GENETIC ANALYSIS OF YIELD ATTRIBUTES IN COCOA (*Theobroma cacao L.*)

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **Genetic Analysis of Yield Attributes in Cocoa (*Theobroma cacao* L.)** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **Genetic Analysis of Yield Attributes in Cocoa (Theobroma cacao L.)** is a record of research work done independently by **Mr. Homey Cheriyan** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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We the undersigned, members of the Advisory Committee of **Mr. Homey Cheriyan**, a candidate for the degree of Master of Science in Agriculture, agree that the thesis entitled **'Genetic Analysis of Yield Attributes in Cocoa (*Theobroma cacao* L.)'** may be submitted by Mr. Homey Cheriyan in partial fulfilment of the requirements for the degree.

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Dedicated to

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CONTENTS

LIST OF TABLES

ILLUSTRATIONS

LIST OF APPENDICES

Introduction

1. INTRODUCTION

Cocoa (*Theobroma cacao* L.) which is one of the most important beverage crops in the world, belongs to the family sterculiaceae. It is believed to have originated from the basins of river Amazon in South America. It is a crop of yesteryears, the earliest of its cultivation having been recorded in sixteenth century in Mexico. It spread from Mexico to the Carribean islands from where it was taken across the pacific to Philippines about the year 1600 (Wood and Lass, 1985). It was introduced to India from Ambon in the Moluccas in 1798 (Ratnam, 1961).

In India, commercial cultivation started in the early 1960s but expansion of area under cocoa gained momentum only from 1970s onwards. By 1980-81 the area under cocoa reached 29000 ha with an annual production of 7700 tonnes of beans. A steep fall in prices during early 1980's due to an increase in production accompanied by inadequate capacity of the grinding units to absorb the increased production led to the decline in area under cocoa. At present, cocoa is grown in an area of 16000 ha with a production of 7000 tonnes (1989-90 estimates). Kerala is the principal cocoa growing state in India, accounting for about 80 per cent of the area under cocoa followed by Karnataka. It is generally grown as an intercrop in coconut and arecanut gardens.

Of late, the grinding capacity in the country has increased considerably. According to the 1989-90 estimates, the internal requirement of cocoa beans will be 20,000 tonnes per annum by the year 2000 A.D. (Velappan, 1991) as against the estimated production potential of 7000 tonnes of the existing cocoa plantations in the country. Besides this, the cocoa beans and its derivatives are now projected as an important export item. Thus there is a need to increase cocoa production in India in order to prevent foreign exchange drain in future. For increasing production, crop improvement for raising the productivity forms an important step.

The attempt by United Fruit Company to identify high yielding trees for vegetative propagation in 1916 in Costa Rica was perhaps the first step towards crop improvement in cocoa. In 1943, Posenette revealed the occurrence of heterosis in outcrosses of Upper Amazon parents. This led to the advent of hybrid seed production. However, these programmes did not make the expected impact probably because of the lack of proper understanding of the genetics of the crop.

A sound understanding of the genetic behaviour of the crop is necessary for the success of any crop improvement programme. In order to formulate efficient breeding programmes for improvement of yield, it is essential to characterise the genetic behaviour and mode of inheritance of yield and yield contributing characters. A knowledge on the variability and inheritance of various economic characters will help in choosing the appropriate method of breeding for effecting improvement towards increasing the yield potential of this crop.

With this view in mind, the present investigations were undertaken to fulfil the following objectives.

1. To study the genetic variability between different crosses of cocoa.

2. To study the genetic variability within crosses of cocoa.

3. To study the heritability of characters determining yield in cocoa.

4. To study genetic divergence among progenies of different crosses in cocoa.

5. To study the relationship between yield and various yield attributes.

Review of Literature

2. REVIEW OF LITERATURE

Crop improvement is an integral part of crop cultivation. Cocoa (Theobroma cacao L.) is no exception to this. Though the importance of this species was recognised and it was domesticated in the sixteenth century, the first major attempt towards a systematic crop improvement in cocoa was the germplasm collection by Pound during 1930s from the banks of river Amazon. The great value of 'Pound collection' stimulated further collections from this area which is considered to be the centre of diversity. 'London Cocoa Trade Amazon Project' was one of the extensive programmes which involved a systematic collection of cocoa types in Eastern Ecuador. Various nations and agencies are now involved in the cocoa germplasm collection.

Being a tree crop with long generation time and outcrossing nature, the progress in understanding the genetics and successful breeding programmes in cocoa has been slow.

Breeding work in cocoa was started in Ivory Coast in 1946 and Cameroon in 1949 by IRCC (Institute de Recherches du Cafe et du Cacao, France) which led to the development of hybrids showing precocity and high yield compared to the local varieties. Similar breeding programmes were initiated in a number of other places. However, these programmes made only a weak impact. The major reason projected was narrow genetic base from which most programmes were developed. This added emphasis to increasing genetic variability in the species.

Breeding progrommes can be well orchestrated only when the genetics of the crop is well understood. Unfortunately, due to the perennial and heterozygous nature of cocoa, information on the genetics of the crop is very scanty. Some of the important pieces of work in assessing the variability and inheritance of yield components are given below.

2.1 VARIABILITY

The main objective of cocoa breeding is to increase yield. Yield is a very variable character, made up of several components of quantitative nature and highly influenced by environment.

Studies on the variability of biometric characters in cocoa by Pound (1932,33) in Trinidad and by Enriquez and Soria (1966) in Costa Rica revealed that yield expressed in dry or wet weight of the bean is a very variable character and of a quantitative nature. The dry weight varied from 0.5 g to 2.5 g per seed. High variability in weight of seed was observed even within a single pod. Their studies have also shown that the thickness of the ridge and depth of furrow in the pods are very descriptive character and are partially affected by the environment.

Soria (1975) reported great variation in fruit characteristics like length, diameter, total weight and weight of the husk. Weight of seeds in each pod also exhibited significant variation.

In the proceedings of the seventh International Cocoa Research Conference held at Douala, Cameroon, 14-12 November 1979, suggestions were made for increasing genetic variability and making available more genetic resources to be utilized for future cocoa improvement programmes. Hybridisation was suggested to be one of the methods of achieving this goal. Since outcrossing is insured in many populations of cocoa due to inherent incompatibility systems (Cope, 1962) progeny which are produced by seeds can be loosely referred to as "hybrids" (Hunter, 1990). However, actual hybridisation programme by means of hand pollination was initiated in Trinidad in the 1930s when Pound (1932,33) successfully cross bred different selections or clones. Subsequently other investigations in this line followed and results obtained from such studies elicited such high expectation that this method of sexual reproduction was soon promoted as the most universally satisfactory means of increasing cocoa production (Hunter, 1990). High degree of variability due to segregation resulting from the highly heterozygous seeds produced from crosses was a general observation of most of the workers. Tan (1981) found considerable variation for yield among progenies of Trinitario x Amazon and Trinitario crosses. Hybrid progenies were generally superior to Trinitario. Mejia and Rondon (1981) reported after comparative study of six cocoa hybrids in the Uraba region of Colombia, that the hybrids with scavina genes, such as SCA 6 x ICS 39 and SCA 6 x IMC 67 gave the lowest yield.

Mossu et al. (1981) studied the influence of flowering and pollination on cocoa yields. Amelonado and Amazonian clones were studied and it was reported that the variation in seed yield was entirely due to the variance in flowering and pollination. The Amazonian clones were more profusely flowering than Amelonado clones by about 30 per cent owing largely to more continuous flowering throughout the year. The Amazonian clones also tended to be the better pollinated to have a lower minimum number of fertilised ovules per ovary to ensure absence of fruit drop and to have more ovules per ovary. A yield equation was presented which allows calculation of the number of pods which will reach maturity with a correlation of $r = 0.8$ between observed and calculated results. Similarly the number of seeds obtained can be predicted with an accuracy of one per cent.

Subramonian and Balasimha (1982) reported significant variation among ten hybrids studied for the seven yield components viz., number of pods, dry bean production, pod weight, dry bean weight, bean number, percentage pulp per bean and total soluble solids (%) in the pulp. They noted statistically significant differences between types in pod weight, dry weight of peeled beans, percentage weight of shell, wet to dry bean weight ratio and percentage weight of pulp. The extent of variability was the largest in dry weight of beans followed by pod value.

Engels (1983a, 1983b, 1983c) attempted to study phenetic relationship between 32 clones using upto 33 descriptors and analysing by several multivariate statistical methods. Comparison of the results with known genetic relationships indicated that in such studies the number of traits is less important than the variability of these traits.

Ooi and Chew (1985) conducted five progeny trials on hybrid cocoa in peninsular Malaysia and found that individual hybrids showed considerable variation in performance between sites.

In a study conducted by Cilas et al. (1985) involving 218 trees belonging to three families of hybrids, there was no significant difference between the hybrid families. However, high yielding material was found in all the three.

Pereira *et al*. (1987) evaluated a number of cocoa hybrids under the conditions of Linhares, Espirito Santo. Based on the number of healthy fruits/plant, weight of moist seeds/plant and weight of moist seeds/fruit, the best crosses identified were SIC 24 x ICSI; SICI 9 x ICSI, TSH 565 x SIAL 169, EEG 48 x ICS 8 and TSA 656 x ICS 8. Statistical analysis showed significant genotype, year and genotype x year interaction effects for all traits.

Martin (1987) through his trials with Amelonado and hybrid cocoa in Fiji showed that the variety Amelonado recorded the highest mean yield, with an annual yield of 2106 kg/ha during 1979-85 at Wainigata, although it was outyielded by the hybrids at some sites. Amelonado also showed acceptable pod value and bean weight, tolerance to black pod and adaptability to farmers's fields, justifying its current position as the only recommended variety for Fiji.

A study was conducted in Costa Rica to determine whether the seed position in cocoa fruits affected the seed length, seedling height and stem diameter by Mora in 1989. Seeds were extracted from the central and apical areas of fruits from varieties SPA 9, IMC 67, EET 400 and UF 613. The seed length was determined and flat seeds were counted and discarded. Of the remaining seeds, 20 were sown per variety. The height of seedlings was determined at 23, 36, 57, 93 and 120 days, and the stem diameter at 1, 2, and 3 months. It was reported that seeds originating from the fruit apex were shorter, and that flat seeds were few and only found in the apical areas of some fruits of varieties EET 400 and SPA 9. The position of the seed within the fruit had no specific effect on the seedling stem diameter and seedling height.

Clones are a group of plants derived from a single plant by vegetative propogation. Clones being genetically similar should be uniform among themselves for various characters. However, variability has been reported among the clones. Cilas et al. (1989) conducted a study with twenty clones belonging to Upper Amazon, Amelonado and Trinitario types. Bean size was extremely variable but tended to be greatest in Trinitario types; average bean weight per 100 fermented and dried beans ranged from 212.6 g for clone UF 66F (Trinitario) to 67.5 g for SCA 6 (Upper Amazon). Bean weight decreased in successive harvest and seemed to depend partly on pod filling rate.

Napitupulu (1990) evaluated clones introduced from Kew Royal Botanical Gardens, U.K. and Wageningen, Netherlands from 1984 to 1989 at Adolina, Indonesia. The best clones yielded

20-40 per cent more than hybrid seedlings. Iquitos Mixed Calabacillo (IMC) clones gave the greatest number of the smallest beans. United Fruit (UF) clones gave a few large beans, while Pa (Parinari) clones gave a moderate number of medium sized beans. Anwar and Napitupulu (1990) reported significant interaction of hybrid x density on growth parameters except for percentage jorquetting of the 12 months old plants. There were significant differences in vegetative growth also between the hybrids.

In one of the studies carried out to evaluate nine accessions of cocoa for yield and related characters, ICS 1 and ICS 6 performed best for number of pods per plant and bean yield (Nair et al., 1990). These two accessions were superior to the rest with respect to plant height and canopy spread as well. Single bean weight was greatest in IMC 67 (2g) and this accession had the best pod value.

In a study carried out in Central Plantation Crop Research Institute, Vittal, Karnataka, India, Bopaiah and Bhat (1989) reported the effect of season on harvest pattern and the pod and bean characters of cocoa. The wet season accounted for 42.75 per cent of the total harvest and the remaining 57.25 per cent was harvested during the dry period. The studies on pod characters indicated that the pod weight was low in wet season as compared with the dry season.

Analysis of the bean characters revealed a high pulp percentage and lower total soluble solids and bean weight in the wet season as compared with the dry season.

In a review on the improvement of cocoa crop, Hunter (1990) has come to the conclusion that at present, there are no effective long range on-going programmes in any tropical country of the Western hemisphere dedicated to the improvement of cocoa. While some efforts are currently made to obtain new acquisitions of cultivars exhibiting desirable characteristics and to maintain genepools of these trees, there are few data from field trials to prove and substantiate these qualities. He further adds that there is a growing concern regarding the disparities between predicted yields of cocoa trees through the use of hybrid seeds and from actual production under field conditions. This has stimulated an awareness of the current inadequate understanding of the genetics of cocoa and the lack of comprehension as to which cultivars under distinct ecological conditions are precocious, resistant to diseases, heavy bearing or demonstrate those traits vital to the success of farming programmes adopted to today's market conditions.

According to Barriga et al. (1992) the systematic collections of germplasm, which have been made in various zones of the Amazon basin since 1965 have revealed large phenotypic variability and wide dispersion of the species.

The accessions have been propagated and maintained in a germplasm bank in Belem. Evaluation of the material since 1982 has identified genotypes of potential value in the breeding programmes.

2.2 HERITABILITY

In crop improvement, the genetic component of variation is most important since only this component is transmitted to the next generation. Heritability denotes the proportion of phenotypic variance that is due to the genotype and is heritable. In cocoa, information on the genetic behaviour of the crop is scanty. Some of the earlier genetic studies of cocoa carried out in Ghana revealed the occurrence of heterosis in outcrosses of Upper Amazon parents (Posnette, 1943). A general occurrence of the heterotic behaviour of outcross progenies of these parents was later confirmed in Trinidad (Montserrin et al., 1957). The discovery of strong interpopulation heterosis provides the basis for almost all modern cocoa breeding programmes (Toxopeus, 1972).

One of the earlier studies on the genetics of yield and yield attributes carried out in Ghana by Glendinning (1963) indicated that the number and size of beans in cocoa are highly heritable traits and pod weight has a direct correlation to these characters.

Soria and Esquivel (1968) studied the number of ovules per tree of crosses between contrasted genotypes and found a high frequency of F_1 progenies approaching the parent with small number of ovules. This suggested a possible dominance of small number of beans per fruit.

The inheritance of fruit size was studied by Soria et al. (1974). They found heritability for fruit length to be 55 per cent, for fruit diameter 63 per cent and total weight 57 per cent indicating that these are highly transmissible character. Studies on the general combining ability and heritability of yield and its components carried out using individual tree bean wet weight records of 48 F_1 hybrids, representing top crosses of six Trinitario and two Criollo clones, crossed to six Amazon clones, showed that heritability estimates by ratio of additive genetic variance to the total phenotypic variance for wet bean production from three year records was 17.3 per cent (Soria et al., 1974). But this was 89 per cent when the estimate was based on one season's production. Heritability for number of beans per fruit calculated based on one season's data was 43 per cent. Open-pollinated F_1 progenies of 57 inter-Nanay and 99 inter-Parinari introductions in Nigeria were assessed for growth, precocity and black pod incidence (Atanda et al., 1975). The results obtained indicated that inter-Nanay were generally superior to inter-Parinari progenies. Of the fourteen progenies selected for outstanding growth and yield, inter-Nanay accounted for about 78 per cent. When pod yield and black pod incidence were considered together, three progenies, all inter-Nanay, came out as most outstanding. In all these three progenies Na 387 was involved either as male or female parent. Eight hybrid progenies and open pollinated progenies of Amelonado and Purboya were tested against DR 2 clones as control at four locations in Central Java (Soenaryo and Soedarsono, 1980). Except the SCA 8 x DR 2 progenies, all the hybrids showed a significantly better growth and precocity and a higher yield during the first year than Amelonado, Purboyo and DR 2. ICS 60 x SCA 12, DR 2 x SCA 12 and SCA 6 x ICS 6 consistently gave the most satisfactory results at all testing locations.

Kumaran and Prasannakumari (1981) studied nine characters in 25 ten year old trees. Heritability estimates were high for weight of bean with pulp and cotyledon weight while it was low for number of beans per pod. Non-additive gene action was indicated for all characters.

In a study conducted for information on compatibility in different pollination systems in cocoa, Capitupulu (1984) reported that self-pollination resulted in lower fruit setting compared to cross-pollination. He also found that reciprocal crosses showed differences between clones used as male or as female parents for fruit setting. The lower fruit setting in related parent crosses suggested that a mixture of hybrid varieties would produce higher setting and pod production than a monohybrid stand.

Engels (1985) using a diallele cross among 7 clones studied the genetics of eight fruit characters. General combining ability effects were significant for all the characters. Specific combining ability effects were significant for maximum number of fruits, total seed weight per fruit and production efficiency (expressed as a formula in the text). There were no significant reciprocal effects and heterosis was not important for any of the characters studied.

Cluster and principal components analysis using 39 characters were carried out to group 294 cultivars (mainly clones) by Engels (1986a). He found that the distribution of these cultivars corresponded roughly to the traditional classification into Criollo, Forastero and their sub-divisions. In a study for systematic description of a germplasm collection, methods were developed to measure and compare the descriminative values of both qualitative and quantitative characters (Engels, 1986b). Relationship between clones were studied to determine their influence on the value of the discriminatory power of a given character for a given group of clones. The inheritances of qualitative and quantitative characters were studied using data from a complete diallele cross to determine the relationship between the discriminative value of a character and its inheritance. No such relationship could be established. At the same time there were strong indications that the qualitative characters examined followed tetraploid rather than diploid inheritance.

Lopez et al. (1988) produced a 7 x 7 diallele cross with clones SCA 6, Pound 7, Cantonga, UF 29, UF 613, UF 676 and CC 42 at Turrialba and La Lola, Costa Rica. From a sample of six flowers per tree, the number of ovules per ovary was determined by staining microscopy. Results suggested that number of ovules is an inherited trait, quantitatively controlled by more than one gene pair. Broad sense heritability was 79.4 per cent and 74.2 per cent at Turrialba and La Lola, respectively. Pound 7 and SCA 6 showed high gca while Cantonga exhibited only moderate gca.

Cilas et al. (1988) studied the growth of the collar diameter in an almost complete 8 x 8 diallele of cocoa trees excluding selfing involving three Upper Amazon, two Trinitario and three Amelonado lines. It indicated that the Upper Amazon trees had significant positive gca for growth of collar diameter between 7 and 14 months after planting. Maternal effects were positive or negligible for Upper Amazon and

Trinitario while it was consistantly negative for all the Amelonado lines. The sca and reciprocal effects were not significant. Growth of collar diameter amongst living plants was inversely related to the number of deaths per cross. It was concluded that Upper Amazon x Upper Amazon crosses could be useful in breeding schemes.

In an experiment of 7 x 7 diallele involving cultivars and double hybrids of cocoa, Ramirez and Enriquez (1988) showed that characters like length, diameter and weight of pods, number of beans, wet bean weight, husk weight and pod and bean indices had high heritability ranging from 63-93 per cent. Low heritability was observed for pod husk thickness.

Cilas et al. (1989) reported that heritability for bean weight in cocoa was very high ($h^2 = 0.66$). This was based on a study using 20 clones.

Two cocoa trials involving twenty five progenies in trial-1 and sixteen progenies in trial-2 grown under inland conditions in peninsular Malaysia were conducted by Palaniappan and Shamsuddin (1989). The results indicated that yield, expressed as both pod production per tree and kg dry bean (kdb) production per ha, showed significant differences among progenies for both trials. Seasonal influences seemed more pronounced than progeny effect for pod production in both trials. The reverse was the trend for kdb production per ha. Progeny x seasonal interaction was non-significant for both trials and for both yield expressions. Heritability (h^2w) was 93 per cent for pod production and .88 for kdb production for trial-1. A factorial analysis of pod weight, bean weight and bean number was carried out for five random progenies from trial-1 and five from trial-2 where UIT 1 was the common female. The first trial exhibited significant differences for bean weight and bean number while the second did not. Bean weight was significantly influenced by season but pod weight was not. Bean and pod weight showed no significant interaction with season. Heritability estimate (h^2w) was 5 per cent for pod weight, 94 per cent for bean weight and 55 per cent for bean number. Significant correlation for pod weight with bean weight and bean number was obtained. Bean number with bean weight generally showed no correlation for various progenies and individual genotypes analysed.

Exploring the possibilities for developing F_1 hybrids of cocoa having good productivity and uniformity, Pinto et al. (1990) after a thorough search of available literature, started work on ways of reducing the long juvinile period and need for large areas for field trials by reducing the number of generations and number of years per cycle of endogamous breeding. They recommended successive self-fertilization or diploidization of haploid obtained from immature seeds as the method of breeding.

Advance genetic techniques are now reported to be applied to cocoa crop. Sirjo-Charrán et al. (1991) attempted isozyme analysis for the identification of duplicate material in the International Cocoa Gene Bank.

Wilde et al. (1991) reported characterisation of cocoa clones using DNA based markers. Randomly amplified polymorphic DNA (RAPD) markers were used to characterize cocoa clones representing the three main cultivated sub population, Criollo, Forastero and Trinitario.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation on variability and estimation of genetic parameters in population of cocoa (Theobroma cacao L.) consisting of F_1 hybrids and their parents maintained at the farm attached to the College of Horticulture, Vellanikkara was undertaken during 1992-93. A brief description of the materials used and methods followed is given below.

3.1 MATERIALS

With the inception of the Kerala Agricultural Development Project (K.A.D.P.) in 1978-79 at the Kerala Agricultural University, germplasm collection and work in crop improvement of cocoa (Theobroma cacao L.) were initiated. From 1987, it was continued under the Cadbury-KAU Co-operative Cocoa Research Project (CCRP). The germplasm available in the KAU farm includes seven different collections, namely, Germplasm I, II, III, IV, V, VI and Mannuthy local. The hybrids included for this study owe their parentage to Germplasm I, II, VI and Mannuthy local.

3.1.1 Germplasm I

This is a group of plants arising from pods of 15 selected trees introduced from the Cocoa Research Institute of Ghana in 1978 and field planted in 1979. The entries of this collection included under the study are GI-4.8, GI-5.9, GI-10.3 and GI-15.5. These are open pollinated Amazonian types. GI-5.9 is a Scavina entry whereas GI-15.5 is an open pollinated Amazonian belonging to the Pound's collection obtained from Equitos.

3.1.2 Germplasm-II

This collection established in 1980 includes seedling population of 80 types collected from promising plants of various plantations of Kerala. The plants included from this collection in the study belong to GII-20.4 and GII-19.5.

3.1.3 Germplasm-VI

This is a collection of vegetatively propagated types, originally established in 1983 with a total of 126 types collected from Central Plantation Crops Research Institute (CPCRI), Regional Station, Vittal, Cadbury farm, Thamarassery, RARS, Pilicode and CPCRI substation, Kannara. This collection includes nearly all the cocoa types introduced into the country till then from time to time. Plants from this group taken for the study represent GVI-54, 55, 56, 61, 64, and 68. GVI-54 is budded from SIAL-93 and GVI-55 from IMC-10. GVI-56 is budded progeny of EET-272 (Equador collection). GVI-61 and

64 are budded progenies of accessions C_6 and C_3 respectively, maintained at Chundale, Wynad district, Kerala. GVI-68 is budded progeny of P_{7c} of Pound's collection.

3.1.4 Mannuthy local

This group of plants were raised from seeds of pods collected from high yielding plants selected from the population maintained at KAU farm at Mannuthy. The plants included under this study belong to M-9.16, M-13.12 and M-16.9.

3.1.5 Hybrids

The hybrids used for this study are the ones produced as part of the first stage of breeding programme of the Cadbury-KAU Co-operative Cocoa Research Project. Two sets of crosses were made. The first set involved three selected plants of Mannuthy local as common parents and these were crossed with 24 selected plants of Germplasm I, II and VI, making a total of 72 cross combinations. The second set of crosses involved five plants from Germplasm I and 11 from Germplasm VI, making a total of 55 cross combinations. Some of these crosses were made during 1984-85 and the rest during 1985-86. The progenies of these crosses are known as series-I hybrids and series-II hybrids, respectively.

3.1.5.1 Series-I hybrids: These are hybrids which were produced by hand pollination during 1984-85 and include crosses of parents from both set-I and set-II combinations. Pods were collected during 1985-86 and seedlings raised. Selection of cross combination was made based on HD^2 (H-height, D-stem diameter) of six months old hybrid seedlings. A total of seven crosses were selected and planted in the field in rows in 1986 along with the budded progenies of their parents. The population reached stable bearing stage by 1990.

3.1.5.2 Series-II hybrids: These hybrids were produced by hand pollination in 1985-86 and include the combinations of set-I and set-II crosses.

Pods were collected and seedlings raised in 1986-87. Selection of the crosses was done based on HD^2 value at seedling stage after six months. A total of 12 hybrids were selected. The selected hybrids were field-planted in rows along with the budded progenies of their parents in 1987. The population reached stable bearing by 1991.

The hybrids included for this study along with the parents are given in Table 1. Plants belonging to the above mentioned 19 hybrid combinations and their parents comprised the material for the present study. The material is planted in two blocks, one with plants of 1986 planting and another with plants of 1987 planting. Each of the hybrids as well as

Table 1. Hybrids and parents of cocoa included for the study

Sl. No.	Hybrids	Sl. No.	Parents
	Series I - 1986 planting		1986 planting
1.	H_1 (G I-5.9 x G VI-54)	1.	G I-15.5
2.	H_2 (G I-10.3 x G VI-54)	2.	G VI-68
3.	H_3 (G I-15.5 x G VI-54)		1987 planting
4.	H_4 (G I-15.5 x G VI-55)	3.	M-9.16
5.	H_5 (G I-10.3 x G VI-61)	4.	M-13.12
6.	H_6 (G I-10.3 x G VI-64)	5.	M-16.9
7.	H_7 (G I-5.9 x G VI-68)	6.	G I-4.8
	Series II - 1987 planting	7.	G I-5.9
8.	H_1 (G I-15.5 x G VI-64)	8.	G I-10.3
9.	H_2 (M-13.12 x G I-5.9)	9.	G II-20.4
10.	H_3 (M-16.9 x G II-20.4)	10.	G II-19.5
11.	H_4 (M-16.9 x G II-19.5)	11.	G VI-54
12.	H_5 (G I-10.3 x G VI-56)	12.	G VI-55
13.	H_6 (G I-5.9 x G VI-61)	13.	G VI-56
14.	H_7 (G I-5.9 x G VI-55)	14.	G VI-61
15.	H_8 (M-16.9 x G I-4.8)	15.	G VI-64
16.	H_9 (M-16.9 x G VI-55)		
17.	H_{10} (M-9.16 x G VI-20.4)		
18.	H_{11} (M-16.9 x G VI-56)		
19.	H_{12} (G I-4.8 x G VI-54)		

parents are planted in single row plots. In case of the hybrids, depending on the availability, 5-12 plants from each row were used for the study. Parents being budded progenies of single plant only 4-5 plants per row were selected.

3.2 METHODS

Observation on yield and 15 yield contributing characters of 244 steady bearing plants were recorded from April, 1992 to March, 1993.

The crop was harvested at an interval of 2-3 weeks and observations recorded. The yield and number of pods were estimated including the pods which were fully formed but damaged by pests and diseases. For all other pod and bean characters only the undamaged ripe pod were considered. The different characters recorded are detailed below.

3.2.1 Characters studied

3.2.1.1 Yield - Yield is estimated in terms of total wet bean weight produced per tree and is calculated by the formula given below.

Yield per tree = Total number of pods x Mean wet bean weight per pod

3.2.1.2. Pod characters

3.2.1.2.1. Number of pods: The pods harvested were numbered in the field itself and the number of pods of each tree in each harvest was recorded.

3.2.1.2.2. Pod length: Length of each pod harvested was measured in centimeters using a scale and data recorded. The average pod length for each tree was calculated.

3.2.1.2.3. Pod width: The width of each pod harvested was measured in centimeters using a scale and data recorded. The average pod width for each tree was calculated.

3.2.1.2.4. Pod weight: The weight of each pod harvested was measured in grams using a common balance and the data recorded. The average pod weight was calculated for each tree.

3.2.1.2.5. Fruit wall thickness at ridge: The thickness of fruit wall at ridge was measured for each pod harvested in millimeters using vernier callipers after cutting open the pod and the data recorded. The average fruit wall thickness at ridge was calculated for each tree.

3.2.1.2.6. Fruit wall thickness at furrow: The procedure was the same as followed in the case of fruit wall thickness at ridge except that the measurement was taken at the furrow.

3.2.1.2.7. Ratio of pod length to pod width: This was calculated for each tree.

$$\text{Ratio PL/PW} = \frac{\sum (\text{Pod length/Pod width})}{\text{Number of pods}}$$

3.2.1.3. Bean characters

3.2.1.3.1. Number of beans per pod: The number of beans in each pod was counted and data recorded. The average number of beans per pod of each tree was calculated.

3.2.1.3.2. Wet bean weight per pod: Pods were broken open and wet beans collected. Weight of wet beans for each pod was taken using a common balance and data recorded. The average wet bean weight per pod of each tree was calculated.

3.2.1.3.3. Dry bean weight: In each harvest, wet beans collected from pods of a tree were mixed together and 20 beans were collected at random. They were peeled and dried in the oven at 50-60°C for 4-5 days. The dried seeds were weighed on a digital balance and data recorded in grams. For analysis, the dry bean weight was weighted against the number of beans and is given by the formula.

$$\text{Weighted dry bean weight} = \frac{\sum (\text{Dry bean weight x Number of beans})}{\text{Total number of beans}}$$

3.2.1.3.4. Seed length: Of the 20 seeds collected per tree for dry bean weight, five beans were selected at random after peeling. The length of the seeds was measured using vernier callipers and data recorded . From this, the average seed length for a tree for a harvest was calculated. For analysis, seed length is weighted against number of seeds as given below.

$$\text{Weighted seed length} = \frac{\sum(\text{Seed length x Number of beans})}{\text{Total number of beans}}$$

3.2.1.3.5. Seed width: The procedure was the same as in the case of seed length.

$$\text{Weighted seed width} = \frac{\sum(\text{Seed width x number of beans})}{\text{Total number of beans}}$$

3.2.1.3.6. Seed thickness: The procedure followed was the same as that of seed length.

$$\text{Weighted seed thickness} = \frac{\sum(\text{Seed thickness x number of beans})}{\text{Total number of beans}}$$

3.2.1.3.7. Ratio of dry bean weight to wet bean weight: This was calculated using the formula,

Ratio of dry bean weight to wet bean weight

$$= \sum\left(\frac{\text{Dry bean weight x Number of beans}}{\text{20 x Wet bean weight}}\right) / \text{Number of pods}$$

3.2.1.3.8. Ratio of seed length to seed width: This was calculated for each tree using the formula,

$$\text{Ratio of seed length to seed width} = \frac{\sum (\text{Seed length/seed width})}{\text{Number of pods}}$$

3.2.2. Statistical analysis

The analysis of variance was worked out for all the 16 characters as done for CRD experiments using M-stat software package.

Coefficient of variation in the hybrid and parent population with respect to each character studied was estimated using the formula:

$$\text{Coefficient of variation} = \frac{\sqrt{\dfrac{\text{Total sum of squares}}{\text{Total degrees of freedom}}}}{\text{Mean}} \times 100$$

Genetic parameters like additive genetic variance, variance due to dominance deviation and coefficient of heritability were estimated by full sib analysis as per the formulae given below. Statistical model adopted for the analysis is,

$$Y_{ijk} = \mu + S_i + d_{ij} + e_{ijk}$$

where,

Y_{ijk} = performance of the k^{th} progeny of the cross between j^{th} female and i^{th} male

μ = effect common to all individuals

S_i = effect due to i^{th} male with $E(S_i) = 0$, $V(S_i) = \sigma^2 s$

d_{ij} = effect due to j^{th} female mated to i^{th} male with $E(dij) = 0$, $V(dij) = \sigma^2 m$

e_{ijk} = random effect due to error with $E(e_{ijk}) = 0$, $V(e_{ijk}) = \sigma_w^2$

i = 1, 2, 3, ... s

j = 1, 2, 3, ... d

k = 1, 2, 3, ... nij

Anova was worked out and variance split as given below:

ANOVA

Source of variation	df	MSS	$\underline{E}$ (MS)
Between male parent	S-1	A	$\sigma_w^2 + \lambda_2 \sigma_m^2 + \lambda_3 \sigma_s^2$
Between female parents within male parents	$\sum_i^s d_1 - 1$	B	$\sigma_w^2 + \lambda_1 \sigma_m^2$
Within female parents within male parents	$\sum_i^s \sum_j^{d_1} (nij-1)$	C	σ_w^2
Total	$\sum_i^s \sum_j^{d_1} nij-1$		

where,

$$\lambda_1 = \frac{1}{\Sigma_i (d_1 - 1)} \left[N - \sum_{i=1}^{s} \left(\sum_{j=1}^{di} \frac{nij^2}{N_i} \right) \right]$$

$$\lambda_2 = \frac{1}{S-1} \left[\sum_{i=1}^{s} \sum_{j=1}^{di} - \frac{nij^2}{N_1} - \sum_{i=1}^{s} \sum_{j=1}^{di} \frac{nij^2}{N} \right]$$

$$\lambda_3 = \frac{1}{S-1} \left[N - \frac{1}{N} \sum_{j} Ni^2 \right]$$

Additive genetic variance is calculated by the formula;

$$\sigma_S^2 = \frac{1}{4} \hat{V}_A$$ where V_A is the additive genetic variance.

Variance due to dominance deviation is calculated using the formula;

$$\sigma_m^2 = \frac{1}{4} \hat{V}_A + \frac{1}{4} \hat{V}_D$$ where V_D is the variance due to dominance deviation.

Coefficient of heritability is calculated using the formula;

$$\hat{h}^2 = \frac{4 \sigma_S^2}{\hat{\sigma}_S^2 + \hat{\sigma}_m^2 + \hat{\sigma}_w^2}$$

where $\hat{h}^2$ is the estimated coefficient of heritability.

σ_S^2 = Variance between male parents

σ_m^2 = Variance between female parents within male parents

σ_w^2 = Variance within female parents within male parents

Genetic divergence was studied by clustering the genotypes based on eucledian distance between every pair of genotypes making use of 15 characters under investigation.

Path coefficient analysis was done using SPAR 1 software package.

Results

4. RESULTS

Observations were taken on 16 characters including yield as well as pod and bean characteristics of 244 cocoa trees consisting of 19 hybrids and 15 parents for a period of one year. The data were subjected to statistical analysis for studying variability, heritability and genetic divergence. The results are presented below.

4.1. VARIABILITY STUDIES

Analysis of variance was performed separately for the hybrids and the parents for each of the 16 characters studied. Separate analysis was carried out for hybrids and parents as a single population for yield recorded as wet bean weight per tree and number of pods per tree. Since the estimates of the coefficient of variation was relatively high for some of the characters, the data were subjected to square root transformation in such cases and further analysis was carried out using the transformed data. Square root transformation of the data was also resorted to in cases where heterogeneity was high as indicated by the Bartlett's test for homogeneity.

4.1.1. Hybrids

Variability studies were carried out using 19 hybrids.

Data were recorded from a total of 176 plants belonging to these crosses. Results obtained for the various characters studied are presented below.

4.1.1.1. Yield - Yield, expressed as the total weight of wet bean produced per tree, was recorded during 1991-92 from 176 trees belonging to 19 hybrids. The data given in Table 2 shows that the yield per tree had a wide range. Plant no.1 in H7 of series I recorded the highest yield of 9271.99 g. The mean yield was also the maximum for H7 of series I crosses with a value of 4897.02 g. The lowest value was recorded in plant no.14 in H4 of series I. But the mean yield was lowest for hybrid H12 of series II crosses. The coefficient of variation was very high with the value of 57.61 per cent. The coefficient of variation on square root transformation came down to 30.53 per cent. Analysis of variance done using transformed data showed that the hybrids differed significantly among themselves, the F-value being significant at P = 0.0007. Hybrid H7 of series I with the highest mean yield was on par with H3 and H4 of series I and H2, H4 and H6 of series II. All the hybrids with G I-15.5 as one of the parents were among the best group of hybrids except for H1 of series II which belongs to the second best group. Out of the five hybrids with G I-5.9 as one of the parents, H7 of series I, H2 and H6 of series II were among the top six hybrids.

Table 2. Range and mean of yield in the 19 hybrids of cocoa

Sl. No.	Genotypes	No. of trees	Range (g)	Mean* (g)		
	Series I (1986 planting)					
1.	H1(G I-5.9 x G VI-54)	7	935.06-4140.98	48.58	(2519.08)	bcdef
2.	H2(G I-10.3 x G VI-54)	10	1027.88-5947.02	53.71	(3121.45)	bcde
3.	H3(G I-15.5 x G VI-54)	5	1852.88-5266.08	61.61	(4032.36)	ab
4.	H4(G I-15.5 x G VI-55)	8	134.27-6310.69	58.37	(3407.10)	abc
5.	H5(G I-10.3 x G VI-61)	8	621.26-6368.94	48.47	(2349.50)	def
6.	H6(G I-10.3 x G VI-64)	10	720.96-5676.56	47.81	(2631.50)	bcdef
7.	H7(G I-5.9 x G VI-68)	10	2139.69-9271.99	68.16	(4897.02)	a
	Series-II (1987 planting)					
8.	H1(G I-15.5 x G VI-64)	12	555.48-6480.60	54.97	(3294.30)	bcd
9.	H2(M-13.12 x G I-5.9)	11	1457.58-6601.98	58.61	(3577.69)	abc
10.	H3(M-16.9 x G II-20.4)	11	916.38-4683.72	51.44	(2786.16)	bcde
11.	H4(M-16.9 x G II-19.5)	11	1826.31-6982.95	57.98	(3554.95)	abc
12.	H5(G I-10.3 x G VI-56)	9	939.44-6458.65	48.00	(2493.54)	bcdef
13.	H6(G I-5.9 x G VI-61)	10	309.33-6083.49	57.24	(3600.35)	abc
14.	H7(G I-5.9 x G VI-55)	9	1268.08-5418.16	48.24	(2472.14)	bcdef
15.	H8(M-16.9 x G I-4.8)	7	459.60-4044.48	44.26	(2232.34)	bcdef
16.	H9(M-16.9 x G VI-55)	9	898.66-3851.40	44.88	(2111.13)	bcdef
17.	H10(M-9.16 x G II-20.4)	11	395.16-4643.13	41.26	(1948.83)	ef
18.	H11(M-16.9 x G VI-56)	9	1076.70-3876.12	46.91	(2201.25)	cdef
19.	H12(G I-4.8 x G VI-54)	9	346.84-2341.17	36.33	(1319.90)	f
F (P = 0.01)				S		
C.V.				30.53%		

* Transformed data. The figures in paranthesis are in the original scale

Mean values with common letters do not differ significantly

Hybrid H1 of series I and H7 of series II crosses were among the medium yielders. Of the five hybrids with M-16.9 as one of the parents, one belonged to the best group identified among the hybrids, three belonged to the second best group while one gave comparatively low yield. Bartlett's test was non-significant, indicating that the error variance was uniform.

4.1.1.2. Pod characteristics

4.1.1.2.1. Number of pods - Data on number of pods harvested during 1992-93 from different genotypes are presented in Table 3. High amount of variation was seen for the number of pods produced per plant. It varied from 1 to 91. The highest pod number of 91 was recorded for plant no.1 of H7 in series I crosses. The average number of pods was also highest for H7 of series I crosses (48). The lowest number of pods was recorded in plant no.14 of H4 in series I crosses (1). The average number of pods per plant was least for H12 in series II crosses. Coefficient of variation was found to be as high as 58.85 per cent. On square root transformation of the data, coefficient of variation came down to 30.97 per cent. Analysis of variance of the transformed data revealed that the hybrids differed significantly among themselves with respect to this character. Hybrid H7 in series I, which gave the highest mean number of pods, was on par with three hybrids of

Table 3. Range and mean of number of pods in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range	Mean*
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	14-62	5.94 (37.71) abc
2.	H2(G I-10.3 x G VI-54)	10	14-81	6.26 (42.50) ab
3.	H3(G I-15.5 x G VI-54)	5	19-81	6.38 (43.40) ab
4.	H4(G I-15.5 x G VI-55)	8	1-47	5.03 (25.37) bcd
5.	H5(G I-10.3 x G VI-61)	8	8-82	5.50 (30.25) bcd
6.	H6(G I-10.3 x G VI-64)	10	8-63	5.03 (29.20) bcd
7.	H7(G I-5.9 x G VI-68)	10	21-91	6.74 (48.00) a
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	6-70	5.71 (35.58) abc
9.	H2(M-13.12 x G I-5.9)	11	17-77	6.33 (41.72) ab
10.	H3(M-16.9 x G II-20.4)	11	9-46	5.09 (27.36) bcd
11.	H4(M-16.9 x G II-19.5)	11	13-65	5.59 (33.09) abc
12.	H5(G I-10.3 x G VI-56)	9	8-55	4.42 (21.22) cd
13.	H6(G I-5.9 x G VI-61)	10	3-59	5.65 (35.10) abc
14.	H7(G I-5.9 x G VI-55)	9	11-47	4.49 (21.44) cd
15.	H8(M-16.9 x G I-4.8)	7	5-44	4.61 (24.28) bcd
16.	H9(M-16.9 x G VI-55)	9	7-30	3.96 (16.44) d
17.	H10(M-9.16 x G II-20.4)	11	4-47	4.15 (19.72) d
18.	H11(M-16.9 x G VI-56)	9	10-36	4.41 (20.44) cd
19.	H12(G I-4.8 x G VI-54)	9	4-27	3.81 (15.22) d
F (P=0.01)				S
C.V.				30.97%

* Transformed data. The figures in paranthesis are in the original scale.

Mean values with common letters do not differ significantly.

series I, namely, H1, H2, and H3 and four hybrids in series II, namely, H1, H2, H4 and H6. All combinations of the parent G I-5.9, except H7 in series II, were placed among the best eight hybrids. Hybrid H7 of series II belonged to the second best group among the hybrids studied. Bartlett's test was not significant.

4.1.1.2.2. Pod length - The values varied from 9.4 cm to 18.35 cm, the highest being for plant no.13 in H9 of series II crosses (Table 4). The average pod length recorded was also highest (15.6 cm) for this hybrid. Pod length was minimum (11.2 cm) in H1 of series I crosses. The data show that in general the pod length was higher for progenies of series II crosses. Coefficient of variation was found to be 9.96 per cent.

Analysis of variance revealed that the crosses differed significantly with respect to this trait. Six hybrids in the series II crosses were ranked first followed by another six of the same series, indicating the general superiority of series II crosses as far as pod length is concerned.

4.1.1.2.3. Pod width - The 19 hybrids differed significantly with respect to pod width recorded during the study period (Table 5). The values ranged from 5.5 cm to 9.3 cm. The

Table 4. Range and mean of pod length in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range (cm)	Mean (cm)
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	9.93-12.62	11.16 i
2.	H2(G I-10.3 x G VI-54)	10	9.40-13.62	12.12 hi
3.	H3(G I-15.5 x G VI-54)	5	10.87-12.30	11.69 hi
4.	H4(G I-15.5 x G VI-55)	8	12.08-15.50	13.76 cdefg
5.	H5(G I-10.3 x G VI-61)	8	11.33-15.25	13.14 efgh
6.	H6(G I-10.3 x G VI-64)	10	11.62-17.16	13.71 defg
7.	H7(G I-5.9 x G VI-68)	10	12.14-14.07	12.84 fgh
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	10.25-16.87	13.08 efgh
9.	H2(M-13.12 x G I-5.9)	11	10.56-15.012	12.82 gh
10.	H3(M-16.9 x G II-20.4)	11	12.16-17.12	14.72 abcd
11.	H4(M-16.9 x G II-19.5)	11	12.53-17.09	15.22 ab
12.	H5(G I-10.3 x G VI-56)	9	13.08-17.44	14.94 abc
13.	H6(G I-5.9 x G VI-61)	10	12.88-15.5	14.04 cdef
14.	H7(G I-5.9 x G VI-55)	9	11.50-16.04	14.06 bcdef
15.	H8(M-16.9 x G I-4.8)	7	12.77-18.00	14.75 abcd
16.	H9(M-16.9 x G VI-55)	9	14.75-18.35	15.62 a
17.	H10(M-9.16 x G II-20.4)	11	12.44-16.33	14.10 bcde
18.	H11(M-16.9 x G VI-56)	9	12.55-16.57	14.88 abcd
19.	H12(G I-4.8 x G VI-54)	9	11.33-14.50	12.35 hi
F (P=0.01)				S
C.V.				9.96%

Mean values with common letters do not differ significantly

Table 5. Range and mean of pod width in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range (cm)	Mean (cm)	
	Series I (1986 planting)				
1.	H1(G I-5.9 x G VI-54)	7	5.75-6.55	6.31	fg
2.	H2(G I-10.3 x G VI-54)	10	6.16-7.95	7.076	bcde
3.	H3(G I-15.5 x G VI-54)	5	6.97-7.80	7.37	abcd
4.	H4(G I-15.5 x G VI-55)	8	7.16-8.37	7.65	ab
5.	H5(G I-10.3 x G VI-61)	8	5.58-6.61	6.04	g
6.	H6(G I-10.3 x G VI-64)	10	6.37-8.06	7.09	bcde
7.	H7(G I-5.9 x G VI-68)	10	5.96-7.00	6.63	efg
	Series-II (1987 planting)				
8.	H1(G I-15.5 x G VI-64)	12	6.12-9.00	7.40	abcd
9.	H2(M-13.12 x G I-5.9)	11	6.86-8.00	7.26	abcd
10.	H3(M-16.9 x G II-20.4)	11	6.07-8.00	7.17	abcde
11.	H4(M-16.9 x G II-19.5)	11	6.00-8.38	7.44	abcd
12.	H5(G I-10.3 x G VI-56)	9	6.07-8.27	7.49	abc
13.	H6(G I-5.9 x G VI-61)	10	5.50-8.00	6.68	ef
14.	H7(G I-5.9 x G VI-55)	9	6.00-7.87	7.15	abcde
15.	H8(M-16.9 x G I-4.8)	7	6.00-9.25	6.91	cdef
16.	H9(M-16.9 x G VI-55)	9	6.85-8.55	7.68	a
17.	H10(M-9.16 x G II-20.4)	11	5.67-8.00	6.68	ef
18.	H11(M-16.9 x G VI-56)	9	6.50-8.10	7.36	abcd
19.	H12(G I-4.8 x G VI-54)	9	5.86-7.71	6.84	def
F (P=0.01)				S	
C.V.				9.01%	

Mean values with common letters do not differ significantly

maximum mean pod width of 7.7 cm was recorded in H9 of series II crosses and this was on par with seven other crosses of this series and two in series I crosses. The coefficient of variation for the character was 9.01 per cent. Bartlett's test for homogeneity was significant at 0.014 level of probability.

4..1.1.2.4. Pod weight - Data on pod weight are presented in Table 6. The maximum pod weight of 640 g was recorded in plant no.2 of H10 in series II crosses and the minimum weight of 138.75 g was in plant no.6 of H1 in series I crosses. With respect to mean pod weight, H9 of series II crosses was showing a maximum of 408.2 g while H1 of series I crosses recorded a minimum of 188.6 g.

The hybrids differed significantly for pod weight as revealed by the analysis of variance. Among the series I crosses, hybrid H4 was found to be significantly superior with a pod weight of 387 g. Of the 12 hybrids of series II crosses, H4, H5, H9 and H11 were on par and superior to the rest of the hybrids. A perusal of the data indicates that hybrids with M-16.9 as female parent generally gives a higher pod weight. Coefficient of variation for the data was calculated to be 24.61 per cent. Bartlett's test for homogeneity showed that Chi-square was significant at P=0.000.

Table 6. Range and mean of pod weight in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range (g)	Mean (g)
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	138.75-248.75	188.64 h
2.	H2(G I-10.3 x G VI-54)	10	163.33-396.25	244.94 fgh
3.	H3(G I-15.5 x G VI-54)	5	252.33-329.68	289.90 defg
4.	H4(G I-15.5 x G VI-55)	8	292.50-467.18	387.00 ab
5.	H5(G I-10.3 x G VI-61)	8	170.33-275.00	219.48 gh
6.	H6(G I-10.3 x G VI-64)	10	227.81-447.66	302.78 def
7.	H7(G I-5.9 x G VI-68)	10	227.81-324.75	265.99 efg
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	188.12-515.00	301.27 def
9.	H2(M-13.12 x G I-5.9)	11	226.25-349.25	282.98 defg
10.	H3(M-16.9 x G II-20.4)	11	249.81-441.52	339.67 bcd
11.	H4(M-16.9 x G II-19.5)	11	272.69-506.78	389.98 ab
12.	H5(G I-10.3 x G VI-56)	9	256.66-475.00	371.78 abc
13.	H6(G I-5.9 x G VI-61)	10	214.37-420.00	281.03 defg
14.	H7(G I-5.9 x G VI-55)	9	165.00-490.00	334.49 bcde
15.	H8(M-16.9 x G I-4.8)	7	183.18-545.00	306.84 cdef
16.	H9(M-16.9 x G VI-55)	9	283.50-563.00	408.17 a
17.	H10(M-9.16 x G II-20.4)	11	182.35-640.00	297.05 def
18.	H11(M-16.9 x G VI-56)	9	232.50-424.00	341.99 abcd
19.	H12(G I-4.8 x G VI-54)	9	200.00-330.71	264.04 fg

F (P=0.01) S
C.V. 24.61%

Mean values with common letters do not differ significantly

4.1.1.2.5. Fruit wall thickness at ridge - Analysis of variance of the data showed that the hybrids differed among themselves significantly for this character. The data are presented in Table 7. The fruit wall thickness at ridge was found to range from 5.5 mm in plant no.2 of H1 in series I crosses to 15.7 mm in plant no.8 of H4 in series II crosses. The highest mean thickness was recorded for H4 of series II crosses (11.2 mm), which was on par with nine other hybrids included in the study. The minimum mean fruit wall thickness at ridge of 6.7 mm was recorded in H1 of series I crosses. Hybrid H7 of the same series with 8.1 mm wall thickness was on par with H1. The coefficient of variation was found to be 16.81 per cent.

4.1.1.2.6. Fruit wall thickness at furrow - Coefficient of variation calculated for this character was 17.56 per cent. But the Bartlett's test was found to be significant at 0.026 level of probability. However, when square root transformation was done Bartlett's test was found non significant. Hence, transformed data were used for analysis. Coefficient of variation of the transformed data was found to be 8.6 per cent.

Data on fruit wall thickness at furrow is presented in Table 8. The maximum value of 12.6 mm was recorded in plant no.7 of H4 in series II crosses and the minimum of 4.5 mm was

Table 7. Range and mean of fruit wall thickness at ridge in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range (mm)	Mean (mm)
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	5.50-7.75	6.76 e
2.	H2(G I-10.3 x G VI-54)	10	6.80-13.50	9.20 bcd
3.	H3(G I-15.5 x G VI-54)	5	8.42-10.53	9.91 abc
4.	H4(G I-15.5 x G VI-55)	8	8.16-11.42	9.83 abc
5.	H5(G I-10.3 x G VI-61)	8	6.33-10.42	8.04 de
6.	H6(G I-10.3 x G VI-64)	10	7.20-11.20	9.51 bcd
7.	H7(G I-5.9 x G VI-68)	10	6.54-9.85	8.09 de
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	7.66-14.25	10.04 ab
9.	H2(M-13.12 x G I-5.9)	11	8.06-11.25	9.73 bc
10.	H3(M-16.9 x G II-20.4)	11	8.01-12.87	10.35 ab
11.	H4(M-16.9 x G II-19.5)	11	8.64-15.66	11.23 a
12.	H5(G I-10.3 x G VI-56)	9	8.38-12.66	10.34 ab
13.	H6(G I-5.9 x G VI-61)	10	6.68-10.90	8.39 cd
14.	H7(G I-5.9 x G VI-55)	9	7.82-14.00	9.84 abc
15.	H8(M-16.9 x G I-4.8)	7	7.27-13.5	10.18 ab
16.	H9(M-16.9 x G VI-55)	9	8.40-12.20	10.57 ab
17.	H10(M-9.16 x G II-20.4)	11	7.71-12.00	9.47 bcd
18.	H11(M-16.9 x G VI-56)	9	7.80-11.85	9.53 bcd
19.	H12(G I-4.8 x G VI-54)	9	8.27-12.14	10.32 ab
F (P=0.01)				S
C.V.				16.81%

Mean values with common letters do not differ significantly

Table 8. Range and mean of fruit wall thickness at furrow in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range (mm)	Mean* (mm)
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	4.50-6.41	2.30 (5.35) f
2.	H2(G I-10.3 x G VI-54)	10	6.00-12.50	2.81 (8.00) abc
3.	H3(G I-15.5 x G VI-54)	5	7.42-9.25	2.93 (8.64) ab
4.	H4(G I-15.5 x G VI-55)	8	6.68-9.85	2.87 (8.29) ab
5.	H5(G I-10.3 x G VI-61)	8	5.30-9.00	2.59 (6.80) cde
6.	H6(G I-10.3 x G VI-64)	10	6.30-9.24	2.84 (8.13) ab
7.	H7(G I-5.9 x G VI-68)	10	5.43-8.05	2.57 (6.65) de
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	5.87-12.25	2.82 (8.10) ab
9.	H2(M-13.12 x G I-5.9)	11	6.73-9.31	2.86 (8.23) ab
10.	H3(M-16.9 x G II-20.4)	11	6.75-10.50	2.92 (8.61) ab
11.	H4(M-16.9 x G II-19.5)	11	7.11-12.64	2.99 (9.02) a
12.	H5(G I-10.3 x G VI-56)	9	7.00-10.88	2.94 (8.72) ab
13.	H6(G I-5.9 x G VI-61)	10	5.28-7.90	2.56 (6.58) e
14.	H7(G I-5.9 x G VI-55)	9	5.00-12.00	2.74 (7.67) bcde
15.	H8(M-16.9 x G I-4.8)	7	6.27-12.00	2.85 (8.22) ab
16.	H9(M-16.9 x G VI-55)	9	6.80-10.30	2.99 (8.98) a
17.	H10(M-9.16 x G II-20.4)	11	6.31-10.00	2.77 (7.75) bcd
18.	H11(M-16.9 x G VI-56)	9	6.60-10.20	2.83 (8.06) ab
19.	H12(G I-4.8 x G VI-54)	9	7.18-10.00	2.91 (8.53) ab
F (P=0.01)				S
C.V.				8.6%

* Transformed data. The figures in paranthesis are in the original scale

Mean values with common letters do not differ significantly

in plant no.2 of H1 in series I crosses. The mean fruit wall thickness at furrow was also the highest (9.0 mm) for H4 of series II crosses. The fruit wall thickness at furrow was minimum (5.3 mm) for H1 of series I and this was significantly lower to all the other hybrids. As far as this character is concerned 15 hybrids were at par indicating a comparatively low degree of variability among themselves.

4.1.1.2.7. Ratio of pod length to pod width - The values for the ratio of pod length to pod width varied from 1.5 to 2.7. The data are presented in Table 9. The Bartlett's test showed that the Chi-square value was significant. However, when square root transformation of the data was done, the Chi-square value became non-significant and therefore the transformed data were used for analysis. The highest ratio was recorded for plant no.4 in H6 of series II crosses. The mean ratio of pod length to pod width was maximum in H5 of series I crosses. Statistical analysis using the transformed data showed that this was significantly superior to all the other hybrids except H8 of series II crosses. Hybrids H1 and H2 of series I as well as series II crosses were the hybrids to show minimum ratio of pod length to pod width (1.7) among all the hybrids.

4.1.1.3. Bean characteristics

Table 9. Range and mean of the ratio of pod length to pod width in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range	Mean*
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	1.59-1.94	1.33 (1.78) ghi
2.	H2(G I-10.3 x G VI-54)	10	1.49-1.92	1.31 (1.73) hi
3.	H3(G I-15.5 x G VI-54)	5	1.58-1.61	1.26 (1.60) i
4.	H4(G I-15.5 x G VI-55)	8	1.65-2.06	1.34 (1.80) fgh
5.	H5(G I-10.3 x G VI-61)	8	1.96-2.68	1.48 (2.20) a
6.	H6(G I-10.3 x G VI-64)	10	1.66-2.24	1.39 (1.93) defg
7.	H7(G I-5.9 x G VI-68)	10	1.79-2.20	1.39 (1.94) def
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	1.55-2.16	1.33 (1.78) ghi
9.	H2(M-13.12 x G I-5.9)	11	1.49-1.96	1.33 (1.77) ghi
10.	H3(M-16.9 x G II-20.4)	11	1.78-2.33	1.43 (2.06) abcd
11.	H4(M-16.9 x G II-19.5)	11	1.88-2.33	1.43 (2.05) abcd
12.	H5(G I-10.3 x G VI-56)	9	1.78-2.27	1.41 (1.99) bcd
13.	H6(G I-5.9 x G VI-61)	10	1.93-2.72	1.45 (2.12) abc
14.	H7(G I-5.9 x G VI-55)	9	1.73-2.34	1.40 (1.98) cde
15.	H8(M-16.9 x G I-4.8)	7	1.89-2.50	1.47 (2.16) ab
16.	H9(M-16.9 x G VI-55)	9	1.83-2.26	1.42 (2.04) abcd
17.	H10(M-9.16 x G II-20.4)	11	1.81-2.57	1.46 (2.13) abc
18.	H11(M-16.9 x G VI-56)	9	1.85-2.45	1.42 (2.03) abcd
19.	H12(G I-4.8 x G VI-54)	9	1.58-2.12	1.34 (1.82) efgh
F (P=0.01)				S
C.V.				4.46%

* Transformed data. The figures in paranthesis are in the original scale

Mean values with common letters do not differ significantly

4.1.1.3.1. Wet bean weight per pod - The data recorded on the wet bean weight per pod in the 19 crosses are presented in Table 10. Bartlett's test for homogeneity was significant as indicated by the Chi-square value. Therefore, square root transformation was done and data were subjected to analysis of variance. The 19 hybrids were found to differ significantly with respect to wet bean weight. The hybrids showing significantly higher wet bean weight are H4 of series I crosses and H5, H7 and H9 of series II crosses with 134.2 g, 117.5 g, 115.3 g and 128.4 g, respectively. Among these four superior hybrids, three, namely, H4 of series I and H7 and H9 of series II have G VI-55 as the common male parent. Among the 19 hybrids studied, H2 of series I gave wet bean weight per pod as low as 66.8 g. In general, this character showed a very high variability ranging from 41 g in plant no.6 of H1 in series I to 220 g in plant no.2 of H10 in series II crosses. The coefficient of variation for the transformed data was found to be 12.01 per cent.

4.1.1.3.2. Dry bean weight - The data recorded as dry weight of 20 randomly selected bean per plant are presented in Table 11. The coefficient of variation for dry bean weight was found to be 20.07 per cent. But the Bartlett's test for homogeneity showed high heterogeneity with Chi-square being significant at P = 0.01. With the square root transformation

Table 10. Range and mean of wet bean weight per pod in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range (gm)	Mean* (gm)
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	41.00-83.65	8.11 (66.79) h
2.	H2(G I-10.3 x G VI-54)	10	55.00-103.95	8.53 (73.42) gh
3.	H3(G I-15.5 x G VI-54)	5	78.61-108.43	9.86 (97.52) cdef
4.	H4(G I-15.5 x G VI-55)	8	107.50-170.00	11.54 (134.27) a
5.	H5(G I-10.3 x G VI-61)	8	60.40-100.00	8.78 (77.67) fgh
6.	H6(G I-10.3 x G VI-64)	10	42.57-126.50	9.40 (90.12) defg
7.	H7(G I-5.9 x G VI-68)	10	89.16-120.29	10.08 (101.89) cde
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	58.87-122.50	9.57 (92.58) def
9.	H2(M-13.12 x G I-5.9)	11	58.75-135.00	9.21 (85.74) efgh
10.	H3(M-16.9 x G II-20.4)	11	74.51-145.00	10.04 (101.82) cde
11.	H4(M-16.9 x G II-19.5)	11	78.63-147.95	10.31 (107.43) bcd
12.	H5(G I-10.3 x G VI-56)	9	82.07-155.62	10.78 (117.53) abc
13.	H6(G I-5.9 x G VI-61)	10	74.87-165.00	10.06 (103.115) cde
14.	H7(G I-5.9 x G VI-55)	9	55.00-170.00	10.64 (115.28) abc
15.	H8(M-16.9 x G I-4.8)	7	49.54-175.00	9.41 (91.92) defg
16.	H9(M-16.9 x G VI-55)	9	85.00-171.50	11.27 (128.38) ab
17.	H10(M-9.16 x G II-20.4)	11	60.29-220.00	9.77 (98.79) cdef
18.	H11(M-16.9 x G VI-56)	9	80.00-148.75	10.32 (107.67) bcd
19.	H12(G I-4.8 x G VI-54)	9	56.66-100.00	9.28 (86.71) defgh

F (P=0.01)	S
C.V.	12.01%

* Transformed data. The figures in paranthesis are in the original scale

Mean values with common letters do not differ significantly

Table 11. Range and mean of dry bean weight per pod in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range (gm)	Mean* (gm)
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	7.78-11.98	3.19 (10.25) i
2.	H2(G I-10.3 x G VI-54)	10	10.00-16.50	3.57 (12.81) efgh
3.	H3(G I-15.5 x G VI-54)	5	10.01-18.47	3.73 (14.09) bcdefg
4.	H4(G I-15.5 x G VI-55)	8	11.46-22.60	4.12 (17.18) ab
5.	H5(G I-10.3 x G VI-61)	8	7.76-13.78	3.23 (10.56) hi
6.	H6(G I-10.3 x G VI-64)	10	9.08-19.25	3.67 (13.68) cdefg
7.	H7(G I-5.9 x G VI-68)	10	8.40-14.28	3.44 (11.92) ghi
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	7.47-17.91	3.47 (12.22) fghi
9.	H2(M-13.12 x G I-5.9)	11	11.69-15.20	3.62 (13.18) defg
10.	H3(M-16.9 x G II-20.4)	11	12.51-20.41	4.062 (16.58) ab
11.	H4(M-16.9 x G II-19.5)	11	11.00-22.59	4.17 (17.60) a
12.	H5(G I-10.3 x G VI-56)	9	11.40-19.43	3.97 (15.89) abc
13.	H6(G I-5.9 x G VI-61)	10	11.6-15.22	3.64 (13.32) cdefg
14.	H7(G I-5.9 x G VI-55)	9	10.92-20.00	3.792 (14.55) bcdef
15.	H8(M-16.9 x G I-4.8)	7	9.42-21.70	3.62 (13.36) defg
16.	H9(M-16.9 x G VI-55)	9	10.52-24.27	4.13 (17.31) ab
17.	H10(M-9.16 x G II-20.4)	11	11.75-19.80	3.90 (15.36) abcd
18.	H11(M-16.9 x G VI-56)	9	11.56-20.83	3.89 (15.27) abcde
19.	H12(G I-4.8 x G VI-54)	9	8.44-17.40	3.47 (12.17) fghi
F (P=0.01)				S
C.V.	-			9.96%

* Transformed data. The figures in paranthesis are in the original scale

Mean values with common letters do not differ significantly

of the data homogeneity could be achieved with the Chi-square being significant only at P = 0.59. Hence, transformed data were used for analysis.

The values ranged from 7.5 g to 24.3 g. The highest value was recorded for plant no.13 in H9 of series II crosses and the lowest value was in plant no.11 of H1 in series II. Analysis of variance revealed that the hybrids differed significantly with respect to dry bean weight. The mean dry weight of the bean was maximum (17.6 g) for H4 of series II crosses which was closely followed by H9 of the same series (17.3 g). Most of the hybrids under series I crosses exhibited low dry bean weight in comparison to the hybrids in series II crosses. Hybrids which are significantly superior in this trait has G VI-55, G VI-56, G II-19.5 and G II-20.4 as their male parents.

4.1.1.3.3. Number of beans per pod - The mean number of beans per pod ranged from 22 in plant no.10 of H7 in series II crosses to 64 in plant no.10 in H6 of this series (Table 12). The coefficient of variation was found to be 12.27 per cent. The hybrids differed significantly as revealed by the analysis of variance. The maximum mean number of beans per pod was recorded in H9 of series II crosses and was followed by H4 of series I. These two hybrids were significantly superior to all the rest of the hybrids for this character. Both these

Table 12. Range and mean of number of beans per pod in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range	Mean
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	28.12-43.50	38.32 ef
2.	H2(G I-10.3 x G VI-54)	10	28.28-45.70	39.08 ef
3.	H3(G I-15.5 x G VI-54)	5	38.53-44.43	41.51 bcdef
4.	H4(G I-15.5 x G VI-55)	8	41.50-52.87	46.89 ab
5.	H5(G I-10.3 x G VI-61)	8	35.27-44.50	41.41 cdef
6.	H6(G I-10.3 x G VI-64)	10	22.57-47.80	39.78 def
7.	H7(G I-5.9 x G VI-68)	10	40.80-50.00	45.08 bc
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	35.53-48.94	40.84 cdef
9.	H2(M-13.12 x G I-5.9)	11	22.06-48.00	36.74 f
10.	H3(M-16.9 x G II-20.4)	11	34.80-42.9	38.77 ef
11.	H4(M-16.9 x G II-19.5)	11	32.54-45.00	39.76 def
12.	H5(G I-10.3 x G VI-56)	9	39.12-56.83	45.00 bc
13.	H6(G I-5.9 x G VI-61)	10	38.09-64.00	43.67 bcd
14.	H7(G I-5.9 x G VI-55)	9	22.00-57.66	44.92 bc
15.	H8(M-16.9 x G I-4.8)	7	37.67-45.5	41.84 bcde
16.	H9(M-16.9 x G VI-55)	9	42.83-55.50	51.83 a
17.	H10(M-9.16 x G II-20.4)	11	34.11-53.00	42.97 bcde
18.	H11(M-16.9 x G VI-56)	9	41.00-48.12	44.97 bc
19.	H12(G I-4.8 x G VI-54)	9	33.00-46.57	40.87 cdef

F (P=0.01)	S
C.V.	12.27%

Mean values with common letters do not differ significantly

hybrids have G VI-55 as the male parent. Another hybrid of series II, namely, H7 which again has G VI-55 as the male parent also was showing comparatively superior performance with respect to the number of beans. The lowest number of beans was recorded in H2 of series II crosses.

4.1.1.3.4. Seed length - The values recorded for seed length ranged from 14.6 mm to 33.8 mm (Table 13). The maximum seed length was for plant no.10 in H2 and the minimum for plant no.7 in H5, both in series I crosses. The coefficient of variation of the data was 9.27 per cent. With respect to seed length, the 19 hybrids differed significantly as evidenced by the analysis of variance. Hybrid H5 of series I and H9 of series II crosses with 21.3 mm and 21.2 mm seed length, respectively, were significantly superior to the rest of the hybrids. Minimum mean seed length of 17.3 mm was recorded in H5 of series I. Of the 19 hybrids studied, eight hybrids gave relatively low mean seed length ranging from 17.3 mm to 18.6 mm. Three of the hybrids, namely, H6 of series I and H7 and H10 of series II showed medium mean seed length.

4.1.1.3.5. Seed width - Out of the three seed characters, seed length, seed width and seed thickness, only width showed homogeneity in the distribution of error variance. The Bartlett's test for homogeneity showed that Chi-square was

Table 13. Range and mean of seed length in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range (mm)	Mean (mm)
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	15.83-18.94	17.78 ef
2.	H2(G I-10.3 x G VI-54)	10	16.80-33.79	20.63 ab
3.	H3(G I-15.5 x G VI-54)	5	18.82-23.10	20.93 ab
4.	H4(G I-15.5 x G VI-55)	8	19.16-24.45	21.26 a
5.	H5(G I-10.3 x G VI-61)	8	14.60-18.57	17.34 f
6.	H6(G I-10.3 x G VI-64)	10	17.61-21.83	19.10 bcde
7.	H7(G I-5.9 x G VI-68)	10	16.60-20.17	18.57 cdef
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	16.52-21.45	18.33 def
9.	H2(M-13.12 x G I-5.9)	11	16.96-20.40	18.415 cdef
10.	H3(M-16.9 x G II-20.4)	11	17.29-21.26	19.79 abcd
11.	H4(M-16.9 x G II-19.5)	11	18.80-23.22	20.79 ab
12.	H5(G I-10.3 x G VI-56)	9	17.72-21.83	19.98 abc
13.	H6(G I-5.9 x G VI-61)	10	17.52-20.80	18.60 cdef
14.	H7(G I-5.9 x G VI-55)	9	17.90-20.92	19.10 bcde
15.	H8(M-16.9 x G I-4.8)	7	15.92-20.64	17.97 ef
16.	H9(M-16.9 x G VI-55)	9	17.32-23.47	21.18 a
17.	H10(M-9.16 x G II-20.4)	11	17.35-23.6	19.33 bcde
18.	H11(M-16.9 x G VI-56)	9	18.77-21.77	20.62 ab
19.	H12(G I-4.8 x G VI-54)	9	16.60-20.81	18.48 cdef
F (P=0.01)				S
C.V.				9.27%

Mean values with common letters do not differ significantly

significant only at P = 0.522. The values ranged from 8.5 mm to 13 mm in plant no.6 of H1 in series I and plant no.12 of H10 in series II, respectively (Table 14). The mean seed width was highest for H4 of series II crosses and lowest for H5 of series I crosses. Coefficient of variation was found to be 7.73 per cent. Analysis of variance showed that the crosses differed significantly among themselves for this character. Hybrid H4 of series II with a mean seed width of 11.7 mm was significantly superior to many hybrids was on par with eight other hybrids among the 19 hybrids studied, while the hybrid H5 of series II with 9.7 mm seed width exhibited significantly lower value. This was, however, on par with five other hybrids.

4.1.1.3.6. Seed thickness - The data on seed thickness are presented in Table 15. Seed thickness was found to vary from 4.2 mm to 9.6 mm in the hybrids. Plant no.15 in H9 of series II crosses recorded the maximum seed thickness. The mean seed thickness was maximum for H4 of series II crosses. The coefficient of variation was found to be 11.27 per cent. Analysis of variance showed F-value to be highly significant (P = 0.000). Hybrid H3 and H4 of series II crosses exhibited significantly higher seed thickness in comparison to all other hybrids. The hybrid showing lowest mean value for this

Table 14. Range and mean of seed width in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range (mm)	Mean (mm)
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	8.48-10.54	9.93 fg
2.	H2(G I-10.3 x G VI-54)	10	10.58-13.00	11.18 abcd
3.	H3(G I-15.5 x G VI-54)	5	10.25-12.96	11.67 ab
4.	H4(G I-15.5 x G VI-55)	8	9.83-13.00	11.49 ab
5.	H5(G I-10.3 x G VI-61)	8	8.40-11.44	9.72 g
6.	H6(G I-10.3 x G VI-64)	10	9.20-11.53	10.65 cdef
7.	H7(G I-5.9 x G VI-68)	10	8.40-10.87	9.97 fg
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	8.88-11.40	10.32 efg
9.	H2(M-13.12 x G I-5.9)	11	9.82-11.51	10.77 bcde
10.	H3(M-16.9 x G II-20.4)	11	9.87-12.71	11.42 ab
11.	H4(M-16.9 x G II-19.5)	11	10.36-12.91	11.68 a
12.	H5(G I-10.3 x G VI-56)	9	10.08-12.72	11.31 abc
13.	H6(G I-5.9 x G VI-61)	10	9.85-11.29	10.47 defg
14.	H7(G I-5.9 x G VI-55)	9	9.36-11.68	10.58 def
15.	H8(M-16.9 x G I-4.8)	7	9.54-11.60	10.32 efg
16.	H9(M-16.9 x G VI-55)	9	8.59-12.91	11.04 abcde
17.	H10(M-9.16 x G II-20.4)	11	9.84-13.09	11.39 ab
18.	H11(M-16.9 x G VI-56)	9	9.87-11.67	10.83 bcde
19.	H12(G I-4.8 x G VI-54)	9	9.99-12.40	10.96 abcde
F (P=0.01)				S
C.V.				7.78%

Mean values with common letters do not differ significantly

Table 15. Range and mean of seed thickness in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range (mm)	Mean (mm)
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	4.24-5.70	5.40 f
2.	H2(G I-10.3 x G VI-54)	10	5.31-7.19	6.16 cde
3.	H3(G I-15.5 x G VI-54)	5	5.63-6.57	5.99 cdef
4.	H4(G I-15.5 x G VI-55)	8	5.45-8.40	6.65 bcd
5.	H5(G I-10.3 x G VI-61)	8	5.20-6.49	5.72 ef
6.	H6(G I-10.3 x G VI-64)	10	5.40-7.86	6.61 bcd
7.	H7(G I-5.9 x G VI-68)	10	5.33-7.01	5.99 def
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	5.79-7.54	6.52 bcd
9.	H2(M-13.12 x G I-5.9)	11	6.03-7.78	6.82 b
10.	H3(M-16.9 x G II-20.4)	11	6.43-8.03	7.48 a
11.	H4(M-16.9 x G II-19.5)	11	6.46-8.99	7.50 a
12.	H5(G I-10.3 x G VI-56)	9	5.38-7.90	6.65 bcd
13.	H6(G I-5.9 x G VI-61)	10	6.09-6.89	6.50 bcd
14.	H7(G I-5.9 x G VI-55)	9	4.93-8.60	6.38 bcde
15.	H8(M-16.9 x G I-4.8)	7	6.06-8.40	6.88 ab
16.	H9(M-16.9 x G VI-55)	9	5.11-9.61	6.63 bcd
17.	H10(M-9.16 x G II-20.4)	11	5.92-7.26	6.65 bcd
18.	H11(M-16.9 x G VI-56)	9	5.34-7.95	6.69 bc
19.	H12(G I-4.8 x G VI-54)	9	4.78-7.80	6.22 bcde

F (P=0.01) S

C.V. 11.27%

Mean values with common letters do not differ significantly

character was H1 of series I (5.4 mm). Most of the hybrids in series I crosses exhibited relatively low seed thickness.

4.1.1.3.7. Ratio of dry bean weight to wet bean weight - Data on ratio of dry bean weight to wet bean weight are presented in Table 16. The values for the ratio ranged from 0.19 to 0.73. The highest ratio recorded was for plant no.4 in H4 of series I crosses and the lowest for plant no.3 in H2 of the same series. Statistical analysis of the data revealed that with respect to the ratio of dry bean weight to wet bean weight the hybrids differed significantly. Hybrid H2 of series I with a mean ratio of 0.39 was superior to all other crosses for this trait. Four other hybrids, namely, H3, H4, H9 and H10 of series II crosses were also on par with the above hybrid. The hybrids that showed the minimum ratio were H7 of series I as well as H1 and H12 of series II with the ratio of 0.28 in all cases. The coefficient of variation estimated for this character was 20.01 per cent. A perusal of the data reveals that hybrids with M-16.9 as the female parent consistently gave higher ratios of dry bean weight to wet bean weight. Out of five such combinations, three, namely, H3, H4 and H9 of series II are among the top five crosses whereas H8 and H11 of same series are on par with the second best group of hybrids.

Table 16. Range and mean of the ratio of dry bean weight to wet bean weight in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range	Mean
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	0.239-0.382	0.319 bcde
2.	H2(G I-10.3 x G VI-54)	10	0.193-0.730	0.396 a
3.	H3(G I-15.5 x G VI-54)	5	0.230-0.402	0.316 bcde
4.	H4(G I-15.5 x G VI-55)	8	0.256-0.357	0.306 cde
5.	H5(G I-10.3 x G VI-61)	8	0.215-0.466	0.301 de
6.	H6(G I-10.3 x G VI-64)	10	0.198-0.403	0.322 bcde
7.	H7(G I-5.9 x G VI-68)	10	0.200-0.348	0.279 e
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	0.238-0.323	0.282 e
9.	H2(M-13.12 x G I-5.9)	11	0.270-0.396	0.305 de
10.	H3(M-16.9 x G II-20.4)	11	0.245-0.467	0.361 abc
11.	H4(M-16.9 x G II-19.5)	11	0.236-0.471	0.348 abcd
12.	H5(G I-10.3 x G VI-56)	9	0.278-0.366	0.316 bcde
13.	H6(G I-5.9 x G VI-61)	10	0.222-0.368	0.299 de
14.	H7(G I-5.9 x G VI-55)	9	0.240-0.602	0.310 cde
15.	H8(M-16.9 x G I-4.8)	7	0.280-0.406	0.329 bcde
16.	H9(M-16.9 x G VI-55)	9	0.252-0.452	0.365 abc
17.	H10(M-9.16 x G II-20.4)	11	0.238-0.485	0.367 ab
18.	H11(M-16.9 x G VI-56)	9	0.290-0.378	0.332 bcde
19.	H12(G I-4.8 x G VI-54)	9	0.244-0.347	0.284 e
F (P=0.01)				S
C.V.				20.01%

Mean values with common letters do not differ significantly

4.1.1.3.8. Ratio of bean length to bean width - The values of the ratio ranged from 1.46 to 3.4 as given in Table 17. The highest value was for plant no.10 in H2 of series I crosses and the lowest for plant no.5 of H10 in series II crosses. Coefficient of variation for the character was 10.49 per cent. Analysis of variance showed that the crosses do not differ significantly. The maximum ratio of 1.4 was given by H9 of series II and was closely followed by H11 of the same series with 1.38. The minimum ratio of 1.3 was also exhibited by one of the hybrids in the above series, namely, H12.

Analysis of variance of the 15 characters studied in 19 hybrid combinations are compiled and presented in Table 18. The hybrids studied were found to differ significantly for all characters except the ratio of seed length to seed width.

4.1.2. Parents

Data were recorded from a total of 68 plants belonging to 15 different genotypes which were used as parents in the hybridisation programme. The data pertaining to yield, seven pod characteristics and eight bean characteristics are presented below.

4.1.2.1. Yield - The yield was recorded from 68 trees belonging to 15 parents. The data are given in Table 19. A very high coefficient of variation of 72.06 per cent was

Table 17. Range and mean of the ratio of bean length to bean width in the 19 hybrids of cocoa

Sl. No.	Crosses	No. of trees	Range	Mean
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	1.54-2.08	1.34
2.	H2(G I-10.3 x G VI-54)	10	1.58-3.40	1.36
3.	H3(G I-15.5 x G VI-54)	5	1.72-1.89	1.34
4.	H4(G I-15.5 x G VI-55)	8	1.72-2.06	1.36
5.	H5(G I-10.3 x G VI-61)	8	1.62-1.93	1.33
6.	H6(G I-10.3 x G VI-64)	10	1.65-1.90	1.33
7.	H7(G I-5.9 x G VI-68)	10	1.69-2.05	1.36
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	1.65-1.98	1.33
9.	H2(M-13.12 x G I-5.9)	11	1.62-1.85	1.31
10.	H3(M-16.9 x G II-20.4)	11	1.55-2.05	1.32
11.	H4(M-16.9 x G II-19.5)	11	1.51-1.89	1.33
12.	H5(G I-10.3 x G VI-56)	9	1.54-1.95	1.33
13.	H6(G I-5.9 x G VI-61)	10	1.64-1.92	1.33
14.	H7(G I-5.9 x G VI-55)	9	1.62-2.00	1.34
15.	H8(M-16.9 x G I-4.8)	7	1.58-2.12	1.32
16.	H9(M-16.9 x G VI-55)	9	1.69-2.81	1.40
17.	H10(M-9.16 x G II-20.4)	11	1.46-1.96	1.30
18.	H11(M-16.9 x G VI-56)	9	1.77-2.12	1.38
19.	H12(G I-4.8 x G VI-54)	9	1.51-1.83	1.30
F (P=0.05)				NS
C.V.				10.49%

Table 18. Analysis of variance of the 16 characters studied in 19 crosses

Sl. No.	Characters	Mean sum of squares between crosses	Mean sum of squares within crosses	Probability of significance of F-test	Bartlett's test probability of significance
1.	Yield*	636.36	241.31	0.0007	0.862
2.	No. of pods*	7.353	2.553	0.0002	0.553
3.	Pod length	13.230	1.823	0.000	0.120
4.	Pod width	1.697	0.406	0.000	0.014
5.	Pod weight	29648.113	5750.944	0.000	0.000
6.	Fruit wall thickness at ridge	9.731	2.601	0.000	0.074
7.	Fruit wall thickness at furrow*	0.255	0.058	0.000	0.121
8.	Pod length/pod wodth	0.030	0.004	0.000	0.065
9.	Wet bean weight per pod*	6.647	1.400	0.000	0.032
10.	Dry bean weight*	0.775	0.138	0.000	0.059
11.	Number of beans per pod	119.966	26.845	0.000	0.000
12.	Seed length	13.090	3.222	0.000	0.000
13.	Seed width	3.121	0.710	0.000	0.522
14.	Seed thickness	2.433	0.545	0.000	0.013
15.	Dry bean wt./ Wet bean wt.	0.010	0.004	0.0016	0.000
16.	Seed length/ Seed width	0.047	0.036	0.1763	0.000

* Transformed data used for analysis

Table 19. Range and mean of yield in the 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (g)	Mean* (g)
1.	M-9.16	5	683.76-3480.96	41.87 (1864.79)
2.	M-13.12	5	789.30-5349.70	50.61 (2823.94)
3.	M-16.9	5	1292.20-3507.40	48.49 (2418.26)
4.	G I-4.8	5	93.37-2427.62	37.76 (1643.30)
5.	G I-5.9	5	1327.62-5594.97	56.20 (3167.32)
6.	G I-10.3	4	1885.20-3393.36	49.70 (2503.63)
7.	G II-20.4	5	1374.94-4910.50	48.97 (2488.02)
8.	G II-19.5	5	1944.54-6265.74	46.69 (2327.36)
9.	G VI-54	4	1811.60-5344.22	61.36 (3894.94)
10.	G VI-55	4	1138.96-14094.63	72.20 (5197.31)
11.	G VI-56	4	2147.40-3865.32	53.70 (2925.83)
12.	G VI-61	4	1110.24-4163.40	47.97 (2428.65)
13.	G VI-64	5	96.38-3855.20	32.00 (1490.92)
14.	G I-15.5	4	996.84-6894.81	61.14 (3738.15)
15.	G VI-68	4	1027.62-3882.12	53.08 (2825.45)
F (P=0.05)				N.S.
C.V.				34.29%

* Transformed data. The figures in parenthesis are in the original scale

noticed. The values were ranging from 93.37 g recorded for plant no.4 of G I-4.8 to 14094.63 g recorded for plant no.3 of G VI-55. The mean yield was also the highest for G VI-55. G VI-54, G I-15.5, G I-5.9, G VI-56 and G VI-68 also gave good yield. The data were subjected to square root transformation, as a result, the coefficient of variation came down to 34.29 per cent. The transformed data when subjected to analysis of variance showed that parents did not differ significantly. Bartlett's test for homogeneity showed that the Chi-square was not significant.

4.1.2.2. Pod characteristics

4.1.2.2.1. Number of pods - Data on number of pods harvested during 1992-93 is given in Table 20. It showed a very high coefficient of variation of 63.13 per cent. The values ranged from 1 to 99. The highest value was recorded for plant no.3 of G VI-55. Bartlett's test for homogeneity showed that Chi-square was not significant. Square root transformation of the data brought down the coefficient of variation to 32.82 per cent. Analysis of variance done with the transformed data showed that the parents do not differ significantly among themselves, the probability of significance of F-value being 0.433. The data presented in Table 18 show that the parent G I-15.5 gave the maximum mean pod number of 45. This was followed by G VI-54 (43), G VI-55

Table 20. Range and mean of number of pods in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range	Mean*
1.	M-9.16	5	11-56	5.31 (30.00)
2.	M-13.12	5	9-61	5.40 (32.20)
3.	M-16.9	5	14-38	5.04 (26.20)
4.	G I-4.8	5	1-26	3.90 (17.60)
5.	G I-5.9	5	14-59	5.62 (33.40)
6.	G I-10.3	4	20-36	5.01 (25.50)
7.	G II-20.4	5	14-50	5.04 (26.80)
8.	G II-19.5	5	18-58	5.53 (32.00)
9.	G VI-54	4	20-59	6.44 (43.00)
10.	G VI-55	4	8-99	5.38 (36.50)
11.	G VI-56	4	20-36	5.18 (27.25)
12.	G VI-61	4	12-45	4.98 (26.25)
13.	G VI-64	5	1-40	3.29 (15.60)
14.	G I-15.5	4	12-83	6.40 (45.00)
15.	G VI-68	4	9-34	4.85 (24.75)
F (P=0.05)				N.S.
C.V.				32.82%

* Transformed data. The figures in parenthesis are in the original scale

(36.5) and G I -5.9 (33.4). The minimum pod number was recorded by G VI-64.

4.1.2.2.2. Pod length - The values were found to range from 9 cm to 17 cm (Table 21), the highest being for plant no.2 of G VI-61 and the lowest for plant no.2 of G I-15.5. The coefficient of variation was calculated to be 7.18 per cent. Analysis of variance showed F-value to be significant at P=0.000. The maximum mean pod length of 16.3 cm was recorded in G VI-61. This parent was significantly superior to all other parents in this trait. Mean pod length of 11.4 cm given by G I-15.5 was the minimum among all the parents studied.

4.1.2.2.3. Pod width - Data on pod width are presented in Table 22. Analysis of variance of the data on pod width showed that the parents differ significantly among themselves, the F-value being significant at P = 0.015. The coefficient of variation was within the permissible limit (10.11 per cent). The values ranged from 5.5 cm to 9.5 cm. Plant no.2 of G VI-55 and plant no.1 of G VI-64 recorded the maximum pod width while plant no.5 of M-13.12 and plant no.2 of G I-15.5 produced pods with minimum width (5.5 cm). With regard to the character under study, the parent G VI-55 was superior to the rest (8.23 cm). This parent, however, was statistically on par with G I-10.3, G II-19.5 and G VI-64, all of which had

Table 21. Range and mean of pod length in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (cm)	Mean (cm)
1.	M-9.16	5	12.58-14.42	13.53 cd
2.	M-13.12	5	12.06-14.57	13.36 d
3.	M-16.9	5	12.50-14.75	13.72 bcd
4.	G I-4.8	5	14.00-15.30	14.41 bcd
5.	G I-5.9	5	11.02-12.00	11.65 e
6.	G I-10.3	4	13.15-14.50	14.01 bcd
7.	G II-20.4	5	14.15-15.05	14.64 bc
8.	G II-19.5	5	13.46-15.68	14.47 bcd
9.	G VI-54	4	11.87-12.14	12.01 e
10.	G VI-55	4	14.68-16.50	14.70 bc
11.	G VI-56	4	12.88-15.05	14.19 bcd
12.	G VI-61	4	14.67-17.00	16.34 a
13.	G VI-64	5	13.25-16.50	14.81 b
14.	G I-15.5	4	9.00-12.83	11.37 e
15.	G VI-68	4	13.05-16.25	14.38 bcd
F (P=0.05)				S
C.V.				7.18%

Mean values with common letters do not differ significantly

Table 22. Range and mean of pod width in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (cm)	Mean (cm)
1.	M-9.16	5	5.88-6.53	6.22 c
2.	M-13.12	5	5.50-7.80	6.78 bc
3.	M-16.9	5	6.05-7.30	6.78 bc
4.	G I-4.8	5	6.08-9.00	7.00 bc
5.	G I-5.9	5	6.08-6.70	6.37 c
6.	G I-10.3	4	6.92-7.72	7.44 ab
7.	G II-20.4	5	6.83-7.15	6.96 bc
8.	G II-19.5	5	7.12-8.04	7.42 ab
9.	G VI-54	4	6.33-7.25	6.73 bc
10.	G VI-55	4	7.02-9.50	8.23 a
11.	G VI-56	4	6.32-7.38	7.00 bc
12.	G VI-61	4	5.79-6.80	6.37 c
13.	G VI-64	5	6.12-9.50	7.41 ab
14.	G I-15.5	4	5.50-7.75	7.08 bc
15.	G VI-68	4	6.20-7.50	6.86 bc

F (P=0.05)	S
C.V.	10.11%

Mean values with common letters do not differ significantly

mean pod width of 7.4 cm. Pod width was minimum (6.2 cm) in M-9.16.

4.1.2.2.4. Pod weight - Data on pod weight showed high amount of variation as seen in Table 23. The values ranged from 132.5 g in plant no.2 in G I-15.5 to 750 g in plant no.2 of G VI-55. The coefficient of variation for this character was 28.03 per cent. The Bartlett's test for homogeneity was found to be highly significant. Square root transformation of the data was done. Transformed data showed a coefficient of variation of 13.38 per cent. However, the Bartlett's test still remained significant, the Chi-square having the probability of significance at 0.020.

Analysis of variance of data on weight of pods has shown that the parents do differ significantly. The mean value of 492.2 g in the parent G VI-55 was the maximum pod weight recorded among the 15 parents. This was significantly different from all the other parents except G I-10.3 (352.8 g) which was on par. The minimum mean pod weight was 260.8 g was recorded in the parent G I-5.9.

4.1.2.2.5. Fruit wall thickness at ridge - The data recorded are presented in Table 24. The thickness varied from 6.3 mm to 14.0 mm. Plant no.2 of G VI-55 and plant no.1 of G VI-64 recorded the highest value. The coefficient of variation was

Table 23. Range and mean of pod weight in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (g)	Mean* (g)
1.	M-9.16	5	190.00-249.61	14.81 (220.01) c
2.	M-13.12	5	175.00-395.00	17.47 (311.34) bc
3.	M-16.9	5	214.00-380.00	16.98 (291.77) bc
4.	G I-4.8	5	255.00-380.00	17.12 (295.16) bc
5.	G I-5.9	5	173.97-240.00	14.70 (216.87) c
6.	G I-10.3	4	307.69-386.90	18.76 (352.81) ab
7.	G II-20.4	5	268.50-347.30	17.93 (322.39) b
8.	G II-19.5	5	282.08-446.21	18.20 (333.85) b
9.	G VI-54	4	231.87-327.14	16.33 (268.08) bc
10.	G VI-55	4	307.63-750.00	21.89 (492.22) a
11.	G VI-56	4	246.47-373.50	18.10 (329.64) b
12.	G VI-61	4	219.41-360.50	17.17 (297.21) bc
13.	G VI-64	5	169.67-620.00	18.04 (341.43) b
14.	G I-15.5	4	132.50-341.66	16.67 (286.77) bc
15.	G VI-68	4	225.50-392.50	17.99 (328.87) b

F (P=0.05) S
C.V. 13.38%

* Transformed data. The figures in parenthesis are in the original scale

Mean values with common letters do not differ significantly

Table 24. Range and mean of fruit wall thickness at ridge in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (mm)	Mean (mm)
1.	M-9.16	5	8.55-10.07	9.25 cd
2.	M-13.12	5	9.84-12.54	10.65 abc
3.	M-16.9	5	7.40-10.50	9.27 cd
4.	G I-4.8	5	8.85-12.00	9.97 bc
5.	G I-5.9	5	6.32-12.00	7.84 d
6.	G I-10.3	4	10.61-13.00	12.01 a
7.	G II-20.4	5	9.11-10.92	10.42 abc
8.	G II-19.5	5	7.66-11.48	9.94 bc
9.	G VI-54	4	8.66-11.25	9.74 bcd
10.	G VI-55	4	9.34-14.00	11.24 abc
11.	G VI-56	4	8.88-11.86	10.43 abc
12.	G VI-61	4	8.64-11.10	9.74 bcd
13.	G VI-64	5	8.00-14.00	11.75 ab
14.	G I-15.5	4	7.00-11.00	9.60 cd
15.	G VI-68	4	8.40-11.00	9.20 cd

F (P=0.05)	S
C.V.	15.03%

Mean values with common letters do not differ significantly

calculated to be 15.03 per cent. Analysis of variance revealed that the parents differed significantly among themselves. The Bartlett's test for homogeneity was not significant. A mean fruit wall thickness of 12.0 mm recorded in G I-10.3 was the maximum and this was followed by G VI-64 with 11.7 mm. Among the different parents tested, the fruit wall thickness at ridge was the least in G VI-68 as evidenced by the minimum fruit wall thickness of 9.2 mm recorded in this case.

4.1.2.2.6. Fruit wall thickness at furrow - The data on fruit wall thickness at furrow recorded in 15 parents are presented in Table 25. Since the coefficient of variation was found to be as high as 50.45 per cent, square root transformation was resorted to and the coefficient of variation was brought down to 16.86 per cent. Analysis of variance was carried out using the transformed data. No significant difference among the parents for the character under study was seen.

The data showed that fruit wall thickness at furrow ranged from 4.85 mm to 13.0 mm in plant no.1 of G I-5.9 and plant no.1 of G VI-64, respectively. With regard to the mean fruit wall thickness at furrow a maximum of 10.19 mm was recorded in the parent G VI-64 while the minimum mean value of 5.86 was recorded in the parent G I-5.9.

Table 25. Range and mean of fruit wall thickness at furrow in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (mm)	Mean* (mm)
1.	M-9.16	5	6.77-8.00	2.75 (7.60)
2.	M-13.12	5	8.00-10.97	2.95 (8.78)
3.	M-16.9	5	6.20-9.40	2.80 (7.90)
4.	G I-4.8	5	7.42-11.00	2.87 (8.30)
5.	G I-5.9	5	4.85-8.00	2.41 (5.86)
6.	G I-10.3	4	8.69-11.50	3.14 (9.92)
7.	G II-20.4	5	7.11-9.15	2.90 (8.46)
8.	G II-19.5	5	6.16-9.45	2.78 (7.80)
9.	G VI-54	4	7.58-9.00	2.85 (8.17)
10.	G VI-55	4	7.65-13.00	3.10 (9.73)
11.	G VI-56	4	7.47-9.22	2.91 (8.48)
12.	G VI-61	4	6.70-9.20	2.79 (7.84)
13.	G VI-64	5	6.25-13.00	3.83 (10.19)
14.	G I-15.5	4	6.00-9.66	2.88 (8.38)
15.	G VI-68	4	6.90-8.50	2.76 (7.63)
F (P=0.05)				N.S.
C.V.				16.86%

* Transformed data. The figures in parenthesis are in the original scale

4.1.2.2.7. Ratio of pod length to pod width - The values of the ratio of pod length to pod width in the 15 parents studied ranged from 0.998 to 2.68 as shown in Table 26. While plant no.3 of G VI-61 recorded the highest ratio, plant no.4 of G VI-64 gave the lowest ratio. The coefficient of variation for this data was 10.92 per cent. Analysis of variance showed that the F-value is significant at P = 0.000. The parent showing the maximum mean pod length to pod width ratio of 2.57 was G VI-61 and it was significantly superior to all the rest of the parents. The mean ratio was minimum in the case of G I-15.5 (1.6).

4.1.2.3. Bean characteristics

4.1.2.3.1. Wet bean weight per pod - Wet bean weight per pod measured in grams showed a high degree of variation in the trees belonging to the 15 parents (Table 27). The maximum weight of 160 g was recorded for plant no.1 of G VI-64 and the minimum of 25 g in plant no.5 of M-13.12. Trees within parents also exhibited a high degree of variation as far as this character is concerned. When the mean data are taken into consideration, parent G VI- 55 with a mean wet bean weight of 142.37 g was significantly superior to all the other parents except G VI-68 which had a mean wet bean weight of 114.18 g. Parent M-9.16 exhibited the minimum mean wet bean weight per pod (62.16 g).

Table 26. Range and mean of the ratio of pod length to pod width in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range	Mean
1.	M-9.16	5	2.04-2.27	2.19 b
2.	M-13.12	5	1.73-2.54	2.01 bcdef
3.	M-16.9	5	1.95-2.14	2.03 bcdef
4.	G I-4.8	5	1.55-2.36	2.10 bcd
5.	G I-5.9	5	1.77-1.87	1.83 efg
6.	G I-10.3	4	1.83-1.93	1.88 cdefg
7.	G II-20.4	5	2.00-2.20	2.11 bc
8.	G II-19.5	5	1.84-2.01	1.95 bcdef
9.	G VI-54	4	1.67-1.90	1.79 fg
10.	G VI-55	4	1.73-1.86	1.79 fg
11.	G VI-56	4	2.01-2.06	2.04 bcdef
12.	G VI-61	4	2.50-2.68	2.57 a
13.	G VI-64	5	0.98-2.61	1.84 defg
14.	G I-15.5	4	1.52-1.67	1.60 g
15.	G VI-68	4	1.94-2.17	2.10 bcde

F (P=0.01) S

C.V. 10.92%

Mean values with common letters do not differ significantly

Table 27. Range and mean of wet bean weight per pod in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (g)	Mean (g)
1.	M-9.16	5	55.77-76.66	62.16 c
2.	M-13.12	5	25.00-157.50	87.70 bc
3.	M-16.9	5	80.00-112.60	92.30 bc
4.	G I-4.8	5	79.23-110.00	93.37 bc
5.	G I-5.9	5	79.41-112.22	94.83 b
6.	G I-10.3	4	80.00-120.00	94.26 b
7.	G II-20.4	5	88.75-106.87	98.21 b
8.	G II-19.5	5	97.30-133.33	108.03 b
9.	G VI-54	4	82.50-98.57	90.58 bc
10.	G VI-55	4	108.02-155.83	142.37 a
11.	G VI-56	4	74.41-123.57	107.37 b
12.	G VI-61	4	75.58-103.92	92.52 bc
13.	G VI-64	5	54.42-160.00	96.38 b
14.	G I-15.5	4	45.00-106.66	83.30 bc
15.	G VI-68	4	70.50-147.50	114.18 ab
F (P=0.05)				S
C.V.				24.76%

Mean values with common letters do not differ significantly

4.1.2.3.2. Dry bean weight - Analysis of variance of dry bean weight recorded as weight of 20 randomly selected seeds per tree, showed that the parents differed significantly among themselves. Bartlett's test showed that the Chi-square was not significant (P = 0.195). The data are presented in Table 28. The data show that dry weight of beans ranged from 8.2 g to 22.3 g. The lowest value was given by plant no.2 of G I-5.9 and the highest in plant no.4 of G I-4.8. The coefficient of variation for this data was calculated to be 18.3 per cent. The significance test indicated that parent G II-20.4 with a mean dry bean weight of 17.5 g was significantly superior and also at par with six other parents. Parent G I-5.9 was the genotype that gave the minimum mean dry bean weight (10.3 g).

4.1.2.3.3. Number of beans - The value of number of beans per pod ranged from 25.2 to 60.1. The data are given in Table 29. Coefficient of variation was calculated to be 12.81 per cent. Plant no.4 of G VI-55 recorded the maximum number of beans per pod. Mean number of beans was also the highest for G VI-55. The parents M-9.16 and G I-15.5 with 29.4 and 34.8 beans per pod, respectively, recorded the lowest mean number among all the parents. Analysis of variance revealed that the parents differed significantly among themselves.

Table 28. Range and mean of dry bean weight in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (g)	Mean (g)
1.	M-9.16	5	12.35-16.09	14.29 abc
2.	M-13.12	5	8.90-14.25	12.35 cd
3.	M-16.9	5	11.10-16.29	13.66 bc
4.	G I-4.8	5	9.71-22.3	13.26 cd
5.	G I-5.9	5	8.20-11.77	10.30 d
6.	G I-10.3	4	10.12-17.42	14.25 abc
7.	G II-20.4	5	16.93-18.44	17.51 a
8.	G II-19.5	5	16.46-20.32	17.44 a
9.	G VI-54	4	13.40-16.89	15.06 abc
10.	G VI-55	4	12.70-16.89	15.55 abc
11.	G VI-56	4	11.31-14.59	13.01 cd
12.	G VI-61	4	9.93-16.13	13.44 bcd
13.	G VI-64	5	12.85-20.18	16.69 ab
14.	G I-15.5	4	9.40-16.20	13.57 bcd
15.	G VI-68	4	11.43-19.28	13.91 bc
F (P=0.05)				S
C.V.				18.30%

Mean values with common letters do not differ significantly

Table 29. Range and mean of number of beans per pod in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range	Mean
1.	M-9.16	5	25.23-34.66	29.42 g
2.	M-13.12	5	38.36-48.50	43.39 abcd
3.	M-16.9	5	39.05-46.20	43.24 abcd
4.	G I-4.8	5	34.00-48.80	41.71 bcde
5.	G I-5.9	5	37.64-44.00	41.44 bcdef
6.	G I-10.3	4	30.00-42.10	36.92 def
7.	G II-20.4	5	32.30-39.77	36.35 ef
8.	G II-19.5	5	34.73-46.41	40.36 cdef
9.	G VI-54	4	36.00-42.50	39.71 cdef
10.	G VI-55	4	41.00-60.16	50.03 a
11.	G VI-56	4	39.70-49.21	45.93 abc
12.	G VI-61	4	38.50-45.10	41.47 bcdef
13.	G VI-64	5	26.00-47.00	36.74 ef
14.	G I-15.5	4	31.00-41.33	34.83 fg
15.	G VI-68	4	40.40-52.50	47.32 ab
F (P=0.01)				S
C.V.				12.81%

Mean values with common letters do not differ significantly

4.1.2.3.4. Seed length - The data presented in Table 30 showed that the values for seed length ranged from 11.8 mm to 24.2 mm. Plant no.4 of G I-4.8 recorded the maximum value of 24.2 mm. Plant no.5 of M-13.12 recording a value of 11.8 mm exhibited the minimum seed length. The mean seed length of 21.9 mm given by G VI-54 was the highest and it was on par with six others, whereas the mean seed length of M-13.12 (18.02 mm) was the lowest. The coefficient of variation was found to be 8.77 per cent. Analysis of variance showed that parents differed among themselves significantly. Bartlett's test was also found significant.

4.1.2.3.5. Seed width - The mean values recorded for seed width showed very little variation as revealed by the data given in Table 31. It ranged from 9.8 mm calculated for M-13.12 to 11.7 mm calculated for G I-10.3, G II-20.4 and G VI-54. However, the values for individual trees showed that plant no.4 of G I-4.8 gave the highest value of 14.2 mm while plant no.5 of M-13.12 gave the lowest value of 7.0 mm. Coefficient of variation for the data was found to be 8.36 per cent. Analysis of variance showed that the parents did not differ among themselves with respect to this trait. Chi-square value in the Bartlett's test was found significant.

4.1.2.3.6. Seed thickness - The values recorded for seed thickness ranged from 4.4 mm to 9.1 mm. The data are given in

Table 30. Range and mean of seed length in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (mm)	Mean (mm)
1.	M-9.16	5	18.28-19.41	18.90 cd
2.	M-13.12	5	11.80-21.80	18.02 d
3.	M-16.9	5	18.12-20.34	18.94 cd
4.	G I-4.8	5	15.69-24.20	18.30 cd
5.	G I-5.9	5	16.86-19.20	18.08 cd
6.	G I-10.3	4	19.00-20.03	19.39 bcd
7.	G II-20.4	5	19.20-21.14	20.00 abcd
8.	G II-19.5	5	18.70-21.23	19.95 abcd
9.	G VI-54	4	20.27-22.87	21.94 a
10.	G VI-55	4	19.42-23.40	21.42 ab
11.	G VI-56	4	18.62-20.43	19.58 abcd
12.	G VI-61	4	17.29-18.57	18.07 cd
13.	G VI-64	5	16.77-19.80	18.61 cd
14.	G I-15.5	4	17.60-21.09	19.59 abcd
15.	G VI-68	4	18.86-21.60	20.27 abc
F (P=0.05)				S
C.V.				8.77%

Mean values with common letters do not differ significantly

Table 31. Range and mean of seed width in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (mm)	Mean (mm)
1.	M-9.16	5	9.97-11.28	10.64
2.	M-13.12	5	7.00-11.00	9.89
3.	M-16.9	5	10.00-10.98	10.58
4.	G I-4.8	5	9.15-14.20	10.91
5.	G I-5.9	5	9.10-10.80	10.02
6.	G I-10.3	4	11.38-12.10	11.71
7.	G II-20.4	5	11.17-12.12	11.70
8.	G II-19.5	5	10.58-11.92	11.40
9.	G VI-54	4	10.73-12.53	11.78
10.	G VI-55	4	10.28-12.00	11.04
11.	G VI-56	4	10.18-11.53	10.72
12.	G VI-61	4	9.62-11.08	10.48
13.	G VI-64	5	9.37-12.00	10.67
14.	G I-15.5	4	10.00-12.06	10.97
15.	G VI-68	4	9.88-11.42	10.84

F (P=0.05) N.S.

C.V. 8.36%

Mean values with common letters do not differ significantly

Table 32. The coefficient of variation was calculated to be 11.71 per cent. The maximum seed thickness was recorded for plant no.3 of G VI-68 whereas the minimum for plant no.2 of G I-5.9. The mean seed thickness was the highest (7.4 mm) for G II-20.4 and lowest (5.7 mm) for G I-5.9. Analysis of variance showed that all the parents were on par with each other for this trait. Bartlett's test indicated homogeneity of the data.

4.1.2.3.7. Ratio of dry bean weight to wet bean weight - The values showed a coefficient of variation of 54.53 per cent. Hence the data was subjected to square root transformation. The coefficient of variation then came down to 20.43 per cent. However, even after square root transformation of the data, the analysis of variance showed that the F-value is not significant (P=0.784). Bartlett's test conducted showed that the Chi-square is highly significant (P = 0.000). The data recorded for the character is given in Table 33. Plant no.2 of M-13.12 gave the lowest ratio of 0.13 and plant no.2 of G VI-61 the highest value of 0.465. The mean of the ratio was the highest for M-9.16.

4.1.2.3.8. Ratio of seed length to seed width - The data in Table 34 reveal that the values for the ratio of seed length to seed width ranged from 1.585 noticed for plant no.1 of G I-10.3 to 1.982 noticed in plant no.2 of M-13.12. The

Table 32. Range and mean of seed thickness in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range (mm)	Mean (mm)
1.	M-9.16	5	5.99-7.73	6.86
2.	M-13.12	5	4.60-6.60	5.92
3.	M-16.9	5	6.09-7.36	6.49
4.	G I-4.8	5	6.04-6.85	6.62
5.	G I-5.9	5	4.40-6.72	5.69
6.	G I-10.3	4	6.10-7.20	6.74
7.	G II-20.4	5	6.48-8.00	7.40
8.	G II-19.5	5	5.92-7.88	6.78
9.	G VI-54	4	5.60-7.18	6.46
10.	G VI-55	4	5.52-7.40	6.29
11.	G VI-56	4	5.42-6.14	5.84
12.	G VI-61	4	6.27-7.51	6.84
13.	G VI-64	5	5.64-7.84	6.71
14.	G I-15.5	4	5.20-7.45	6.49
15.	G VI-68	4	5.96-9.07	7.05
F (P=0.05)				N.S.
C.V.				11.71%

Table 33. Range and mean of the ratio of dry bean weight to wet bean weight in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range	Mean*	
1.	M-9.16	5	0.29-0.43	0.61	(0.37)
2.	M-13.12	5	0.30-0.38	0.64	(0.29)
3.	M-16.9	5	0.31-0.34	0.57	(0.33)
4.	G I-4.8	5	0.26-0.34	0.53	(0.28)
5.	G I-5.9	5	0.19-0.25	0.48	(0.23)
6.	G I-10.3	4	0.20-0.38	0.52	(0.28)
7.	G II-20.4	5	0.31-0.38	0.58	(0.34)
8.	G II-19.5	5	0.29-0.41	0.58	(0.34)
9.	G VI-54	4	0.31-0.37	0.58	(0.34)
10.	G VI-55	4	0.22-0.34	0.52	(0.28)
11.	G VI-56	4	0.26-0.31	0.53	(0.29)
12.	G VI-61	4	0.25-0.46	0.59	(0.35)
13.	G VI-64	5	0.24-0.33	0.54	(0.29)
14.	G I-15.5	4	0.24-0.33	0.53	(0.28)
15.	G VI-68	4	0.25-0.34	0.55	(0.31)
F (P=0.05)				N.S.	
C.V.				20.43%	

* Transformed data. The figures in parenthesis are in the original scale

Table 34. Range and mean of the ratio of seed length to seed width in 15 cocoa types used as parents

Sl. No.	Parents	No. of trees	Range	Mean
1.	M-9.16	5	1.75-1.83	1.78 cde
2.	M-13.12	5	1.68-1.98	1.81 bcd
3.	M-16.9	5	1.72-1.85	1.79 bcde
4.	G I-4.8	5	1.61-1.71	1.67 fg
5.	G I-5.9	5	1.72-1.85	1.80 bcd
6.	G I-10.3	4	1.58-1.76	1.65 g
7.	G II-20.4	5	1.63-1.79	1.72 efg
8.	G II-19.5	5	1.67-1.83	1.75 def
9.	G VI-54	4	1.82-1.88	1.86 abc
10.	G VI-55	4	1.88-1.96	1.94 a
11.	G VI-56	4	1.78-1.90	1.84 bc
12.	G VI-61	4	1.65-1.79	1.72 defg
13.	G VI-64	5	1.65-1.81	1.74 def
14.	G I-15.5	4	1.76-1.86	1.78 cde
15.	G VI-68	4	1.81-1.90	1.87 ab

F (P=0.01)	S
C.V.	3.37%

Mean values with common letters do not differ significantly

average of the ratio of seed length to seed width was maximum for G VI-55. The parent G VI-55 was on par with G VI-54 and G VI-68 and they differed significantly from the rest as revealed by the analysis of variance. Four parents viz., G I-10.3, G I-4.8, G II-20.4 and G VI-61 were on par with each other of which G I-10.3 recorded the lowest mean value. The coefficient of variation was found to be 3.37 per cent. The Chi-square for Bartlett's test was non-significant.

A compilation of the analysis of variance of the 16 characters studied in 15 parents is presented in Table 35. Yield did not show any significant difference among the parents. Among the pod characters, number of pods per tree and fruit wall thickness at furrow did not differ significantly in the parents. Of the eight bean characters studied, the parents were found to differ significantly except for seed width, seed thickness and ratio of dry bean weight to wet bean weight.

4.1.3. Parents and hybrids

Analysis of variance was done considering the hybrid and parent populations together with respect to yield and number of pods.

4.1.3.1. Yield - Analysis of variance of yield in the 34 genotypes included in the study indicated that the genotypes

Table 35. Analysis of variance of the 16 characters studied in 15 parents

Sl. No.	Characters	Mean sum of squares between crosses	Mean sum of squares within crosses	Probability of significance of F-test	Bartlett's test probability of significance
1.	Yield*	409.99	295.86	0.1930	0.199
2.	No. of pods*	2.94	2.836	0.4338	0.431
3.	Pod length	7.476	0.988	0.000	0.031
4.	Pod width	1.140	0.496	0.015	0.000
5.	Pod weight*	12.609	5.432	0.0141	0.020
6.	Fruit wall thickness at ridge	5.264	2.283	0.0147	0.510
7.	Fruit wall thickness at furrow*	0.448	0.242	0.0553	0.000
8.	Pod length/pod wodth	0.214	0.047	0.000	0.000
9.	Wet bean weight per pod	1299.872	571.031	0.0161	0.000
10.	Dry bean weight	18.342	6.854	0.005	0.195
11.	Number of beans per pod	122.537	26.826	0.000	0.322
12.	Seed length	6.084	2.877	0.0257	0.000
13.	Seed width	1.511	0.826	0.0585	0.017
14.	Seed thickness	1.002	0.588	0.0828	0.535
15.	Dry bean wt./* Wet bean wt.	0.011	0.014	0.784	0.000
16.	Seed length/ Seed width	0.024	0.004	0.000	0.533

* Transformed data used for analysis

differed among themselves significantly. The parent G VI-55 gave the highest mean yield and was on par with 14 other genotypes as given in Table 36. Parents which were found not to differ among themselves when taken alone, were found to differ among themselves when analysed along with the hybrids.

4.1.3.2. Number of pods - Analysis of variance of number of pods also revealed that the 34 genotypes taken for the study differed among themselves significantly with respect to this character (Table 37). Hybrid H7 of series I with maximum mean value for number of pods was on par with 17 other genotypes. Here again the parents which showed no significant difference among themselves when taken alone, were found to differ among themselves significantly when analysed along with the hybrids.

4.1.4. Coefficient of variation of hybrid and parent populations

Coefficient of variation for each character under the study was calculated separately for parent and hybrid populations (Table 38). Yield and number of pods showed the maximum variability both for the parent as well as hybrid populations. Yield gave a coefficient of variation of 62.18 per cent in hybrids and 74.07 per cent in parents. For number of pods, the coefficient of variation for hybrid and parent populations were 64.10 per cent and 62.09 per cent, respectively. Moderate variability was shown by pod weight,

Table 36. Range and mean of yield in 34 genotypes including 19 hybrids and 15 parents

Sl. No.	Genotypes	No. of trees	Range	Mean* (g)
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	935-4140	50.18 (2519) bcdef
2.	H2(G I-10.3 x G VI-54)	10	1027-5947	53.71 (3121) abcd
3.	H3(G I-15.5 x G VI-54)	5	1852-5266	61.61 (4032) ab
4.	H4(G I-15.5 x G VI-55)	8	134-6310	58.37 (3407) abc
5.	H5(G I-10.3 x G VI-61)	8	621-6368	48.47 (2349) def
6.	H6(G I-10.3 x G VI-64)	10	720-5677	51.29 (2631) bcdef
7.	H7(G I-5.9 x G VI-68)	10	2139-9271	68.16 (4897) a
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	555-6480	57.39 (3294) abcd
9.	H2(M-13.12 x G I-5.9)	11	1457-6601	58.61 (3577) abc
10.	H3(M-16.9 x G II-20.4)	11	916-4683	51.44 (2786) bcde
11.	H4(M-16.9 x G II-19.5)	11	1826-6982	57.98 (3554) abc
12.	H5(G I-10.3 x G VI-56)	9	939-6458	49.92 (2493) bcdef
13.	H6(G I-5.9 x G VI-61)	10	309-6083	60.00 (3600) abc
14.	H7(G I-5.9 x G VI-55)	9	1268-5418	48.24 (2472) bcdef
15.	H8(M-16.9 x G I-4.8)	7	459-4044	44.26 (2232) bcdef
16.	H9(M-16.9 x G VI-55)	9	898-3851	44.88 (2111) bcdef
17.	H10(M-9.16 x G II-20.4)	11	395-4643	44.13 (1948) def
18.	H11(M-16.9 x G VI-56)	9	1076-3876	46.91 (2201) cdef
19.	H12(G I-4.8 x G VI-54)	9	346-2341	36.33 (1319) f

Table 36 (Contd.)

Sl. No.	Genotypes	No. of trees	Range	Mean* (g)
	Parents			
20.	M-9.16	5	683-3480	41.87 (1864) cdef
21.	M-13.12	5	789-5349	50.61 (2823) bcdef
22.	M-16.9	5	1292-3507	48.49 (2418) bcdef
23.	G I-4.8	5	93-2427	37.76 (1643) def
24.	G I-5.9	5	1327-5594	56.20 (3167) abcd
25.	G I-10.3	4	1885-3393	49.70 (2503) bcdef
26.	G II-20.4	5	1374-4910	48.97 (2488) bcdef
27.	G II-19.5	5	1944-6265	46.69 (2327) bcdef
28.	G VI-54	4	1811-5344	61.36 (3894) abc
29.	G VI-55	4	1138-14094	72.20 (5197) a
30.	G VI-56	4	2147-3865	53.70 (2925) abcde
31.	G VI-61	4	1110-4163	47.97 (2428) bcdef
32.	G VI-64	5	96-3855	32.00 (1490) f
33.	G I-15.5	4	996-6894	61.14 (3738) abc
34.	G VI-68	4	1027-3882	53.08 (2825) abcde

* Transformed data. The figures in parenthesis are in the original scale

Mean values with common letters do not differ significantly

Table 37. Range and mean of number of pods in 34 genotypes including 19 hybrids and 15 parents

Sl. No.	Genotypes	No. of trees	Range	Mean*
	Series I (1986 planting)			
1.	H1(G I-5.9 x G VI-54)	7	14-62	5.94 (37.71) abc
2.	H2(G I-10.3 x G VI-54)	10	14-81	6.51 (42.50) ab
3.	H3(G I-15.5 x G VI-54)	5	19-81	6.38 (43.40) ab
4.	H4(G I-15.5 x G VI-55)	8	1-47	5.03 (25.37) abcdef
5.	H5(G I-10.3 x G VI-61)	8	8-82	5.50 (30.25) bcdef
6.	H6(G I-10.3 x G VI-64)	10	8-63	5.40 (29.20) bcdef
7.	H7(G I-5.9 x G VI-68)	10	21-91	6.74 (48.00) a
	Series-II (1987 planting)			
8.	H1(G I-15.5 x G VI-64)	12	6-70	5.71 (35.58) abc
9.	H2(M-13.12 x G I-5.9)	11	17-77	6.33 (41.72) ab
10.	H3(M-16.9 x G II-20.4)	11	9-46	5.09 (27.36) bcdef
11.	H4(M-16.9 x G II-19.5)	11	13-65	5.59 (33.09) abcd
12.	H5(G I-10.3 x G VI-56)	9	8-55	4.42 (21.22) cdef
13.	H6(G I-5.9 x G VI-61)	10	3-59	5.65 (35.10) abc
14.	H7(G I-5.9 x G VI-55)	9	11-47	4.49 (21.44) cdef
15.	H8(M-16.9 x G I-4.8)	7	5-44	4.61 (24.28) bcdef
16.	H9(M-16.9 x G VI-55)	9	7-30	3.96 (16.44) def
17.	H10(M-9.16 x G II-20.4)	11	4-47	4.15 (19.72) def
18.	H11(M-16.9 x G VI-56)	9	10-36	4.41 (20.44) cdef
19.	H12(G I-4.8 x G VI-54)	9	4-27	3.81 (15.22) ef

Table 37 (Contd.)

Sl. No.	Genotypes	No. of trees	Range	Mean* (g)
	Parents			
20.	M-9.16	5	11-56	5.31 (30.00) abcdef
21.	M-13.12	5	9-61	5.60 (32.20) abcde
22.	M-16.9	5	14-38	5.04 (26.20) bcdef
23.	G I-4.8	5	1-26	3.90 (17.60) def
24.	G I-5.9	5	14-59	5.62 (33.40) abcd
25.	G I-10.3	4	20-36	5.01 (25.50) bcdef
26.	G II-20.4	5	14-50	5.04 (26.80) bcdef
27.	G II-19.5	5	18-58	5.53 (32.00) abcde
28.	G VI-54	4	20-59	6.44 (43.00) ab
29.	G VI-55	4	8-99	6.04 (36.50) abcdef
30.	G VI-56	4	20-36	5.18 (27.25) abcdef
31.	G VI-61	4	12-45	4.98 (26.25) bcdef
32.	G VI-64	5	1-40	3.29 (15.60) f
33.	G I-15.5	4	12-83	6.70 (45.00) ab
34.	G VI-68	4	9-34	4.85 (24.75) bcdef

* Transformed data. The figures in parenthesis are in the original scale
Mean values with common letters do not differ significantly

Table 38. Coefficient of variation for different characters in the population

Sl. No.	Character	Hybrid (%)	Parent (%)
1.	Yield	62.18	74.07
2.	Number of pods	64.10	62.09
3.	Pod length	12.63	11.06
4.	Pod width	10.36	11.39
5.	Pod weight	29.40	31.72
6.	Fruit wall thickness at ridge	19.03	16.95
7.	Fruit wall thickness at furrow	19.98	55.71
8.	Wet bean weight per pod	28.70	27.86
9.	Dry bean weight	24.27	21.25
10.	Number of beans per pod	14.29	16.90
11.	Seed length	10.62	9.73
12.	Seed width	9.03	9.05
13.	Seed thickness	13.12	12.54
14.	Pod length/pod width	11.74	14.30
15.	Dry bean weight/wet bean weight	21.44	52.98
16.	Seed length/seed width	10.66	5.00

wet bean weight per pod, dry bean weight and ratio of dry bean weight to wet bean weight. In hybrids, pod weight, wet bean weight per pod, dry bean weight and ratio of dry bean weight to wet bean weight gave a coefficient of variation of 29.40 per cent, 28.76 per cent, 24.27 per cent and 21.44 per cent, respectively. Similarly in the parent population, pod weight, wet bean weight per pod, dry bean weight and ratio of dry bean weight to wet bean weight gave a coefficient of variation of 31.72 per cent, 27.86 per cent, 21.25 per cent and 52.98 per cent, respectively. In hybrids other characters showed very low variation. However, in parents abnormally high variation was noticed for fruit wall thickness at furrow with a coefficient of variation of 55.7 per cent. Other characters in parent population also showed very low variation. Except for fruit wall thickness at furrow and ratio of dry bean weight to wet bean weight, variation in various character show a similar trend both in parent and hybrid populations.

4.2. HERITABILITY STUDIES

Observations recorded on 12 characters studied were subjected to statistical analysis to estimate the coefficient of heritability, additive genetic variance and variance of dominance deviation. The estimate of each parameter for all the characters taken are presented in Table 39. The characters studied are discussed below.

Table 39. Additive genetic variance, variance of dominance deviation and coefficient of heritability of the 12 characters in cocoa

Sl. No.	Characters	Additive genetic variance	Variance of dominance deviation	Coefficient of heritability
1.	No. of pods	47.579	-76.53	0.456
2.	Pod length	4.677	-3.94	1.431
3.	Pod width	0.299	-0.033	0.528
4.	Pod weight	9349.422	-7459.081	1.055
5.	Fruit wall thickness at ridge	0.573	1.597	0.169
6.	Fruit wall thickness at furrow	-0.179	2.483	-0.703
7.	Wet bean weight per pod	851.802	-702.886	0.970
8.	Dry bean weight	12.790	-9.226	1.027
9.	Number of beans	36.237	-28.875	0.934
10.	Seed length	1.382	1.739	0.309
11.	Seed width	0.371	0.207	0.388
12.	Seed thickness	0.583	-0.328	0.759

4.2.1. Pod characteristics

4.2.1.1. Number of pods - The coefficient of heritability estimated for the number of pods per tree was 0.456, which shows that only about 50 per cent of the character is heritable. The additive genetic variance calculated was 45.57. The variance of dominance deviation was negative with the value -76.53.

4.2.1.2. Pod length - This character showed a very high heritability. The coefficient of heritability was estimated to be 1.43. The additive genetic variance was 4.677. The variance of dominance deviation was again negative, the estimated value being -3.946.

4.2.1.3. Pod width - Unlike pod length, pod width showed a low heritability. The estimated coefficient of heritability being 0.528. Additive genetic variance was 0.299 while variance due to dominance deviation was negative with the value of 3.358.

4.2.1.4. Pod weight - Estimates of heritability for pod weight showed that the character is highly heritable. The coefficient of heritability was calculated at 1.055. The additive genetic variance was 9349.42, whereas the variance due to dominance deviation was negative with the value of -7459.08.

4.2.1.5. Fruit wall thickness at ridge - The heritability for this character was very low. The coefficient of heritability was only 0.169. The additive genetic variance was 0.573. The variance of dominance deviation was 2.483.

4.2.1.6. Fruit wall thickness at furrow - The heritability for this character was found to be negative. The coefficient of heritability was -7.03. Additive genetic variance was also found to be negative with the value of -0.179. However, the variance due to dominance deviation was positive (2.483).

4.2.2. Bean characteristics

4.2.2.1. Wet bean weight - Heritability was comparatively high for wet bean weight. The coefficient of heritability estimated was 0.970. The additive genetic variance was 851.8, whereas the variance of dominance deviation was negative at -702.88.

4.2.2.2. Dry bean weight - Dry bean weight also showed a high heritability with the coefficient of heritability estimated being 1.027. The variance of dominance deviation was again negative with the value of -9.226. The additive genetic variance was 12.79.

4.2.2.3. Number of beans - The number of beans per pod gave a coefficient of heritability of 0.934, indicating that the character is highly heritable. The additive genetic variance was calculated at 36.23. The variance due to dominance deviation was negative with the value of -28.87.

4.2.2.4. Seed length - Heritability was found to be very low for seed length. The coefficient of heritability estimated was 0.309. The additive genetic variance was 1.382, whereas the variance of dominance deviation was 1.739.

4.2.2.5. Seed width - Seed width also showed a low heritability, the coefficient of heritability being 0.388. The additive genetic variance was 0.371 and the variance of dominance deviation was 0.207.

4.2.2.6. Seed thickness - Comparatively high heritability was noticed for seed thickness. The coefficient of heritability estimated was 0.759. The additive genetic variance was 0.583. The variance due to dominance deviation was negative, the value being -0.328.

4.3. GENETIC DIVERGENCE STUDIES

Genetic divergence was studied by attempting to cluster the 34 apparently different genotypes taken for the study. Clustering was done based on the difference in means of all characters studied. Eucleidian distance for clustering was employed. Initially the genotypes were grouped into two clusters and the average intra cluster distance calculated. This was repeated grouping the genotypes into 3, 4, 5 etc. till 20 clusters as shown in Table 40. Employing the method of maximum curvature, a graph was drawn plotting the number of clusters in the X-axis against the corresponding average intracluster distance in the Y-axis as shown in Fig.1. The graph was found to move steadily downwards without showing any recovery. The average intracluster distance kept on decreasing steadily with the increase in number of clusters, indicating that natural clustering was not possible. Tables 41 and 42 shows the grouping of genotypes into five and ten clusters, respectively.

4.4. PATH COEFFICIENT STUDIES

Yield is a contribution of a number of characters referred to as yield contributing characters. Path coefficient analysis was done to partition the association of various yield contributing characters into direct and indirect effects. Viewing yield in terms of total weight of wet bean produced per tree, path coefficient analysis was done taking 10 yield contributing characters, namely, number of pods, pod length, pod width, pod weight, wet bean weight per pod, dry bean weight, number of beans per pod, seed length, seed width and seed thickness. Direct and indirect effects of each character was found out and is presented in Table 43.

Table 40. Average intracluster distances for different number of clusters

Number of clusters	Average intracluster distances
2	697.1
3	656.0
4	620.0
5	599.0
6	561.28
7	537.8
8	479.6
9	462.0
10	425.6
11	408.0
12	382.0
13	359.4
14	314.15
15	277.1
16	231.6
17	206.6
18	181.23
19	155.41
20	135.37

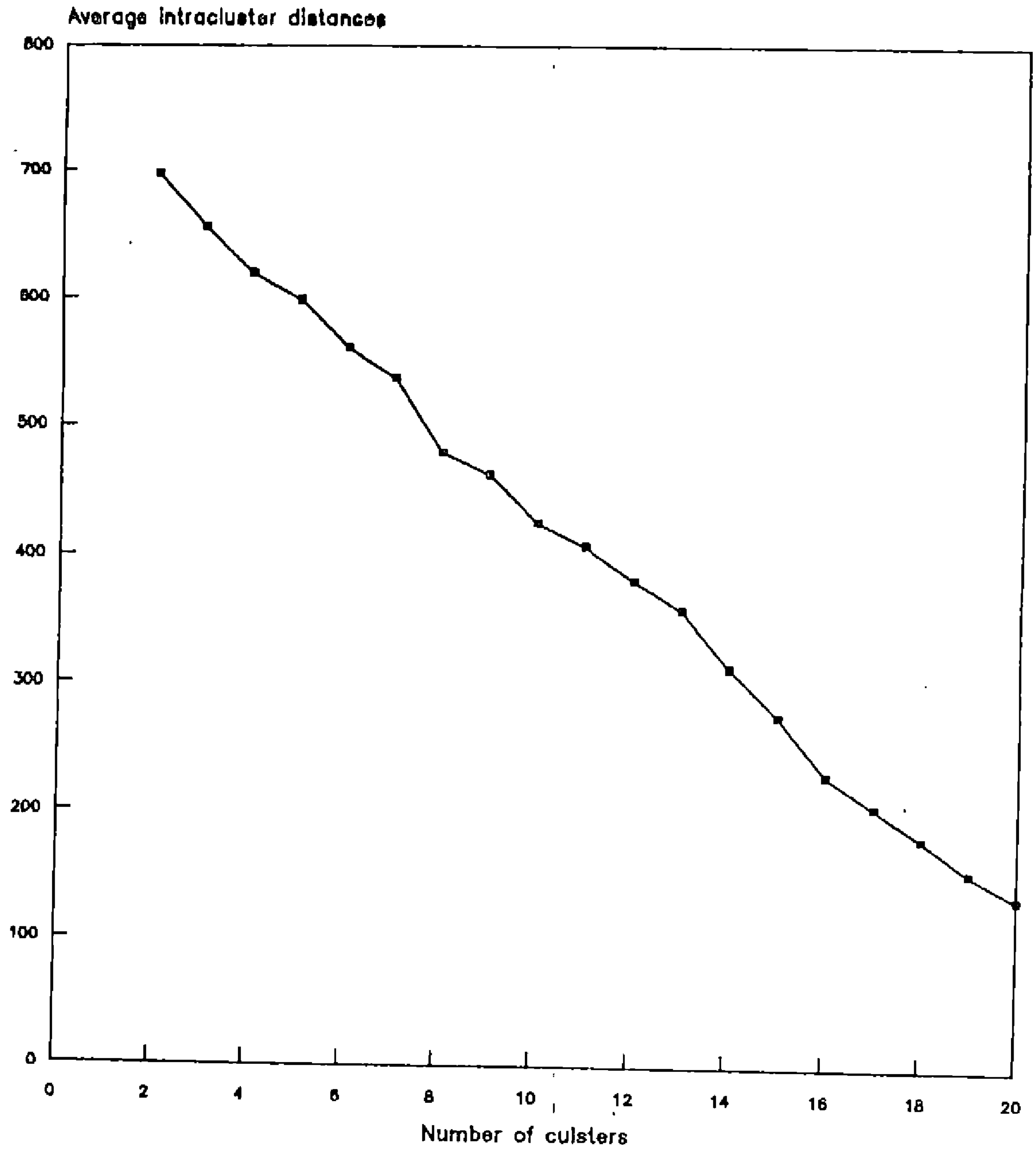

Fig.1 Average intracluster distance for different number of clusters.

Table 41. Distribution of 34 genotypes of cocoa into 5 groups following cluster analysis

Cluster I

G I-10.3 x G VI-61, M-16.9 x G II-20.4, M-16.9 x G I-4.8, M-16.9, G II-19.5, G VI-64

Cluster II

G I-15.5 x G VI-55, M-16.9 x G II-19.5, M-16.9 x G VI-55, M-13.12, G VI-54, G I-15.5

Cluster III

G I-5.9 x G VI-68, G I-10.3 x G VI-56, M-9.16 x G II-20.4, G I-5.9, G VI-55, G VI-68

Cluster IV

G I-10.3 x G VI-54, M-13.12 x G I -5.9, G I-5.9 x G VI-55, G I-4.8 x G VI-54, G II-20.4, G VI-61

Cluster V

G I-5.9 x G VI-5.4, G I-15.5 x G VI-54, G I-10.3 x G VI-64, G I-15.5 x G VI-64, G I-5.9 x G VI-61, M-16.9 x G VI-56, M-9.16, G I-4.8, G I-10.3, G VI-56

Table 42. Distribution of 34 genotypes of cocoa into 10 groups following cluster analysis

Cluster I

G I -10.3 x G VI-61, M-16.9, G II-19.5

Cluster II

G I-15.5 x G VI-55, M-16.9 x G VI-55, M-13.12, G I-15.5

Cluster III

G I-5.9 x G VI-68

Cluster IV

M-13.12 x G I-5.9, G I-5.9 x G VI-55, G II-20.4, G VI-61

Cluster V

G I-10.3 x G VI-64, M-16.9 x G II-19.5, G I-4.8, G VI-54

Cluster VI

G I-5.9 x G VI-54, G I-5.9 x G VI-61, M-16.9 x G VI-56, G VI-56

Cluster VII

M-16.9 x G II-20.4, M-16.9 x G I-4.8, G VI-64

Cluster VIII

G I-15.5 x G VI-54, G I-15.5 x G VI-64, M-9.16, G I-10.3

Cluster IX

G I-10.3 x G VI-56, M-9.16 x G II-20.4, G VI-55, G VI-68

Cluster X

G I-10.3 x G VI-54, G I-4.8 x G VI-54, G I-5.9

Table 43. Path coefficient values - direct and indirect effect of various yield components on yield

Sl. No.	Characters	Direct effect	Indirect effect via									
			No. of pods	Pod length	Pod width	Pod weight	Wet bean weight per pod	Dry bean weight	No. of beans per pod	Seed length	Seed width	Seed thickness
1.	No. of pods	0.9925	--	-0.0007	-0.0011	0.0035	-0.0499	-0.0048	-0.0058	0.0014	-0.0009	-0.0011
2.	Pod length	0.0254	-0.0289	--	0.0068	-0.0157	0.1124	0.0445	0.008	-0.0029	0.0016	-0.0216
3.	Pod width	0.0142	-0.0801	0.0121	--	-0.0179	0.1343	0.0481	0.0064	-0.0058	0.0037	-0.0162
4.	Pod weight	-0.0219	-0.1596	0.0183	0.0116	--	0.1715	0.0517	0.0102	-0.0053	0.0035	-0.0213
5.	Wet bean wt. per pod	0.2079	-0.2382	0.0138	0.0092	-0.0180	--	0.0433	0.0169	-0.0053	0.0034	-0.0134
6.	Dry bean wt.	-0.0748	0.0633	0.0152	0.0091	-0.0151	0.1204	--	0.0013	-0.006	0.0051	-0.262
7.	No. of beans per pod	0.0274	-0.2118	0.0074	0.0033	-0.0082	0.1283	0.0037	--	-0.0019	0.000	0.0089
8.	Seed length	-0.0102	-0.1370	0.0073	0.0081	-0.0113	0.1086	0.0440	0.0051	--	0.0048	-0.0108
9.	Seed width	0.0076	-0.1144	0.0053	0.0069	-0.0102	0.0923	0.0504	0.000	-0.0065	--	-0.0148
10.	Seed thickness	-0.0409	-0.0263	0.0134	0.0056	-0.0114	0.0680	0.0478	-0.0059	-0.0027	0.0027	--

Residual = 0.0632

4.4.1. Direct effect

Number of pods showed the maximum contribution to yield with a direct effect of 0.9925. This was followed by the contribution of wet bean weight per pod (0.2079). Dry bean weight, number of beans per pod, pod length, pod width and seed width showed low positive direct effect. Pod weight, seed length and seed thickness exhibited low degree of negative effect to yield in cocoa.

4.4.2. Indirect effect

4.4.2.1. Number of pods - Number of pods showed very low indirect effect. It was negative via pod length (-0.0007, pod width (-0.0011), wet bean weight per pod (-0.0499), dry bean weight (-0.0048), seed width (-0.0009), seed thickness (-0.0011) and number of beans (-0.0058). It was positive via pod weight (0.0035) and seed length (0.0014).

4.4.2.2. Pod length - Pod length showed negative indirect effect via number of pods (-0.02), pod weight (-0.015), seed length (-0.002) and seed thickness (-0.021). It had positive indirect effects through pod width (0.0068), wet bean weight per pod (0.1124), dry bean weight (0.044), seed width (0.0016) and number of beans per pod (0.008).

4.4.2.3. Pod width - The indirect effect was maximum via wet bean weight of this trait with a value of 0.134. The indirect effect of this character through other characters were negligible.

4.4.2.4. Pod weight - This character showed a positive indirect effect via wet bean weight per pod (0.171) and negative indirect effect via number of pods. The indirect effect via other characters were negligible.

4.4.2.5. Wet bean weight per pod - The negative indirect effect of this character via number of pods was prominent with a value of -0.238. The character showed negative indirect effects via other characters also but had low values. Positive indirect effect through some of the characters were found but had low values.

4.4.2.6. Dry bean weight - This character gave a negative indirect effect via seed thickness (-0.26). The positive indirect effect via wet bean weight per pod was found to be 0.12. Indirect effects through other character were negligible.

4.4.2.7. Number of beans per pod - The indirect effect of this character via number of pods was negative with a value of -0.21. It also gave a positive direct effect via wet bean weight per pod (0.128). Other indirect effects were negligible.

4.4.2.8. Seed length - Seed length had negative indirect effect via number of pods (-0.10) and a positive indirect effect via wet bean weight per pod (0.10). Indirect effects through other characters were negligible.

4.4.2.9. Seed width - Like seed length, seed width also had a negative indirect effect via number of pods (-0.11) and a positive indirect effect via wet bean weight per pod (0.92). Indirect effects via other characters were negligible.

4.4.2.10. Seed thickness - Indirect effects of this character were negligible.

Discussion

5. DISCUSSION

Information on genetic behaviour and inheritance of yield and yield contributing characters are vital for the success of any breeding programme. It is a basic requirement for the formulation of any viable breeding methodology.

Studies on genetic behaviour of characters generally become difficult in perennial crops because of the fact that the juvenile phase of the plant is comparatively very long and it may take a few years for the plant to enter into the reproductive phase. Study of a few generations, therefore, becomes time consuming, costly and cumbersome. The problem is further compounded due to the fact that most of the perennial crops are outcrossing and highly heterozygous.

Cocoa (Theobroma cacao L.) is one crop which has remained largely elusive to the scientific world on its genetic behaviour. With all the drawbacks of a perennial crop, genetic studies in cocoa become all the more complicated due to its self-incompatibility and even cross-incompatibility in certain cases. Hence, the conventional designs of experimentation which require production of a desired set of crosses for analysis becomes very difficult. The present investigation in cocoa carried out in order to understand the inheritance and genetic behaviour of yield and yield contributing characters should be viewed with this background in mind.

In this study, variability between and within 34 genotypes of cocoa with respect to 16 different characters were assessed by analysis of variance. Heritability in narrow sense was estimated for each of these characters. Genetic divergence was studied by clustering the genotypes based on the difference in means of the various traits studied. Path coefficient analysis was done to assess the contribution of different yield components to yield.

5.1. VARIABILITY STUDIES

An insight into the magnitude of variability present in a crop species is of utmost importance as it provides the basis for effective selection. Assessment of variability is the first step in any breeding programme, since it gives an idea about the specific methodology to be adopted as well as the extent to which improvement can be achieved.

Studies on variability of biometric characters in cocoa have been reported as early as 1932-33 by Pound in Trinidad. This, as well as studies carried out in subsequent years, revealed that yield of cocoa expressed in dry or wet bean weight is a very variable character and of a quantitative nature. High variability in weight of seed was observed even within a single pod (Enriquez and Soria, 1966).

In the present investigation, high amount of variability has been found to be existing for most of the characters studied. The genotypes differed significantly for almost all characters. When the variability was estimated for the hybrid population and the parent population separately, it has been indicated that most of the characters have more or less uniform pattern of variability in both the populations (Table 38).

The discovery of heterotic vigor in cocoa by Posnette (1943) in the outcrosses of Upper Amazon parents and the supporting evidence of high amount of interpopulation heterosis (Montserrin *et al*., 1957) gave a strong basis for the breeders all over the world to produce hybrid seeds of cocoa. However, these programmes failed to produce the expected impact on production and the reason attributed was the narrow genetic base from which the programmes were initiated. In the proceedings of the seventh international cocoa research conference held at Douala, Cameroon in 1979, suggestions were made to increase genetic variability and hybridisation was projected as a method to achieve this. However, in the present study the variability in the parent population and hybrid population are comparable with respect to most of the characters. The lack of comparatively higher amount of variability in the hybrid population may be due to the outcrossing behaviour of cocoa where any seed produced naturally can be considered as a hybrid, except for the self compatible lines (Hunter, 1990).

Among the 16 characters studied, yield and number of pods exhibited the maximum variability both in hybrid and parent populations. Yield in terms of wet bean weight per tree, showed a coefficient of variation of 62.18 per cent in hybrid population and 74.07 per cent in parent population (Table 38). The yield ranged from 0.134 kg to 9.27 kg in hybrids with a mean of 2.87 kg (Table 2). In parents it ranged from 0.093 kg to 14.09 kg, the mean being 2.83 kg (Table 19). It indicates that variability was more in parents than the hybrids with respect to yield. However, the hybrids together gave a slightly higher mean for yield, which indicates a superiority in the production potential of hybrids.

Among the various hybrids, H7 of series I gave the highest mean yield and was on par with H3 and H4 of this series and H2, H4 and H6 of series II (Table 2). The different genotypes in the parent population, however, did not differ among themselves significantly with respect to yield. Parents G VI-55, G VI-54, G I-15.5 and G I -5.9 which recorded high mean values (Table 19) were the parents of the top five high yielding hybrids. Similarly, these parents were also on par with the best among the hybrids (Table 36), of which they are one of the parents. This suggests that yield which is a quantitative character by itself or through one or more of the yield contributing characteristics can be transmitted to the progenies.

Hybrid H4 of series II, however, gave a superior mean yield eventhough both of its parents recorded low mean yields indicating the possibility of rare recombinants appearing in the crosses. This also points to the possibility that heterotic effect for this trait as suggested by Posnette (1943);Montserrin et al. (1957) and Toxopeus (1972) cannot be ruled out.

Glendinning (1963) found a very high correlation between number of pods produced and total wet weight of their seeds, indicating that in some populations number of fruits is a good estimate of yield. The results in the present study is in accordance with the findings of Glendinning. Number of pods per tree seems to contribute the most to the yield. Variability of yield in the two populations of hybrid and parent is almost comparable with that of number of pods. In hybrid population, the coefficient of variation of number of pods is found to be 64.1 per cent whereas in parents it is

62.09 per cent (Table 38). As in the case of yield, hybrids showed a significant difference among themselves with respect to number of pods (Table 3) whereas the parents did not differ significantly (Table 20). Hybrid H7 of series I, which was ranked first with respect to yield (Table 2), was also the first with respect to the number of pods (Table 3). Similarly, H3 of series I and H2, H4 and H6 of series II which were on par with H7 of series I for yield, were also on par with H7 of series I for the number of pods. Other hybrids which were on par with H7 of series I for number of pods are H1 of series I as well as series II.

The non-significant differences between parents with regard to yield and number of pods can be attributed to the high within variability in these parents. Since plants of the parent genotypes are vegetatively propagated progenies of a single tree, within variability to this extent goes against the belief that clones are uniform in their performance. Such variation among clones has been reported by Cilas et al. (1989) from a study with twenty clones belonging to Upper Amazon, Amelonado and Trinitario types. He has observed that the bean size was extremely variable but tended to be greatest in Trinitario types.

However, it remains open for investigation whether the root stock has any role in disturbing the uniformity of cloned progenies.

Among the parents, G I-15.5 G VI-54, G VI-55 and G I-5.9 recorded the highest mean number of pods per tree as in the case of yield. This trend hints at the close association of the number of pods with yield.

It may be noted here that the first seven ranked hybrids with respect to number of pods (Appendix-II), owe their ancestry to the four parent genotypes giving the highest mean number of pods, namely, G I-15.5, G VI-54, G VI-55 and G I-5.9. This suggests that the number of pods produced per tree is also heritable to some extent as was the case in yield.

The possibility of heterotic vigor for the number of pods is also evidenced by the performance of H4 of series II which gave a mean number of pods per tree comparable to the best among the hybrids. This hybrid owes its parentage to G II-19.5 and M-16.9, the former having a moderate mean number of pods whereas the latter a poor performer for this trait.

Hybrids have often been associated with superior performance in comparison to parent genotypes. However, in the present results no such general superiority of the hybrids could be envisaged as far as the yield and number of pods are concerned. Genotypes with comparable performance are found to be present in both the populations. Earlier reports available regarding the performance of hybrid cocoa also are conflicting. Tan in 1981 reported that the crosses between Trinitario types and Amazon were much superior to Trinitario types. In contrast, Cilas et al. (1985) studying 218 trees belonging to three families of hybrids reported that there was no significant differences between the hybrid families. However, high yielding material was found in all the three. Similarly, Martin (1987) through his trials with Amelonado and hybrid cocoa in Fiji, showed that the variety Amelonado recorded the highest mean yield during 1975-85 at Wainigata, although it was out-yielded by hybrids at some other sites. Amelonado showing good pod value, bean weight, tolerance to black pod and adaptability to farmers' field is still the only recommended variety for Fiji.

Napitupulu in 1990 evaluated clones introduced from Kew Royal Botanical Gardens, U.K. and Wageningen, Netherlands from 1984 to 1989 at Adolina, Indonesia. He reported that the best clones yielded 20-40 per cent more than the hybrid seedlings. Iquitos Mixed Calabacillo (IMC) clones gave the greatest number of the smallest beans. United Fruit (U.F.)

clones gave a few large beans, while Pa (Parinari) clones gave a moderate number of beans.

The data used in the present study pertains to only one year and therefore the observation made need not be conclusive as they may not be truly representing the actual potentialities of these hybrids.

Yield in cocoa expressed as wet bean weight per plant is assumed to be directly influenced by characters like number of beans per pod, wet bean weight per pod and also the dry bean weight of beans. In the present study, the hybrids in general have shown a comparatively higher magnitude of variability for most of the above characters. The average wet bean weight per pod ranged from 66.71 g to 134.27 g (Table 10) in the hybrids and 62.16 g to 142.37 g (Table 27) in the parents. The coefficients of variation for the former population was 28.7 per cent (Table 38) and for the latter it was 27.86 per cent. For dry bean weight, the coefficient of variation was 24.27 per cent in hybrids and 21.25 per cent in parents. Coefficients of variation of 16.9 per cent and 14.29 per cent were exhibited by the parent and hybrid, respectively, for number of beans per pod.

Similar observations have been reported by some of the earlier workers also. Enriquez and Soria (1966) have shown high variability in dry bean weight ranging from 0.5 g to 2.5 g. They reported variability in weight of seed even within a single pod. Subramonian and Balasimha (1982) reported significant variation among ten hybrids studied for the seven yield components viz., number of pods, dry bean production, pod weight, dry bean weight, bean number, percentage pulp per bean and total soluble solids. They noted statistically significant differences between types in pod weight, dry weight of peeled beans, percentage weight of shell, wet to dry bean weight ratio and percentage weight of pulp. The extent of variability was the largest in dry bean weight followed by pod value. In another study, Kumaran and Prasannakumari (1981) reported high variability for weight of wet beans per pod.

Analysis of variance in the hybrids showed significant differences for wet bean weight per pod. Hybrid H4 of series I and H5, H7 and H9 of series II showed the maximum mean values for wet bean weight per pod. The parents also differed significantly for this character. Parents G VI-55 and G VI-68 recorded very high mean values of 142.5 g and 114.18 g, respectively, for this trait. Interestingly, all the hybrid combinations which have G VI-55 as one of the parents, namely, H4 of series I, H7 and H9 of series II are among the best in the hybrids. This indicates that the character is highly heritable. Hybrid H5 of series II which has performed well for this character has G VI-56 as one of its parents, which also gave fairly good mean values for wet bean weight per pod.

Dry bean weight has bean described as a variable character in the literature. The weight of dry bean may even vary within a pod (Enriquez and Soria, 1966). Significant difference was noticed among the hybrids for this trait. Hybrid H4 of series I, H3, H4, H5, H9, H10 and H11 of series II produced the maximum dry bean weight and were comparable with each other. Parents also differed significantly among themselves for this trait, the best among them being G II-20.4. All hybrid combinations having G II-20.4 and G II-19.5 have recorded the best performance in this character. However, hybrid combination with G VI-64 and G VI-54 as one of the parents has recorded low mean dry bean weight, suggesting that the two parents have poor combining ability with respect to this trait. Hybrid H4 of series I, H7 and H9 of series II which have G VI-55 as one of the parents have shown good performance. Hybrid H10 of series II owing its parentage to M-9.16 also gave good performance. Out of the three hybrids involving G I-10.3 as a parent, only one, H5 of series II, showed good mean values for the character.

Analysis of variance with number of beans showed significant difference between hybrids. Hybrid H9 of series II and H4 of series I were ranked first and second, respectively, for this trait. Among parents also significant difference was noticed. Parents G VI-55, G VI-68, G VI-56, M13.12 and M16.9 were among the best in parents. Hybrid H9 of series II and H4 of series I had G VI-55 as the common parent. This is indicative of high heritability of the character as well as good combining ability of G VI-55. Other hybrids like H7 of series I, H5, H11 and H7 of series II had parents showing high mean values for number of beans per pod.

Pod characters like pod length, pod width, pod weight, fruit wall thickness at ridge and fruit wall thickness at furrow are also reported to show high variability. These traits can be assumed to have indirect effect on yield through pod size. Enriquez and Soria (1966) have shown that the thickness at ridge and depth of furrow in pods are very descriptive characters and are partially affected by environment. Soria (1975) reported great variation in fruit characteristics like length, diameter, total weight and weight of husk. Subramonian and Balasimha (1982) also reported significant variation among ten hybrids for pod weight.

Among the pod characteristics, pod weight showed the maximum variation with a coefficient of variation of 29.4

per cent, in the hybrids. This was followed by fruit wall thickness at ridge and fruit wall thickness at furrow, the values of coefficient of variation for the characters being 19.03 per cent and 19.98 per cent, respectively. The variability for pod length and pod width was comparatively less. Pod length showed a coefficient of variation of 12.63 per cent whereas for pod width the value was 10.36 per cent. The parent population also showed a similar trend in variability for all the pod characteristics except for fruit wall thickness at furrow, for which the coefficient of variation was as high as 55.71 per cent. The high value of coefficient of variation for fruit wall thickness at furrow lacks an explanation. In the parent population pod length, pod width, pod weight and fruit wall thickness at furrow showed the coefficient of variation values as 11.06 per cent, 11.39 per cent, 31.72 per cent and 16.95 per cent, respectively.

The hybrids showed significant difference with respect to pod length. Hybrid H9, H4, H5, H11, H8 and H3 all of series II showed high values for pod length. Significant difference was noticed among the parents too. G VI-61 showed the maximum pod length with a mean value of 16.3 cm and this parent differed significantly from the rest. However, the hybrids which has G VI-61 as one of the parents showed low mean values for pod length. Similarly G VI-64, G VI-55 and G II-20.4 which gave comparatively high mean values for pod length did not show much influence in the hybrids in which they are one of the parents. This probably indicates the higher influence of environment in this character. Hybrid H9 and H3 of series II are exceptions where G VI-55 and G II-20.4 which have recorded high mean values for pod length appear as one of the parents..

Pod width although showed significant differences among hybrids is comparatively less variable. This can be seen from the fact that nearly ten out of the 19 hybrids studied are on par with each other. The list is headed by H9 of series II.

Among parents too, significant differences were seen with respect to pod width. G VI-55, G I-10.3, G II-19.5 and G VI-64 were the ones to record highest mean values for pod width. Hybrid H4 of series I and H1, H4, H5 and H9 of series II which gave high mean values for pod width had the four genotypes with high pod width values as one of the parents. This signifies that pod width is an inherited trait.

Pod weight also showed significant differences among the hybrids as well as parents. Among the hybrids, H9 of series II had the highest pod weight followed by H4 of series I and among the parents, G VI-55 and G I-10.3 topped the list with mean values of 492 g and 352 g, respectively. The H9 of series II and H4 of series I had G VI-55 as one of the parents suggesting the direct influence of parents in the expression of this trait in the progeny.

For all the three characters, pod length, pod width and pod weight, the same hybrids are seen topping the list, namely, H9, H4, H3 and H11 of series II. This suggests a definite positive relation among the three characters. However, hybrid H9, H3 and H11 are ranked very low with respect to yield and number of pods indicating negative relationships, the hybrid H4 of series II being the exception.

With respect to fruit wall thickness at furrow and ridge, the hybrids differed significantly. However, the variability is very low. Ten out of the 19 hybrids are on par with each other for fruit wall thickness at ridge whereas for thickness at furrow 13 hybrids were found to be on par with each other. The two characters are assumed to have some relation with pod length, pod width and pod weight as reflected by the correspondence of the hybrids in the rank list (Appendix-I).

Among the genotypes in the parent population studied, significant difference was seen only with respect to the fruit wall thickness at ridge. In case of fruit wall thickness at furrow the within variability was so high that F-value was not significant at 5 per cent level of probability. This may be due to the effect of environment on this character. G I-10.3, G VI-64, G VI-55, M-13.12, G II-20.4 and G VI-56 were the parents with high mean values for fruit wall thickness at ridge. When only the mean values are considered, the same parents recorded the highest values for fruit wall thickness at furrow also.

The seed size characteristics such as seed length, seed width and seed thickness showed very less amount of variability both in hybrids and parent population. In hybrid population seed length, seed width and seed thickness showed a coefficient of variation of 9.03 per cent, 13.12 per cent and 11.74 per cent. In the parent population the variability for the three characters were comparable with that in the hybrid.

Hybrids H2, H3 and H4 of series I and H3, H4, H5, H9 and H11 of series II were among the best in the hybrids for high seed length. Parents also showed significant differences among themselves with respect to this character. Parents G VI-54, G VI-55, G VI-68, G II-20.4, G II-19.5, G I-15.5 and G VI-56 were the ones recording high mean values for this trait. It is worth noticing that all the hybrids giving high values for seed length had one of the parents with high mean seed length as their ancestor, indicating that the trait is heritable.

However, for seed width and seed thickness, eventhough there was significant difference among hybrids, parents were generally uniform and on par with each other. There seems to be no relation between the two characters which is reflected from the fact that the hybrids and even parents showing high mean values for seed width did not show the same level of performance for seed thickness. For both the characters, hybrids giving high mean values had at least one of the parents with high mean value as their ancestor, showing that the character is transmissible.

The main objective of cocoa breeding is to increase yield. Yield is a very variable character, made up of several components of quantitative nature and highly influenced by environment.

Mossu et al. (1981) studied the influence of flowering and pollination on cocoa yields. Amelonado and Amazonian clones were studied and it was reported that the variation in seed yield was entirely due to the variance in flowering and pollination. The Amazonian clones were more profusely flowering than Amelonado clones by about 30 per cent owing largely to more continuous flowering throughout the year. Ooi and Chew (1985) conducted five progeny trials on hybrid cocoa in peninsular Malaysia and found that individual hybrids showed considerable variation in performance between sites. In a trial, Nair et al. (1990) reported that the cocoa clones ICS 1 and ICS 6 which performed best for number of pods per plant and bean yield were also superior to the rest with respect to plant height and canopy spread.

The estimation of variability within and between the hybrid populations as well as their parents has been carried out based on the data on various characters recorded for a period of one year. There are 15 genotypes in the parent population. The 19 crosses considered in the hybrid population, however, do not have equal representation of the different parents. While some of the parents appear only in one cross some other parents are involved in three or four hybrids considered. Hence the variability in the hybrid population can not be considered as the result of equal contribution from all the parental genotypes.

However, within the limited scope of the experiment an attempt was made to get an insight into the variability within and between these two populations with respect to yield and various yield attributes. A general observation made in the study is that the hybrids are more uniform than the parents with respect to yield. The parents showed very high within variability with respect to yield, the difference being prominent at the tree level. This is against the expected high degree of variability in hybrids due to segregation resulting from the highly heterozygous seeds produced from crosses (Hunter, 1990). The low degree of variability observed in the present study can not be considered as unique. Lack of significant differences between 218 trees belonging to three hybrid families has been reported by Cilas *et al*. (1985). All the parents used in the crossing programme in the present study belong to Amazonian Forestero and therefore lack of high degree of genetic divergence within this group can be one of the reason for comparatively low variability in the hybrid population. The possibility of getting a slightly different picture in the pattern of variability can not be ruled out when the estimation is done using the data recorded for a longer period.

5.2. HERITABILITY STUDIES

The concept of heritability is one of the most important and most used in quantitative genetics. Heritability values express the proportion of variation in the population that is attributed to genetic difference among individuals. The most useful estimate of heritability is the heritability in narrow sense which being the additive portion of genetic variance can be exploited in most of the crop improvement programmes.

An important but often overlooked aspect of heritability estimate is that they apply only to a particular population growing in a particular environment at a particular point in time (Zobel and Talbert, 1984). There is an accumulating body of evidences which suggests that heritability values do change markedly with age, environmental changes, the type of data and the statistical approach (Namkoong et al., 1972; Lopez et al., 1988; Namkoong and Conkle, 1976; Franklin, 1979). Variation in the heritability estimates of cocoa has been reported by Soria et al. (1974).

After a detailed consideration on heritability estimates in perennial crops, Zobel and Talbert (1984) have cautioned that since heritability values are not estimated without error, the ratios obtained are only a relative indication of genetic control under a given condition and should not be interpreted as absolute or invariable values.

In the present investigation, heritability in narrow sense was estimated following full-sib analysis for various characters studied. The data used for the analysis were recorded from six and seven year old trees which are expected to have reached the steady bearing age. One year data were recorded from all the trees starting from April 1992 to March 1993. The heritability estimates in general appear to be slightly to the upper side for all the characters (Table 39) probably because the trees are comparatively young and the data are relatively for a small period. Besides, the high within variability in clonal progenies of parents which is attributed to non-genetic reasons might have influenced the heritability estimates. Over estimates of heritability value in cocoa has been reported earlier by Soria et al. (1974). He reported that the heritability for wet bean weight was 17.3 per cent when calculated based on 3 years record while it was 89 per cent when estimated based on one season's record.

Coefficient of heritability was high for pod length (1.43), pod weight (1.05), wet bean weight per pod (0.97), dry bean weight (1.027) and number of beans per pod (0.93). However, the heritability values for pod length and pod weight were reported to be only moderate by Soria et al. (1974) the estimates being 55 and 57 per cent, respectively, as against the high heritability values for these characters in the present study.

Cilas et al. (1989) have reported that the heritability estimate for wet bean weight per pod was very high. High heritability value for wet bean weight per pod has also been reported earlier (Kumaran and Prasannakumari, 1981).

The number of ovules per ovary which ultimately contributes to the number of beans per pod has been found to be a highly heritable trait controlled by more than one gene pair (Lopez et al., 1988). This probably has been ascribed to be the reason for high heritability for this particular character. A heritability estimate of 79.4 per cent for the number of beans per pod has been observed by Lopez et al. (1988). In contrast to these observations, Kumaran and Prasannakumari (1981) have reported a relatively low heritability for this character.

Moderately high heritability has been estimated for some of the pod and bean characteristics. The estimates were 0.54 for number of pod per tree, 0.52 for pod width and 0.75 for seed thickness. Earlier studies on heritability of yield components have shown high heritability for pod width. Soria et al. (1974) reported a high heritability of 63 per cent for pod width. Ramirez and Enriquez (1988) also observed high heritability for pod diameter. These reports are in conflict with the heritability estimate obtained in the present study. Similarly, high heritability is also reported for pod production in contrast to the findings in the present study. Palaniappan and Shamsuddin (1989) reported as high as 93 per cent heritability for pod production.

Size of bean is one character which directly contributes to the yield. Glendinning (1963) observed that the size of beans is highly heritable. In the present study seed thickness showed only a moderate heritability (0.75) whereas seed length and seed width showed low heritability with the coefficient of heritability of 0.3 and 0.38.

Fruit wall thickness at ridge and fruit wall thickness at furrow also gave low values for coefficient of heritability indicating that it is more influenced by environment. Enriquez and Soria (1966) have also made an observation to this effect. This is further supported by the study of Ramirez and Enriquez (1988), who observed low heritability for pod husk thickness.

Cilas (1991) in a review, presented the estimation of different genetic parameters including genetic variance (genotypic, additive and dominance deviation) and heritabilities in narrow and broad senses for a number of crossing schemes, together with examples of calculations obtained from genetic trials in cocoa. According to him, comparative trials involving hybrids from unprogrammed crosses do not allow access to the genetic parameters. Access to the genetic parameters can be obtained only through programmed crosses like hierarchial, factorial or diallele crosses. When numerous crosses need to be studied it is preferable to adopt hierarchial or factorial breeding schemes. If, in contrast, the trial objective is to determine with accuracy the heritability of a given character, a diallele system is more suitable. Since this experiment was not basically designed to estimate genetic parameters, the estimates of heritability obtained in this experiment may be used only for the relative comparison between characters and not in absolute terms.

5.3. GENETIC DIVERGENCE

Genetic divergence study is useful for an understanding of the course of evolution of the group of plants and also for classifying the population into sub-units on the basis of their diversity. Such studies utilizing multivariate analysis have been successfully completed in several groups of crops. Besides its use in taxonomic problems and unraveling the phylogenetic relationships within a species, such a study helps in choosing parents for specific breeding objective. Now it is well established that exploitation of hybrid vigour and success in getting desirable segregants in any breeding programme depends to a large measure on the degree of genetic divergence between the parents chosen.

In the present investigation, genetic divergence between the genotypes was studied by cluster analysis based on eucledian distance. The method of maximum curvature employed to decide on the number of clusters showed that there was no natural clustering of genotypes, indicating that genetically they do not differ much among themselves.

A classical work in clustering a number of different genotypes of cocoa was done by Engels (1986a). He reported that the distribution of cultivars only roughly corresponded to the traditional classification into Criollo, Forastero and their sub-divisions.

All the genotypes included under the present study owe their origin to Amazonian Forestero types. Tables 41 and 42 show that the distribution of genotypes into 5 and 10 groups did not give any meaningful trend. Failure to get natural cluster may be due to the genetic similarity between the genotypes.

5.4. PATH COEFFICIENT ANALYSIS

Yield is viewed as a composite character influenced by a number of other characters referred to as yield attributes. Correlation exists between these yield attributes and yield.

The correlated variables exert their influence both directly and indirectly through other variables. Path coefficient analysis is done to understand the role of causative factors (yield attributes) on the ultimate effect (yield). Path coefficient analysis is applied to partition the genetic association between yield and its component characters into direct and indirect effects on yield. This type of analysis has been identified as a potent method for resolving accurate and dependable criteria in selection procedures.

Taking yield in term of wet bean weight per tree as the dependable variable, path coefficient analysis was done with 10 yield contributing characters, namely, number of pods per tree, pod length, pod width, pod weight, wet bean weight per pod, dry bean weight, number of beans per pod, seed length, seed width and seed thickness.

Number of pods showed a very high direct effect of 0.9925 on yield (Table 43). Direct effect of no other character was in any way comparable to the number of pods. This is in accordance with the results discussed earlier and in agreement with the observation of Atanda and Toxopeus (1969), that the heterosis in the hybrids is apparently manifested through higher pod production rather than on pod value components.

This suggests that number of pods with moderately high heritability will be the best criterion for crop improvement through selection.

Wet bean weight per pod gives a direct effect of 0.2079 on yield indicating that this character also contributes to yield and may be considered for breeding work.

Direct effects of pod length (0.0254), pod width (0.0142), dry bean weight (0.0748) seed width (0.0076) and number of beans per pod were negligible.

Pod weight, seed length and seed thickness gave a low negative direct effect indicating that higher the values for these characters less will be the yield. All the characters studied showed low indirect negative effect on yield via number of pods.

Taking all the factors together, one can suggest that yield can be increased effectively through selection of genotypes with more number of small sized pods having small sized seeds and higher wet bean weight per pod. However, the optimum pod and seed size has to be standardised considering the economic yield and market preferences.

In the present study it becomes very evident that number of pods is the major contributing character to yield followed by wet bean weight per pod. Hence phenotypic selection based on number of pods will be effective in increasing yield.

Variability studies discussed earlier makes it clear that variability with respect to yield and number of pods exists to a good extent in both parent as well as hybrid populations. The high within variability in the parent population can be considered as non-genetic since parents are clonal progenies of a single tree. Hence the variability in the parent population is something which is difficult to be exploited through clonal multiplication. Parent G VI-55 has been ranked first among the 34 genotypes under study (Table 44) with respect to yield. It is of interest to note that, of the five cloned progenies of G VI-55 taken for the study, plant no.3 gave an yield as high as 14.09 kg whereas plant no.2 gave only an yield of 1.13 kg. The very same plant of G VI-55 i.e. plant no.3 was responsible for boosting the average yield of parent population making it comparable to the hybrid population. The average of parent population which is calculated to be 2.83 kg per plant would have been 2.66 kg if this plant was not considered. This indicates that the mean values of the parents are not indicative of its true potential. The needle of suspicion regarding the high variation seen within the clonal progenies of parents is directed towards the rootstock-scion interaction, which should be investigated.

The hybrid population also showed good amount of variability in yield and number of pods. The variability seen within crosses is low and also uniformly distributed, which is essential for accuracy of yield predictions. Further, the average yields of hybrids is much higher, with certain hybrid families performing exceptionally well with respect to some of the traits. Prominent heterosis has also been noticed in certain crosses as in the case of H4 of series II. This gives ample scope for hybridisation and selection.

The 34 genotypes taken for the study are ranked with respect to yield and number of pods (Tables 44 and 45). Cocoa is a self compatible crop with outcrossing nature and hence the seeds produced naturally can be loosely called hybrid seeds (Hunter, 1990). Therefore, disregarding whether the genotype is a hybrid or a parent, high yielding trees can be selected for further crossing to obtain possible recombinants with higher yield potential. High yielding trees selected based on number of pods and wet bean weight per pod can also be used for establishing polycross gardens from where the seeds can be utilized for commercial planting programmes.

Table 44. Ranking of 34 genotypes based on yield per tree

Ranks	Genotypes	Mean yield (g)
1.	G VI-55	5197
2.	H 7.I	4897
3.	H 3.I	4032
4.	G VI-54	3894
5.	G I-15.5	3738
6.	H 6.II	3600
7.	H 2.II	3577
8.	H 4.II	3554
9.	H 4.I	3407
10.	H 1.II	3294
11.	G I-5.9	3167
12.	H 2.I	3121
13.	G VI-56	2925
14.	G VI-68	2825
15.	M 13.12	2823
16.	H 3.II	2786
17.	H 6.I	2631
18.	H 1.I	2519
19.	G I-10.3	2503

Table 44 (Contd.)

Ranks	Genotypes	Mean yield (g)
20.	H 5.II	2493
21.	G II-20.4	2488
22.	H 7.II	2472
23.	G VI-61	2428
24.	M-16.9	2418
25.	H 5.I	2349
26.	G II-19.5	2327
27.	H 8.II	2232
28.	H 11.II	2201
29.	H 9.II	2111
30.	H 10.II	1948
31.	M-9.16	1864
32.	G I-4.8	1643
33.	G VI-64	1490
34.	H 12.II	1319

The digit after the decimal appearing in the names of hybrids denote the series number of the crosses

Table 45 Ranking of 34 genotypes based on number of pods per tree

Ranks	Genotypes	Mean number of pods per tree
1.	H 7.I	48.00
2.	G I-15.5	45.00
3.	H 3.I	4340
4.	G VI-54	43.00
5.	H 2.I	42.5
6.	H 2.II	41.72
7.	H 1.I	37.71
8.	G VI-55	36.50
9.	H 1.II	35.58
10.	H 6.II	35.10
11.	G I-5.9	33.40
12.	H 4.II	33.09
13.	M 13.12	32.20
14.	G II-19.5	32.00
15.	H 5.I	30.25
16.	M 9.16	30.00
17.	H 6.I	29.20
18.	H 3.II	27.36
19.	G VI-56	27.25

Table 45 (Contd.)

Ranks	Genotypes	Mean number of pods per tree
20.	G II-20.4	26.80
21.	G VI-61	26.25
22.	M 16.9	26.20
23.	G I-10.3	25.50
24.	H 4.I	25.37
25.	G VI-68	24.75
26.	H 8.II	24.28
27.	H 7.II	21.44
28.	H 5.II	21.22
29.	H 11.II	20.44
30.	H 10.II	19.72
31.	G I-4.8	17.60
32.	H 9.II	16.44
33.	G VI-64	15.60
34.	H 12.II	15.22

The digit after the decimal appearing in the names of hybrids denote the series number of the crosses

Summary

SUMMARY

Genetic analysis of yield attributes in cocoa (<u>Theobroma</u> <u>cacao</u> L.) was undertaken in the Department of Agricultural Botany, College of Horticulture, Vellanikkara, Trichur during 1992-93, with an objective to assess the extent of variability present in the population and to get an insight into the genetic behaviour and mode of inheritance of yield and the different yield attributes in cocoa.

A total of 244 steady bearing trees consisting of 19 hybrids and 15 parents were taken for the study. Observations were recorded on 16 characters including yield and yield attributes. Statistical analysis of the data led to the following conclusions.

Variability in most of the characters followed the same trend in both the hybrid and the parent populations.

Variability was maximum for yield and number of pods, moderate for pod weight, wet bean weight per pod, dry bean weight and ratio of dry bean weight to wet bean weight. For all other characters taken, variability was low.

Hybrids showed significant difference among themselves for almost all characters. Parents, on the other hand, did not show significant difference among themselves with respect to yield, number of pods, fruit wall thickness at furrow, seed width, seed thickness and the ratio of dry bean weight to wet bean weight.

Parents, eventhough were budded progenies, displayed high amount of within variability. It is assumed that the within variability is due to non-genetic reason. It may be due to the influence of the root stock.

In general, the hybrids were more uniform and better yielding than the parents. Heterosis was noticed in certain combinations.

Characters such as pod length, pod weight, wet bean weight per pod, dry bean weight and number of beans per pod showed high heritability. Number of pods, pod width and seed thickness were moderately heritable. Genetic divergence studies showed that the 34 genotypes taken for the study did not show a natural grouping, indicating that the genotypes were genetically similar with common ancestry.

Path coefficient analysis brought to the fore the fact that number of pods was the major contributing character to yield followed by wet bean weight per pod. Pod weight and seed size showed negative direct effect on yield. This indicated that selection based on number of pods and wet bean weight per pod would be effective.

It has become clear from this experiment that there is ample scope for hybridisation in cocoa. Since cocoa is an outcrossing crop with self-incompatibility, the high yielding genotypes may be selected for hybridisation. Seeds of high yielding progenies may be used for establishing poly cross gardens. This will help in increasing the frequency of favourable genes in the population.

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Appendices

APPENDIX-I

Ranking the 19 hybrids based on mean values for each character studied

Ranks	Yield	No. of pods	Pod length	Pod width	Pod weight	Thickness of fruit wall at ridge	Thickness of fruit wall at furrow	Wet bean weight per pod	Dry bean weight	Number of beans	Seed length	Seed width	Seed thick-ness	Pod length/ pod width	Dry bean weight/ wet bean weight
1	H7.I	H7.I	H9.II	H9.II	H9.II	H4.II	H9.II	H4.I	H4.II	H9.II	H4.I	H4.II	H4.II	H5.I	H2.I
2	H3.I	H3.I	H4.II	H4.I	H4.II	H9.II	H4.II	H9.II	H9.II	H4.I	H9.II	H3.I	H3.II	H8.II	H10.II
3	H4.I	H2.II	H5.II	H5.II	H4.I	H3.II	H5.II	H5.II	H4.I	H7.I	H3.I	H4.I	H8.II	H10.II	H9.II
4	H2.II	H2.I	H11.II	H4.II	H5.II	H5.II	H3.I	H7.II	H3.II	H5.II	H4.II	H3.II	H2.II	H6.II	H3.II
5	H4.II	H1.I	H8.II	H1.II	H11.II	H12.II	H3.II	H11.II	H5.II	H11.II	H2.I	H10.II	H11.II	H3.II	H4.II
6	H6.II	H1.II	H3.II	H3.I	H3.II	H8.II	H12.II	H4.II	H10.II	H7.II	H11.II	H5.II	H5.II	H4.II	H11.II
7	H1.II	H6.II	H10.II	H11.II	H7.II	H1.II	H4.I	H7.I	H11.II	H6.II	H5.II	H2.I	H4.I	H9.II	H8.II
8	H2.I	H4.II	H7.II	H2.II	H8.II	H3.I	H2.II	H6.II	H7.II	H10.II	H3.II	H9.II	H10.II	H11.II	H6.I
9	H3.II	H4.I	H6.II	H3.II	H6.I	H7.II	H8.II	H3.II	H3.I	H8.II	H10.II	H12.II	H9.II	H5.II	H1.I
10	H1.I	H3.II	H4.I	H7.II	H1.II	H4.I	H6.I	H3.I	H6.I	H3.I	H6.I	H11.II	H6.I	H7.II	H3.I
11	H7.II	H6.I	H6.I	H6.I	H10.II	H2.II	H11.II	H10.II	H6.II	H5.I	H7.II	H2.II	H1.II	H7.I	H5.II
12	H5.II	H5.I	H5.I	H2.I	H3.I	H11.II	H1.II	H1.II	H2.II	H12.II	H6.II	H6.I	H6.II	H6.I	H7.II
13	H6.I	H8.II	H1.II	H8.II	H2.II	H6.I	H2.I	H8.II	H8.II	H1.II	H7.I	H7.II	H7.II	H12.II	H4.I
14	H9.II	H7.II	H7.I	H12.II	H6.II	H10.II	H10.II	H6.I	H2.I	H6.I	H12.II	H6.II	H12.II	H4.I	H2.II
15	H8.II	H5.II	H2.II	H10.II	H7.I	H2.I	H7.II	H12.II	H1.II	H4.II	H2.II	H8.II	H2.I	H1.I	H5.I
16	H11.II	H11.II	H12.II	H6.II	H12.II	H6.II	H5.I	H2.II	H12.II	H2.I	H1.II	H1.II	H3.I	H1.II	H6.II
17	H5.I	H10.II	H2.I	H7.I	H2.I	H7.I	H7.I	H5.I	H7.I	H3.II	H8.II	H7.I	H7.I	H2.II	H12.II
18	H10.II	H9.II	H3.I	H1.I	H5.I	H5.I	H6.II	H2.I	H5.I	H1.I	H1.I	H1.I	H5.I	H2.I	H1.II
19	H12.II	H12.II	H1.I	H5.I	H1.I	H1.I	H1.I	H1.I	H1.I	H2.II	H5.I	H5.I	H1.I	H3.I	H7.I

The digit after the decimal appearing in the names of hybrids denote the series number of the crosses

APPENDIX-II

Ranking the 15 parents based on mean values for each character studied

Ranks	Yield	No. of pods	Pod length	Pod width	Pod weight	Thickness of fruit wall at ridge	Thickness of fruit wall at furrow	Wet bean weight	Dry bean weight	Number of beans	Seed length	Seed width	Seed thick-ness	Pod length/ pod width	Seed length/ seed width
1	G VI-55	G I-15.5	G VI-61	G VI-55	G VI-55	G I-10.3	G VI-64	G VI-55	G II-20.4	G VI-55	G VI-54	G VI-54	G II-20.4	G VI-61	G VI-55
2	G VI-54	G VI-54	G VI-64	G I-10.3	G VI-64	G I-64	G I-10.3	G VI-68	G II-19.5	G VI-68	G VI-55	G I-10.3	G VI-68	M-9.16	G VI-68
3	G I-15.5	G VI-55	G VI-55	G II-19.5	G II-19.5	G VI-55	G VI-55	G II-19.5	G VI-64	G VI-56	G VI-68	G II-20.4	M-9.16	G II-20.4	G VI-54
4	G I-5.9	G I-5.9	G II-20.4	G VI-64	G VI-56	M-13.12	M-13.12	G VI-56	G VI-55	M-13.12	G II-20.4	G II-19.5	G VI-61	G I-4.8	G VI-56
5	G VI-56	M-13.12	G II-19.5	G I-15.5	G VI-64	G II-20.4	G VI-56	G II-20.4	G VI-54	M-16.9	G II-19.5	G VI-55	G II-19.5	G VI-68	M-13.12
6	G VI-68	G II-19.5	G I-4.8	G VI-56	G VI-68	G VI-56	G II-20.4	G VI-64	M-9.16	G I-4.8	G I-15.5	G I-15.5	G I-10.3	G VI-56	G I-5.9
7	M-13.12	M-9.16	G VI-68	G I-4.8	G II-20.4	G I-4.8	G I-15.5	G I-5.9	G I-10.3	G VI-61	G VI-56	G I-4.8	G VI-64	M-16.9	M-16.9
8	G 10.3	G VI-56	G VI-56	G II-20.4	M-13.12	G II-19.5	G I-4.8	G I-10.3	G VI-68	G I-5.9	G I-10.3	G VI-68	G I-4.8	M-13.12	G I-15.5
9	G II-20.4	G II-20.4	G I-10.3	G VI-68	G I-4.8	G VI-61	G VI-54	G I-4.8	M-16.9	G II-19.5	M-16.9	G VI-56	M-16.9	G II-19.5	M-9.16
10	M-16.9	G VI-61	M-16.9	M-16.9	G VI-61	G VI-54	M-16.9	G VI-61	G I-15.5	G VI-54	M-9.16	G VI-64	G I-15.5	G I-10.3	G II-19.5
11	G VI-61	M-16.9	M-9.16	M-13.12	M-16.9	G I-15.5	G VI-61	M-16.9	G VI-61	G I-10.3	G VI-64	M-9.16	G VI-54	G VI-64	G VI-64
12	G II-19.5	G I-10.3	M-13.12	G VI-54	G VI-54	M-16.9	G II-19.5	G VI-54	G I-4.8	G VI-64	G I-4.8	M-16.9	G VI-55	G I-5.9	G VI-61
13	M-9.16	G VI-68	G VI-54	G I-5.9	G I-15.5	M-9.16	G VI-68	M-13.12	G VI-56	G II-20.4	G I-5.9	G VI-61	M-13.12	G VI-55	G II-20.4
14	G I-4.8	G I-4.8	G I-5.9	G VI-61	M-9.16	G VI-68	M-9.16	G I-15.5	M-13.12	GI-15.5	G VI-61	G I-5.9	G VI-56	G VI-54	G I-4.8
15	G VI-64	G VI-64	G I-15.5	M-9.16	G I-5.9	G I-5.9	G I-5.9	M-9.16	G I-5.9	M-9.16	M-13.12	M-13.12	G I-5.9	G I-15.5	G I-10.3

GENETIC ANALYSIS OF YIELD ATTRIBUTES IN COCOA (*Theobroma cacao L.*)

By

HOMEY CHERIYAN

Abstract of Thesis

Submitted in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

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Kerala Agricultural University

Department of Agricultural Botany

College of Horticulture

Vellanikkara - Thrissur

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ABSTRACT

Genetic analysis of yield attributes in cocoa (*Theobroma cacao* L.) was carried out in College of Horticulture, Kerala Agricultural University, Vellanikkara, Trichur during the period 1992-93. Observations recorded on 16 characters including yield and yield attributes in 244 trees consisting of 19 hybrids and 15 parents revealed that variability in most of the characters were almost same for both the parent and the hybrid populations. Variability was maximum for yield expressed in terms of wet bean weight per tree and number of pods. It was moderate for pod weight, wet bean weight per pod, dry bean weight and ratio of dry bean weight to wet bean weight.

Hybrids showed significant difference among themselves for almost all characters. Yield, number of pods, fruit wall thickness at furrow, seed width, seed thickness and the ratio of dry bean weight to wet bean weight did not show significant difference among the parents.

Parents, which are budded progenies of a single tree showed high amount of within variability. The within variability is ascribed to non-genetic reasons. Hybrids were more uniform and better yielding than parents.

High heritability was obtained for pod length, pod weight, wet bean weight per pod, dry bean weight and number of beans per pod. Heritability was moderate for number of pods, pod width and seed thickness.

Genetic divergence studies showed that the 34 genotypes did not show a natural grouping indicating that the genotypes were genetically similar.

Path coefficient analysis revealed that number of pods contributes the maximum to yield followed by wet bean weight suggesting that selection based on number of pod and wet bean weight per pod would be effective in increasing yield.

This experiment conveys that there is ample scope for hybridisation in cocoa. High yielding genotypes may be used as parents for hybridisation and high yielding progenies identified. These may be utilized in establishing poly cross gardens, thereby increasing the frequency of favourable genes in the population. Seeds from such gardens can be used for raising commercial plantations.

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