

# DIVERSITY CONSERVATION AND UTILIZATION STRATEGIES IN IMPROVEMENT OF COCOA (*THEOBROMA CACAO* L.)

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## Introduction

Cocoa (*Theobroma cacao* L.) the 'Food of Gods' is an important plantation crop grown for chocolates around the world. Cocoa originated in Amazon basin of South America which is the primary centre of origin and spread to other secondary centres such as African and Asian countries. Depending on the degree of human involvement in the establishment of cocoa population they were divided into three basic categories such as (i) spontaneous, a situation in which the population had been established and developed naturally, (ii) sub-spontaneous, in which the establishment of the population resulted from human action but at present there is no evidence of actual human involvement in its development or exploitation and (iii) cultivated or domesticated, are those formed by human action and have been exploited continuously. These populations of different countries showed considerable diversity in their natural and adopted habitats.

The effective achievement of any crop improvement programme depends not only on the quantity of genetic resources, but also on the qualities of the diversity that they represent. In India, large scale cultivation of cocoa started in 1970's (Vikraman Nair *et al.*, 2002) and it is found as a suitable mixed crop in coconut, arecanut and oil palm gardens of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. In order to obtain the diversity and develop varieties adaptable in the introduced environment, conservation and evaluation of genetic resources is crucial. With this background, CPCRI has taken up the cocoa improvement programmes with the following breeding strategies of germplasm collection, conservation, characterization, evaluation, selection and hybridization.

## I. Diversity in cocoa population

There are three types of populations identified in cocoa namely, Criollo, Forastero and Trinitario. Certain morphological characters of pods and beans are used as the basis for classification of varieties, cultivars, types or populations of cocoa.

### Criollo

The criollo populations are characterized by various traits such as the soft pod texture with red colour. The average number of beans per pod ranged from 20-30 with white coloured beans fermenting very quickly. Yield is less but produces good quality cocoa. Criollo populations are extremely susceptible to diseases like pod rot by *Phytophthora* sp. and *Ceratocystis* wilt and mirid bugs. These populations are subdivided into two geographical groups, Central and South American Criollos.

### Forastero

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

### Trinitario

These are natural hybrids between Criollo and Forastero, originated typically in Trinidad, very heterogeneous and exhibiting a wide range of morphological and physiological characters (Barrau, 1979). Trinitarios are hardier and more productive than Criollos and have fine cocoa.

## **II. Morphological diversity/ Indicators of variability**

Several expressions of diversities are conserved in cocoa collections throughout the world with different indicators of variability. The variation in the phenotypic expressions is the result of the action of different alleles that occur in the genes, which control the specific characteristics and the total of the alleles make up the plant's genotype (Bartley, 2005). Bioversity International has standardized the descriptor status for cocoa which comprised of 60 characteristics including plant habit, leaf, floral, fruit, seed traits and special features like reaction to biotic and abiotic stresses. At CPCRI, passport data documentation was done with 56 clones (Elain Apshara and Rajan, 2009) and cataloguing of other 100 clones showed the extend of genetic variability in the available genetic resources. Based on that 'cocoa germplasm database' was prepared and provided in the CPCRI website for access. Some of the important attributes are discussed here.

### **1. Cocoa tree structure and development**

Structure and development of cocoa tree is very typical. Germination is of epigeal type with the cotyledons being raised above the soil with two opposite cotyledonary leaves. Vertical or orthotropic growth continues with successive new growth and the leaves on the main stem are arranged in a spiral phyllotaxy. These leaves differ from the lateral branches by their long petioles. At a certain height the terminal bud of the main stem ceases to be active and is replaced by buds which form lateral branches and the process is called jorquetting. These arise in whorls usually consisting of five unequal branches called fans, which resulted from three successive divisions of the terminal bud. Growth of the lateral branches continues through elongation and successive new growths. The leaves of the lateral or plagiotropic branches are arranged in an alternate and opposite phyllotaxy. The large leaves have short petioles that may be thick with prominent pulvini. Vertical growth (chupon) continues on the main stem by the activation of the orthotropic buds in the leaf axils below the whorl of lateral branches. In the course of time a whorl of lateral branches is produced. Further growth occurs with successive development of vertical stems and lateral branches and there is no limit to the height of a cocoa tree.

### **2. Leaf characters**

Much difference observed is with colour of young developing leaves or the flushes, which ranged from lightest green to various shades of red. The red shades of flush leaves are produced by the presence of anthocyanins in the tissues and associated with red fruits. This association also expressed as pigment in the petiole and leaf axil known as axil spot in developing leaves.

### **3. Flowers**

Inflorescences are produced from all leaf axils and most commonly found on old wood called as cauliflorous. An inflorescence produces many flowers in succession which is a cyme on the flower base called cushion. The genera *Theobroma* and *Herrania* have two unusual organs called infertile staminodes and the ligule attached to the petal pouch. Intensity of flowering, variation in colour of peduncle, shape, size and pigmentation of flower buds recorded. Narrow elongated sepals results in elongate buds and short sepals produce buds of round shape. The numbers of ovules per ovary varies considerably. Maximum seed numbers counted per fruit have a range of 40-77 according to the genotype. The period of time taken from fertilization to fruit development ranged from 135 to 180 days which differed with genotypes.

### **4. Fruits**

The fruit is an indehiscent drupe which remains attached to the tree by its peduncle after it matures. The most notable aspects of the fruits are those of shape and colour. Shapes range from spherical, sometimes oblate with length less than diameter to very narrow elongate where the length: diameter ratio is  $>3$ . Form of the apex is important, short fruit have rounded or obtuse apices while the elongate fruits have attenuate apices. The surfaces have superficial ridges that vary in their prominence, width and arrangement

on the fruit. Basically there are five pairs of ridges. One specialized character of fruits of certain varieties is the covering of the surfaces with or without small protuberances or lenticels and termed the fruits as mealy or pimply or granular. Hardness of husk, colour and size of pods exhibited considerable variability. Husk characteristics with penetrometer studies under the Asia Pacific breeding programme are being taken up, to identify clones resistant to pod borer attack.

## 5. Seeds

The seeds are recalcitrant, having no dormancy period and germinate when they are exposed to a moist environment. Besides the embryo, the seed contains two cotyledons which are convoluted. When the fruits become ripe the seeds are enclosed in a white or yellow pulp which is produced from ovary wall. The weight of seeds in their dry condition ranged from 0.5 g to 2.0 g. The shapes of seed vary from almost spherical to flat, being broad at the hilum and tapering towards the distal end. Apart from colour, few genotypes have pulps with sweet and pleasant taste whereas criollos, notable for their acid or even disagreeable pulp.

## 6. Self incompatibility

Self incompatibility is common in cocoa. Gametophytic incompatibility is observed, it was described as the rejection by the egg nucleus of a male gamete carrying the same incompatibility allele as the female gamete (Cope, 1962 and Bartley and Cope, 1973). Self compatible, self incompatible and cross compatible groupings were assessed by carrying out controlled pollinations. Compatibility reaction of 57 trees belonging to 7 Malaysian and 25 Nigerian cocoa accessions was reported from CPCRI. Out of 23 Malaysian trees studied, 12 trees were self incompatible and 11 self compatible. Out of the 34 from the Nigerian collections, 22 were self incompatible and 12 self compatible. Both Malaysian and Nigerian collection had similar pattern of distribution for self compatible and self incompatible trees. The studies further revealed that different trees belong to same accession shouldn't be identical with regard to their compatibility reaction (Nair and Rekha, 1996).

**Table 1. Variabilities in the cocoa population**

Tree architecture	Erect, Intermediate and Pendulous growth habits
Leaves	Shades of green and purple, with or without pulvinus in the petiole
Flowers	Colour, Petal diameter, Pedicel length
Fruit shape	Angoleta- deeply ridged, warty, square at the stalk end Cundeamor- bottle necked angoleta Amelonado- smooth, shallow furrows, melon shaped, blunt end, slight bottle neck Calabacillo- small and nearly spherical Oblong/ Elliptic/ Obovate/ Orbicular
Basal constriction	Absent/ Slight/ Intermediate/ Strong
Apex form	Attenuate/ Acute/ Obtuse/ Rounded/ Mammilate
Surface rugosity	Absent/ Slight/ Intermediate/ Intense
Prominence of ridges	Slight/ Distinct
Primary furrow depth	Superficial/ Intermediate/ Deep
Husk hardness	Soft/ Intermediate/ Hard
Anthocyanin in ripe pods	Absent/ Slight/ Intermediate/ Intense
Pod size	Big/ Medium/ Small
Beans	Shape, Color, Size

### III. Germplasm collection and conservation programme at CPCRI

Attempts are underway to exploit the available variability in all cocoa producing countries of the world, which is the base for breeders to produce varieties with good economic characteristics. Earlier a few Malaysian cocoa accessions were introduced into India in 1969 and later the collections enhanced with clones of Ghana, Nigeria, England, Amazon, Mexico, Jamaica, Brazil, Ecuador and local collections from farmer's fields of Wynad in Kerala.

**Table 2. Cocoa germplasm at Vittal**

Source	Number	Year	Material
Malaysian Estates	11	1970	Seeds
Cocoa Research Institute, Nigeria	44	1975	Seeds
Kew, London	5	1981	Clones
Kew, Lalbaugh Garden, Bangalore	9	1983	Clones
Cocoa Research Institute, Ghana	12	1986	Clones
Wynad	10	1988	Seeds
	23	1998	Clones
Kallar	1	1988	Seeds
KAU, Thrissur	12	1991	Clones
KAU, Thrissur	20	1996	Clones
Reading University, UK	9	2001	Clones
Reading University, UK	13	2005	Clones
Reading University, UK	36	2007	Clones
Reading University, UK	40	2008	Clones
Reading University, UK	29	2009	Clones
Reading University, UK	11	2010	Clones
Local collections	6	2010	Seeds/Clones
<b>Total</b>	<b>291</b>		

Some clones are obtained from KAU, Lalbaugh gardens, Bangalore, Kallar and Kanyakumari in Tamil Nadu. All these are being conserved in field gene banks of CPCRI, Regional Station, Vittal, Karnataka under arecanut and at Research Centre, Kannara, Kerala under coconut. Reading University, UK is identified as the international quarantine center for cocoa, which is involved in the germplasm exchange activities. In India, National Bureau for Plant Genetic Resources (NBPGR), New Delhi is acting as the nodal agency for import of cocoa germplasm.

### IV. Utilization

#### 1. Selection

An easy approach to yield improvement in cocoa is to select plants superior in yield and their subsequent development into clones. The major selection criteria followed are, trees yielding not less than 70-100 pods/tree/year, pods 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 and with favourable compatibility reaction. Seven high yielding clones were selected and utilized as parents in the breeding programmes of CPCRI (Bhat, 1999).

**Table 3. Selected high yielding parents**

S.No.	Tree No.	Genotype	Bean wt. (g)	SI/ SC
1	I-56	PA-7 x NA-32	1.20	SI
2	I-14	Jerangau Red axil	1.17	SI
3	II-67	Landas-364	1.34	SI
4	III-35	Amelonado x NA-32	1.09	SI
5	III-105	Amelonado x PA-7	1.06	SI
6	IV-20	Landas-357	1.06	SC
7	NC-42/94	T-86/2	1.08	SI
SC= Self Compatible			SI= Self Incompatible	

## 2. Clonal orchards

Based on the compatibility reactions self incompatible but cross compatible high yielding parents were selected and planted in clonal orchards. Two self incompatible parents grown together in a bi-clonal orchard will produce F1 pods of specific identity or known parentage through natural crossing. In poly-clonal orchard more self incompatible clones are assembled together and all the pods harvested are F1 hybrids. These clonal orchards were established at CPCRI, Research Centre, Kidu, Nettana, Karnataka.

**Table 4. Details of clonal orchards**

Bi-clonal	Poly-clonal
I-56 & NC-42/ 94	I-14
ICS-6 & SCA-6	I-56
I-56 & III-105	III-105
I-14 & NC-42/94	NC-42/94
I-14 & I-56	
I-14 & IV-20	
Total: 1170 trees	

## 3. Hybridization

Hybridization programme was started at Vittal in 1980 with selected self incompatible but cross compatible parents with specific objectives of more number of pods, high dry bean yields, more fat content and drought tolerance. Four sets of hybrids were produced at Vittal, planted and evaluated under progeny trials from 1983 to 1991. A comparison of parents and hybrids in progeny trials indicated that more vigour is exhibited by the progenies than parents and showed positive and significant heterosis over their mid-parental value (Bhat and Ananda, 1997).

### Progeny Trial I

The parents in the first progeny trial included Upper Amazon collections/ Imperial College Selections, Scavina and Nanay series *i.e.* NA-31, NA-33, SCA-6, ICS-6, ICS-95, IMC-67 and their five hybrids. Progenies belonging to NA-33 x ICS-89 excelled in bean yield.

### Progeny Trial II

It had a total of 17 hybrids, their parents and a check line I-56 seedling. All showed significant differences with regard to their bean yield. The progenies of hybrid I-56 x II-67 gave the maximum bean yield, followed by I-14 x I-56 and I-56 x III-35.

### Progeny Trial III

It involved 9 hybrids, 4 Malaysian hybrids and bulk Forasteros. From consistency point of view the progenies ICS-6 x SCA-6, ICS-6 x SCA-12 and IMC-67 x ICS-6 considered as high yielders. The Malaysian hybrid, Amelonado x NA-33 also yielded more.

### Progeny Trial IV

Under the fourth set, nine hybrids with their seven parents were evaluated and among them the crosses II-67 x NC-29/66 and II-67 x NC-42/94 registered the highest pod index. They were evaluated for bio-chemical components, which showed significant differences among hybrids and parents (Balasimha and Ananda, 1999). These hybrids were evaluated and selected for water limited conditions and considered as drought tolerant.

## Clonal Trial

Eight high yielding trees of Nigerian origin (NC-102, NC-119, NC-73, NC-63, NC-13, NC-116, NC-53 and NC-8) were selected and multiplied clonally and further evaluated. Among them the clone NC-45/53 had the highest yield range of 0.930-1.726 kg dry bean yield/tree/year and this clone is both self and cross compatible. Another clone NC-38/119 was also selected as it showed the best stability indices.

**Table 5. Progeny trials**

Trial	Progenies	Best lines	Dry bean yield (kg/tree)
Progeny I (1983)	5	NA-33 x ICS-89	1.01
Progeny II (1984)	25	I-56 x II-67	1.48
		I-14 x II-67	1.47
		I-56 x III-105	1.42
		I-14 x NC-42/94	1.39
Progeny III (1987)	13	Amelonado x NA-33	1.08
Progeny IV (1992)	15	II-67 x NC-42/94	1.25
		II-67 x NC-29/66	1.52
Clonal (1985)	10	NC-45/53	1.33

## Varieties

These hybridization works resulted in development of hybrids *viz.*, VTLCH-1,2,3 & 4 which are vigorous, early, heavy bearing, stable yielders and a clone VTLCC-1 with standard bean characters (Elain Apshara *et al.*, 2008). These are suitable for cultivation in Kerala, Karnataka, Tamil Nadu, Goa, Maharashtra and North Eastern states.

**Table 6. High yielding varieties of CPCRI**

Variety	Single bean wt (g)	Shelling (%)	Dry bean yield (kg/tree/year)	Dry bean yield (kg/ha)	Special features
VTLCC-1	1.05	12.0	1.15	904	Early, heavy bearer, self & cross compatible
VTLCH-1	1.00	13.0	1.48	1007	Early, high yielder
VTLCH-2	1.10	10.9	1.15	800	High yielder with medium canopy
VTLCH-3	1.06	13.7	1.48	1005	High yielder & drought tolerant
VTLCH-4	1.01	12.1	1.25	847	High yielder & drought tolerant

## 4. Breeding for Stress

Breeding for drought tolerance was taken up, since cocoa is sensitive to water scarcity and it has to undergo a period of six months in its growth period without rains in the western ghats region. The germplasm was screened for physiological parameters like stomatal resistance, chlorophyll fluorescence, proline accumulation under stress and seed germination under low osmotic potential. The Nigerian collections were found to be good source for drought tolerance. Balasimha *et al.* (1985) observed considerable genotypic difference in specific leaf weight and epicuticular wax content and those with high values were found to perform better under stress conditions. Five accessions selected for drought tolerance were, NC-23, NC-29, NC-31, NC-39 and NC-42. Hybridization programmes identified the hybrids I-21 x NC-42/94, I-29 x NC-23/43, II-67 x NC-42/94 and II-67 x NC-29/66 as drought tolerant.

## Screening for Black Pod Disease

*In-vitro* screening of majority of the available germplasm against the black pod disease using isolates of prevailing three *Phytophthora spp.*, viz., *P. palmivora*, *P. capsici*, *P. citrophthora* has indicated few Nigerian collections exhibited certain degree of tolerance (ChandraMohanana, 1982).

## 5. Multiplication

Vegetative propagation through soft wood grafting method was standardized for multiplication of selected accessions and high yielding hybrids for quality planting material production as well as for early evaluation. Grafts, F<sub>1</sub> seedlings and seed pods are being supplied to cocoa growers, demonstration farmers and developmental agencies regularly (Elain Apshara, 2007).

**Table 7. Supply of Planting Materials**

Year	No. of grafts	Revenue (Rs.)
2000	69,287	8,31,444
2001	26,992	3,23,904
2002	54,697	6,56,364
2003	36,718	4,40,616
2004	48,572	5,82,864
2005	51,244	6,14,928
2006	44,876	5,38,512
2007	72,034	8,64,408
2008	38,000	4,56,000
2009	25,000	3,00,000
2010	25,000	3,00,000

Cocoa graft is sold @ Rs. 12/-

## 6. Evaluation

Growth and yield performance of all germplasm collections are being recorded annually and studied for their adaptability under local conditions. Fifteen Lalbaugh clones were evaluated for their nature and degree of genotype x environment interaction over different seasons of growth. Based on magnitudes of stability parameters and high yield, the clones V-1, IMC-10, NA-242, IMC-67 were found to be stable performers at Vittal, Karnataka whereas, the clones EET-272, ICS-6, I-14 and SIAL-93 performed better under Kannara, Kerala conditions (Elain Apshara *et al.*, 2002). Eleven Malaysian clones were tested for their adaptability under Kerala and Karnataka conditions and assessed for their pod yield performance with respect to number of pods and pod weights over different growth periods. The clones Amelonado x NA-32, Jerangau Red Axil, Landas-357 and Landas-364 have recorded high yields under both the environments. Computation of phenotypic and genotypic coefficients of variation, heritability and genetic advance studies with 44 Nigerian clones resulted in identification of the following best performing clones NC-37, NC-23, NC-26, NC-50, NC-20, NC-51, NC-27 and NC-25 (Elain Apshara *et al.*, 2009; Elain Apshara and Nair, 2011).

## 7. Comparative Yield Trial

Comparative studies were conducted on 21 elite progenies, the hybrids PII-5, PII-3, PIII-I-23 and PI-IV-478 were grouped as vigorous plants with sturdy stems and well spread canopies. Early bearing nature was observed in the hybrids PIII-II-89, PI-IV-478, PI-I-18 and PI-I-38 from second year of their growth as clones. The hybrids PI-IV-478, PI-I-38, PIII-I-23, PIII-II-54 and PI-I-18 recorded high pod yield potential with more than 50 pods and >1.5 kg dry bean yields per tree per year and quality beans (Elain Apshara *et al.*, 2008). Comparative studies of cocoa varieties under arecanut and coconut canopies, different spacings, parents and progenies, performance of clones and seedlings are going on.

## Quality assessment

Fat content was estimated in 152 samples comprised of hybrids and clones and expressed in percentage. Among the 21 progenies the fat content ranged from 26.66 to 61.58% and 9 progenies recorded a highest of >45% fat. Among the clones the fat content ranged from 18.18 to 47.05% and 4 clones recorded >45% fat content. A comparative estimation of fat in open and oven dried beans were done in 14 elite clones. The fat content in beans dried in open ranged from 21.32 to 37.83% whereas, the beans dried in oven recorded a high percentage of fat ranged from 37.59 to 58.53%. Among the 9 elite clones planted at Kidu under coconut the fat content ranged from 40 to 52.43%. Some beans were collected from Andhra Pradesh and the fat estimates showed that the beans of coconut garden recorded a highest of 44.53% fat compared to beans of oil palm shade which has 40.06% fat. From the fatty acid profile it was clear that there are 11 fatty acids viz., lauric, myristic, palmitic, palmitoleic, stearic, oleic, linoleic, arachidic, eicosapentaenoic, behenic and lignoceric acids involved in quality of cocoa beans. The fatty acids palmitic, stearic, oleic, linoleic and arachidic acids were present in all the accessions invariably. The percentage of stearic acid was the highest among all in a range of 30.50% in VTLC-7 to 44.20% in VTLC-1 followed by oleic, linoleic and arachidic acids. Myristic acid was present in only one accession. The other fatty acids differed among the accessions in percentage of expression.

## 8. Multi Location Trial

To assess the adaptability and stability of hybrids and clones evolved out of the breeding programmes a multi location trial was laid out with hybrids and their parents. Elite clones were planted at Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, West Bengal and Assam under different agro climatic conditions and are being evaluated. Apart from arecanut and coconut shades elite clones are being evaluated under oil palm and old rubber plantations.

## 9. Biotechnology and Bioinformatics

The genetic diversity in the cultivated species should be studied using morphological, isoenzyme and molecular markers. If the phenotypic characters are considered along with the fingerprinting data the identification process is foolproof and will serve as a valuable data to be documented in the germplasm holdings. With this view RAPD work was carried out and DNA fingerprinting was done in 76 accessions. Jaccard's coefficient assembled 6 groups based on genetic distance and the clones BE-10, EQX-78, I-56 and SCA-12 were proved as highly divergent (Anuradha Sane, 2002). Bioinformatics approaches to identify the biosynthetic pathways related to quality aspects of beans and biotic and abiotic stresses were taken up.

## 10. Demonstration plots

94 farmer's plots were established under participatory research cum demonstration plots scheme funded by Directorate of Cashewnut and Cocoa Development (DCCD), Kochi, Kerala over 8 taluks in Karnataka and 1 taluk of northern Kerala. They were supplied each with 500 grafts and other technologies on cocoa cultivation. Apart from these 17 regional nurseries were established in four states.

## Conclusion

Though a lot of work is done on cocoa improvement by CPCRI and KAU in India the progress achieved in terms of yield is not very substantial and so still more explorative collections in centers of diversity is needed. Wider genetic base will enable identification of more desirable characteristics to meet the production and processing needs. Flavour improvement should be given importance in the future breeding programmes. There is a scope for successful breeding of cocoa cultivars with satisfactory levels of resistance to one or more important diseases according to national priorities. Quantitative traits tend to

be greatly influenced by genotype/ environment interactions and thus screening for such traits has to be done locally and molecular studies has to be taken up to confirm the breeding results. In the National level public private partnerships, collaborative approach between research institutes, universities, state horticulture departments and developmental agencies is needed. In the International level participation of India in cocoa genetic resources networking and regional breeding groups of both developed and developing countries is important.

## REFERENCES

1. Anuradha Sane. 2002. Final report of the *Ad- hoc* scheme on DNA fingerprinting of Cocoa accessions using PCR based markers. ICAR, New Delhi.
2. Balasimha, D. and Ananda, K.S. 1999. Final report of the *Ad- hoc* scheme (from AP Cess Fund, ICAR) on drought tolerance in Cocoa- submitted to ICAR, New Delhi: 7-8 and 31-33.
3. Balasimha, D., Subramanian, N. and Chenchu Subbiah, C. 1985. Leaf characteristics in cocoa (*Theobroma cacao* L.) accessions. *Cafe Cacao The* 29: 95- 98.
4. Barrau, J. 1979. The origin of cacao, *Theobroma cacao* Linne, Sterculiaceae. *J. d'Agric. Traditionnelle Botanique Appliquee* 26: 171-180.
5. Bartley, B. G. D. 2005. The genetic diversity of cocoa and its utilization. CABI publication. UK. 341 p.
6. Bartley, B. G. D. and Cope, F. W. 1973. Practical aspects of self-incompatibility in cocoa. In: Moav, R. (ed.) *Agricultural Genetics-Selected Topics*, John Wiley & Sons, New York. pp. 109-134.
7. Bhat, V.R. 1999. Cocoa germplasm, characterization, conservation and utilization. In: Improvement of plantation crops. (eds. Ratnambal, M.J., Kumaran, P.M., Muralidharan, K., Niral, V. and Arunachalam, V.), CPCRI, Kasaragod. pp. 77-85.
8. Bhat, V.R. and Ananda, K.S. 1997. Evolving high yielding varieties by selection and hybridization in cocoa. *Annual Report*. CPCRI. pp. 71-72.
9. ChandraMohan, R. 1982. Studies on the reaction of pods of different cocoa accessions to *Phytophthora palmivora*. *Planter* 58: 99-103.
10. Cope, F. W. 1962. The mechanism of pollen incompatibility in cocoa. *Heredity* 17: 157-182.
11. Elain Apshara, S. 2007. Producing quality planting material of cocoa. *Indian Horticulture* 52(5): 6-8.
12. Elain Apshara, S. and Nair, R. V. 2011. Genetic analysis in cocoa collections obtained from Nigeria. *Journal of Plantation Crops* 39 (1): 153-156.
13. Elain Apshara, S. and Rajan, P. 2009. *Profile of cocoa collections at CPCRI, Research Centre, Kannara*, CPCRI, Kasargod. 61 p.
14. Elain Apshara, S., Bhat, V. R. and Nair, R. V. 2008. Comparative studies on elite cocoa progenies in their initial years of growth. *Journal of Plantation Crops* 36 (1): 38- 44.
15. Elain Apshara, S., Bhat, V. R. and Rajan, P. 2002. Stability of pod yield in cocoa under Kannara conditions. In: *Proceedings of National seminar on technologies for enhancing productivity in cocoa*, CPCRI, Regional Station, Vittal, November 29- 30, 200., pp. 40- 43.
16. Elain Apshara, S., Bhat, V. R., Ananda, K. S. and Nair, R. V. 2008. High yielding cocoa varieties of the Central Plantation Crops Research Institute, India. *INGENIC Newsletter* 11: 12-15.
17. Elain Apshara, S., Bhat, V. R., Ananda, K. S., Nair, R. V. and Suma, D. 2009. Evaluation and identification of high yielding trees in Nigerian cocoa germplasm. *Journal of Plantation Crops* 37 (2): 111-116.
18. Nair, R. V. and Rekha, A. 1996. Incompatibility in cocoa germplasm. *Indian Journal of Genetics* 56(2): 17- 20.
19. Vikraman Nair, R., Mallika, V.K. and Prasannakumari Amma, S. 2002. Breeding and Genetics. In: *Cocoa*. Ed. Balasimha, D., CPCRI, Kasaragod. pp. 18-47.