of such regional nursery.

Standardization of grafting techniques is one of the novel contributions of research in the propagation front of cocoa. Several State and Central Institutes are now available to make available such grafts. F1 hybrid seedlings of compatible parentage are also being advocated for large scale plantings.

**Future**

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, attaining 30,000 MT by 2009 is possible, if annual growth rate of 20% is achieved. In order to achieve this production level, at least 20,000 ha will have to be brought under cocoa during the $10^{th}$ Five Year Plan. In order to attain self sufficiency, increasing the area by intercropping 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 $10^{th}$ 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 $10^{th}$ Five Year Plan to attain self sufficiency.

# CULTIVATION, PERFORMANCE AND PROSPECTS OF COCOA IN TAMIL NADU

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Cocoa (*Theobroma Cacao* L: Family: Sterculiaceae) is a tropical crop, native of the Amazon region of South Africa, (Pound, 1938) was introduced to India as early as in 1973. Its commercial value was recognized recently and started to cultivate during 1960's in India. Systematic cultivation of cocoa as an intercrop of coconut and arecanut gardens started in 1970's in India. At present, cocoa is grown in India in an area of 14,618 hectares with an annual production of 7,837 tonnes against mean requirement of 14,000 tonnes. Kerala accounts for 71 per cent of the area and 80 per cent of the production (Anon, 1999). Since cocoa has great potential to be introduced in Tamil Nadu (besides Karnataka and Andhra Pradesh), the present preliminary studies were taken up to observe the cultivation and performance of cocoa as a mixed crop in Pollachi tract of Tamil Nadu.

An extensive survey was carried out in block wise in selected districts of Tamil Nadu during 2000-2001. The cocoa plantations in farmers' fields were evaluated throughout the year. The informations pertaining to area under cultivation, age of crop, yield potential, extent and nature of damage of insect pests and diseases on cocoa plantations were evaluated.

The field observations on the cultivation and performance of cocoa as an intercrop / mixed crop in selected districts of Tamil Nadu are given in the Table 1. From the survey, it is observed that the area under cocoa cultivation in Tamil Nadu was around 1300 acres with an annual production of 50 tonnes. In Tamil Nadu for the past two decades cocoa has been grown in larger areas of 300 acres in Kanyakumri district followed by (Kodaikanal hills area) Dindugal district of 120 acres as traditional area (25 years old crop of cocoa) with an annual production of 28 and 15 tonnes respectively. In Pollachi tract at Anaimalai block cocoa was grown as mixed crop component in coconut, Arecanut plantations in an area of 600 acres with annual production of 7 tonnes only. The stage of the crop is in matured stage and started yielding from 0.5 kg to 2 kg per tree annually. However, stabilized yield can be obtained from 5 th year onwards. Although matured pods being obtained throughout the year, the peak season for harvesting cocoa pods at Pollachi tract were June-August and October-December. Cocoa crop is in juvenile stage in other places of Tamil Nadu viz., Coimbatore, Pollachi, Vellore, Kangeyam, Udumalpet, Erode and Kinathukadavu.

The predominant ruling variety in Tamil Nadu, especially in Pollachi tract was Forestero variety. F1 hybrid seedlings (Forestero type) cocoa were found to show better establishment, vigour and yield than vegetatively propagated materials in Pollachi tract.

Cocoa plants were vulnerable to many insect pests and diseases. The extent and nature of damage of insect pests and diseases on cocoa plants at Pollachi tract were identified and given in Table 2 and 3.

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It is evident from the table 2 that among the sucking pests, Aphid *Toxoptera aurantii* recorded the damage level of up to 12 per cent followed by mealy bug *Planococcus* sp. 10 per cent. But, whereas stem borer and stem girdler showed negligible damage level of 3 and 1 per cent respectively. Among leaf feeders, *Euproctis* sp. registered 5 per cent damage, followed by *Dasychira* sp. 2 per cent. Leaf eating weevil *Mylloceros* sp. caused significantly more damage up to 25 per cent. Apart from insect pests, non-insect pests of rodents viz,. squirrels *Funambulus tristriatus* recorded significant damage up to 30 per cent followed by rats, *Rattus rattus* 25 per cent.

Among diseases, Cherelle wilt showed significantly high up to 20 per cent evidence on cocoa plants. Other disease viz., black pod disease, canker, charcoal pod rot appeared in negligible level between 1 and 3 per cent only. On the other hand, pink disease, white thread blight and vascular streak dieback disease did not occurred in cocoa plantations in Pollachi tract of Tamil Nadu. However, Zinc deficiency observed significantly very high up to 30 per cent on cocoa plantations. Suitable management practices were recommended to combat pest and diseases in cocoa in South India (Chandramohan and Kaveriappa, 1982).

Cocoa is gaining importance in the national economy and this has necessitated the identification of superior genotypes with high yield potential (Bhat *et al.,* 1990), development of high yielding and locally adaptable varieties with standard bean characters (Nair *et al.,* 1996). Since cocoa is best suited perennial intercrop in larger tracts of coconut and arecanut in Tamil Nadu with lesser incidence of pest and diseases, lesser gestation period, eradication of weed growth, enhancement of organic matter @ 600-800 kg / ha / year and coconut yield to the tune of 68-115%, provision of supplementary income to the farmer and export potential, cultivation of cocoa can be very well encouraged in Tamil Nadu.

**Acknowledgement**

The authors are grateful to M/S Cadbury India Limited, Annaimalai, Coimbatore. Department of Agriculture and Horticulture for visiting the cocoa fields during the survey and collection of data on cocoa cultivation in Tamil Nadu.

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**Table 1: Area, Production of cocoa in Tamil Nadu (2000-2001)**

| Sl. No | Location | Nature of planting | Area in acres | Age in years | Production in MT |
|---|---|---|---|---|---|
| 1 | Anaimalai | New | 600 | 4 | 7 |
| 2 | Kanyakumari | Traditional (old) | 300 | 25 | 28 |
| 3 | Dindugal (Kodaikanal Hills) | Traditional (old) | 120 | 25 | 15 |
| 4 | Coimbatore | New | 100 | 3 | - |
| 5 | Pollachi | New | 50 | 3 | - |
| 6 | Vellore | New | 30 | 1 | - |
| 7 | Udumalpet | New | 25 | 1 | - |
| 8 | Kangeyam | New | 30 | 3 | - |
| 9 | Erode | New | 10. | 3 | - |
| 10 | Kinathukadavu | New | 5 | 1 | - |

**Table 2: Intensity of insect damage on cocoa in Pollachi tract**

| Sl. No. | Name of the pest | Percentage of pest damage |
|---|---|---|
| 1 | Aphids: *Toxoptera aurantii* | 12.00 |
| 2 | Mealy bugs: *Planococcus* sp. | 10.00 |
| 3 | Stem borer: *Zeuzera coffeae* | 3.00 |
| 4 | Stem girdler: *Glenea* sp. | 1.00 |
| 5 | Leaf eating caterpillars: *Enproctis* sp.<br>*Dasychira* sp. | 5.00<br>2.00 |
| 6 | Leaf eating weevil: *Mylloceros* sp. | 25.00 |
| 7 | Squirrels: *Funambulus tristriatus* | 30.00 |
| 8 | Rats: *Rattus rattus* | 25.00 |

**Table 3. Intensity of diseases on cocoa in Pollachi tract**

| Sl. No. | Name of the diseases | Percent incidence of disease |
|---|---|---|
| 1 | Black pod disease: *Phytophtora palmivora* | 3.00 |
| 2 | Canker: *P.palmivora* | 1.00 |
| 3 | Charcoal pod rot: *Botryodiplodia theobromae* | 2.00 |
| 4 | Cherella wilt | 20.00 |
| 5 | Pink disease | - |
| 6 | White thread blight | - |
| 7 | Vascular streak die-back | - |
| 8 | Zinc deficiency | 30.00 |

# COCOA PRODUCTION IN INDIA: A TIME SERIES AND ACREAGE RESPONSE ANALYSIS+

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The commercial cultivation of cocoa started in India in 1970 and the area under cocoa reached 29,000 hectares by 1980-81, mainly due to the attractive prices during that period (Velappan, 1995). This trend of area expansion did not continue further because of the subsequent steep fall in price and the area under cocoa started declining year after year till 1996. Thereafter cocoa acreage showed an increasing trend due to the reasonable and consistent prices for cocoa beans. Notwithstanding the decline in area there was a gradual increase in production because whatever area remained was attaining full bearing stage. The present paper attempts to study,

1. The time series analysis of price behavior of cocoa in India.
2. The trend and growth rate of area and production of cocoa in India.
3. The acreage response of cocoa production in India.

i) Data used

Secondary data on area, production, productivity and wet bean prices for the last 25 years were collected from Directorate of Cashewnut and Cocoa Development, Cochin. Monthly price history of cocoa wet beans was collected from CAMPCO, Puttur.

ii) Analytical framework

The time series analysis of price consists of separating and studying the behavior of it's various components (Acharya and Agarwal, 1994). Additive model has been used for the decomposition of time series.

Model: Pt=T+C+I Where,

Pt = Observation on price for period t
T = Trend component
C = Cyclical component
I = Irregular component

Monthly cocoa price data of Kerala and Karnataka for the last four years was used for the analysis of seasonal pattern. Seasonal indices were constructed using link relative method.

The compound growth rates were computed for area and production of cocoa, based on the exponential function.

The compound growth rate was calculated as follows,

Exponential production function $Y=AB^T$ (Singh,2001)

where,

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+ CPCRI contribution No. 1164

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Y is the variable for which growth rate is calculated.
T is the time variable.
A and B are regression coefficients.

The improved version of the Nerlovian lagged adjustment model has been used for supply response analysis. Nerlove introduced the element of dynamism by incorporating the concept of distributed lags. The simplest form of acreage response model is,

At= a + bAt-1 + b1Pt-1 + vt (Ranjit kumar,2001)

The above framework of the model does not change by including more independent variables in the model. The final form of the model is

$lnAt = bo + b1\ lnAt\text{-}1 + b2lnYAt\text{-}1 + b3lnPct_{1\text{-}5} + b4lnYRc + b5lnPRc + b6lnPAt\text{-}1 + v$

Where,

| | |
|---|---|
| At | =Acreage under cocoa in current period. |
| At-1 | = One year lagged cocoa acreage. |
| Yat-1 | = One year lagged arecanut yield |
| $Pct_{1\text{-}5}$ | = Weighed average of cocoa price for previous five years. |
| Yrc | = Yield risk of cocoa crop measured by the standard deviation of three preceding year's yield |
| PRc | = Price risk of cocoa measured by the standard deviation of three preceding year's market prices of wet beans. |
| PAt-1 | = one year lagged arecanut prices. |
| b0 | = intercept |

b1,b2...b6 are elasticity's of respective independent variables.

v = disturbance term.

Based on the step down regression procedure the non-significant variables were eliminated from the above model to arrive at the final regression model. The log linear form of acreage response function was chosen because it provides direct estimates of supply elasticities. The ordinary least square method was used for estimating the regression coefficients of the selected variables in acreage response function.

Analysis of trend component in the annual series of prices involves ascertaining the general direction of the price movements over years. The trend is shown in the Fig. 2 Trend equation is Y=5.4+0.54X.

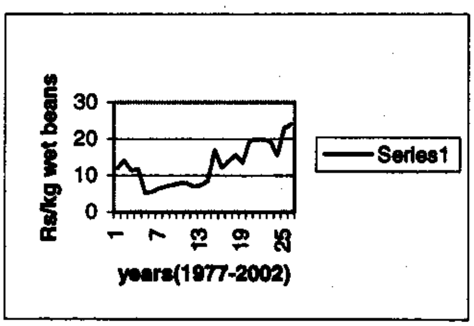


**Fig. 1. General price movement**

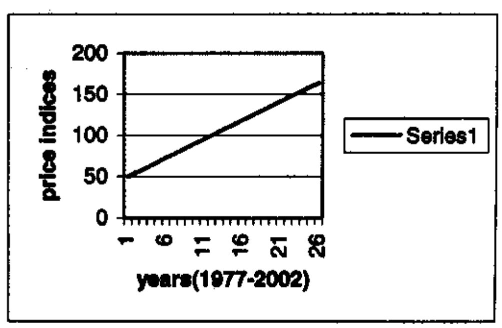


**Fig. 2. Trend component**

Cyclical and irregular components were isolated from annual series of cocoa prices using least square method (Fig. 3 and 4).

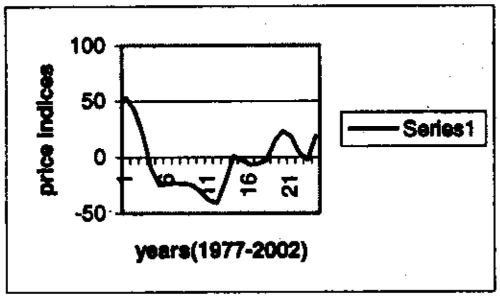


Fig. 3. Cyclical component

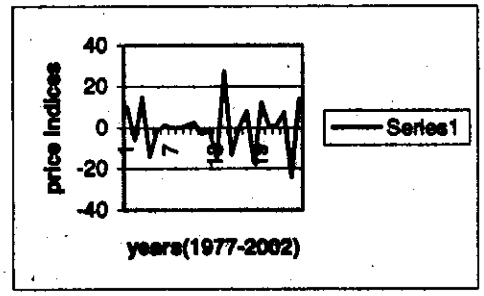


Fig. 4. Irregular component

It can be observed from the graphs that there were no regular oscillations in cocoa prices, but irregularity was very much prevalent over the years.

Seasonal analysis of cocoa market price in Kerala and Karnataka have shown similar pattern (Fig. 5 and 6) where the prices are peek in the months of March to May and prices are low in the post monsoon months.

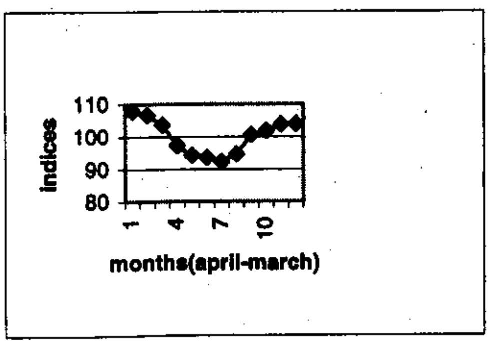


Fig. 5. Seasonal price pattern (Karnataka)

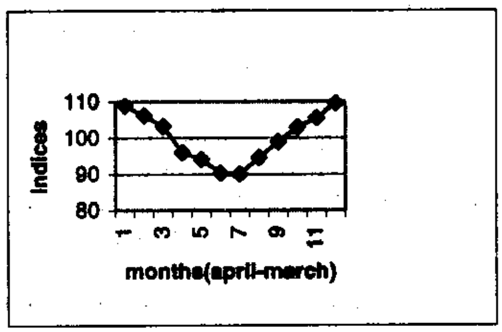


Fig. 6. Seasonal price pattern (Kerala)

Trend in area has been analyzed for 3 different intervals (Table 1). The entire study period was divided into 3 intervals on the basis of increasing and decreasing trend in cocoa area. Period1 and 3 had shown an increasing trend of area but period 2 had shown a decreasing trend. This is clearly evident from the compound growth rate of different periods. The general trend in area and different trend lines for the entire period were depicted in Fig. 7 and 8.

**Table 1 Trend in area.**

| Period | Trend equation | Compound growth rate(%) |
|---|---|---|
| Period 1(1976-80) | Y=-220+5740X (0.95) | 43.5 |
| Period 2(1981-94) | Y=25371-102.8X (0.98) | -5.9 |
| Period 3(1995-02) | Y=10643+775.5X (0.91) | 5.68 |
| Entire period (1976-02) | Y=19721.5-229.13X (0.126) | -0.95 |

Figures in parentheses denote $R^2$ values

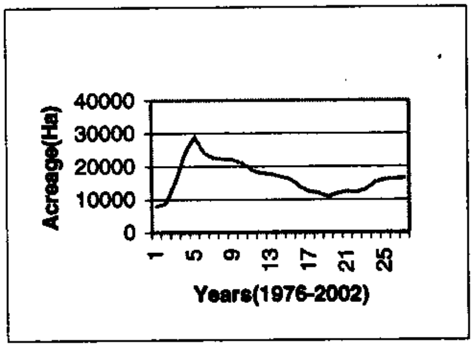


Fig. 7. General pattern (area)

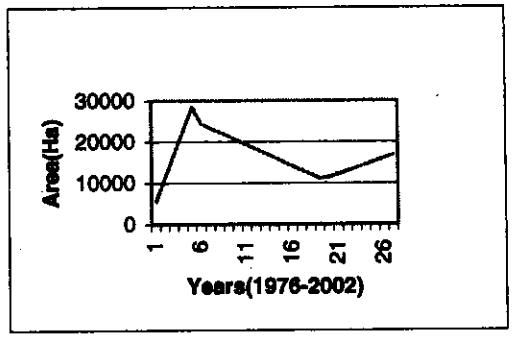


Fig. 8. Trend lines of area (3 periods)

The trend and compound growth rate of cocoa production have been analyzed for 3 different intervals (Table 2). The intervals were purposively selected on the basis of increasing and decreasing trend of cocoa production over the years. Fig. 9 and 10 show the general pattern of cocoa production and the trend lines for production in different periods.

**Table 2. Trend in cocoa production**

| Period | Trend equation | Compound growth rate(%) |
|---|---|---|
| Period 1(1976-85) | Y=-1886.7+857.6X (0.92) | 55.7 |
| Period 2(1986-96) | Y=7895.8-178.7X (0.8) | -2.65 |
| Period 3(1997-02) | Y=4612+584.6X (0.98) | 10.08 |
| Entire period(1976-02) | Y=1885.8+247.7X (0.5) | 11.56 |

Figures in parentheses denote $R^2$ values

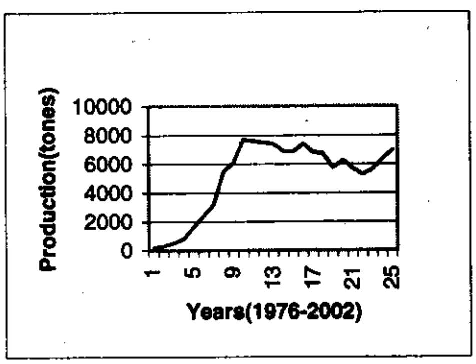


Fig. 9. General pattern (production)

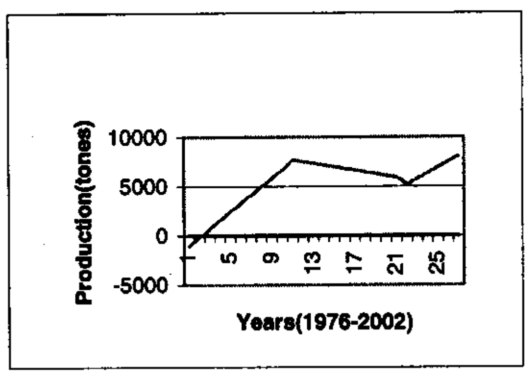


Fig. 10. Trend lines of production (3 periods)

Based on the step down regression procedure, the final form of the regression equation is $\ln A_t = b_0 + b_1 \ln A_{t-1} + b_2 \ln Pc_{t_{1-5}} + b_3 \ln PR_c$

The estimated acreage response function revealed that weighed average of lagged cocoa prices, lagged cocoa area and standard deviation of cocoa prices had significant impact on area allocation. Lagged cocoa area had a positive and significant impact with elasticity 0.62, lagged cocoa prices had a positive and significant impact with elasticity 0.38. Standard deviation of cocoa prices found significant with negative elasticity coefficient (-.042).

The time series analysis had revealed that irregular component is prevalent in cocoa prices during the entire study period. Seasonal analysis of cocoa market prices in Kerala and Karnataka have shown similar pattern, where the prices are peek in the months of March to May and low in the post monsoon months. The compound growth rate of area, which was 43.5 per cent in period 1 had shown negative growth rate (-5.9) in period 2. In period 3 the growth rate was positive with 5.68 per cent. The compound growth rate of production, which was 55.7 per cent in period 1, had turned negative (-2.65 per cent) in period 2. However in period 3 it has shown positive growth rate (10.08 per cent). Acreage response function had shown that weighed lag of cocoa prices and lagged cocoa area had significant impact on cocoa acreage.

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