173501

ANALYSIS OF BEAN CHARACTERS IN COCOA (*Theobroma cacao* L.) HYBRIDS BRED FOR BOLD BEANS

By

RUBEENA M.

(2012-11-116)

THESIS

Submitted in partial fulfillment of the

requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF PLANT BREEDING AND GENETICS
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR – 680 656
KERALA, INDIA
2015

DECLARATION

I hereby declare that this thesis entitled **"Analysis of bean characters in cocoa (*Theobroma cacao* L.) hybrids bred for bold beans "** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

Place: Vellanikkara

Date: 24/03/2015

RUBEENA M.

(2012-11-116)

Dr. K.T. Presannakumari

Professor

Department of Plant Breeding & Genetics

College of Horticulture

Kerala Agricultural University, Vellanikkara

Date: 24\03\2015

CERTIFICATE

Certified that this thesis, entitled **"Analysis of bean characters in cocoa (*Theobroma cacao* L.) hybrids bred for bold beans"** is a record of research work done independently by **Smt. RUBEENA M. (2012-11-116)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Presannakumari

Place: Vellanikkara

Dr. K.T. Presannakumari

Chairperson

Advisory Committee

CERTIFICATE

We, the undersigned members of the advisory committee of **Smt.RUBEENA M. (2012-11-116)** a candidate for the degree of **Master of Science in Agriculture** with major field in **Plant Breeding and Genetics** agree that this thesis entitled **"Analysis of bean characters in cocoa (*Theobroma cacao* L.) hybrids bred for bold beans"** may be submitted by **Smt.RUBEENA M.** in partial fulfillment of the requirement for the degree.

Dr. K.T. Presannakumari
Professor
Dept. of Plant Breeding and Genetics
College of Horticulture, Vellanikkara
(Chairperson)

Dr. C.R. Elsy
Professor & Head
Dept. of Plant Breeding and Genetics
College of Horticulture, Vellanikkara
(Member)

Dr. Minimol J.S.
Asst. Professor (Sr. Scale)
(Plant Breeding and Genetics)
Cocoa Research Centre, Vellanikkara
(Member)

Dr.Suma B.
Professor & Head
Cocoa Research Centre, Vellanikkara
(Member)

Sri. S. Krishnan
Associate Professor & Head
Dept. of Agricultural Statistics
College of Horticulture, Vellanikkara
(Member)

External Examiner

डा. एम. लता, वरिष्ठ वैज्ञानिक
Dr. M. Latha, Senior Scientist
राष्ट्रीय पादप आनुवंशिक संसाधन ब्यूरो
NATIONAL BUREAU OF PLANT GENETIC RESOURCES
(Indian Council of Agricultural Research)
Regional Station, K.A.U. P.O., Thrissur-680 656, KERALA

ACKNOWLEDGEMENT

*First and foremost I praise and thank the **Almighty** for being the unfailing source of support, comfort and strength throughout the completion of my thesis work. I submit this small work before God with immense pleasure and full satisfaction.*

*My words cannot express the deep sense of immeasurable gratitude and unboundful indebtedness to the chairperson of my advisory committee **Dr. K.T. Presannakumari,** Professor, Plant Breeding and Genetics for her meticulous and immaculate guidance, learned counsel and scintillating suggestions in garnishing this study.With great respect and devotion, I wish to place my heartfelt thanks to her for the inspiring guidance, untiring interest, unstinted co-operation, esteemed advice, constructive criticism, valuable suggestions and immense help rendered by her during the course of the investigation and preparation of the thesis. I am genuinely indebted to her for the constant encouragement and affectionate advice rendered throughout the academic programme.*

*I place a deep sense of obligation and heartful thanks to the members of my advisory committee, **Dr. C.R. Elsy,** Professor and Head, Department of Plant Breeding and Genetics, **Dr. S. Prasannakumari Amma,** former Professor and Head, CRC, Vellanikkara , **Dr.Suma B,** Professor and Head ,CRC ,Vellanikkara and **Dr. Minimol J.S.,** Assistant Professor (sr. Scale), CRC, Vellanikkara for their sustained guidance, constructive ideas, valuable suggestions, unfailing patience, direct approach, constant support and encouragement throughout the study.*

*I would like to express my profound gratitude and humble respect to Sri. **S. Krishnan,** Associate Professor and Head, Department of Agricultural Statistics (member, advisory committee) for his valuable guidance and suggestions made in this study. Without his inputs the study would have been incomplete.*

I owe my deep sense of gratitude and grateful regards to Dr.K. Nandini Professor and Head, Department of Plant Physiology, for the help rendered in completing the total polyphenol estimation associated with this study. My sincere thanks to lab assistant of the Department of Plant Physiology for the help extended during my lab work.

*I am deeply obliged to **Dr. C. Beena,** Associate Professor, AICRP on Medicinal and Aromatic Plants ,COH, Vellanikkara, for her unfailing support and enthusiasm, relevant suggestion whole hearted co-operation throughout the period of investigation.*

I am very thankful to Asna A.C., Phd first year student for her prompt help and co-operation during the entire period of study.

*Whole hearted thanks to **Dr. Dijee Bastian,** Associate Professor, **Dr. Jiji Joseph,** Associate Professor, **Dr. Rose Mary Francis,** Associate Professor, Department of Plant Breeding and Genetics for their co-operation throughout the period of study.*

*I am thankful to **Joicy T.John** , Scientific officer, COH, Vellanikkara for rendering necessary help whenever needed.*

I take this opportunity to extend my gratitude to all non-teaching staff of Department of Plant Breeding and Genetics and Cocoa Research Centre, Vellanikkara, for their support in different stages of the study.

*Words fall short, as I place on record my indebtedness to my dear friends-**Nahla A.P, Aparna V.S.** for being with me for last six years of life and never give up their support to me in all aspects of life.*

*I acknowledge all people who contributed in different ways to this thesis. I am very grateful to all my teachers, batch mates-**Preethy T.T.,Vilas, Sreeremya,Sajeera***

C.C, Anila M.A seniors –Asna A.C, Hilario,Amaranth Reddy,Ashish juniors –Tincy ,Jeevan, Sarath and all my friends for their whole hearted support and encouragement at different stages of my work.

Above all, with gratitude and affection, I recall the moral support, boundless affection, constant encouragement, warm blessings and motivation of my beloved parents and my husband without which this endeavour would never have become a reality.

RUBEENA M.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Introduction

1. INTRODUCTION

Cocoa (*Theobroma cacao* L.) originally belonging to Sterculiaceae and now included in the expanded family of Malvaceae (Alverson *et al* ., 1999) is an important beverage crop. This tropical tree crop is commercially cultivated for its nibs which are used for the production of an array of products like chocolate and cocoa butter (Amma *et al.*, 2011).

The term 'cocoa' is believed to have been derived from the word 'cacahoatl' used by the Aztec Indians of the high Mexican plateau. Cocoa, according to Aztec Indians, was brought to earth by the God 'Quet zacoatl' whom they called as 'Xocohatl'. Hence, cocoa is believed to have a divine origin and is popularly known as 'food of God'. It may be with this legend in mind that Carl Linnaeus, the Swedish botanist, gave the name *Theobroma cacao* to the cultivated cocoa plant using the Greek words 'theos' meaning God and 'broma' meaning food (Mossu, 1992).

Round the year income and women friendly agro and processing techniques have led to a massive increase in the area under this crop in India in recent years. Cocoa cultivation has now spread even to the non-traditional areas having high temperature like Andhra Pradesh.

Many of the cocoa varieties cultivated by the farmers, even though high yielders, are having small beans. However, the standard for cocoa bean in the international market is one gram (Wood and Lass, 1985). This is an important constraint to the chocolate manufactures and cocoa exporters. Even in the domestic market the major companies hesitate to procure small sized beans. Besides, the bean size is significantly influenced by the environmental conditions especially temperature, prevailing during the formation and development of pod. This has to be considered in the present scenario, where the cocoa cultivation is spreading to non-traditional areas with high temperature.

To overcome this situation it is necessary to breed varieties with large beans, (preferably more than 2.5g wet peeled bean) so that even if reduction in size occurs bean will have enough size to meet the international standards. An organized breeding programme was hence, initiated at Cocoa Research Centre (CRC), KAU, Vellanikkara in 2005 for the development of varieties with bold beans without sacrificing yield. Parental lines identified as having bold beans were crossed with high yielders. The hybrid progenies from the compatible crosses, now in the bearing stage, are to be evaluated for bean characters.

It was in this background the present study entitled 'Analysis of bean characters in cocoa (*Theobroma cacao* L.) hybrids bred for bold beans' which forms part of the ongoing project at Cocoa Research Centre (CRC) was taken up with the following objectives:

(i) To study the inheritance of various pod and bean characters

(ii) To estimate the threshold bean size

(iii) To assess the heterotic effect for various characters bean in the hybrid progenies

Review of Literature

2. REVIEW OF LITERATURE

Cocoa belongs to the genus *Theobroma,* a group of small trees which occur wild in the Amazon basin and other tropical areas of South and Central America. The genus *Theobroma* is divided into six sections containing 22 species (Table 1) by Cuatrecasas in 1964. Though there are over 20 species in the genus *Theobroma,* the only one widely cultivated is *T. cacao*. *T. cacao* is a diploid species with a chromosome number of 20. The traditionally grown cultivars under the species *cacao* are classified into three main groups *viz*., *Criollo*, *Forastero* and *Trinitario*, based on the morphological features and geographical origins (Cheesman, 1944). Among these, Trinitarios are considered as hybrids of Criollo and Forastero and are indigenous to Trinidad and Tobago (Cheesman, 1944). Criollo and Trinitario beans are collectively known as "fine or flavor" cocoa because of its premium quality and high demand among manufactures of fine chocolates (Mooleedhar, 1995). Besides, different groups of cocoa had been recognized by scholars on the basis of pod and seed morphology: cundeamor, amelonado, angoleta and calabacillo (Marita *et al*., 2001 and Sounigo *et al*., 2003).

Pod and bean characters

Paterson and Reed, 1934, studied the variations in the size of Trinidad cacao beans and methods of its assessment. The number of cacao beans required to fill a Capstan cigarette tin level full, any projecting bean being rubbed off with a light ruler, served as a useful index of the size of bean and therefore of the standard of quality in Gold Coast region. Vanderknaap (1954) observed that seedlings produced by beans from different positions in the pods did not show any differences in growth. They also did not find any relationship between bean weight and cotyledon colour.

Bean yield as well as pest and disease resistance are the traits that receive the attention of cacao breeders. Emphasis has to be put on sexual compatibility and bean quality (flavor, chemical composition). Yield in cocoa is usually measured as the weight of the dry (often wet and converted to dry) beans produced per plant or area. The three components of yield are number of pods per tree or area, number of beans per pod and weight of individual beans (Wood and Lass,1955).

Table 1. Different sections and species under genus Theobroma

Sl. No.	Section	Species
1.	Rhytidocarpus	*T. bicolor*
2.	Oreanthes	*T. sylvestre* *T. speciosum* *T. velutinum* *T. glaucum* *T. bernouillii*
3.	Theobroma	*T. cacao*
4.	Telmatocarpus	*T. gileri* *T. microcarpum*
5.	Glossopetalum	*T. cirmolinae* *T. stipulatum* *T. simiarum* *T. chocoense* *T. angustifolium* *T. grandiflorum* *T. obovatum* *T. sinuosum* *T. canumanense* *T. subincanum* *T. hylaeum* *T. nemorale*
6.	Andropetalum	*T. mammosum*

Cocoa types having high seed index are of better economic value for chocolate industries (Ruinard, 1961). Mora and Bullard (1961) in a study on variations in bean characteristics of hybrid cocoa progenies observed a positive correlation (significant at the 5% level) between bean size and fat content and a negative correlation (significant at the 1% level) between bean size and hull percentage. No significant difference was observed among the clones or hybrids in flavour or fermentation ratings.

Enriquez and Soria (1966) reported that yield expressed as dry or wet weight of bean is a highly variable character. They also observed high variability for weight of bean even within a single pod. The inheritance of fruit size was studied by Soria *et al.*, 1974, and estimated the heritability for fruit length as 55 percent, for fruit diameter as 63 percent and total weight as 57 percent indicating that these are highly transmissible characters. In 1975, Soria reported great variation in fruit characters like length, diameter, total weight, weight of the husk and weight of seeds in each pod. Adenikinju(1977) studied the growth and dry matter accumulation in cocoa seedlings as influenced by bean size. The beans were graded into four sizes by mean weights. The total dry matter/seedling was found to increase linearly during the nursery period and was influenced by bean size.

Engles (1982), based on a study of 32 clones of cocoa concluded that selection for seed size could lead to higher cocoa production per fruit than selection for seed number per fruit. Study on the effect of season on pod and bean characters of cocoa indicated that pod weight, TSS and bean weight were low, but pulp percent was high in wet season compared to dry season (Bopaiah and Bhat, 1989). Cilas *et al.*, 1989, based on a study on 20 clones belonging to Amelonado and Trinitario types reported that bean size was extremely variable and tended to be the greatest in Trinitario types. It was also observed that seeds originating from fruit apex were smaller and free from flat beans.

Mora (1989) reported that seeds originating from the fruit apex were smaller and free from flat beans. Flat beans were found only in the apical areas of some fruits of the varieties EET 400 and SPA 9.

Seedlings of the open pollinated biclonal and hand pollinated hybrids, synthetic variety No. 3 and F3 Amazon were evaluated in trials in Adolina and Tinjowan, North Sumatra during 1987-91. Results showed that variations in yield and related characters were highly heritable. Selection based on bean quality was effective in improving yield (Napitupulu, 1992).

Francis (1998) observed that variability was the highest for yield and dry beans per tree as well as precocity of bearing and was the lowest for pod width and bean width. Bekele *et al.*, 2008, identified promising Trinitario accessions in terms of bean size, pod index (less than 20), pod wall thickness and cotyledon colour. The mean cotyledon weights for the types DOM, GA, GDL, GS, ICS, MAR and TRD were 0.94g, 1.02g, 1.22g, 1.11g, 1.14g, 0.89g and 1.03g respectively.

Alvarez, *et al.* (2003) compared the morphology and physical-chemical characteristics of fruits and some quality parameters of raw mucilage of cocoa fruits collected from plants of Chuao, Cuyagua and Cumboto States, Venezuela. Mature fruits were evaluated for colour of fresh beans, shape and texture of fruits. The results revealed variations among the genotypes evaluated in each area.

Ramos *et al.* (2004) conducted a study on cocoa populations from Guasare (10 genotypes) and Andean foothills (6 genotypes) in western Venezuela based on 40 morphological characters related to flowers, fruits and seeds. The Guasare population was characterized by pronounced ruggedness of the surface of the fruit, roundness of seeds (width: thickness ratio of almost 1:1), and white cotyledons. For the population from the Andean foothills, the most important descriptors were the length of style, intensity of pigmentation, width of sepals, number of ovules, and smooth surface of fruit. Fruit traits, such as thickness and pigmentation of the ridge, thickness of the primary furrow, presence of basal constriction, thickness of seeds, ratio of the number of ovules to number of seeds, and length of ovary were not determinants. This methodology reduced the quantity of observations as well as number of variables and facilitated characterization of morpho-geographic groups.

In a study to determine the effects of temperature and light on fruit growth and development of five cocoa genotypes (Amelonado, AMAZ 15/15, SCA 6, SPEC 54/1 and

UF 676) negative relationship between temperature and bean size was observed for Amelonado and UF 676 (Daymond and Hadley, 2008).

Cocoa genotypes with mean seed weight higher than one gram are considered to be superior (Monteiro *et al.*, 2009). Apshara *et al.* (2009) conducted a study on 44 Nigerian cocoa clones which are being conserved in the field gene banks of Central Plantation Crops Research Institute, Regional Station, Vittal, Karnataka. These clones were assessed for their growth and yield performance based on pod and bean characters. Among the clones, NC-37, NC-23, NC-26, NC-50, NC-20, NC-51, NC-27 and NC-25 were identified as heavy bearers with an average of 61.9, 53.3, 49.4, 48.4, 45.1, 44.2, 43.9 and 43.0 pods per tree per year respectively and with high dry bean yields of more than one kilogram per tree per year. These clones recorded single bean weight of more than one gram, 10-15 per cent shelling percentage and more than 50 per cent fat which made them suitable for industries as well.

Dried beans of 14 genotypes of cocoa were evaluated for bean values by Oyedokun *et al.* (2011) and found that the genotypes differed significantly in weight of single bean, bean length, width, thickness, 100 bean weight, ratio of bean length to width, length to thickness and width to thickness. Number of seeds per pod and mean seed weight were studied in more than 200 clones of cocoa by Cilas *et al.* (2010). They found that the number of ovules per ovary showed high heritability and mean seed weight per pod showed intermediate heritability. Evaluation of 14 hybrid genotypes for bean traits revealed that genotypes differed significantly with respect to single bean weight, bean length, width, thickness, 100 bean weight, ratio of bean length to width, bean length to thickness and bean width to thickness (Oyedokun *et al.*, 2011). All the morphometric characters evaluated exhibited high (>70%) broad sense heritability.

Study of 20 TSH (Trinidad Selected Hybrid) varieties of cocoa by Maharaj *et al.* (2011) revealed that the characters of economic interest viz., bean number, cotyledon weight, pod index ranged from 42.2 to 61.4, 0.74 to 1.49g 12 to 26.1 respectively.

Minimol *et al.* (2011) observed the influence of fruit apex on fruit shape in a study involving 23 accessions. The results of the study also showed that 12 among 23 were with angoleta type fruits, seven were with calabacillo type fruits and three were with cundeamor type fruits. One accession, RED 127 alone was having amelonado type fruits. With respect to fruit apex, eleven accessions were obtuse tipped, seven acute, four mammelate and one round tipped.

The 14 hybrids evaluated by Oyedokun *et al.* (2011) differed significantly in weight of beans as well as length, width and thickness of beans.

Velayutham *et al.* (2013) assessed the variability and yield performance of 151 cocoa trees in the farmers' field in Tamil Nadu. Variability among the trees for pod and bean characters as well as yield were studied for all the trees selected. The trees having the following traits were identified as promising mother trees : Dry bean yield per tree (> 2.4 kg), number of pods per tree (> 60), number of beans per pod (> 35) and single dry bean weight (>1 g). A total of 27 trees *viz.*, KUL-2, 18, 25, SMJ-3, 4, 10, 15, 18, 21, 25, 33, 34, 37, 50, SME-2, 5, 6, 9, 16, 21, 24, 26, 28, 29, VPS-12, 13 and 15 were identified as promising mother trees.

Hybrids and heterosis

By the middle of 1940s breeding work in West Africa and elsewhere had progressed to a stage where selections were made from the most productive trees in plantations. These selections were propagated vegetatively because cutting or budding reproduce the characters of the selected plants more closely than seedlings. Although such seed showed little or no improvement over the West African Amelanado (Voelcker, 1939), monoclonal blocks were planted for large scale production of selfed seed from the best selections. Next step was to cross local selections from different countries. In Nigeria, N38 was crossed with selections derived from open-pollinated ICS (Imperial College Selections from Trinidad) parents. The progeny were found to be strikingly vigourous. This served as an early example of heterosis in cocoa (Russell, 1952, Atanda and Toxopeus (1971).

The development of hybrid varieties and large scale production of hybrid seeds involve long programme of research. Local selections as well as introductions helped in the development of successful hybrids. Many crosses were made and resulting progenies were tested both in farmers fields as well as controlled conditions. The whole programme requires at least tweleve year. The main aim of cacao breeding is to increase yield of the dry cacao bean without sacrificing bean quality. Since dry bean yield is difficult trait to evaluate, selection can be practiced based on more easily measurable correlated traits. Several traits in isolation or in combination have been mentioned as important in discriminating genotypes for yield (Wood and Lass, 1955).

Hybrids of ICS clones and the witches'-broom resistant Amazonian clones, SCA6 and SCA12, have exhibited marked precocity in bearing and higher yield of dry cocoa per acre than other types at the age of 3-4 years (Bartley, 1957).

Montserin *et al.* (1957) studied the yield, pod value, bean weight and resistance to *Marasmius perniciosus* (*Crinipellis perniciosa*) of a number of hybrids which originated from crosses between Amazonian clones and between Amazonian and Trinitario clones of cocoa. Although planted unusually close together, the seedlings were high yielding and early bearing with satisfactory dry beans weight of more than 1 gm.

Vernon (1975) conducted a study to determine the seedling performance of seven hybrids produced by crossing Amelonado with ICS and SCA clones. Amelonado X ICS39 (Hybrid A) and Amelonado X SCA 12 (Hybrid C) gave the best seedling performance and were subsequently planted in yield trials with Amelonado. Hybrid A initially gave double the yield of Amelonado. It was much superior under unfavourable conditions. Yield of Hybrid C was high compared to Amelonado, being 2170-3180 kg/ha dry cocoa for the former and 590-1790 kg/ha for the latter in 1975.

Pereira *et al.* (1987) and Dias *et al.* (1998) used the number of healthy fruits per plant and the weight of fresh beans per plant as well as per fruit to select promising hybrids in Linhares. The increase in the first two yield components increased the yield.

Evaluation of the full bearing populations of 19 hybrids and the budded progenies of their parents revealed that weight of bean and number of pods showed maximum variability (Cheriyan *et al.*, 1996). They also observed that hybrids differed among themselves for most of the characters studied.

Mallika *et al.* (2000) conducted a study on 661 hybrids and 735 parental clones of cocoa. The hybrids yielded a higher number of pods than the clones. The hybrids exhibited high early yield, while clones showed low early yield.

Apshara *et al.* (2008) assessed the growth and vigour of the hybrids based on pod yield and bean characters. The hybrids PII-5, PII-3, PIII-I-23 and PI-IV-478 were vigorous with sturdy stem and well spread canopies. Early bearing, from second year of field planting was observed in the hybrids PIII-II-89, PI-IV-478, PI-I-18 and PI-I-38. The hybrids PI-IV-478, PI-I-38, PIII-I-23, PIII-II-54 and PI-I-18 showed high pod yield potential with an annual yield of more than 50 pods per tree per year at the age of six years.

Balasimha *et al.* (2008) conducted crossing works using high yielding and drought tolerant parent trees. Nine promising hybrid lines were developed through their programme and were planted at CPCRI Research Centre, Kidu along with parents. There was variability among the hybrids with respect to photosynthetic characters. Significant differences in these photosynthetic parameters with respect to season were also observed. Drought tolerance was observed in I-21 × NC 42/94 and I-29 × NC 23/43 hybrid progenies. The results also showed that these hybrids retained higher water potential and stomatal regulation comparable to drought tolerant parents. Variability was observed for bean yield among the hybrids and parents. High yield was recorded in hybrids I-21 × NC 29/66, II-67 × NC 29/66 and II-67 × NC 42/94.

A study was undertaken to assess the phenolic and antioxidant capacity of cocoa hybrid and traditional cocoa varieties in Ghana. The hybrid beans had antioxidant capacity ranging from 21.6 to 45.5 μmol TE g^{-1}, and was significantly higher than that of traditional cocoa varieties (Jonfia-Essien *et al.*, 2008).

Oyedokun *et al.* (2011) found that among the 14 hybrids evaluated for bean traits G 8, the hybrid between T 53/5 and N 38, was the most superior genotype for bean weight and some other bean characteristics. The mass of 74 dried cocoa beans of G 8 approximated 100g.

Biochemical characters

Cocoa butter is the major commercial product from the seeds of cocoa. Cocoa seeds contain more fat than any other major oil crop other than coconut (Luhs and Friedt, 1994). Duncan and Veldsman, 1994, observed that fat content directly influenced the value of commercial seeds, representing the increased cost of grinding during processing of seeds with low fat content.

The average fat content of the unfermented seeds of 490 accessions evaluated by Pires *et al.* (1998) was found to be 53.2 per cent, ranging from 45.4 per cent in CC 57 to 60.3 per cent in NA 312.

Kim and Keeney, 1984, reported that polyphenols accounting for 12-18 per cent of the whole bean weight is associated with the flavor and colour of chocolate. The reactions of polyphenol with sugar and amino acids is contributing flavor and colour to cocoa beans whereas the alkaloids are contributing bitterness (Lehrian and Patterson, 1983; Afaokwa and Paterson, 2010).

Soluble solids (Brix) and pH of mucilaginous part of fresh fruits collected from cocoa genotypes belonging to Chuao, Cuyagua and Cumboto States, Venezuela were measured by Álvarez, *et al.*, (2003). The content of soluble solids in the mucilage of the fruits of different genotypes from the 3 zones also differed significantly: 19.89-22.26% for Chuao, 14.48-17.52% for Cuyagua, and 7.83-15.68% for Cumboto. The pH values showed less differences: 3.03-3.09 for Chuao, 3.01-3.68 for Cuyagua, and 3.36-3.76 for Cumboto.

Nazaruddin *et al.* (2006) reported that the total polyphenol content ranged from 45 to 52 mg/g in cocoa liquor, 34 to 60 mg/g in beans, and 20 to 62 mg/g in powder. The place of origin as well as the method of processing were found to influence the polyphenol content of cocoa products (Jalil and Ismail, 2008).

Afoakwa *et al.* (2012) observed a reduction in total polyphenol content with increase in the storage and fermentation time. Prayoga *et al.*, (2013) reported that extracts from unfermented dry cocoa beans have higher polyphenol content and stronger antioxidant activity than partially fermented cocoa beans and can be used as natural food color at three per cent level.

Cluster analysis

Engles (1986) carried out cluster analysis as well as principal component analysis using 39 characters in a group of 294 cultivars and found that the distribution of these cultivars corresponded roughly to the traditional classifications into Criollo, Forastero and their subdivisions.

Bekele and Bekele (1996) characterized hundred accessions from the germplasm maintained at International Cocoa Gene Bank, Trinidad for phenetic diversity with morphological descriptors and associations among them were examined by hierarchical average linkage cluster analysis. Cluster analysis indicated rich phenetic diversity in this sample of germplasm. At 75 percent level of similarity, nine accessions remained ungrouped and the remaining accessions grouped into 11 clusters. The observed link between geographic origin and accession grouping suggested that it is necessary to collect and conserve germplasm representing a broad geographic range.

The stability of the genetic divergence among five non-commercial cocoa cultivars at advanced ages for over a five-year period was investigated and cluster analysis was done on five yield components measured on harvests from each crop year and on the data pooled over five years by Dias *et al.*,(1997). The comparison of D^2 values and of clusters based on pooled analysis with D^2 values and clusters obtained from each year showed a stable clustering pattern in the most favorable years.

Santos *et al.* (1997) quantified multivariate phenetic divergence among SIC and SIAL series clones by cluster and principal component analyses. SIC 17 and SIAL 244 clones showed the highest divergence (3.05). SIC 18 and SIC 765 clones formed the highest similar pair (0.33) based on the Euclidean distance matrix.

In 2011, Maharaj *et al.*, carried out cluster analysis using 15 quantitative variables to study the relationships among 20 Trinidad Selected Hybrids (TSH) of cocoa and five parental types. This study revealed that SCA 6, ICS 95 and ICS 1 were very distinct from the TSH progeny. SCA 6 was very distinct even at the lowest level of similarity. The two TSH types in this group had descriptive fruit values which were similar to the parental types and possessed strong IMC 67 ancestry.

Oyedokun *et al.* (2011) employed Principal Component Analysis (PCA) to identify the distinguishing traits and to group the 14 genotypes based on similarities. PCA grouped the 14 genotypes into four distinct clusters. Clusters I and II had a membership of five and seven genotypes with a mean bean weight of 1.07g and 1.02g respectively. Clusters III and IV had G1 and G8 as single members. They also showed an outstanding bean weight of 1.12g and 1.30g respectively.

Santos *et al.* (2012) conducted a study to determine the morphological variability of four wild species, one semi-cultivated and one cultivated species of *Theobroma cacao* L., indigenous to Brazil and introduced to Bahian cocoa-growing region and to characterize them based on 35 quantitative and 13 qualitative traits. The statistical analysis revealed great variability in the evaluated traits.

Materials & Methods

3. MATERIALS AND METHODS

The present study entitled 'Analysis of bean characters in cocoa (*Theobroma cacao* L.) hybrids bred for bold beans' was carried out in the Department of Plant Breeding and Genetics, College of Horticulture and the Cocoa Research Centre (CRC), Vellanikkara during the period 2012-2014.

Fourty healthy, vigorous and disease free hybrid progenies derived from four crosses involving five parents (S IV 1.26, TISSA, P II 12.11, S IV 5.20 and S IV 6.18) formed the material for the study. The details of crosses and the hybrid progenies are presented in Table 2. These hybrids as well as the budded progenies of the five parents, which have reached bearing stage are maintained at CRC, Vellanikkara.

3.1 Morphological evaluation

Both qualitative and quantitative characters of the pods and beans were considered for morphological evaluation. The descriptor list developed by Bekele and Butler (2000) was used for recording the observations on qualitative and quantitative characters. The descriptor and the descriptor states are presented in Table 3.

3.1.1 Qualitative evaluation

For the qualitative evaluation, observations on eight qualitative characters were recorded. Main qualitative characters recorded were color of unripe pod, colour of ripe pod (ridge and furrow colour), pod shape, pod apex form, pod basal constriction, husk hardiness, pod rugosity and colour of bean (colour of cotyledon) (Table 3). The genetic associations among the genotypes evaluated were estimated by Jaccard's similarity coefficients (Jaccard, 1908) using NTSYS pc version 2.1 (Rohlf, 1992). Cluster analysis was done based on the similarity matrix and a dendrogram was constructed by Unweighted Pair-Group Method (UPGMA) (Sneath and Sokal, 1973).

3.1.2 Quantitative evaluation

Quantitative evaluation was based on 14 quantitative characters (Table 3). A measuring device fabricated by Cocoa Research centre was used for measuring the length

Table 2. The hybrid progenies and their parentage

Sl. No.	Hybrid progeny No.	Parentage
H1	Hybrid 2.1	S IV 1.26 X TISSA
H2	Hybrid 3.1	S IV 1.26 X TISSA
H3	Hybrid 4.5	S IV 1.26 X TISSA
H4	Hybrid 4.7	S IV 1.26 X TISSA
H5	Hybrid 4.8	S IV 1.26 X TISSA
H6	Hybrid 5.7	S IV 1.26 X TISSA
H7	Hybrid 5.9	S IV 1.26 X TISSA
H8	Hybrid 7.8	S IV 1.26 X P II 12.11
H9	Hybrid 8.9	S IV 1.26 X P II 12.11
H10	Hybrid 9.3	S IV 1.26 X P II.12.11
H11	Hybrid 9.8	S IV 1.26 X P II 12.11
H12	Hybrid 10.4	S IV 1.26 X P II 12.11
H13	Hybrid 10.6	S IV 1.26 X P II 12.11
H14	Hybrid 11.6	S IV 1.26 X P II 12.11
H15	Hybrid 11.8	S IV 1.26 X P II 12.11
H16	Hybrid 11.9	S IV 1.26 X P II 12.11
H17	Hybrid 12.4	S IV 1.26 X P II 12.11
H18	Hybrid 12.5	S IV 1.26 X P II 12.11
H19	Hybrid 12.6	S IV 1.26 X P II 12.11
H20	Hybrid 12.8	S IV 1.26 X P II 12.11
H21	Hybrid 13.5	S IV 1.26 X P II 12.11
H22	Hybrid 13.6	S IV 1.26 X P II 12.11
H23	Hybrid 13.7	S IV 1.26 X P II 12.11
H24	Hybrid 14.6	S IV 1.26 X P II 12.11
H25	Hybrid 14.8	S IV 1.26 X P II 12.11
H26	Hybrid 15.4	S IV 1.26 X P II 12.11
H27	Hybrid 15.6	S IV 1.26 X P II 12.11
H28	Hybrid 15.7	S IV 1.26 X P II 12.11
H29	Hybrid 16.4	S IV 1.26 X P II 12.11
H30	Hybrid 16.5	S IV 1.26 X P II 12.11
H31	Hybrid 16.7	S IV 1.26 X P II 12.11
H32	Hybrid 16.8	S IV 1.26 X P II 12.11
H33	Hybrid 17.4	S IV 1.26 X P II 12.11
H34	Hybrid 17.6	S IV 1.26 X P II 12.11
H35	Hybrid 28.5	S IV 5.20 X TISSA
H36	Hybrid 28.6	S IV 5.20 X TISSA
H37	Hybrid 28.10	S IV 5.20 X TISSA
H38	Hybrid 29.4	S IV 5.20 X TISSA
H39	Hybrid 30.5	S IV 6.18 X P II 12.11
H40	Hybrid 31.6	S IV 6.18 X P II 12.11

Table 3. Descriptor and descriptor states used for recording observations

Sl. No.	Descriptor	Descriptor state	Description
1	Colour of unripe pod	3 5 9	Light Intermediate Dark green
2	Pod shape	1 2 3 4 5	Cundeamor Angoleta Amelonado Calabacillo Criollo
3	Colour of ripe pod (Ridge & furrow colour)	0 3 5 7	Absent (green) Slight (greenish yellow) Intermediate (yellowish green) Intense (yellow)
4	Pod apex form	1 2 3 4 5	Attenuate Acute Obtuse Rounded Mammelate
5	Pod basal constriction	0 1 2 3	Absent Slight Intermediate Strong
6	Husk hardiness (cm) (difference between ridge and furrow thickness)	3 5 7	Soft (<1) Intermediate (1-1.5) Hard (>1.5)
7	Pod rugosity	0 3 5 7	Absent Slight Intermediate Intense
8	Cotyledon colour (Bean colour)	1 2 3 4 5 6 7	White Grey Light purple Medium purple Dark purple Mottled Mixed
9	Pod weight (g)	-	
10	Number of beans/pod	-	
11	Number of flat beans/pod	-	
12	Length of pod (cm)	-	
13	Breadth of pod (cm)	-	
14	Furrow thickness (cm)	-	
15	Ridge thickness (cm)	-	

16	Total wet bean weight/pod (g)	-	
17	Weight of unpeeled bean (g)	-	
18	Wet weight of peeled bean (g)	-	
19	Dry weight of peeled bean (g)	-	
20	Length of peeled bean (mm)	-	
21	Breadth of peeled bean (mm)	-	
22	Thickness of peeled bean (mm)	-	
23	TSS (%)	-	

and breadth of pods (Plate 1). The thickness of husk as indicated by ridge thickness and furrow thickness was measured with the help of vernier calipers (Plate 2). The Pod Index (PI) value (the number of pods required to produce 1kg of dry peeled bean or cocoa bean without testa), peeling ratio (wet weight of peeled bean / wet weight of unpeeled), dry matter recovery (dry weight - wet weight ratio of peeled beans) for the different hybrids were also worked out. Analysis of variance was done for all the quantitative characters observed.

Clustering of genotypes based on quantitative characters was also done with the help of NTSYS pc version 2.1software (Rohlf, 1992) and a dendrogram was constructed.

The descriptive statistics *viz.*, mean, variance, standard deviation, coefficient of variation, heritability, and genetic gain were worked out for each of these 14 quantitative characters.

3.1.3 Threshold bean size

To estimate the threshold bean size the relative performance based on year round observation was assessed in CRD with respect to major characters affecting boldness of beans *viz.*, weight, length, breadth and thickness of beans. Further to group the genotypes having similar performance, subsets were formed using post hoc test DMRT. Based on the best subset values an inclusive scale was developed prescribing the minimum and maximum values for the major characters contributing to bean size.

Weight of pod

Length of pod

Breadth of pod

Plate 1.Pod measurements

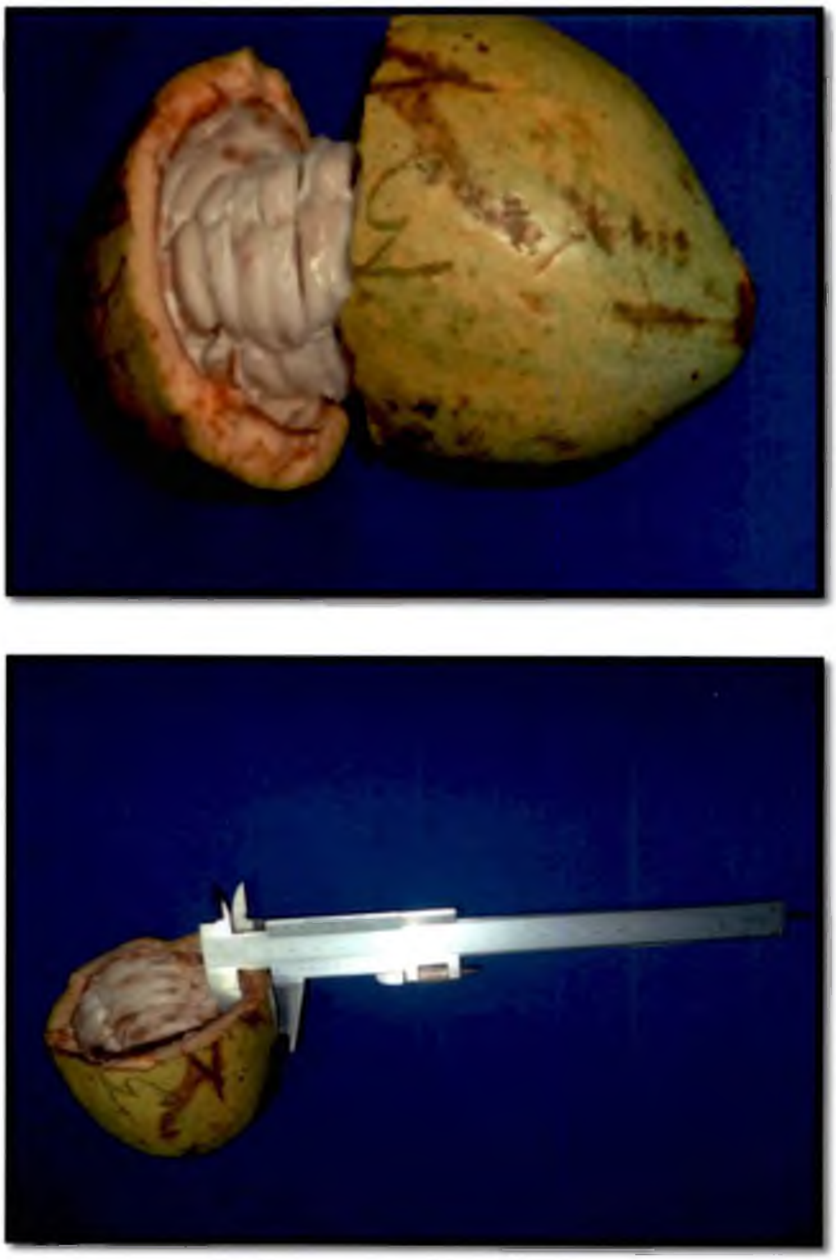

Plate 2. Measurement of husk thickness

3.2 Biochemical evaluation

The hybrids along with parents were evaluated based on biochemical parameters also. For biochemical evaluation, fat and total polyphenol contents were estimated following standard procedures as detailed below.

Twenty beans were selected at random from each of the genotypes. After removing the outer slimy layer the beans were dried to have moisture content below 8 per cent either by sun drying or by oven drying. Under normal sunny weather drying could be completed within seven days. The dry beans were then ground to fine powder using laboratory grinder and the powder was stored in polyethylene bottles for analysis.

3.2.1 Determination of fat

Unfermented bean samples were used for estimation of fat content in the present study as it is difficult to standardize the fermentation process. Cocoa nibs were defatted by extracting the fat with petroleum ether (40-60°C) in a soxhlet extraction apparatus (Sadasivam and Manickam, 1996). Ten grams of the powdered sample wrapped in blotting paper was put in the extraction tube of soxhlet extraction apparatus. The total fat present in the sample was extracted along with the siphoning of petroleum ether and was collected in pre-weighed flask of the apparatus. The petroleum ether in the extract was evaporated to dryness. The cream coloured fat left behind after the evaporation of solvent was weighed and expressed as percentage.

3.2.2 Determination of polyphenol

The powdered defatted bean samples were used for the estimation of total polyphenol content. The defatted samples were extracted exhaustively with ethanol. The total phenols in the extracts were then determined by Folin – Ciocalteau reagent method described by Malick and Singh (1980). The procedure followed is presented below in detail.

Exactly 500 mg of defatted sample was ground with mortar and pestle in 10 volumes of 80 per cent ethanol and centrifuged at 10,000 rpm for 20 min. Supernatant was collected, the residue was re-extracted with 5 times the volume of 80% ethanol, centrifuged and pooled the supernatant. Supernatant was allowed to evaporate. The residue was dissolved in 5ml of distilled water. Pipetted out 0.2ml of the solution into test tube, and the volume was made up to 50 ml using distilled water followed by the addition of 0.5 ml of Folin-ciocalteu reagent. After 3 min, 2ml of 20 per cent Na_2CO_3solution was added and mixed well. The test tubes were placed in boiling water bath for exactly one minute. Exactly after one minute the tubes were removed from the bath and cooled to room temperature. A blue coloured complex, molybdenum blue was formed in the tube as the phenol undergoes a complex redox reaction with phosphomolibdic acid in Folin – Ciocalteau reagent in alkaline medium. The absorbance was read at 650 nm against reagent blank.

The detector was calibrated for quantification of total polyphenols by the following procedure. The total polyphenols in the extracts were assayed in terms of catechin taken as the reference. Exactly 100mg of Catechol is dissolved in a 100 ml of distilled water was used as stock solution. From this working standards were prepared. From the stock solution pipette out one ml of aliquot into a 10 ml standard flask and made up the volume into 10 ml. For the measurement of absorbance pipetted out 0.2ml of aliquot from this into a test tube and made up to 3ml. Then add 0.5 ml Folin-ciolateu reagent and after 3minutes added 2ml 20 per cent Na_2CO_3 solution into the tube. The absorbance was read at 650 nm.

Concentration of phenols in the extract (expressed as catechin) was worked out by substituting the absorbance value thus obtained in the calibration equation developed for the purpose. The total polyphenol content was calculated as mg. catechol equivalent of phenol/ g. sample and expressed as percent.

The total fat and polyphenol contents in the samples were calculated and expressed as percent. Jaccard's similarity coefficients among the genotypes based on the fat and polyphenol content were worked out using NTSYS pc version 2.1(Rohlf, 1992). Based on the similarity matrix cluster analysis was performed, and dendrogram was constructed by UPGMA (Sneath and Sokal, 1973).

The correlation of fat and polyphenol contents with bean weight was also worked out.

3.3 Scoring for pest and diseases

A preliminary scoring of the genotypes evaluated was done for their susceptibility to pest, diseases and rodents. The pods were observed every month from each genotype and any infestation if found was recorded. This was continued for one year and the results were then expressed as percentage of total number of pods observed.

3.4 Heterotic effect in the hybrids

The heterotic effects of hybrid progenies were estimated with respect to mid parental value (Relative heterosis) as well as better parent value (Heterobeltiosis).

3.5 Seasonal effect on pod and bean characters

The seasonal effect on various pod and bean characters was computed by standard statistical procedures. For convenience of analysis the whole year was divided into 4 seasons *viz.*, December to February representing winter, March to May representing summer, July to August representing rainy and September to November representing spring season and the data was subjected to statistical analysis.

Appropriate statistical analysis were carried out wherever necessary.

Results & Discussion

4. RESULTS & DISCUSSION

Fourty hybrid progenies derived from four crosses involving five parents were evaluated during 2012-2014 at College of Horticulture, Vellanikkara along with parental types. Among these hybrids, seven were the progenies from the cross, S IV 1.26 X TISSA, twenty seven were from the cross S IV 1.26 X P II 12.11, four were from S IV5.20 X TISSA and two were from the SIV 6.18 X PII 12.11. The results of the present investigation are presented below.

4.1 Morphological evaluation

Qualitative as well as quantitative characters of pods and beans were considered for evaluating the hybrid progenies morphologically.

Among the 40 hybrid progenies, 13 hybrids *viz.*, hybrids 2.1, 3.1 ,4.5 and 4.7 from the cross S IV 1.26 X TISSA, hybrids 9.3,10.4,11.8,12.4,12.8,13.6 ,14.8 and 15.4 from the cross S IV 1.26 X P II 12.11 and hybrid 30.5 from the cross S IV 6.18 X P II 12.11 flowered profusively but did not set pods. This indicates that some incompatibility mechanisms may be operating in these hybrid progenies which needs further detailed investigation.

Even though pod setting was noticed in the hybrids 8.9 and 11.9 from the cross S IV 1.26 X P II 12.11, mature fruits were not obtained due to pod shedding in the early stages of development itself. The cause of pod shedding in these hybrids also needs further investigation. Hence, observations on pod and bean characters could not be taken from the four hybrids derived from the cross S IV 1.26 X TISSA, ten hybrids from S IV1.26 X P II 12.11 and one from S IV 6.18 X P II 12.11. So, further detailed observations were limited to the twenty five hybrid progenies which flowered and set pods. This consisted of the three hybrid progenies from the cross

S IV 1.26 X TISSA, 17 hybrid progenies from the cross S IV1.26 X P II 12.11, four hybrid progenies from the cross S IV 5.20 X TISSA and one from the cross S IV 6.18 X P II 12.11.

4.1.1 Qualitative evaluation

The observations on various qualitative characters of the hybrid progenies and parents are presented in Tables 4 and 5.

The colour of unripe pod was light green in majority of the hybrids except hybrids 11.6, 12.6 from the cross S IV1.26 X P II 12.11 as well as hybrids 28.5, 28.6, and 28.10 from the cross S IV 5.20 X TISSA. In these hybrids the unripe pods were intermediate green in colour. All the parents except TISSA were also having unripe pods of intermediate green colour (Table 4 and Plate 3).

The colour of ripe pod is indicated by the colour of ridges and furrows on the pod. All the five parental genotypes were yellow poded, with yellow coloured ridges and furrows. However, in the hybrid progenies a gradation of colours and their combinations were observed (Plate 4a & Plate 4b). Even the progenies from the same cross itself exhibited variability in the colour of ridges and furrows. This is evident from the progenies of the cross S IV 1.26 X P II 12.11. Among the seventeen hybrid progenies from this cross yellow, yellowish green, greenish yellow or green ridged types could be observed (Table 4). Similar type of variation could be observed among these progenies for furrow colour also.

Variability was observed for bean colour also among the progenies from different as well as same cross (Plate 5). It can be seen from Table 4 that in the progenies (hybrid 7.8 to 17.6) from the cross S IV 1.26 and P II 12.11, both having medium purple beans, dark purple, medium purple, light purple and white coloured types were observed.

Light green

Intermediate green

Dark green

Plate 3. Descriptor states for colour of unripe pods

Absent (Green)

Slight (Greenish yellow)

Intermediate (Yellowish green)

Intense (Yellow)

Plate 4a. Descriptor states for colour of ripe pods

Yellow poded parents

Ripened fruits of hybrids

Plate 4b. Ripe pods of cocoa genotypes evaluated

White

Light purple

Medium purple

Dark purple

Plate 5. Descriptor states for colour of bean

Table 4. Pod and bean colour of cocoa hybrids and their parents

Hybrids / parents	Colour of unripe pod	Colour of ripe pod		Bean colour
		Ridges	Furrows	
Hybrid 4.8	Light green	Greenish yellow	Greenish yellow	Light purple
Hybrid 5.7	Light green	Greenish yellow	Greenish yellow	Medium purple
Hybrid 5.9	Light green	Yellow	Yellow	Medium purple
Hybrid 7.8	Light green	Greenish yellow	Greenish yellow	Light purple
Hybrid 9.8	Light green	Yellow	Yellow	Light purple
Hybrid 10.6	Light green	Yellow	Yellow	Medium purple
Hybrid 11.6	Intermediate green	Yellow	Yellow	Medium purple
Hybrid 12.5	Light green	Greenish yellow	Greenish yellow	Dark purple
Hybrid 12.6	Intermediate green	Yellow	Yellow	Dark purple
Hybrid 13.5	Light green	Greenish yellow	Yellow	Medium purple
Hybrid 13.7	Light green	Yellowish green	Yellowish green	Medium purple
Hybrid 14.6	Light green	Greenish yellow	Greenish yellow	Medium purple
Hybrid 15.6	Light green	Yellow	Greenish yellow	Medium purple
Hybrid 15.7	Light green	Yellow	Yellow	Light purple
Hybrid 16.4	Light green	Yellow	Yellow	Light purple
Hybrid 16.5	Light green	Yellow	Yellow	Medium purple
Hybrid 16.7	Light green	Greenish yellow	Greenish yellow	Medium purple
Hybrid 16.8	Light green	Yellow	Yellow	Light purple
Hybrid 17.4	Light green	Greenish yellow	Greenish yellow	white
Hybrid 17.6	Light green	Green	Yellow	Light purple
Hybrid 28.5	Intermediate green	Greenish yellow	Green	Light purple
Hybrid 28.6	Intermediate green	Yellow	Yellow	Light purple
Hybrid 28.10	Intermediate green	Yellow	Yellow	White
Hybrid 29.4	Light green	Yellow	Yellow	Light purple
Hybrid 31.6	Light green	Greenish yellow	Yellow	Light purple
Parents				
P II 12.11	Intermediate green	Yellow	Yellow	Medium purple
S IV 1.26	Intermediate green	Yellow	Yellow	Medium purple
S IV5.20	Intermediate green	Yellow	Yellow	Medium purple
S IV 6.18	Intermediate green	Yellow	Yellow	Light purple
TISSA	Light green	Yellow	Yellow	Light purple

Table 5. Pod shape and rugosity of cocoa hybrids and their parents

Hybrids/parents	Pod shape	Pod apex	Pod basal constriction	Rugosity
Hybrid 4.8	Cundeamor	Acute	Intermediate	Slight
Hybrid 5.7	Cundeamor	Obtuse	Slight	Slight
Hybrid 5.9	Cundeamor	Obtuse	Slight	Slight
Hybrid 7.8	Angoleta	Attenuate	Slight	Slight
Hybrid 9.8	Angoleta	Acute	Intermediate	Slight
Hybrid 10.6	Angoleta	Obtuse	Slight	Slight
Hybrid 11.6	Amelonado	Obtuse	Slight	Slight
Hybrid 12.5	Cundeamor	Obtuse	Strong	Slight
Hybrid 12.6	Amelonado	Acute	Slight	Slight
Hybrid 13.5	Angoleta	Acute	Slight	Intense
Hybrid 13.7	Amelonado	Acute	Slight	Slight
Hybrid 14.6	Angoleta	Obtuse	Absent	Slight
Hybrid 15.6	Angoleta	Acute	Absent	Absent
Hybrid 15.7	Angoleta	Obtuse	Slight	Slight
Hybrid 16.4	Amelonado	Acute	Slight	Slight
Hybrid 16.5	Amelonado	Obtuse	Slight	Slight
Hybrid 16.7	Angoleta	Acute	Slight	Slight
Hybrid 16.8	Amelonado	Obtuse	Slight	Slight
Hybrid 17.4	Amelonado	Mammelate	Slight	Slight
Hybrid 17.6	Cundeamor	Obtuse	Slight	Slight
Hybrid 28.5	Cundeamor	Obtuse	Slight	Slight
Hybrid 28.6	Cundeamor	Obtuse	Slight	Slight
Hybrid 28.10	Cundeamor	Acute	Slight	Slight
Hybrid 29.4	Cundeamor	Attenuate	Absent	Slight
Hybrid 31.6	Angoleta	Acute	Slight	Slight
Parents				
PII 12.11	Amelonado	Obtuse	Slight	Slight
SIV 1.26	Calabacillo	Attenuate	Slight	Slight
SIV5.20	Amelonado	Acute	Slight	Absent
SIV 6.18	Amelonado	Acute	Slight	Slight
TISSA	Amelonado	Acute	Slight	Absent

The pod shape and rugosity of hybrids and their parents are presented in Table 5. The features of different types of pods (Plate 6) have already been described by Wood and Lass (1955). According to them cundeamor types are characterized by the presence of pods which are deeply ridged and warty as well as having bottle neck. Pods are square shaped at the stalk end and devoid of bottleneck in angoleta type. Smooth melon shaped pods with blunt end; shallow furrows and slight bottle neck are the features of amelonado type. Calabacillo types are small, nearly spherical in shape with a point at its apex. Among the five parental types S IV 1.26 alone was having calabacillo type pods. All the others were producing amelonado type pods. However, in the hybrid progenies cundeamor, amelonado and angoleta types were noticed.

The pod apex was acute in parental genotypes S IV 5.20, S IV 6.18 and TISSA where as it was obtuse in P II 12.11 and attenuate in S IV 1.26. Among the hybrid progenies acute, obtuse, attenuate and mammelate types could be observed (Plate 7). All the four types were present even among the progenies from the same cross. The hybrid 17.4 alone was having mammelate type pods.

All the parental genotypes were having slight basal constriction (Plate 8) for the pods. However, even types devoid of basal constriction were present in the hybrid progenies. Basal constriction was absent in hybrids 14.6 and 15.6 from the cross S IV 1.26 X P II 12.11 as well as hybrid 29.4 from the cross S IV 5.20 X TISSA. The hybrid 12.5 was having strong basal constriction. Intermediate basal constriction was present in hybrid 9.8. Pod surface was smooth (rugosity absent) in parental types S IV 5.20 and TISSA. However, slight rugosity was present in P II 12.11, S IV 1.26 and TISSA. Rugosity was intense in the hybrid 13.5 and absent in 15.6 (Table 5). The remaining 23 hybrids exhibited slight rugosity (Plate 9).

The husk hardiness of the pod is indicated by the difference between ridge thickness and furrow thickness. The difference was observed to be less than one cm

Cundeamor

Angoleta

Amelonado

Calabacillo

Criollo

Plate 6. Descriptor states for pod shape

Attenuate

Acute

Obtuse

Rounded

Mammelate

Plate 7. Descriptor states for pod apex


Absent


Slight


Intermediate


Strong

Plate 8. Descriptor states for pod basal constriction

Absent

Slight

Intermediate

Strong

Plate 9. Descriptor states for pod rugosity

in all the hybrid progenies as well as the parental types. Hence, all of them can be classified as soft husked.

4.1.1.1 Clustering based on qualitative characters

Agglomerative hierarchical clustering was performed based on the Jaccard's similarity coefficient using UPGMA method considering eight qualitative characters and the dendrogram was constructed.

The 25 hybrids and the 5 parents used in the present study could be grouped into 16 clusters at 70% similarity level (Fig. 1). The 16 clusters obtained and the accessions included in each cluster are presented in Table 6.

The cluster V was the biggest one with 8 accessions. It can be seen that the hybrids 10.6, 11.6, 15.7, 16.5 and 16.8 along with their pollen parent, P II 12.11, belonged to the same cluster showing that these hybrids are similar to one another and also to their pollen parent with respect to qualitative characters. From the dendrogram (Fig.1) it can be seen that hybrids 15.7 and 16.8 with the same parental combination, S IV 1.26 X P II 12.11, were exactly identical at qualitative level. Similar was the case with hybrids 9.8 and 16.4 from the same parental combination.

Clusters I, II, IV, VI, VII, IX, XI, XII, XIII, XV and XVI included single accession each. The parental types P II 12.11, S IV 1.26 and TISSA could be considered as distinct at qualitative level as they fell into different clusters. S IV 5.20 and S IV 6.18 falling in the same cluster were found to be qualitatively similar. The cluster diagram also revealed that hybrids 7.8, 12.5, 13.5, 17.4 and 17.6 derived from the cross S IV 1.26 X P II 12.11were distinct at qualitative level. Similar is the case with hybrids 28.5, 28.10 and 29.4 from the cross S IV 5.20 and TISSA.

Fig.1. Dendrogram based on similarity coefficient among cocoa hybrids and parents

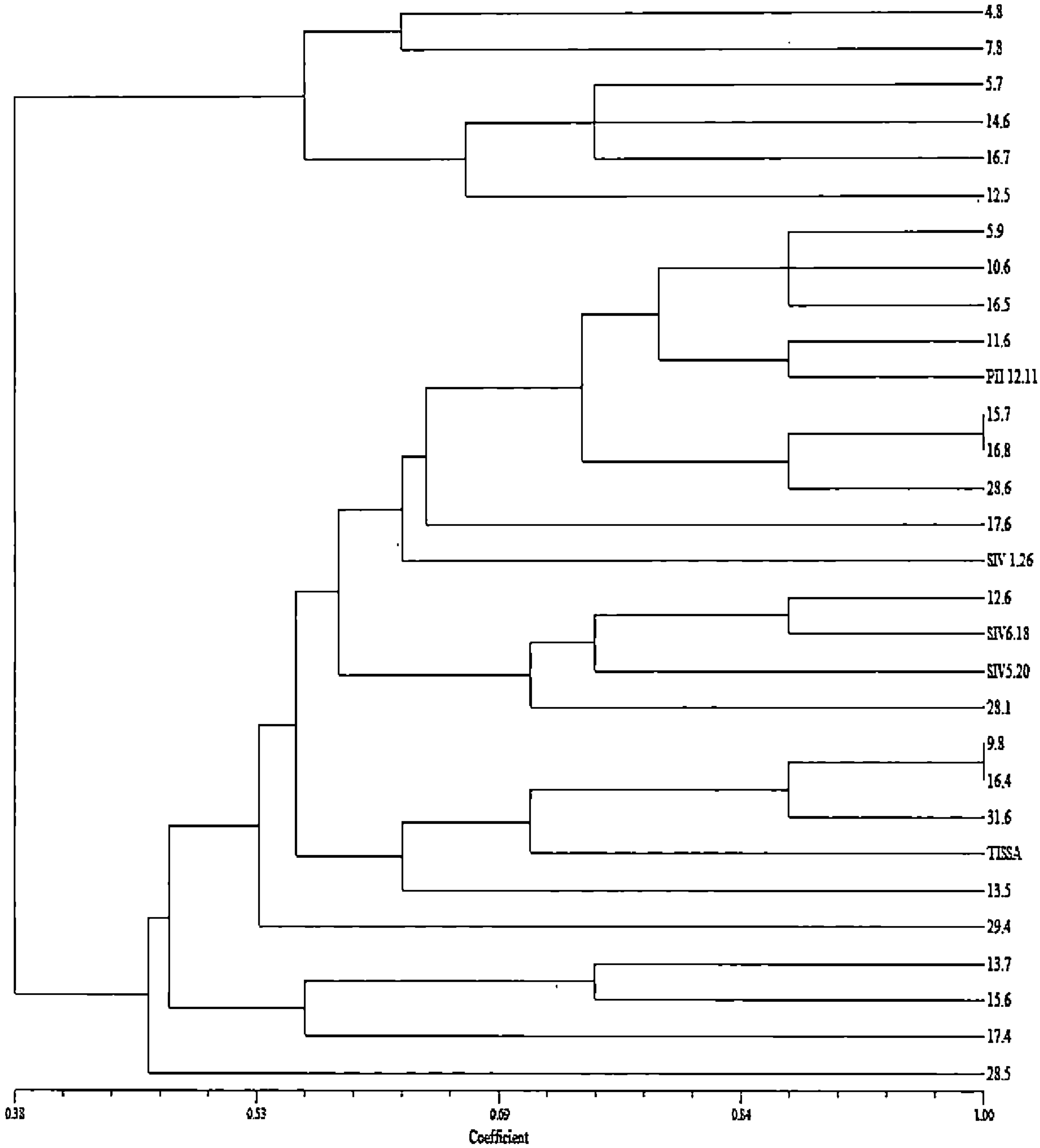

Table 6. Clustering of cocoa hybrids and parents based on qualitative characters

Cluster No.	No. of accessions	Name of accession
I	1	Hybrid 4.8
II	1	Hybrid 7.8
III	3	Hybrid 5.7, Hybrid 14.6, Hybrid 16.7
IV	1	Hybrid 12.5
V	8	Hybrid 5.9, Hybrid 10.6, Hybrid 16.5, Hybrid 11.6 Hybrid 15.7, Hybrid 16.8, Hybrid 28.6, P II 12.11
VI	1	Hybrid 17.6
VII	1	SIV 1.26
VIII	3	SIV5.20, SIV 6.18, Hybrid 12.6
IX	1	Hybrid 28.10
X	3	Hybrid 31.6, Hybrid16.4, Hybrid 9.8
XI	1	TISSA
XII	1	Hybrid 13.5
XIII	1	Hybrid 29.4
XIV	2	Hybrid 15.6, Hybrid 13.7
XV	1	Hybrid 17.4
XVI	1	Hybrid 28.5

4.1.2 Quantitative evaluation

Analysis of variance was done for each of the 14 quantitative characters observed in the hybrids and their parents. Since significant difference was observed between hybrids and parents for all the characters studied, further analysis was carried out separately for hybrids and parents.

The mean values for pod and bean quantitative characters of hybrids as well as parents are presented in Tables 7a, 7b, 8a, and 8b respectively. Variations expressed by the hybrids in terms of pod and bean quantitative traits were very high. This reflects the heterogeneity expected among the hybrids evaluated. Parental genotypes also exhibited significant differences for all the quantitative traits observed.

Among the hybrids, hybrid 13.7 recorded the highest pod weight (700g) and pod breadth (9.50cm). It was also having the third highest value for ridge thickness (1.35cm) and second highest value (1.15cm) for furrow thickness (Table 7a). Its wet bean weight accounted for 26 percent of the pod weight. The pod weight and wet bean weight/pod were the lowest in hybrid 7.8, 112.50g and 28.38g respectively. Here, the wet bean/pod content was 20.78 percent of the pod weight. The hybrid 29.4, with the lowest pod breadth (5.34cm), ridge thickness (0.34) and furrow thickness (0.19) recorded the highest wet bean content of 45.08 percent. This was followed by hybrid 28.10 and hybrid 12.5 with a wet bean contents, 39.43 percent and 38.37 percent respectively. These results indicated the significant role played by the husk in deciding pod weight. Pound (1932) as well as Enriquez and Soria (1966) had reported that yield expressed as wet or dry weight of beans is a highly variable character. However, the thickness of ridges and furrows in the pods are descriptive traits.

The TSS was the highest in hybrid 4.8 and the lowest in hybrid 7.8. Among the parents the lowest TSS was observed in the case of S IV 5.20 (17.50%).

Among the parents the highest pod weight was observed in P II 12.11 (481.17g) and the lowest in S IV 6.18 (256.00g). The wet bean content was the highest in S IV 5.20 (33.61%) and the lowest in TISSA (24.04%) (Table 7b).

The various bean characters *viz.*, wet weight of unpeeled and peeled beans, dry weight of peeled bean, breadth and thickness of peeled beans showed significant differences among the hybrids. The mean values for these characters in hybrids depicted in Table 8a.

The wet weight of unpeeled bean was the highest in hybrid 13.7 (4.60g) and the lowest in hybrid 7.8 (1.14g). The highest wet weight of peeled bean, 1.78g was exhibited by hybrids 12.5 and 12.6. They were followed by hybrids 13.7 and 16.5 which were on par statistically. The dry weight of peeled bean also varied significantly among the hybrids, with hybrid 12.6 exhibiting the highest value of 1.31g. The lowest value for dry weight of peeled bean was observed in hybrid 17.4 (0.22g). According to the international standards the dry weight of peeled bean must be 0.8g or more (Wood and Lass, 1985). Among the 25 hybrids evaluated, ten failed to satisfy the international standards.

The flat beans in cocoa are considered to be developing from unfertilized ovules. The presence of flat beans is an undesirable character in cocoa and hence, the crop improvement programmes in cocoa aims at reducing the flat bean content of the pods. The flat bean content was the highest in hybrid 28.10 (18.53%) followed by hybrid 4.8 (6.52%). The flat beans were absent in hybrid 13.5 (Table 8a).

The length of peeled bean was the highest in hybrid 16.8 (17.78mm). The breadth of peeled bean was the highest in hybrid 14.6 (10.81mm) and the thickness in hybrid 12.6. (4.98mm). Table 8b depicts the bean characters of parental lines.

Table 7a. Mean values for pod characters of cocoa hybrids

Hybrids	Pod length (cm)	Pod breadth (cm)	Pod weight (g)	Ridge thickness (cm)	Furrow thickness (cm)	Wet bean weight/Pod (g)	Wet bean content/Pod (%)	TSS (%)
Hybrid 4.8	10.90	6.30	200.00	0.60	0.50	67.50	33.75	28.00
Hybrid 5.7	12.15	7.07	255.71	0.88	0.72	73.75	28.84	18.28
Hybrid 5.9	11.16	6.00	155.62	0.59	0.41	50.75	32.61	23.62
Hybrid 7.8	11.01	5.60	112.50	0.68	0.39	28.38	20.78	10.87
Hybrid 9.8	14.82	8.10	453.33	1.27	1.04	102.72	22.66	18.76
Hybrid 10.6	14.67	7.58	343.63	1.07	0.89	97.95	28.50	22.80
Hybrid 11.6	13.95	8.12	330.00	0.88	0.65	101.85	30.86	25.75
Hybrid 12.5	12.62	6.92	222.50	0.75	0.45	85.37	38.37	25.00
Hybrid 12.6	13.81	7.78	402.12	1.31	1.08	106.64	26.52	19.31
Hybrid 13.5	17.00	8.20	500.00	1.60	1.10	123.80	24.76	22.00
Hybrid 13.7	14.20	9.50	700.00	1.35	1.15	182.00	26.00	13.50
Hybrid 14.6	11.80	7.73	323.33	0.87	0.66	110.50	34.18	20.33
Hybrid 15.6	12.42	6.94	275.88	0.91	0.71	76.68	27.79	16.70
Hybrid 15.7	12.97	7.99	386.84	1.23	0.99	102.60	26.52	19.19
Hybrid 16.4	12.46	7.08	273.33	0.93	0.68	78.65	28.77	21.53
Hybrid 16.5	13.18	7.86	387.00	1.26	1.02	105.55	27.27	21.00
Hybrid 16.7	13.50	7.59	306.66	1.07	0.81	85.94	28.02	21.53
Hybrid 16.8	14.00	9.00	460.00	1.40	1.30	86.60	18.82	19.00
Hybrid 17.4	11.50	5.85	190.00	0.95	0.65	54.85	28.86	12.50
Hybrid 17.6	11.36	6.23	195.00	0.90	0.70	59.75	30.64	25.08
Hybrid 28.5	10.73	6.22	181.50	0.65	0.47	68.30	37.63	23.95
Hybrid 28.6	11.93	6.86	240.00	0.75	0.58	86.74	36.14	25.50
Hybrid 28.10	12.36	6.42	200.00	0.66	0.44	78.86	39.43	20.80
Hybrid 29.4	11.65	5.34	120.00	0.34	0.19	54.10	45.08	22.40
Hybrid 31.6	14.97	7.50	340.00	1.19	0.93	86.39	25.41	20.95
C. D (0.05)	0.83	0.49	55.64	0.11	0.10	16.28	-	2.34
C. V (%)	11.78	12.53	33.21	20.83	25.99	34.06	-	18.98

Table 7b. Mean values for pod characters of parents

Parents	Pod length (cm)	Pod breadth (cm)	Pod weight (g)	Ridge thickness (cm)	Furrow thickness (cm)	Wet bean weight/pod (g)	Wet bean content/Pod (%)	TSS (%)
P II 12.11	15.61	8.30	481.17	1.28	1.11	135.41	28.14	19.82
S IV 1.26	13.05	8.00	430.00	1.20	1.00	123.50	28.72	19.50
S IV 5.20	15.80	8.25	440.00	1.05	0.85	147.90	33.61	17.50
S IV 6.18	12.46	6.69	256.00	0.78	0.60	80.29	31.36	20.20
TISSA	15.00	8.46	352.00	1.24	1.00	84.62	24.04	23.60
C D (0.05)	1.34	0.88	109.9	0.21	0.182	29.5	-	3.63
C.V (%)	10.12	12.08	30.38	20.54	21.70	27.95	-	19.56

36

It can be seen that all the parental types are meeting the international standard for dry weight of peeled bean. The flat beans content was the highest in S IV 1.26 (6.10%). The length and breadth of beans were the highest in P II 12.11, 18.19mm and 11.22mm respectively. The thickness of bean was the highest in S IV 5.20 (3.99mm).

The peeling ratio, dry matter recovery in peeled beans and Pod Index (PI) values in hybrids and parents are presented in Table 9. The peeling ratio expressed in percent, was the highest in hybrid 12.5 (82.4%) and the lowest in hybrid 17.4 (27.1%). The hybrid 29.4 also exhibited a high peeling ratio (75.60%). This indicated that the peel portion (testa) was thick in hybrid 17.4 and thin in hybrids 12.5 and 29.4. The dry matter recovery for peeled bean was the highest in hybrid 7.8 (97%) indicating the low water content in its beans. The lowest dry matter recovery for peeled bean was observed in hybrid 29.4 (47.7%) pointing to the fact that a major part of the bean weight is contributed by its water content.

From the Table 9 it can also be seen that the PI value ranged from 21 in hybrid 13.7 to 121 in hybrid 7.8. The PI value indicates the number of pods required to produce 1kg of dry cocoa without testa (peeled bean) (Maharaj *et al.*, 2011). The low PI values are associated with high yield potential.

Among the hybrids evaluated, hybrid 13.7 can be considered as a desirable one with low PI value, broad pods, high pod weight with wet bean content accounting 26 per cent of pod weight as well as high wet weight and dry weight of peeled bean meeting international standards. The hybrid 12.6 with PI value 24 and having the highest wet weight and dry weight of peeled bean as well as peeled bean thickness can also be considered as a desirable hybrid. High wet weight, dry weight and thickness of peeled bean coupled with low PI make hybrid 16.5 also desirable. Hybrids 12.5 and 16.4, though having comparatively higher PI values, possess superior bean characters.

Table 8a. Mean values for bean characters of cocoa hybrids

Hybrids	Wet weight of unpeeled bean (g)	Weight of peeled bean(g)		No. of beans/pod	Flat beans/pod (%)	Peeled bean(mm)		
		Wet	Dry			Length	Breadth	Thickness
Hybrid 4.8	1.71	0.88	0.67	43.00	6.52	14.99	7.95	2.36
Hybrid 5.7	2.48	1.09	0.66	42.10	2.97	15.26	8.20	2.29
Hybrid 5.9	1.54	1.05	0.60	40.62	4.83	14.75	7.95	1.99
Hybrid 7.8	1.14	0.34	0.33	32.63	5.78	09.59	3.98	2.12
Hybrid 9.8	2.61	1.21	0.84	41.90	3.70	15.70	8.41	3.29
Hybrid 10.6	2.98	1.42	1.09	43.63	0.62	17.38	10.28	3.25
Hybrid 11.6	2.58	1.48	0.93	39.25	0.63	17.68	9.46	3.13
Hybrid 12.5	2.16	1.78	0.86	37.75	1.31	14.78	9.57	3.22
Hybrid 12.6	3.36	1.78	1.31	35.00	5.74	17.17	10.27	4.98
Hybrid 13.5	2.93	1.42	1.04	43.00	0.00	17.05	9.32	3.33
Hybrid 13.7	4.60	1.61	1.18	42.00	1.18	16.12	10.01	4.68
Hybrid 14.6	3.56	1.48	1.16	29.60	3.27	16.51	10.81	4.36
Hybrid 15.6	1.62	1.08	0.64	47.00	0.61	13.68	7.71	2.69
Hybrid 15.7	2.64	1.39	1.00	36.26	5.87	16.34	8.57	4.53
Hybrid 16.4	3.01	1.56	1.13	34.06	6.07	15.62	9.24	3.96
Hybrid 16.5	3.00	1.63	1.13	35.00	2.78	17.08	9.79	4.42
Hybrid 16.7	2.94	1.44	0.93	38.80	0.84	15.58	8.04	3.70
Hybrid 16.8	2.29	1.28	0.93	39.00	4.88	17.78	9.83	2.83
Hybrid 17.4	1.44	0.39	0.22	37.00	3.90	08.20	3.94	1.46
Hybrid 17.6	1.76	1.19	0.58	37.91	1.51	13.52	7.55	2.43
Hybrid 28.5	1.72	1.19	0.72	43.65	1.24	16.16	8.40	2.51
Hybrid 28.6	2.37	1.24	0.90	45.08	0.73	17.42	9.94	2.75
Hybrid 28.10	2.72	1.23	0.93	46.60	18.53	17.03	9.71	2.77
Hybrid 29.4	1.44	1.09	0.52	41.00	1.20	15.78	8.89	1.16
Hybrid 31.6	1.99	1.01	0.74	43.54	1.40	14.81	7.51	2.52
C. D (0.05)	0.21	0.13	0.02	3.04	-	0.18	0.11	0.03
C. V (%)	17.00	18.40	25.70	13.80	-	17.16	18.80	31.81

38

Table 8b. Mean values for bean characters of parents

Parents	Wet weight of unpeeled bean (g)	Weight of peeled bean (g)		No. of beans/pod	Flat beans/pod (%)	Peeled bean (mm)		
		Wet	Dry			Length	Breadth	Thickness
P II 12.11	3.20	1.73	1.28	42.94	1.20	18.19	11.22	3.94
S IV 1.26	3.41	1.54	1.18	38.50	6.10	18.17	10.15	3.70
S IV5.20	3.33	1.54	1.09	45.50	4.21	16.32	9.97	3.99
S IV 6.18	2.50	1.46	0.90	37.90	3.32	16.29	8.96	2.87
TISSA	1.94	1.13	0.87	44.20	1.78	15.9	8.94	2.73
CD	0.19	0.11	0.01	6.56	-	0.14	0.08	0.06
CV (%)	20.10	18.90	19.70	16.99	-	12.13	11.42	25.74

39

Table 9. The peeling ratio, dry matter recovery and PI value of hybrids and parents

Hybrid/Parents	Peeling ratio (%)	Dry matter recovery (%)	PI value	Yield(No of pods/plant/year)
Hybrid 4.8	51.40	76.13	38.00	11
Hybrid 5.7	44.00	60.50	51.00	17
Hybrid 5.9	68.10	57.10	51.00	11
Hybrid 7.8	29.80	97.00	121.00	18
Hybrid 9.8	46.30	69.40	31.00	21
Hybrid 10.6	47.60	76.70	28.00	31
Hybrid 11.6	57.40	62.80	27.00	14
Hybrid 12.5	82.40	48.30	29.00	22
Hybrid 12.6	52.90	73.50	24.00	30
Hybrid 13.5	48.50	73.20	23.00	27
Hybrid 13.7	35.00	73.30	21.00	37
Hybrid 14.6	41.60	78.30	28.00	26
Hybrid 15.6	66.60	59.20	33.00	22
Hybrid 15.7	52.70	71.90	26.00	34
Hybrid 16.4	51.80	72.40	34.00	25
Hybrid 16.5	54.30	69.30	25.00	20
Hybrid 16.7	48.90	64.50	37.00	13
Hybrid 16.8	55.90	72.60	28.00	11
Hybrid 17.4	27.10	56.40	119.0	13
Hybrid 17.6	67.60	48.70	51.00	12
Hybrid 28.5	69.10	60.50	35.00	26
Hybrid 28.6	52.30	72.50	30.00	14
Hybrid 28.10	45.20	75.60	37.00	15
Hybrid 29.4	75.60	47.70	51.00	20
Hybrid 31.6	50.70	73.20	31.00	12
P II 12.11	54.10	73.90	18.00	27
S IV 1.26	45.16	76.60	23.00	12
S IV 5.20	46.25	70.70	21.00	12
S IV 6.18	58.40	61.60	35.00	20
TISSA	58.20	76.90	26.00	15

The PI values of parents ranged from 18 in P II 12.11 to 35 in TISSA. For breeding purpose a PI value of less than 15 is considered as desirable (Pound, 1932).

4.1.2.1 Clustering based on quantitative characters

Cluster analysis was done based on Jaccard's similarity coefficient using UPGMA method with the quantitative data and the resulting dendrogram is presented in (Fig.2). Majority of the accessions remained ungrouped even at 5 per cent level indicating that they are highly variable with respect to quantitative traits. The accessions which were found identical in the dendrogram are presented in Table 10. The hybrids 4.8 and 5.7 from the cross of S IV 1.26 and TISSA were identical. Among the progenies of the cross S IV 1.26 and P II 12.11, hybrids10.6 and 13.5, hybrid 12.6 and 16.5, Hybrids 12.5, 13.7 and 29.4, Hybrids 16.4 and 16.7, Hybrids 11.6 and17.4, as well as Hybrids 7.8 and16.8 were found to be exactly identical. The parental lines S IV 1.26, one of the parents of Hybrids 12.5 and 13.7 as well as TISSA one of the parents of Hybrid 29.4 were identical in quantitative clustering. This may be the reason for the quantitative level similarity of Hybrids 12.5 and 13.7 as well as Hybrid 29.4.

4.1.2.2 Descriptive statistics

The descriptive statistics *viz.*, range, mean, standard deviation (SD), standard error (SE), phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), broad sense heritability (H^2) and genetic gain (GG) for the 14 quantitative characters in the hybrids and parental lines are presented in Tables 11a and 11b.

Among the pod and bean characters of hybrids, wet weight of peeled bean exhibited maximum variability (Table11a) as indicated by its high PCV (570.40%) and GCV (510.00%). The high amount of variability coupled with high heritability for wet weight of peeled bean indicates the scope for selection based on this character. From the Table 11a, it can also be seen that selection based on this character can bring about more than 1000 per cent improvement in the population. Number of flat beans/pod also showed high variability as indicated by its high PCV (245.02%) and GCV (127.07). However, this character exhibited only low heritability as per the classification proposed by Johnson *et al* (1955).

Fig.2. Dendrogram based on similarity coefficient among cocoa hybrids and parents

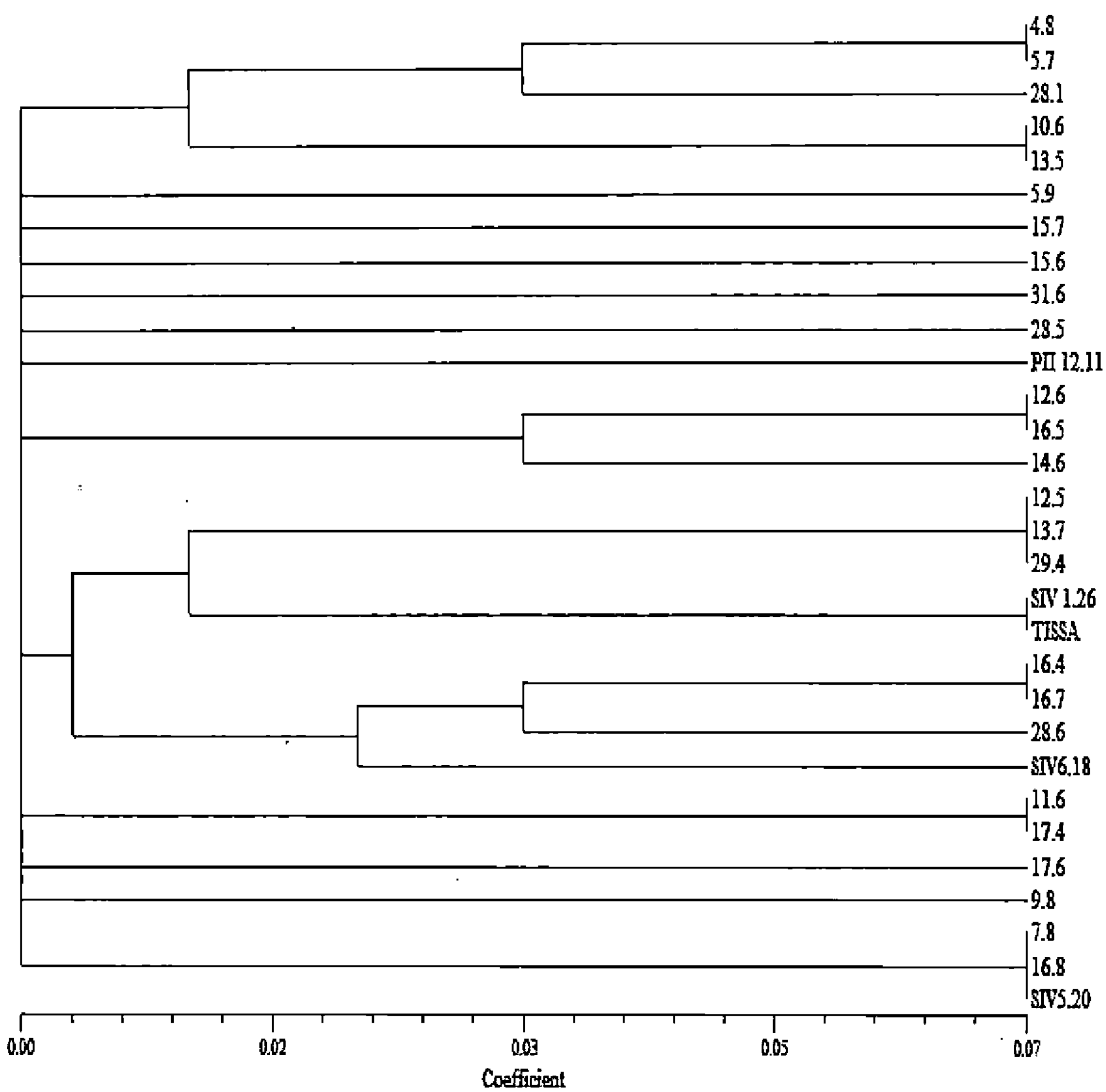

Table 10. Accessions found identical in quantitative clustering

Sl. No.	Accessions
1	Hybrid 4.8, Hybrid 5.7
2	Hybrid 10.6, Hybrid 13.5
3	Hybrid 12.6, Hybrid 16.5
4	Hybrid 12.5, Hybrid 13.7, Hybrid 29.4
5	SIV 1.26, TISSA
6	Hybrid 16.4, Hybrid 16.7
7	Hybrid 11.6, Hybrid 17.4
8	Hybrid 7.8, Hybrid 16.8, SIV5.20

Among the pod and bean characters studied in hybrids, pod weight, ridge thickness, furrow thickness and wet weight of peeled bean were having high heritability. Medium heritability was observed for all the other characters evaluated, except number of flat beans/pod. High genetic gain as per the classification of Johnson *et al.*, 1955 was observed in all the characters of hybrids except number of beans/pod and length of peeled bean.

In the case of parental types also wet weight of peeled bean exhibited the highest values for PCV (317.49%) and GCV (306.37%) (Table 11b).This was followed by number of flat beans/pod with a PCV of 130.75% and GCV of 65.21%. High genetic gain (606.70%) along with high heritability (93%) as well as high PCV and GCV for wet weight of peeled bean points to the scope for selection based on this character.

Table 11a. Descriptive statistics of cocoa hybrids

Character	Range		Mean	SD	SE	PCV	GCV	H^2	GG
	Minimum	Maximum				(%)	(%)	(%)	(%)
Pod weight (g)	112.5	700.00	297.02	172.02	23.65	57.91	47.03	65.95	73.08
Ridge thickness (cm)	0.34	1.60	0.97	0.41	0.04	42.45	37.22	76.87	65.97
Furrow thickness (cm)	0.19	1.30	0.75	0.38	0.04	50.90	44.13	75.16	78.66
Pod length (cm)	10.73	17.00	12.88	2.38	0.35	18.54	14.33	59.74	22.67
Pod breadth (cm)	5.34	9.50	7.15	1.41	0.21	19.85	15.33	59.70	24.10
No of beans /pod	29.6	47.00	40.14	7.58	1.29	18.89	13.03	47.54	18.48
No of flat beans/pod	0	2.26	1.33	3.26	0.65	245.02	127.07	26.89	135.30
Weight of beans/pod (g)	54.10	182	83.61	39.87	6.92	47.68	32.23	45.70	44.88
Wet weight of peeled bean (g)	0.34	1.78	1.25	7.13	0.07	570.40	570.00	99.00	1163.20
Dry wt. of peeled bean (g)	0.33	1.18	0.91	0.42	0.01	45.91	32.65	50.56	30.76
Length of peeled bean (mm)	8.20	17.68	15.94	3.37	0.09	21.19	13.19	38.76	16.88
Breadth of peeled bean (mm)	7.51	10.28	8.91	2.27	0.05	25.52	17.87	49.03	25.70
Thickness of peeled bean (mm)	1.16	4.90	3.51	1.62	0.03	46.28	32.97	50.95	48.43
TSS (%)	10.87	25.95	20.89	5.79	0.99	27.72	18.99	46.90	26.75

*PCV & GCV (Sivasubramanian & Madhavamenon, 1973) - Low: Less than 10%, Moderate: 10-20%, High: More than 20%

*H^2 (Johnson *et al.*, 1955) - Low: Less than 30%, Moderate: 30-60%, High: More than 60%

*GG (Johnson *et al.*, 1955) - Low: Less than 10%, Moderate: 10-20%, High: More than 20%

44

Table 11b. Descriptive statistics of parents

Character	Range		Mean	SD	SE	PCV (%)	GCV (%)	H^2 (%)	GG (%)
	Minimum	Maximum							
Pod weight (g)	256.00	481.17	395.55	177.70	42.08	44.92	33.35	55.12	51.01
Ridge thickness (cm)	0.78	1.28	1.11	0.37	0.08	34.01	27.24	64.13	45.22
Furrow thickness (cm)	0.60	1.11	0.93	0.36	0.06	39.39	33.23	71.15	57.84
Pod length (cm)	12.46	15.80	14.51	2.46	0.51	16.95	13.65	64.90	22.67
Pod breadth (cm)	6.69	8.46	7.85	1.37	0.33	17.48	12.50	51.16	18.34
No of beans /pod	37.90	45.50	41.61	7.31	2.51	17.57	4.21	57.40	20.76
No of flat beans/pod	0.52	2.50	0.97	1.26	0.38	130.75	65.21	24.87	67.00
Weight of beans/pod (g)	80.29	147.90	113.08	48.85	11.30	43.20	32.67	57.18	50.86
Wet wt. of peeled bean (g)	1.13	1.73	1.48	4.69	0.87	317.49	306.37	93.00	606.70
Dry wt. of peeled bean (g)	0.87	1.20	1.09	0.28	0.01	26.99	19.41	51.72	28.35
Length of peeled bean (mm)	15.9	18.19	17.15	2.37	0.07	13.87	6.96	25.19	7.23
Breadth of peeled bean (mm)	8.93	11.21	10.07	1.68	0.03	16.69	12.42	55.38	19.10
Thickness of peeled bean (mm)	2.73	3.94	3.49	1.10	0.03	31.77	19.42	37.34	24.46
TSS (%)	17.50	23.60	20.30	4.03	1.39	19.89	4.50	51.20	20.99

45

High heritability was also noticed for characters ridge thickness (64.13%), furrow thickness (71.15%) and pod length (64.90%).

High PCV and GCV for flat beans /pod was also observed by Asna, (2013). Unlike in the present study, she has reported high heritability for flat beans/pod. Based on a study on the inheritance of pod size, Soria *et al.* (1974) reported that the heritability for pod length was 55%.

4.1.3 Threshold bean size

The analysis of bean characters based on year round observations revealed that the major factors contributing significantly to boldness of beans were bean weight, bean breadth and bean thickness which were showing high seasonal variability . The subsets obtained in the post hoc test, DMRT, for the hybrids and parents for weight, breadth and thickness of beans are presented in Table 12.

Confirming to the international standards a descriptor for assessing the performance of cocoa types was developed (Fig.3) based on the parameters weight, breadth and thickness of beans which are the three major characters decisive of the boldness of beans.

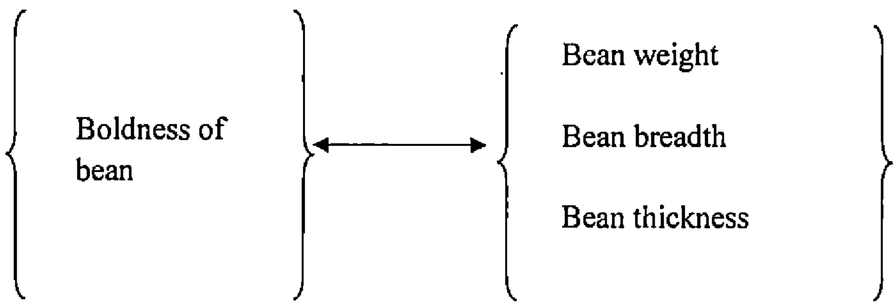

Fig.3. Descriptor for bean size

Inclusive scales for this descriptor were prescribed based on the values of superior subsets for weight, breadth and thickness of beans and are presented below.

1.16g - 1.31g

10.29mm - 11.22mm

4.35mm - 4.98mm

Thus, the threshold bean size can be considered as one where the bean weight, bean breadth or bean thickness fall within the range of the scales prescribed for each.

Among the twenty five hybrids investigated three hybrids, hybrids 12.6, 13.7 and 14.6 can be categorized as having threshold bean size (Table12a.). Among the parents P II 12.11 and S IV 1.26 were also falling in this category (Table12b). Hybrids with maximum bean size in the present study came from the crosses involving S IV 1.26 and P II 12.11.

4.2 Biochemical evaluation

The biochemical evaluation of the hybrids and parents were based on fat and polyphenol contents and the results are presented in Table 13.

4.2.1 Fat content

The fat content in the hybrids ranged from 33.3% in hybrid 7.8 to 58.5% in hybrid 10.6 (Table 13). Hybrid 7.8 was closely followed by hybrid 14.6 with a fat content of 57.3%. Among the parents TISSA was having the highest fat content (52.7%).The distribution of fat content in hybrids and parents is shown in Fig.4.

High fat content in the beans is an important factor contributing to the characteristic flavors and aroma of chocolate (Mossu, 1992).

Table 12a. Descriptive statistics of boldness of beans of hybrids

Sl. No.	Parentage	Hybrid name	Bean weight (g)	Bean breadth (mm)	Bean thickness (mm)
1	S IV 1.26 X P II 12.11	Hybrid 12.6	1.31^{a}	10.29^{bc}	4.98^{a}
2	S IV 1.26 X P II 12.11	Hybrid 13.7	1.18^{abc}	10.01^{cd}	4.68^{ab}
3	S IV 1.26 X P II 12.11	Hybrid 14.6	1.16^{bc}	10.81^{ab}	4.35^{bc}
4	S IV 1.26 X P II 12.11	Hybrid 10.6	1.09^{cd}	10.28^{bc}	3.24^{cd}
5	S IV 1.26 X P II 12.11	Hybrid 16.5	1.13^{cd}	9.79^{cd}	4.41^{bc}
6	S IV 1.26 X P II 12.11	Hybrid 16.4	1.13^{cd}	9.24^{defgh}	3.96^{cd}
7	S IV 1.26 X P II 12.11	Hybrid 13.5	1.04^{cde}	9.32^{defg}	3.32^{ef}
8	S IV 1.26 X P II 12.11	Hybrid 15.7	1.00^{def}	8.57^{ghij}	4.53^{bc}
9	S IV 5.20 X TISSA	Hybrid 28.6	0.90^{efg}	9.94^{cd}	2.74^{hijk}
10	S IV 1.26 X P II 12.11	Hybrid 16.8	0.93^{efg}	9.83^{cd}	2.83^{fghij}
11	S IV 5.20 X TISSA	Hybrid 28.10	0.93^{efg}	9.71^{cde}	2.77^{ghijk}
12	S IV 1.26 X P II 12.11	Hybrid 11.6	0.94^{efg}	9.46^{cdef}	3.12^{fghi}
13	S IV 1.26 X P II 12.11	Hybrid 16.7	0.93^{efg}	8.04^{jkl}	3.69^{de}
14	S IV 1.26 X P II 12.11	Hybrid 12.5	0.86^{fgh}	9.57^{cdef}	3.22^{efgh}
15	S IV 1.26 X P II 12.11	Hybrid 9.8	0.84^{ghi}	8.41^{ijk}	3.28^{efg}
16	S IV 6.18 X P II 12.11	Hybrid 31.6	0.74^{hij}	7.51^{l}	2.51^{jk}
17	S IV 5.20 X TISSA	Hybrid 28.5	0.72^{ijk}	8.48^{hijk}	2.50^{jk}
18	S IV 1.26 X TISSA	Hybrid 4.8	0.67^{jk}	7.95^{jkl}	2.36^{jkl}
19	S IV 1.26 X P II 12.11	Hybrid 15.6	0.64^{jkl}	7.71^{kl}	2.69^{ijk}
20	S IV 1.26 X TISSA	Hybrid 5.7	0.66^{jkl}	8.20^{ijkl}	2.28^{kl}
21	S IV 1.26 X TISSA	Hybrid 5.9	0.60^{jkl}	7.95^{jkl}	1.99^{l}
22	S IV 1.26 X P II 12.11	Hybrid 17.6	0.58^{kl}	7.55^{l}	2.42^{jkl}
23	S IV 5.20 X TISSA	Hybrid 29.4	0.52^{l}	8.89^{fghi}	1.16^{m}
24	S IV 1.26 X P II 12.11	Hybrid 7.8	0.34^{m}	3.98^{m}	2.12^{k}
25	S IV 1.26 X P II 12.11	Hybrid 17.4	0.22^{m}	3.94^{m}	1.46^{l}

Table 12b. Descriptive statistics of boldness of beans of parents

Sl. No.	Parents	Bean weight (g)	Bean breadth (mm)	Bean thickness (mm)
1	PII 12.11	1.28^{ab}	11.22^{a}	3.94^{bcde}
2	SIV 1.26	1.18^{abc}	10.15^{bc}	3.70^{bcdef}
3	SIV5.20	1.09^{cd}	9.97^{cd}	3.99^{bcde}
4	SIV 6.18	0.91^{efg}	8.96^{efghi}	2.87^{bcdef}
5	TISSA	0.87^{fgh}	8.94^{efghi}	2.73^{bcdef}

Table 13. Fat and polyphenol contents in hybrids and parents

Sl. No.	Hybrid	Fat content (%)	Polyphenol content (%)
1	4.8	45.30	4.22
2	5.7	43.30	5.64
3	5.9	49.30	2.70
4	7.8	33.30	3.75
5	9.8	51.50	3.34
6	10.6	58.50	2.77
7	11.6	50.60	3.36
8	12.5	43.00	5.09
9	12.6	51.80	3.24
10	13.5	54.60	4.03
11	13.7	40.60	4.09
12	14.6	57.30	4.13
13	15.6	52.50	4.02
14	15.7	48.30	3.40
15	16.4	50.50	3.31
16	16.5	56.80	2.86
17	16.7	45.70	4.07
18	16.8	45.60	1.51
19	17.4	33.30	3.51
20	17.6	48.60	2.77
21	28.5	47.60	4.12
22	28.6	46.30	3.14
23	28.10	43.10	2.44
24	29.4	34.00	2.68
25	31.6	53.00	4.54
CD		2.82	2.38
CV		12.41	2.69
Parents			
1	PII12.11	42.28	5.97
2	SIV 1.26	38.51	5.16
3	SIV5.20	42.36	6.10
4	SIV 6.18	42.38	4.85
5	TISSA	52.7	5.25
CD (0.05)		3.14	0.83
CV (%)		8.27	2.72

4.2.2 Poly phenol content

The total poly phenol content in unfermented samples of the evaluated hybrids ranged from 1.51 % in hybrid 16.8 to5.64 % in hybrid 5.7 (Table 13). Among the parents S IV 5.20 recorded the highest polyphenol content (6.10%).The distribution of polyphenol content in hybrids and parents evaluated are presented in Fig.5.

Nazaruddin *et al.* (2006) reported that the polyphenols ranged from 34 to 60 mg/g in beans. According to Asna (2013) the total polyphenols in the unfermented samples ranged from 2.25% to 9.09% in different cocoa accessions.

Polyphenols have long been associated with flavor and colour of chocolate (Kim and Keeney, 1984). Very high polyphenol content in the beans is undesirable as it will impart bitterness and astringency to the final product and will mask the characteristic flavor of chocolate. However, polyphenols have antioxidant property beneficial to human health, the level of the property being decided by the level of content. Hence, types with high polyphenol content can be selected for therapeutic use.

4.2.3 Cluster analysis based on biochemical data

The cluster analysis was done using Jaccard's similarity coefficient matrix by unweighted pair group method (Sneath and Sokal, 1973) and the resulting dendrogram is presented in Fig.6. It can be seen that the accessions (hybrids and parents) were remaining as independent units in the cluster diagram except hybrid 15.6 and TISSA as well as hybrid 7.8 and 17.4 indicating that they are highly variable with respect to fat and polyphenol contents.

4.2.4 Correlation of fat and polyphenol contents with bean weight

The correlation between fresh and dry bean weight as well as fat and polyphenol contents were worked out. The results are presented in Tables 14a and 14b. No significant correlation was observed among these traits in the case of hybrids and parents.

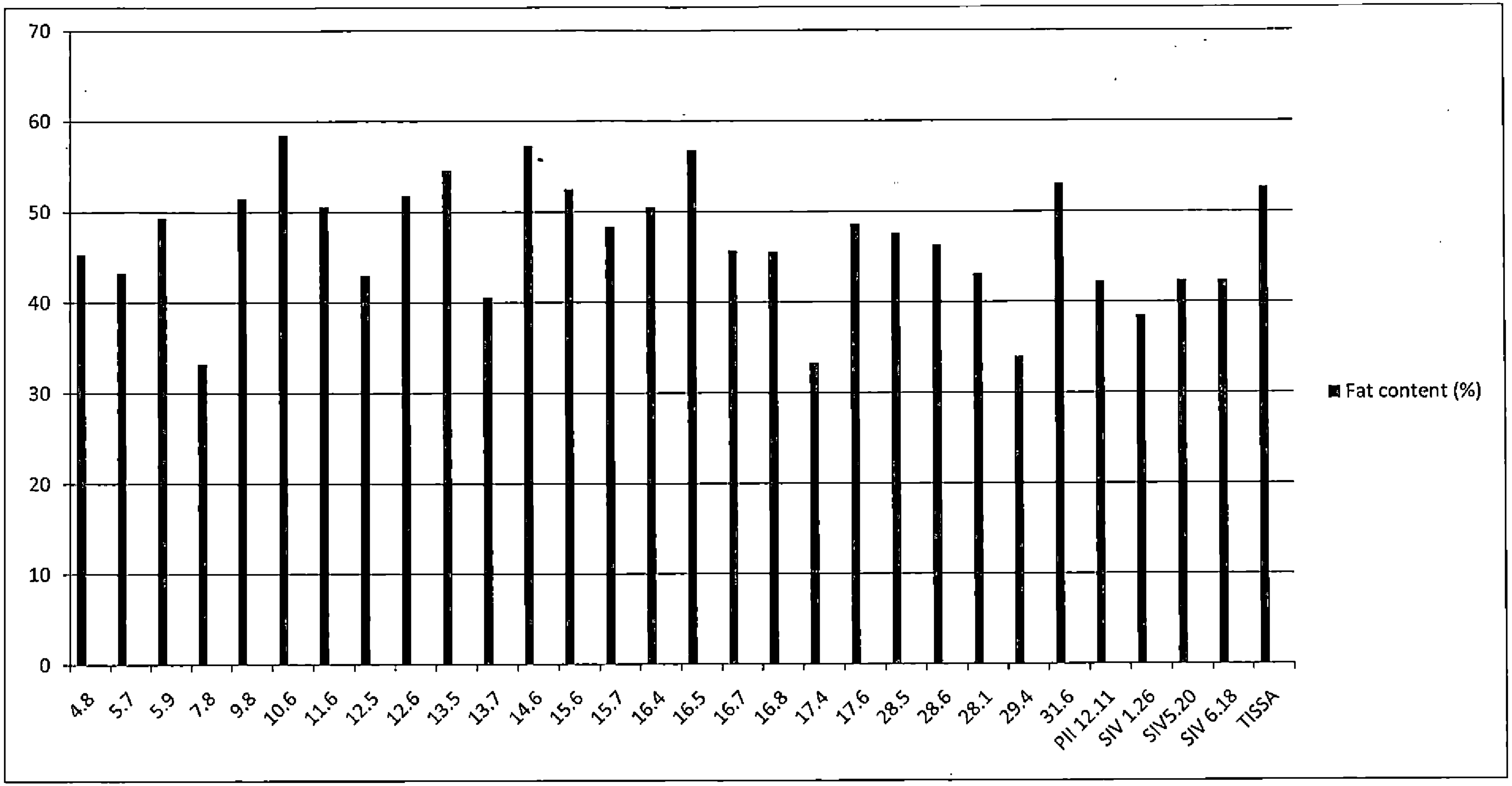

Fig.4. Distribution of fat content in cocoa hybrids and parents

173501
KERALA AGRICULTURAL UNIVERSITY
CENTRAL LIBRARY

51

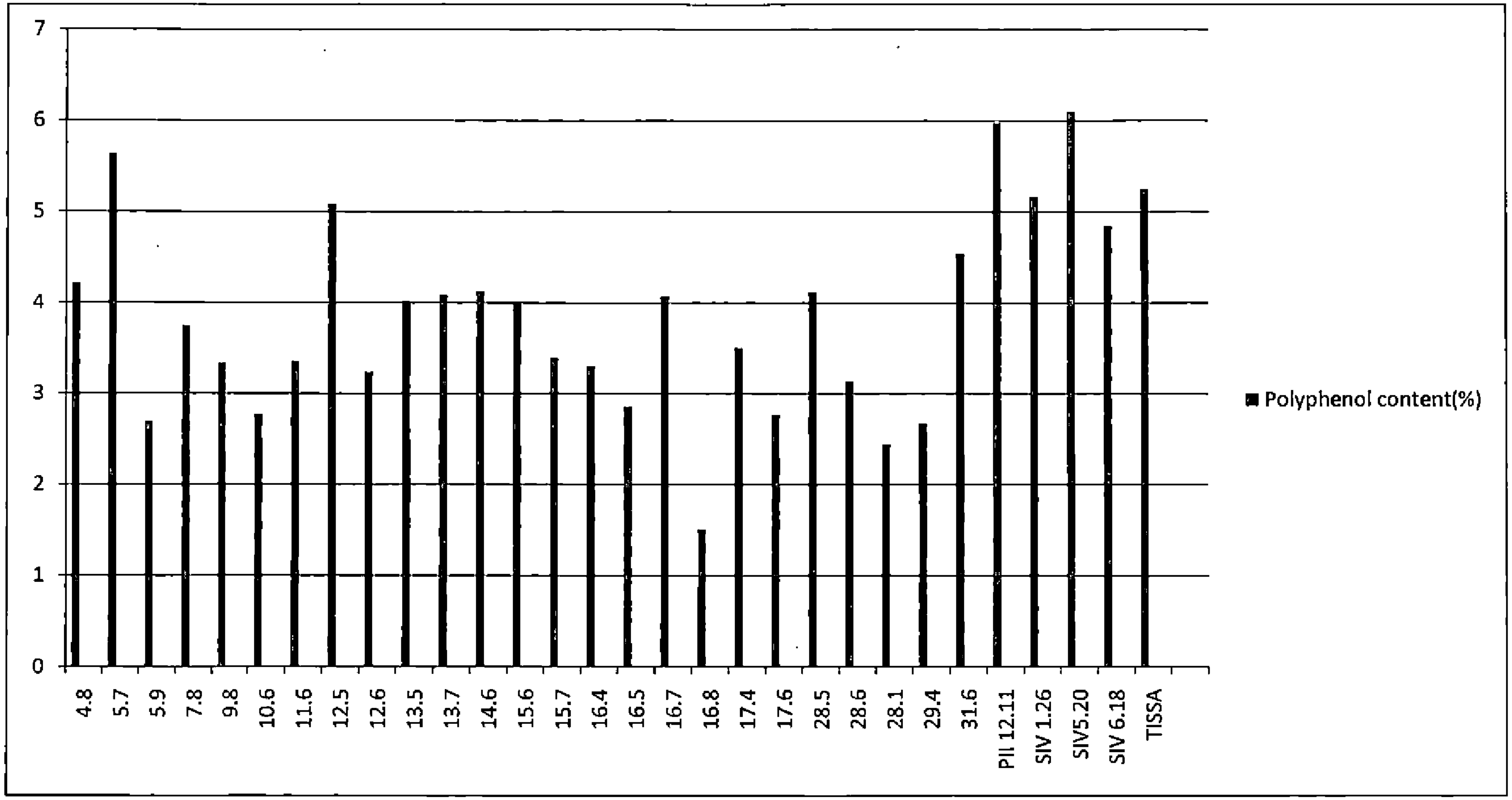

Fig.5. Distribution of total polyphenol in cocoa hybrids and parents

52

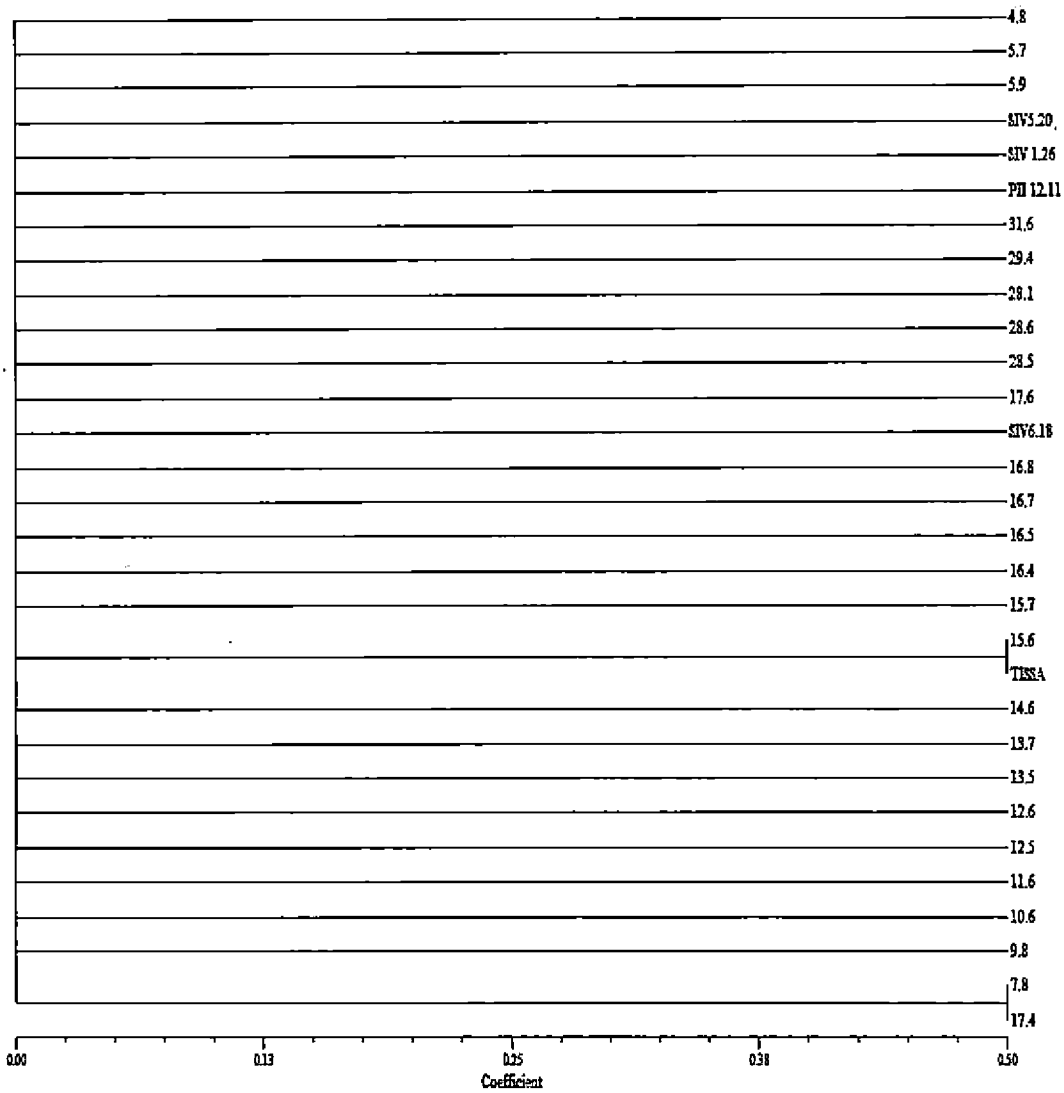

Fig.6. Dendrogram based on biochemical characters of cocoa hybrid and parents

Table 14a. Correlation of fat and polyphenol contents with bean weight in hybrids

	Fat content	Polyphenol content	Wet weight of bean	Dry weight of bean
Fat content	1	-0.085	0.035	-0.052
Polyphenol content	-0.085	1	0.048	-0.113
Wet weight of bean	0.035	0.048	1	0.653**
Dry weight of bean	-0.052	-0.113	0.653**	1

Table 14b. Correlation of fat and polyphenol contents with bean weight in parents

	Fat	Polyphenol	Wet weight of bean	Dry weight of bean
Fat content	1	-0.138	-0.120	-0.056
Polyphenol content	-0.138	1	-0.139	-0.152
Wet weight of bean	-0.120	-0.139	1	0.727**
Dry weight of bean	-0.056	-0.152	0.727**	1

4.3 Scoring for pest and diseases

The incidence of pest and diseases were negligible in hybrids and parents during the period of evaluation. Tea mosquito attack and black pods were noticed at negligible levels (less than 1%) in hybrids 9.8 and 11.6.

4.4 Heterotic effect in hybrids

Heterotic effect in various pod and bean characters of hybrids were analyzed using standard methods and the results are presented in Tables 15a, 15b, and 15c. All most all the hybrids exhibited negative heterosis for most of the characters evaluated.

The relative heterosis for pod weight was significant in hybrid 13.7 (53.64%) (Tables 15a). Heterotic effect of pod length was significant and positive in hybrids 9.8, 10.6, and 13.5. Maximum relative heterosis for pod length was observed in hybrid 13.5 (18.63%). The highest relative heterosis for pod breadth was exhibited by hybrid 13.7 and was followed by hybrid 16.8. Significant negative relative heterosis was observed for ridge and furrow thickness in hybrid 5.9. Hybrids which expressed positive relative heterosis for ridge thickness were hybrids 9.8, 12.6, 13.5, 13.7, 16.5 and 16.8. High ridge thickness is an undesirable character with respect to pod weight in cocoa breeding. However, thick ridges offer protection to the pods by reducing the damage caused by rodents. Furrow thickness was also having positive heterotic effects in the case of hybrids 12.6, 13.5 and 13.7. Significant negative relative heterosis for furrow thickness was observed in hybrid 7.8 (-63.27 %) (Table15a). TSS also showed significant positive relative heterosis in hybrids 4.8, 5.9, 10.6, 11.6, 12.5, 13.5, 14.6, 16.4, 16.5, 16.7, 17.6, 28.5, 28.6, 29.4, and 31.6. Maximum relative heterosis and heterobeltoisis for TSS was observed in hybrid 11.6 (31.04% and 30.05% respectively).

Heterobeltiosis for pod weight was positive and significant in hybrid 13.7 (45.47%). Positive and significant heterobeltiosis was observed for pod length in hybrid 13.5 and 16.7 and for pod breadth in hybrids 13.7 and 16.8. Heterobeltiosis for pod length and breadth were negative in all the hybrids except 12.6, 13.5, 13.7, and 16.8. The highest negative heterobeltiosis for ridge thickness was observed in hybrid 5.9 (-52.41%). However, in hybrid 13.7 heterobeltiosis for ridge thickness was positive and significant (Tables 15a).

Relative heterosis for bean weight/pod (Tables 15b) was maximum in hybrid 13.7 (40.61%). All other hybrids showed negative values. Relative heterosis for number of beans/pod was significant and positive in hybrids 4.8, 9.8, 10.6, 13.5, 13.7, 15.6, 28.10, and 31.6 with the highest value in hybrid 15.6 (15.42%). Less number of flat beans is taken as a desirable character in cocoa breeding progrmmes. Positive heterosis for flat beans is an indication of the presence of high amount flat beans in the progenies. Hundred per cent negative relative heterosis was recorded in the case of hybrid 13.5 for flat beans which makes the type distinct and useful in breeding programmes. Hybrid 28.10 was having high positive relative heterosis for flat beans which makes it undesirable (Table15b).

Heterobeltiosis was significant and positive for weight of beans/pod in hybrid 13.7 (34.40%). With respect to number of beans /pod, heterobeltiosis was significant and positive in hybrid 15.6 (9.45%) and hybrid 28.10 (2.41%). The highest negative heterobeltiosis for flat beans /pod was observed in hybrid 13.5. It was positive and significant in hybrid 28.10 (Table15b).

Relative heterosis and heterobeltiosis for wet weight of unpeeled bean was maximum in the hybrid 13.7 with values 39.39% and 34.89% (Table 15c). With respect to relative heterosis and heterobeltiosis for wet weight of peeled bean, hybrid 12.5 and 12.6 were superior. However, in the case of dry weight of peeled bean, hybrid 12.6 was the best (Table 15c). Regarding bean length, relative heterosis and heterobeltiosis were positive and significant in hybrids 28.6 and 28.10. Significant positive relative heterosis was observed for bean breadth in hybrids 14.6, 28.6 and 28.10. Significant and positive relative heterosis and heterobeltiosis were noticed in hybrid 12.6 for thickness of peeled bean (30.78%). Hybrid 12.6 was followed by hybrids 13.7, 15.7, 16.5, and 14.6 with respect to heterosis for bean thickness.

Table 15a. Relative heterosis and heterobeltiosis for the pod characters

Hybrid name	Pod weight		Pod Length		Pod breadth		Ridge thickness		Furrow thickness		TSS	
	RH (%)	HB (%)	RH (%)	HB (%)	RH (%)	HB (%)	RH (%)	HB (%)	RH (%)	HB (%)	RH (%)	HB (%)
4.8	-48.84	-53.48*	-22.25*	-27.33*	-23.45*	-25.53*	-50.81*	-51.61*	-50.00*	-50.00*	29.93*	18.64*
5.7	-34.59	-40.53*	-13.33*	-19.00*	-14.09*	-16.43*	-27.86*	-29.03*	-28.00*	-28.00*	-15.14*	-22.51*
5.9	-60.19*	-63.80*	-20.39*	-25.6*	-27.09*	-29.07*	-51.63*	-52.41*	-59.00*	-59.00*	9.62*	0.10
7.8	-75.30*	-76.61*	-23.16*	-29.46*	-31.28*	-32.53*	-45.16*	-46.87*	-62..85*	-64.86*	-44.65*	-45.07*
9.8	-0.49	-5.78	3.41*	-5.06*	-0.61*	-2.40*	2.41*	-0.78*	-0.95*	-6.30*	-4.51*	-5.24*
10.6	-24.57	28.58	2.37*	-6.02*	-6.99*	-8.67*	-13.70*	-16.40*	-15.23*	-19.81*	16.12*	15.24*
11.6	-27.56	-31.41	-2.65*	-10.63*	-0.36	-2.16*	-29.03*	-31.25*	-38.09*	-41.44*	31.04*	30.05*
12.5	-51.16*	-53.75*	-11.93*	-19.15*	-15.09*	-16.62*	-39.51*	-41.40*	-57.14*	-59.45*	27.22*	26.26*
12.6	-11.73	-16.42	-3.62*	-11.53*	-4.53*	-6.26*	5.64*	2.34*	2.85*	-2.70*	-1.71	-2.46*
13.5	9.74	3.91	18.63*	8.90*	0.61*	-1.20*	29.03*	25.00*	4.76*	-0.90*	11.95*	11.11*
13.7	53.64*	45.47*	-0.90*	-9.03*	16.56*	14.45*	8.87*	5.46*	9.52*	3.60*	-31.29*	-31.81*
14.6	-29.02	-32.80*	-17.65*	-24.40*	-5.15*	-6.86*	-29.83*	-32.03*	-37.14*	-40.54*	3.47*	2.69*
15.6	-39.44	-42.66*	-13.32*	-20.43*	-14.84*	-16.38*	-26.61*	-28.90*	-32.38*	-36.03*	-14.68*	-15.32*
15.7	-15.08	-19.60	-9.49*	-16.91*	-1.96*	-3.73*	-0.80*	-3.90*	-5.71*	-10.81*	-2.32*	-3.06*
16.4	-40.00	-43.19*	-13.04*	-20.17*	-13.12*	-14.69*	-25*	-27.34*	-35.23*	-38.73*	9.58*	8.75*
16.5	-15.05	-19.57	-8.02*	-15.56*	-3.55*	-5.30*	1.61*	-1.56*	-2.85*	-8.10*	6.87*	6.06*
16.7	-32.68	-36.26*	-5.79*	13.51*	-6.87*	-8.55*	-13.70*	-16.40*	-22.85*	-27.02*	9.58*	8.75*
16.8	0.96	-4.40	-2.30*	-10.31*	10.42*	8.43*	12.90*	9.37*	23.80*	17.11*	-3.30*	-4.04*
17.4	-58.29*	-60.51*	-19.74*	-26.32*	-28.22*	-29.51*	-23.38*	-25.78*	-38.09*	-41.44*	-36.38*	-36.86*
17.6	-57.19*	-59.47*	-20.72*	-27.22*	-23.55*	-24.93*	-27.41*	-29.68*	-33.33*	-36.93*	27.65*	26.68*
28.5	-54.16*	-58.75*	-30.32*	-32.08*	-25.50*	-26.47*	-42.98*	-47.58*	-48.91*	-53.00*	16.54*	1.48*
28.6	-39.39	-45.45*	-22.53*	-24.49*	-17.84*	-18.91*	-34.21*	-39.51*	-36.95*	-42.00*	24.08*	8.05*
28.10	-49.49*	-54.54*	-19.74*	-21.77*	-23.11*	-24.11*	-42.10*	-46.77*	-52.17*	-56.00*	1.21	-11.86*
29.4	-69.69*	-72.72*	-24.35*	-26.26*	-36.04*	-36.87*	-70.17*	-72.58*	79.34*	-81.00*	9.00*	-5.08*
31.6	-7.75	-29.33	6.69*	-4.09*	0.13	-9.63*	15.58*	-7.03*	9.41*	-16.21*	4.79*	3.75*

57

Table 15b. Relative heterosis and heterobeltoisis for the pod characters

Hybrid name	Weight of bean/pod		No of bean/pod		No of flat bean/pod	
	RH(%)	HB(%)	RH(%)	HB(%)	RH(%)	HB(%)
4.8	-35.13*	-45.34*	3.99*	-2.71*	65.48*	6.88*
5.7	-29.12*	-40.28*	1.81	-4.75*	-24.61*	-51.31*
5.9	-51.23*	-58.90*	-1.76	-8.09*	22.58*	-20.81*
7.8	-78.10*	-79.04*	-19.86*	-23.11*	58.35*	-5.24*
9.8	-20.65*	-24.14*	2.89*	-2.42*	1.36*	-39.34*
10.6	-24.34*	-27.66*	7.14*	1.60	-83.01*	-89.83*
11.6	-21.32*	-24.78*	-3.61*	-8.59*	-82.73*	-89.67*
12.5	-34.06*	-36.95*	-7.29*	-12.08	-64.10*	-78.52*
12.6	-17.62*	-21.24*	-14.04*	-18.49*	57.26*	-5.90*
13.5	-4.36	-8.57	5.59*	0.13	-100*	-100*
13.7	40.61*	34.40*	3.14*	-2.18*	-67.67*	-80.65*
14.6	-14.64*	-18.39*	-27.30*	-31.06*	-10.41*	-46.39*
15.6	-40.78*	-43.37*	15.42*	9.45*	-83.28*	-90.00*
15.7	-20.74*	-24.23*	-10.95*	-15.55*	60.82*	-3.77*
16.4	-39.25*	-41.91*	-16.35*	-20.68*	66.30*	-0.49*
16.5	-18.46*	-22.05*	-14.04*	-18.49*	-23.83*	-54.42*
16.7	-33.62*	-36.53*	-4.71*	-9.64*	-76.98*	-86.22*
16.8	-33.11*	-36.04*	-4.22*	-9.17*	33.69*	-20.00*
17.4	-57.65*	-59.49*	-9.13*	-13.83*	6.84	-36.06*
17.6	-53.86*	-55.87*	-6.90*	-11.71*	-58.63*	-75.24*
28.5	-41.25*	-53.82*	-2.67	-4.06*	-58.52*	-70.54*
28.6	-25.39*	-41.35*	0.51	-0.92	-75.58*	-82.66*
28.10	-32.16*	-46.68*	3.90*	2.41*	519.73*	340.0*
29.4	-53.46*	-63.42*	-8.58*	-9.89*	-59.86*	-71.49*
31.6	-19.89*	-36.20*	7.71*	1.39	-38.05*	-57.83*

Table15c. Relative heterosis and heterobeltoisis for the bean characters

Hybrid	Wet weight of unpeeled bean		Wet Weight of peeled bean		Dry weight of peeled bean(g)		Single bean length		Single bean breadth		Single bean thickness	
	RH (%)	HB(%)	RH(%)	HB(%)	RH(%)	HB(%)	RH(%)	HB(%)	RH(%)	HB(%)	RH(%)	HB(%)
4.8	-35.95*	-49.85*	-33.83*	-42.85*	-34.31*	-43.22*	-12.97*	-17.50*	-16.62*	-21.63*	-26.41*	-35.98*
5.7	-7.11*	-27.27*	-18.04*	-29.22*	-35.29*	-44.06*	-10.39*	-16.01*	-13.98*	-19.16*	-28.81*	-38.07*
5.9	-42.32*	-54.83*	-21.05*	-31.81*	-41.17*	-49.15*	-13.38*	-18.82*	-16.60*	-21.61*	-37.91*	-45.98*
7.8	-65.45*	-66.56*	-79.14*	-80.34*	-73.17*	-74.21*	-47.24*	-47.27*	-62.68*	-64.47*	-44.12*	-45.96*
9.8	-20.90*	-23.46*	-25.76*	-30.05*	-31.70*	-34.37*	-13.64*	-13.68*	-21.14*	-24.94*	-13.30*	-16.16*
10.6	-9.69*	-12.61*	-12.88*	-17.91*	-11.38*	-14.84*	-4.40*	-4.45*	-3.64*	-8.28*	-14.72*	-17.53*
11.6	-21.81*	-24.34*	-9.20*	-14.45*	-24.39*	-27.34*	-2.75*	-2.80*	-11.32*	-15.59*	-17.97*	-20.68*
12.5	-34.54*	-36.65*	9.20*	2.89*	-30.08*	-32.81*	-18.70*	-18.74*	-10.28*	-14.60*	-15.38*	-18.17*
12.6	1.81*	-1.46*	9.20*	2.89*	6.50*	2.34*	-5.55*	-5.60*	-3.59*	-8.24*	30.78*	26.47*
13.5	-11.21*	-14.07*	-12.88*	-17.91*	-15.44*	-18.75*	-6.21*	-6.26*	-12.69*	-16.90*	-12.72*	-15.60*
13.7	39.39*	34.89*	-1.22*	-6.93*	-4.06*	-7.81*	-11.33*	-11.37*	-6.17*	-10.69*	22.83*	18.78*
14.6	7.87*	4.39*	-9.20*	-14.45*	-5.69*	-9.37*	-9.18*	-9.23*	1.34*	-3.54*	14.35*	10.58*
15.6	-50.90*	-52.49*	-33.74*	-37.57*	-47.96*	-50*	-24.75*	-24.79*	-27.78*	-31.26*	-29.31*	-31.64*
15.7	-20*	-22.58*	-14.72*	-19.65*	-18.69*	-21.87*	-10.12*	-10.17*	-19.71*	-23.58*	18.89*	14.97*
16.4	-8.78*	-11.73*	-4.29*	-9.82*	-8.13*	-11.71*	-14.30*	-14.12*	-13.44*	-17.61*	3.96*	0.53
16.5	-9.09*	-12.02*	0	-5.78*	-8.13*	-11.71*	-6.05*	-6.10*	-8.27*	-12.69*	15.87*	12.05*
16.7	-10.90*	-13.78*	-11.65*	-16.76*	-24.39*	-27.34*	-14.30*	-14.34*	-24.64*	-28.27*	-2.96*	-6.16*
16.8	-30.60*	-32.84*	-21.47*	-26.01*	-24.39*	-27.34*	-2.20*	-2.25*	-7.90*	-12.33*	-25.69*	-28.14*
17.4	-56.36*	-57.77*	-76.07*	-77.45*	-82.11*	-82.81*	-54.8*	-54.92*	-63.06*	-64.84*	-61.67*	-62.94*
17.6	-46.66*	-48.38*	-26.99*	-31.21*	-52.84*	-54.68*	-25.63*	-25.67*	-29.28*	-32.69*	-36.24*	-38.35*
28.5	-34.60*	-48.34*	-10.52*	-22.72*	-26.53*	-33.94*	0.31	-0.98*	-10.24*	-14.90*	-25.13*	-36.98*
28.6	-9.88*	-28.82*	-6.76*	-19.48*	-8.16*	-17.43*	8.13*	6.74*	5.20*	-0.26	-18.00*	-30.97*
28.10	3.42*	-18.31*	-7.51*	-20.12*	-5.10*	-14.67*	5.71*	4.35*	2.71*	-2.61*	-17.22*	-30.32*
29.4	-45.24*	-56.75*	-18.04*	-29.22*	-46.93*	-52.29*	-2.04*	-3.30*	-5.97*	-10.86*	-65.28*	-70.77*
31.6	-30.17*	-37.81*	-36.47*	-41.61*	-32.11*	-42.18*	-14.09*	-18.58*	-25.4*	-32.97*	-25.92*	-36.08*

59

Hybrid 13.7 can be considered as superior as it was having significant positive heterotic effects in pod weight, pod breadth, bean weight/pod, wet weight of unpeeled bean and peeled bean thickness. Hybrid 13.7 was followed by 12.6 with significant positive heterotic effects in wet and dry weights of peeled bean and in dry bean thickness. Hybrid 13.5 was positioned as third hybrid with desirable heterotic effects in pod length and number of flat beans/pod.

4.5 Seasonal effect on pod and bean characters

The effect of season on pod characters *viz.*, pod weight, length, breadth and thickness of pods (thickness of ridges and furrows), number of beans/pod, number of flat beans /pod, weight of beans/pod and TSS of hybrids and parents are presented in Table 16a and 16b.

Pod characters varied significantly with season both in the hybrids and parents. The poorest performance was observed in season III representing the period from June to August. Season II (March to May) and IV (September to November) were found to be the favorable seasons, pod weight and bean weight/pod were high in season IV. However, with respect to the other pod characters season II was found to be superior.

The effect of season on the bean characters of hybrids and parents are depicted in Table 17a and 17 b. The bean weight in hybrids was the highest in season IV (September to November) followed by season II (March to May) and the lowest in season III (June to August). With respect to length and breadth of beans, the highest values were observed in season II followed by season IV. Both season II and IV were equally good with respect to bean thickness (Table17a). In the case of parents, beans with superior characters were recorded in season IV. Bean characters were inferior during season III (June to August).

According to the international standards, the dry weight of unpeeled bean must be one gram or above and peeled bean must be 0.8g or above (Anon., 1970; Wood and Lass, 1985). Small sized beans are not preferred in the market due to difficulty in processing. Wood and Lass, (1985) has reported that the bean size is significantly influenced by environmental conditions especially temperature prevailing during the formation and development of pod. Present investigation also confirms this as is evident from the lowest

Table 16a. Effect of season on pod characters of hybrids

Season	Pod weight (gm)	Pod length (cm)	Pod breadth (cm)	Ridge thickness (cm)	Furrow thickness (cm)	No of beans/pod	No of flat beans/pod	Weight of bean/pod (gm)	TSS (%)
Season I (Dec-Feb)	8.7	2.01	1.60	0.94	0.91	3.02	0.88	4.65	2.32
Season II (March-May)	11.27	2.87	2.07	1.043	0.96	5.02	1.22	6.25	3.81
Season III (June-Aug)	4.92	1.46	1.25	0.85	0.82	2.23	0.88	2.84	1.65
Season IV (Sept-Nov)	12.41	2.45	2.01	1.04	0.99	3.80	1.01	6.74	2.76
CD (0.05)	0.29	0.02	0.02	0.011	0.01	0.05	0.11	0.19	0.06
CV (%)	9.84	3.5	3.39	3.67	3.91	5.21	35.33	11.94	6.64

Table 16b. Effect of season on pod characters of parents

Season	Pod weight (gm)	Pod length (cm)	Pod breadth (cm)	Ridge thickness (cm)	Furrow thickness (cm)	No of beans/pod	No of flat beans/pod	Weight of bean/pod (gm)	TSS (%)
Season I (Dec-Feb)	5.02	1.32	1.13	0.83	0.82	1.8	0.88	2.65	1.46
Season II (March-May)	2.54	1.23	1.05	0.75	0.74	1.8	0.83	1.90	1.58
Season III (June-Aug)	0.70	0.70	0.70	0.70	0.70	0.7	0.70	0.70	0.70
Season IV (Sept-Nov)	20.75	3.89	2.97	1.29	1.20	6.56	1.39	11.10	4.39
CD (0.05)	0.67	0.04	0.03	0.02	0.02	0.144	0.17	0.34	0.079
CV (%)	13.34	3.61	3.45	3.34	3.87	7.41	25.21	11.89	5.44

Table 17a. Effect of season on bean characters of hybrids

Season	Single bean			
	Weight(g)	Length(mm)	Breadth(mm)	Thickness(mm)
Season I (Dec-Feb)	0.936	2.13	1.73	1.25
Season II (March-May)	1.026	3.17	2.46	1.54
Season III (June-Aug)	0.813	1.58	1.27	1.03
Season IV (Sept-Nov)	1.057	2.76	2.16	1.54
CD (0.05)	0.02	0.05	0.05	0.04
CV (%)	5.47	6.08	7.79	10.19

Table 17b. Effect of season on bean characters of parents

Season	Single bean			
	Weight(g)	Length(mm)	Breadth(mm)	Thickness(mm)
Season I (Dec-Feb)	0.81	1.35	1.22	0.96
Season II (March-May)	0.77	1.33	1.13	0.88
Season III (June-Aug)	0.70	0.70	0.70	0.70
Season IV (Sept-Nov)	1.28	4.27	3.29	2.02
CD (0.05)	0.02	0.098	0.04	0.05
CV (%)	3.53	7.19	4.11	6.42

values recorded for pod and bean characters in season III (Table16a, 16b, 17a &17b). It takes nearly three to three and half month for the pod to reach maturity after its formation. The pods which are formed and developing in season II (March to May) will be ready for harvest in season III (June to August) only. The high temperature in season II, representing the summer months from March to May, may be responsible for reduction in the quality of pods then formed and reaching maturity in season III (June to August). Hence, the quality of pods and also the beans harvested in season III (June to August) will be inferior.

4.6 Future line of work

i. The incompatibility reactions of the hybrid progenies with flower drop and fruit drop are to be studied in detail.

ii. The performance of the desirable hybrids with bold beans identified in the present study in comparison with check varieties has to be taken up.

Summary

6. SUMMARY

The study entitled "Analysis of bean characters in cocoa (*Theobroma cacao* L.) hybrids bred for bold beans" was carried out in the Dept of plant breeding and Genetics, College of Horticulture and Cocoa Research Centre, KAU, Vellanikkara during the period 2012-2014. The objectives of the study were to estimate the thresh hold bean size and heterotic effect for various pod and bean characters. The investigation also aims at studying the inheritance of pod and bean characters.

Fourty hybrids derived from four crosses S IV 1.26 X TISSA, S IV 1.26 X P II 12.11, S IV 5.20 X TISSA and S IV 6.18 X PII 12.11 and maintained at Cocoa Research Centre, Vellanikkara formed the material for the study. Among the 40 hybrids, 13 flowered but did not set seeds indicating the possibility of some incompatibility mechanisms operating. Two hybrids though flowered and set pods, mature pods could not be obtained due to pod shedding in the early stages of development. Hence, detailed observations were recorded only from 25 hybrids which flowered and set seeds.

Variability was observed among the hybrids for various qualitative characters of pods and beans. All the five parental types were yellow poded while the hybrid progenies exhibited a gradation of colours and their combinations. Even the hybrid progenies from the same cross itself exhibited variability for pod colour, described by the colour of ridges and furrow. Variability was observed for bean colour, pod shape, rugosity, pod basal constriction and shape of pod apex.

The cluster analysis based on qualitative characters following unweighted pair group method done with the help of NTSYS pc version 2.1 software (Rohlf, 1992) resulted in 16 clusters at 70 percent similarity.

Significant variability was observed for all the 14 quantitative characters studied. Hybrid 13.7 as having the largest pod weight (700g) and pod breadth (9.50cm). The hybrid 29.4 with the lowest pod breadth, ridge thickness and furrow thickness recorded the highest wet bean content / pod (45%). The content of flat beans, believed to be developing from unfertilized ovules, was absent in hybrid 13.5.

Clustering of genotypes based on quantitative characters was done with the help of NTSYS pc version 2.1 software (Rohlf, 1992) and the dendrogram constructed revealed that majority of the accessions were remaining as independent units even at 5 percent level of similarity. This points to the high variability among the accessions at quantitative level.

Among the pod and bean characters of hybrids, wet weight of peeled bean exhibited maximum variability as indicated by its high PCV (570.40%) and GCV (510%). The high variability coupled with high heritability for this character indicates the scope for selection based on this character.

Analysis of bean characters based on an year round observations revealed that major factors contributing to boldness of beans were bean weight, bean breadth and bean thickness. Confirming to international standards a descriptor for assessing the performance of cocoa types was developed based on the three characters mentioned above. Inclusive scales for this descriptor were developed based on the values of superior subsets for these characters in post hoc test DMRT and are presented below.

Bean weight	⇒	1.16g - 1.31g
Bean breadth	⇒	10.29mm - 11.22mm
Bean thickness	⇒	4.35mm - 4.98mm

Thresh hold bean size can thus be considered as one where the weight, breadth, and thickness of bean fall within the range of scales prescribed for each. Among the twenty five hybrids investigated three hybrids, hybrids 12.6, 13.7 and 14.6 can be categorized as having threshold bean size .Among the parents P II 12.11 and S IV 1.26 were also falling in this category. Hybrids with maximum bean size in the present study came from the crosses involving S IV 1.26 and P II 12.11.

The hybrid progenies differed significantly in fat and polyphenol contents. The fat content ranged from 33.33% in hybrid 7.8 to 58.5% in hybrid 10.6 and poly phenol ranged from 1.51% in hybrid 16.8 to 5.64% in hybrid 5.7. No significant correlation was observed among bean weight and polyphenol as well as fat contents.

With respect to heterotic effects of various pod and bean characters, hybrid 13.7 can be considered superior followed by hybrid 12.6.

Pod characters varied significantly with the season. Bean weight in the hybrids was the highest in September to November period harvests and the lowest in June to August period harvests. The bean size is reported to be significantly affected by temperature (Wood and Lass, 1985) prevailing at the time of formation and development of pods. The pods take three to three and a half months to reach maturity. Hence, the pods formed in March to May period will be ready for harvest in June to August period and was having the lowest bean weight.

References

6. REFERENCES

[Anonymous]. 1970. International Cocoa Standards. *Cocoa Growers' Bull.*, **14**: 28-32.

Adenikinju, S. A. 1977. Observation on growth and dry matter accumulation in cocoa seedlings as influenced by bean size. *J. Acta Hort.* 53: 279-285

Afoakwa, E.O. and Paterson, A. 2010. Cocoa fermentation: chocolate flavour quality. In: *Encyclopaedia of Biotechnology in Agriculture and Food.* Taylor & Francis Publishing Inc. Oxford, U.K, pp. 457-486.

Afoakwa, E.O., Quao, J., Takrama, F.S., Budu, A.S. and Saalia, F.K. 2012. Changes in total polyphenols, o-diphenols and anthocyanin concentrations during fermentation of pulp pre-conditioned cocoa (*Theobroma cacao*) beans. *Int. Food Res. J.* 19(3): 1071-1077.

Álvarez, C., Pérez, E. and Lares, M. 2003. Fruit morphology and physical-chemical characteristics of cocoa mucilage from three areas of Aragua State. *JournalAgronomía Tropical* (Maracay) **52** (4): 497-506.

Alverson, W.S., Whitlock, B.A., Nyfeller, R., Bayer, C. and Baum, D.A. 1999. Phylogeny of the core Malvales: Evidence from ndhF sequence data. *Am. J. Bot.* 86: 1474-1486.

Amma, S.P., Mininol, J.S. and Bai, L.E.S. 2011. Utilization of introduced genetic resources in cocoa. *Cashew Cocoa J.* 3(1): 16-18.

Apshara, S. E., Bhat, V. R., Ananda, K. S., Nair, R. V. and Suma, D. 2009. Evaluation and identification of high yielding trees in Nigerian cocoa germplasm *J. Plant. Crops.* 37 (2) : 111-116

Apshara, S. E., Bhat, V. R. and Nair, R. V. 2008. Comparative studies on elite cocoa progenies in their initial years of growth. *J. Plant. Crops* **36** (1): 38-44.

Asna, A.C. 2013. Performance analysis of selected accessions of cocoa (*Theobroma cacao* L.). Msc (Ag) thesis, Kerala Agricultural University, Thrissur,

Atanda, O.A. and Toxopeus, H. 1971.A proved case of heterosis in *Theobroma cacao* L. In:*Proceedings of 3rd international Cocoa Research conference,*Accra,Ghana pp. 545-51.

Balasimha, D., Kumar, V. A., Ananda, K. S. 2008.Photosynthetic characteristics and yield in cocoa hybrids.Central Plantation Crops Research Institute, Regional Station, Vittal , Karnataka, *J. Plant. Crops* **36** (1): 8-11.

Bartley, B. G. D. 1957. Trinitario-Scavina hybrids, new prospects for cocoa improvement. In: *Report of the Cocoa Conference* ,Grosvenor House, London, pp. 36-40.

Bekele, F.L. and Bekele, I. 1996. A sampling of the phenetic diversity of cacao in the International Cocoa Gene Bank of Trinidad. *Crop Sci.* **36**(1): 57-64.

Bekele, F.L. and Butler, D.R. 2000. Proposed short list of cocoa descripfors for characterisation. In: Eskes, A.B., Engels, J.M.M., and Lass, R.A. (eds.), *Working Procedures for Cocoa Germplasm Evaluation and Selection.* Proceedings of the CFC/ICCO/IPGRI project workshop, Montpellier, France, pp 41-48.

Bekele, F.L., Bidaisee, G.G., and Bhola, J. 2008. Examining phenotypic relationships among Trinitario cacao clones held in the international cocoa genebank, Trinidad. In: *Annual Report 2008.* Cocoa Research Unit, The University of The West Indies, Trinidad and Tobago, 30p

Bopaiah, B.M. and Bhat, K.S. 1989. The influence of season on harvest pattern, pod and bean characters of cacao under cacao mixed cropping system. *Indian Cocoa, Arecanut Spices J.* **12**(3): 79-81.

Cheesman, E.E. 1944. Notes on the nomenclature, classification and possible relationships of cacao populations. *Trop. Agric.* (Trinidad) **21**(8): 144-159.

Cheriyan, H., Vijayakumar, N. K. and Nair, R.V. 1996. Evaluation of variability in crosses and their parent populations of cacao (*Theobroma cacao* L*). J. Plantn. Crops* **24**(1): 43-49.

Cilas, C., Duchenin, C., and Lotode, R. 1989. *L'amelioration genetique de la qualite 'du cacao: e'tude de la grenulometric. Café Cacao The'* **33**(1): 3-8.

Cilas, C., Machado, R. and Motamayor, J. C. 2010. Relations between several traits linked to sexual plant reproduction in *Theobroma cacao* L. number of ovules per ovary, number of seeds per pod, and seed weight. *Tree Genet. Genomes* **6** (2): 219-226

Cuatrecasas, J. 1964. Cacao and its alleles – a taxonomic revision of the genus *Theobroma. Contribution from the U.S. Herbarium* **35**(6): 379-614.

Daymond, A. J., Hadley, P. 2008. Differential effects of temperature on fruit development and bean quality of contrasting genotypes of cacao (*Theobroma cacao*). *Annu. Appl. Biol* .**153** (2): 175-185.

Dias, L.A., Dos, S., and Kageyama, P.Y. 1997. Temporal stability of multivariate genetic divergence in cacao (*Theobroma cacao* L.) in southern Bahia conditions. *Euphytica* 93(2): 181-187.

Dias, L.A.S. and Kageyama, P.Y. 1998. Repeatability and minimum harvest period of cacao (*Theobroma cacao* L.) in Southern Bahia. *Euphytica* 102: 29-30.

Duncan, R.J.E. and Veldsman, I. 1994. An European chocolate manufacturer's experience for fermented Sulawesi cocoa. *Cocoa Growers' Bull.* **48**: 24-35.

Engles, J.M.M. 1982. A systematic description of cacao clones. III. Relationships between characteristics and some consequences for the cacao breeding. *Euphytica* **32**: 719-733.

Engles, J.M.M. 1986. The systematic description of cacao clones and its significance for taxonomy and plant breeding. Ph.D thesis, Agricultural University of Wageningen, Netherlands, 90p.

Enriquez, C.G.A. and Soria, V.J. 1966. *Estudio de la variabilidad de varias characteristicas delas mazorcas de cacao* (*Theobroma cacao* L.). *Fitotecnia Latino-americana* **3**(1): 99-118.

Francis, R. 1998. Genetic analysis of certain clones, hybrids and inbreds in cocoa. Ph.D (Ag) thesis, Kerala Agricultural University, Thrissur, 257p.

Jaccard, P. 1908. *Nourelles recherché sur la distribution florale. Bull. Vaud. Sci. Nat.* 44: 223-270

Jalil, A.M. and Ismail, A. 2008. Polyphenols in cocoa and cocoa products: Is there a link between antioxidant properties and health? *Molecules* **13**: 2190-2219.

Johnson, H.W., Robinson, H.F., and Comstock, R.E. 1955. Estimation of genetic and environmental variability in soyabean. *Agronomy J.* **47**: 314-318.

Jonfia-Essien, W. A.,West, G.. Alderson, P. G., Tucker, G. 2008. Phenolic content and antioxidant capacity of hybrid variety cocoa beans. *Food Chem.* **108**(3): 1155-1159.

Kim, H. and Keeney, P.G. 1984. (-) Epicatechin content in fermented and unfermented cocoa beans. *J. Food Sci.* **49**: 1090-1092

Lehrian, D.W. and Patterson, G.R. 1983. Cocoa fermentation. In: Reed, G., Chemie, V., Basel, (eds.), *Biotechnology* pp. 529–575.

Luhs, W. and Friedt, W. 1994. Designer oil crops: breeding, processing, and biotechnology. In: Murphy, D.J. (ed.), *Designer Oil Crops*, Weinheim, Germany, 198p

Maharaj, K. Maharaj, P., Bekele, F.L., Ramnath, D., Bidaisee, G.G., Bekele, I., Presad, C., Jennings, K. and Sankar, R. 2011. Trinidad selected hybrids: an investigation of the phenotypic and agro-economic traits of 20 selected cacao cultivars. *Trop. Agric.* (Trinidad) **88**(4): 175-185.

Malik, C.P. and Singh, M.B., 1980. Plants Enzymology and Histo-Enzymology, Kalyani Publishers, New Delhi, p. 286.

Mallika, V.K.,Vikraman, N. R.,Prasannakumari, A. S. and Abraham Koshy.2000.Comparison of yield in hybrids and clones of cocoa (*Theobroma cacao* L.).College of Horticulture, Kerala Agricultural University, Vellanikkara, *J. Plant. Crops* **28** (3): 222-225.

Marita, J.M., Nienhuis, J., Pires ,J.L. and Aitken, W.M. 2001.Analysis of genetic diversity in *Theobroma cacao* with emphasis on witches' broom disease resistance. *Crop Sci.* 41:1305-1316.

Minimol, J.S., Amma, P.S., Krishnan, S. and Vasudevan, N.R. 2011. Influence of fruit apex on fruit shape in selected accessions of cocoa. In: Apshara, E.S., Jaganathan, D., and Balasimha, D. (eds.), *Proceedings of Seminar on Strategies for Enhancing Productivity of Cocoa.* Central Plantation Crops Research Institute, Vittal, pp. 23-25.

Monteiro, W.R., Lopez, U.V. and Clement, D. 2009. Genetic improvement in cocoa. In: Jain, S.M. and Priyadarshan, D (eds.), *Breeding Plantataion Tree Crops: Tropical Species.* Springer Science, Bussiness Media, pp. 589-626.

Montserin, B. G., Verteuil, L. L. and Freeman, W. E. 1957.A note on cocoa hybridisation in Trinidad with reference to clonal selection and hybrid seed. *Journal of the Agricultural Society* (Trinidad and Tobago) 57 : 19-27.

Mooleedhar, V. 1995. *"Fine" flavour cocoa – a Trinidadian and Tobagonian tradition.* Cocoa Research Unit ,Newsletter No. 2, Trinidad and Tobago, 6p.

Mora,A. R. and Bullard, E. T. 1961.Variation of bean characteristics in hybrid cacao progenies.In: *Proceedings of the Caribbean Region.* American Society for Horticultural Science, Miami, pp. 105-11.

Mora, P.W.T. 1989. *Relacion entre la posicion de la semilla en frutos de cacao (Theobroma cacao* L.), *su longitudy el diumetro y altura de las plantulas. Programme de Mejoramiento de Cultivos Tropicals* 39(4): 530-533.

Mossu, G. 1992. *Cocoa.* The Macmillan Press Ltd., London, 103p.

Napitupulu, L. A. 1992.Performance of some cocoa hybrids and derived selected clones. *Perkebunan bull.* **23** : 1 pp.

Nazaruddin, R., Seng, L.K., Hassan, O., and Said, M. 2006. Effect of pulp preconditioning on the content of polyphenols in cocoa beans (*Theobroma cacao*) during fermentation. *Ind. Crops Products* **24**:87-94.

Oyedokun, A.V., Omoloye, A.A., Adewale, B.D., Adeigbe, O.O., Adenuga, O.O. and Aikpokpodion, P.O. 2011. Phenotypic variability and diversity analysis of bean traits of some cocoa hybrids in Nigeria. *Asian J. Agric. Sci.* 3(2): 127-131.

Paterson, A. W. and Reed, R. L.1934 .Variation in the size of Trinidad cacao beans and methods of its assessment. *Trop. Agric.* 11: 252-61.

Pereira, M.G., Cartello, G.A. and Dias, L.A.S. 1987.Avaliação de híbridos de cacaueiros nas condiçõesde Linhares-ES. Boletim Técnico, 150. CEPLAC,Ilhéus.

Pires, J.L., Cascardo, J.C.M., Lambert, S.V. and Figueira, A. 1998. Increasing cocoa butter yield through genetic improvement of *Theobroma cacao* L.: Seed fat content variability, inheritance, and association with seed yield. *Euphytica* **103:** 115-121.

Pound, F.J. 1932. The genetic constitution of the cacao crop. In: *First Annual Report on Cacao Research for 1931*. Trinidad and Tobago, pp. 25-28.

Prayoga, R. D., Murwani, R. and Anwar, S. 2013. Polyphenol extracts from low quality cocoa beans: antioxidant, antibacterial and food colouring properties. *International Food Research Journal* 20(6): 3275-3281.

Ramos ,C. G., Gómez, M. A. and Ascencao, A. 2004. Morphological characters of two populations of criollo cocoa from western Venezuela.*JournalAgronomia Tropical (Maracay)* **54** (1): 45-62.

Rohlf, F.J. 1992. *NTSYSpc. Numerical Taxonomy and Multivariate Analysis System Version 2.0.* Department of Ecology and Evolution, State University of New York. 38p.

Ruinard, J. 1961. Variability of various pod characters as a factor in cocoa selection. *Euphytica* **10**: 134-146.

Russell,T.A .1952. The vigour of some cacao hybrids. *Trop.Agric.* (Trinidad) 29:4-6.

Sadasivam, S. and Manickam, A. 1996. *Biochemical methods* (2nd Ed.). New Age International Publishers, New Delhi, 256p.

Santos, R.C., Pires, J.L., and Correa, R.X. 2012. Morphological characterization of leaf, flower, fruit and seed traits among Brazilian *Theobroma* L. species. *Genet. Resourc. Crop Evol.* 59(3): 327-345.

Santos, R.C., Dias, L.A., Kageyama, P.Y. and Castro, G.C.T. 1997. Multivariate phenetic divergence in germplasm preservation of cacao (*Theobroma cacao* L.). *Agrotrópica* 9(1): 29-40.

Sivasubramanian, S. and Madhavamenon, P. 1973. Genetic analysis of quantitative characters in rice through diallel cross. *Madra Agric. J.* 66: 1097-1102.

Sneath P.H. and Sokal R.R. 1973. *Numerical Taxonomy.* Freeman, San Francisco, 573p

Soria, V.J. 1975. The genetics and breeding of cacao. In: *Proceedings of the Fifth International Cocoa research Conference.* Cocoa Producers' Alliance, Ibadan, Nigeria, pp. 18-24.

Soria, V.J., Ocampo, F. and Paez, G. 1974. Parental influence of some cacao clones on the yield performance of their progenies. *Turrialba* **24**(1): 58-65.

Sounigo,O., Lachenaud, P., Bastide, P., Cilas, C., N'Goran ,J. and Lanaud ,C. 2003. Assessment of the value of doubled haploids as progenitors in cocoa (*Theobroma cacao* L.) breeding. *J. Appl. Genet.* 44:339-353.

Vanderknaap, W. P. 1954 .The relation between bean size and growth of cacao plants. *J.Bergcultures* 23 : 421-432.

Velayutham,T., Rajamani, K., Shoba, N., Joel, A. J. and Senthil, N. 2013 Variability studies and identification of high yielding plus trees of cocoa (*Theobroma cacao* L.) in Tamil Nadu. *African J.Agric.Res.* 8(26): 3444-3453.

Vernon, A. J .1975. Hybrid cocoa: progress report on trials, seed gardens and extension.

Voelcker,O.J. 1939. Growth rate of cross and self-fertilised cacao. *Trop. Agric.* (Trinidad) 16: 203-205.

Wood G.A.R. and Lass R.A. 1955. *Cocoa.* Longman Group Limited, Longman house, England, 620p.

Wood, G. A. R and Lass R.A. 1985. Cocoa. Longman Group Ltd., Harlow, U.K, 620p.

ANALYSIS OF BEAN CHARACTERS IN COCOA (*Theobroma cacao* L.) HYBRIDS BRED FOR BOLD BEANS

By

RUBEENA M.

(2012-11-116)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the

requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF PLANT BREEDING AND GENETICS
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR – 680 656
KERALA, INDIA

2014

ABSTRACT

Cocoa is a tropical tree crop cultivated for its beans which form the main source of chocolate. Many of the cocoa varieties cultivated by the farmers, even though high yielders, are having small beans. However, the standard for cocoa bean in the international market is one gram or above. The size of bean is significantly influenced by various environmental conditions especially temperature, prevailing during the pod formation stage. Hence, the cocoa beans produced in summer months may fail to keep the international standards. To overcome this, it is necessary to evolve varieties with large beans of more than 2g so that even if reduction occurs during summer months the beans will have enough size to meet the international standards. The present study which forms part of an ongoing project at Cocoa Research Centre (CRC), KAU, Vellanikkara was hence, taken up during 2012-14 to evaluate the inheritance of various bean characters and to assess the threshold bean size as well as the heterotic effect for various bean characters.

Forty hybrid progenies derived from four crosses involving five parents, which are in full bearing stage and maintained at CRC, Vellanikkara formed the material for the study. These hybrids were subjected to morphological and biochemical evaluation along with their parents. The morphological evaluation based on eight qualitative and 14 quantitative characters was done using the descriptor developed by Bekele and Butler (2000). Fat and polyphenol contents were estimated following standard procedures for biochemical characterization.

Variability was observed among the hybrid progenies for all the qualitative characters evaluated. Variations expressed by the hybrid progenies in terms of pod and bean quantitative characters were also significant, indicating the heterogeneity among them.

Analysis of bean characters revealed that the hybrids 13.7, 16.8, 14.6 and 12.5 expressed higher values with respect to wet weight of unpeeled bean (460g), length of

peeled bean (17.78mm), breadth of peeled bean (10.81mm) and peeling ratio 82.4% respectively. The highest wet weight of peeled bean (1.78g) was recorded by hybrids 12.5 and 12.6. The dry weight of peeled bean (1.31g) and thickness of peeled bean (4.98mm) were the highest in hybrid 12.6. The fat content ranged from 33.3% in hybrid 7.8 to 58.5% in hybrid 10.6 and polyphenol content ranged from 0.15% in hybrid 16.8 to 0.56 % in hybrid 5.7. Among the pod and bean characters evaluated wet weight of peeled bean exhibited high GCV (510%), high heritability and high genetic gain (1163%). The bean characters varied significantly over seasons in hybrids as well as parents. Relatively higher bean weights were observed in September- November period harvests in contrast to the lower bean weights during June to August period.

Assessment of performance of hybrids based on year round observation on bean characters revealed that the major factors contributing significantly to boldness of bean were weight, breadth and thickness of beans. Based on these parameters a descriptor was developed confirming the international standards, for deciding the threshold bean size. The descriptor scales were prescribed based on the best subset values in the post hoc tests. Hybrids 12.6, 13.7 and 14.6 satisfied the developed scales

Significant positive heterotic effect (average heterosis as well as heterobeltiosis) for various bean characters was expressed by hybrids 13.7 and 12.6.

Among the hybrid progenies evaluated hybrid 13.7 was found to be a desirable one with low pod index value (PI value), high pod breadth, pod weight and wet weight of unpeeled bean coupled with significant positive heterotic effect for various bean character followed by hybrids 12.6, 16.5 and 14.6.

173501

KERALA AGRICULTURAL UNIVERSITY
CENTRAL LIBRARY
THRISSUR