STANDARDISATION OF SELECTION CRITERIA FOR COCOA HYBRIDS

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Plant Breeding and Genetics
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 654
KERALA, INDIA

1998

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EXTERNAL EXAMINER

Dedicated

To

My Parents

ACKNOWLEDGEMENT

It is with great pleasure that I express my deep sense of gratitude and sincere thanks to ***Dr. K. Pushkaran,*** *Professor and Head, Department of Plant Breeding and Genetics, College of Horticulture, Vellanikkara and Chairman of my Advisory Committee for his esteemed advice, constant inspiration and valuable suggestions during the course of research work and preparation of the thesis. My sincere and heartfelt gratitude ever remains with him.*

I wish to thank ***Dr. V.K. Mallika,*** *Associate Professor, College of Horticulture and member of the Advisory Committee for her valuable help and constructive criticisms which assisted me much in the successful completion of my master's programme.*

I wish to place on record my profound gratitude to ***Dr. V.K.G. Unnithan,*** *Associate Professor of Agricultural Statistics and member of the Advisory Committee for his valuable advice and help rendered in the statistical analyses of the data and subsequent interpretation. I thank him whole heartedly.*

I am grateful to ***Dr. Achamma Oommen,*** *Associate Professor, College of Horticulture, Vellanikkara and member of the Advisory Committee for her timely help and valuable suggestions during various stages of my work.*

A special word of thanks to ***Dr. R. Vikraman Nair,*** *Professor, CCRP, College of Horticulture for having provided all the facilities in the field which was instrumental for the successful completion of this work.*

I am thankful to all the staff and students of the Department of Plant Breeding and Genetics, College of Horticulture who helped me in carrying out my research work successfully.

It is with great pleasure that I express cordial thanks to Mr. Roy, M.D., and Ms. Ancy, T.K. who have put in a helping hand in this venture.

I thank Sri. R. Noel for the neat and prompt typing of this document.

I express my thanks to the workers of the CCRP project for their co-operation in carrying out the field work.

My classmates and friends were of immense help to me giving me all possible support right from the beginning till the end of this programme. I gratefully acknowledge their services.

I have no words to express my thanks to my husband for the sincere encouragement and moral support.

I lovingly thank my parents, sisters and brother whose inspiration, timely persuasion and good wishes were very vital for successful completion of this work.

It is my proud privilege to express gratitude to ICAR for the award of Junior Research Fellowship .

I pay obeisance to Almighty for making it possible for me to complete this venture successfully.

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Introduction

1. INTRODUCTION

Cocoa, *Theobroma cacao* L., of the family Sterculiaceae, is the only economically important species from among the 22 which comprise the genus. It is a predominantly outbreeding diploid (2n = 20), understorey plant indigenous to the Amazon and Orinoco rain forests of South America (Wood and Lass, 1985). The word 'Theobroma' came from a Greek word which means 'food of the gods'. The crop was introduced to India from Ambon in the Maluccas in 1798 (Ratnam, 1961).

The classification of cocoa varieties is based on the historic trade in the product. Criollo cocoa is a high quality product with plump beans, light break, and fine aroma where as trinitario is of lower quality than the criollo with more or less flattened beans, darker break and coarser flavour. The forastero types are of Amazonian origin giving cocoa of bulk flavour. The variety more preferred and suited to Kerala is the Forastero type.

In India, commercial cultivation of cocoa started in early 1960's and there was a substantial increase in area under the crop in 1970's. By 1980, the total area, mainly as mixed crop with perennials like coconut and arecanut, was estimated as 25,000 ha. (Anon, 1981) with a potential to produce about 12,500 tonnes of dry beans annually. The area under the crop decreased from the peak in 1980 to 16000 ha. with a production of 7000 tonnes (1989-90 estimates). The area and production targets for the 9th plan are 24,000 ha. and 20,000 tonnes respectively.

It is estimated that by the end of the plan (2002 AD), the requirement of the domestic processing industry will be 16,000 tonnes to 20,000 tonnes against the present capacity of about 9,250 tonnes.

Cocoa is predominantly a homestead crop in Kerala, mainly grown as intercrop in coconut and arecanut gardens. For increase in productivity, crop improvement works for evolving high yielding and better quality genotypes, better suited to agroclimatic and farming systems need urgent attention.

Crop improvement in cocoa can trace its history to the first half of the present century. These early efforts often relied solely upon the selection of local clones rather than breeding *per se*. Interpopulation heterosis was demonstrated in Ghana (Poinsette, 1963) and later confirmed in Trinidad. But cocoa being a heterozygous and heterogeneous crop, show high degree of variability in F_1 generation. Such a variability also makes it difficult to rely only on the combining ability of parents as the criteria for selection.

The evaluation of a cocoa cultivar or hybrid can be facilitated by using easily obtainable simple measurements, yield and yield contributing factors, which accurately reflects its genetic potential. Cocoa yield forecasting also requires the understanding of nature of correlations of different yield components between parents and progenies.

Cocoa being a perennial heterozygous crop, the selection of planting material is very important to perpetuate high yielding, uniform quality plants. Seedling populations of cocoa show a very high degree of variability in nearly all the characters

including yield. Hence standardisation of techniques for seedling selection is essential.

With these views in mind, the present investigations were undertaken to fulfil the following objectives.

(1) To assess the relationship between seedling characters and yield.

(2) To study the nature of inheritance of some pod and bean characters.

(3) To estimate the correlation between yield of the progeny and yield attributes of parents which gives a fair knowledge of the potential of the parent in producing high yielding offsprings.

(4) To study the relationship of characters of female parent vs. characters of all the hybrids involving that parent.

(5) To assess relationship between midparental value and characters of the hybrids of that cross.

(6) To evolve prediction models using parental characters as well as seedling characters for the performance of cocoa in terms of stabilized yield of quality beans.

Review of Literature

2. REVIEW OF LITERATURE

All perennials including cocoa (*Theobroma cacao* L.) are outbreeders though with the one exception of arabica coffee which is a self pollinated allotetraploid. Out breeders will be mostly heterozygous and intolerant of strong inbreeding. With all the drawbacks of a perennial crop, genetic studies in cocoa become more complicated due to its self incompatibility and even cross-incompatibility in certain cases. As such, the progress in understanding the genetics and successful breeding programme in cocoa has been slow.

The first major attempt towards a systematic crop improvement in cocoa was the germ plasm collection by Pound in 1930's from the bank of river Amazon which is the primary centre of genetic diversity of cocoa (Cheesman, 1944). Various nations and agencies are now involved in the cocoa germplasm collection.

Breeding work in cocoa was started in Ivory coast in 1949 by IRCC (Institute de Recherches du cafe du Cacao, France). Poinsette made first crosses in collections of cocoa from Peru involving Pound's (1938) seedling collections. The hybrids showed exceptional vigour, precocity and high yield in Ghana. These observations and similar ones in Trinidad were attributed to hybrid vigour. They led to the breeding of seedling cocoa by seeking heterosis through crossing Pound's Peruvian material with parents of different geographic origin.

Occurrence of a relation between seedling vigour and yield was perhaps, noted since early and it was being used for screening seedlings arising from the breeding programme in many countries including the Cocoa Research Institute of Ghana. Reported experimental results on such a relation are, however, scanty and the available informations are given below.

2.1 Seedling selection

Cocoa being a heterozygous crop, seedling populations show very high degree of variability in nearly all the characters including yield. Such a variability also makes it difficult to rely only on the combining ability of parents as the criteria for selection. The long productive phase of perennial crops like cocoa emphasises the need for judicious selection of seed and planting materials to ensure high production potential.

The relationship between vegetative characters and yield was noticed by Glendinning (1960) and he reported that the yield in cocoa was positively correlated with the rate of trunk diameter during early stages of growth. A difference of 1.2 centimetre per annum in the pre-bearing rate of trunk diameter increase seemed to be roughly equivalent to a difference in yielding capacity of 1600 lbs of dry cocoa per annum.

Precocious varieties are of greater importance because they can contribute efficiently to a faster recovery of the capital invested. Visser (1964) working with apples and pears demonstrated that vegetative vigour, measured by the diameter of the

trunk was correlated with the precocity and there was genetic correlation between precocity of the parents and their progenies.

Carvalho (1952) reported that selection by precocity of production in coffee was not efficient in the obtention of high yielding mother trees.

Glendinning (1965) reported that correlations were found to exist between the rate of growth before bearing and the total yield upto five years. After bearing, vegetative growth slowed down and there was a high correlation between the reduction in growth rate and total yield. This suggests that an equation "Growth rate before bearing = Growth rate after bearing + yield" may be used. A high yielding variety will be thus the one making vigorous early growth, which is later reduced relatively.

Nya-Ngatchou and Lotode (1967) found highly significant correlations between trunk diameter at 0.20 m from the ground level and precocity. The highest correlations were found at 22 months of age. Soria and Esquivel (1970) also found the high positive relationship between - quick growth and yield and they concluded that the highest correlation between trunk diameter and production occurs between 2nd and 3rd years of age.

In Nigeria, the growth of F_3 cocoa seedlings over a period of 50 weeks was analysed, comparing F_3 Amazon by Atanda (1971) and West African Amelonado seedlings. The main conclusion was that the superior growth of F_3 Amazon over Amelonado seedlings is due to the most rapid increase and bigger size of their

photosynthetic system, viz. this area rather than the photosynthetic efficiency of their leaves. The experiment thus concluded that the leaf area can be taken as an important factor in assessing the growth of seedlings.

Adenikinju (1972) studied the effect of pod maturity on viability and seedling vigour in cocoa. He conducted the experiment in hand pollinated pods of the cocoa progeny (C77 x C23) and reported that pod maturity based on pod age significantly affect bean viability as well as leaf area, leaf number, height and girth of the seedlings produced.

Influence of specific gravity of seeds on early seedling growth and development in cocoa was analysed by Ravindran (1981) and found out that the growth of stem and roots was more vigorous in materials with higher specific gravity though the correlation varied with genotype. He concluded that selection of seeds for specific gravity is recommended as a means of ensuring the better establishment and growth of cocoa seedlings.

Monte *et al.* (1985) used the seedling character, dry weight, leaf area, rate of water uptake, relative growth rate and leaf area index of four cultivars to relate with the yield of these parent cultivars. Seedling characters were measured 105 days after sowing and then at fortnightly intervals. The only two characters that were found to be related to yield of these cultivars were total dry weight and leaf area. Leaf area was found to show relationship with earliness.

Ravindran *et al.* (1985) conducted mass pedigree selection in arecanut as a case history on the application of that method in perennial tree crops breeding. Physical parameters such as number of nodes and height were found to be highly correlated with nut yield. Significant phenotypic correlations were observed in height, girth at permanent mark and node number. The three characters together with girth at last exposed node and leaf number showed significant genotypic correlations. But the parent-progeny correlations for yield characters were found to be low.

Allen (1986) used stem diameters of 405 plants from 50 collections over a period of two years to rank the cocoa collections made from the Amazon region of Ecuador.

Study on growth of collar diameter in an almost complete 8 x 8 diallele of cocoa seedlings was conducted by Cilas *et al.* (1988). Results from a diallele excluding selfing involving three upper Amazon, two Trinitario and three Amelonado has indicated that the upper Amazon trees had significant positive GCA for growth of collar diameter between 7 and 14 months after planting.

The relationship of seed position in cocoa pods and seed length with stem diameter and height of seedlings was analysed in cultivars SPA-9, IMC-67, EET-400 and UF-613. Seeds were extracted from central and distal parts of the pods. Seed length was determined. Flat seeds were discarded and remaining seeds were sown. Seedling height was determined at 23, 36, 57, 93 and 120 days and stem diameter at 1, 2 and 3 months after sowing. No appreciable effect of the

position of well developed seeds on seedling quality was noted and it is suggested that once the poorly developed seeds are discarded all the remaining seeds can be sown (Philips Mora, 1989).

Seedlings from 64 open pollinated families of slash pine (*Pinus elilotis* var */elilottis*) were analysed for getting the relationship of seedling dry weight traits with perennial breeding values. Destructive harvests were conducted 3,6, and 10 months after sowing to measure dry weight of needles, stem, taproots and lateral roots. Genotypic correlations between family means of seedling dry weight traits and parental additive genetic breeding values for 15 years field volume growth were relatively high at the 3 months measurement, but the values were lowered for the 6th and 10th month measurements.

The best early selection indices were more effective at identifying the bottom ranked families and the top ranked over (Sarles *et al.*, 1995).

On the basis of work at Trinitario and Cameroon and after a brief examination of constraint associated with experimental fields and species *Theobroma cacao* L., the choice of experimental designing for selection is examined, particularly the advantage of design with single tree plots (Cilas, 1995). He conducted that the plants can be used for crossing systems of different types such as single plot factorial and diallele system.

2.2 Variability in pod and bean characters

The amount of cured cocoa produced annually per acre is the ultimate interest of the cocoa farmer. Thus yield is a function of number of pods produced per acre and pod value. Pod value is the amount of cured cocoa produced per pod and this is the product of the mean number of beans per pod and mean cured bean weight. Thus yield is made up of several components of quantitative nature showing high degree of variability and is highly influenced by the environment.

Variability of pod and bean characters contributing to yield was a matter of a research to most of the cocoa breeders in first decades of 1900's. Stockdale (1928) studied the variability in width, length, and thickness of seeds of 609 cocoa trees in forestero populations pointing out the great variability of these features. Pound (1933) reported that the number of beans produced within the pods even much more variable than the linear measurements of the seeds and concluded that the number of beans was not reliable in classification.

Glendinning (1963) reported difference in bean length and width between trees of a population. He also suggested that bean size and bean number are genetically controlled, eventhough they are influenced to some extent by other factors such as pod size, and ratio of the number of potential and actually developed beans within the pods.

Studies on variability of biometric characters in cocoa by Enriquez and Soria (1966) in Costa rica revealed that yield expressed in dry or wet weight of

the bean is a variable character of quantitative nature. The dry weight varied from 0.5 g to 2.5 g/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 characters and are potentially affected by environment.

Enriquez and Soria (1968) also studied the variability of several pod and bean characters namely wet weight, length, width, thickness, shell percentage, pulp percentage and number of beans per pod. All these characteristics showed highly statistical differences between clones. In their study, it was also estimated that the best sample size taking as a basis wet weight was three seeds of 20 pods per clone.

In Nigeria studies on pod and bean values of open pollinated cocoa pods harvested from monoclonal, biclonal and polyclonal plots and for Amazon seedling trees over various periods showed that season, genotype and their interaction have a significant effect on number of beans per pod. They concluded that the character showed a high variability as a result of the natural pollination process (Toxopeus and Jacob, 1970).

Seasonal influence on some yield factors in four varieties of cocoa were studied by Are and Atanda (1972). Records of three factors namely the percentage conversion rate for weight of wet beans to fermented dry cocoa, mean cured bean weight and number of beans per 100 pods for mature cocoa cultivars Amelonado, F_2 Amazon, F_3 Amazon and Local Trinitario were kept for four years. The magnitude

of all three factors were greater during the dry main crop season than during the wet light crop season. Amelonado cocoa had the highest overall mean conversion rate of 44.35 per cent; highest number of beans per 100 pods (3530.6) and mean weight of dry beans per pod (39.54g). In the dry season 10.6 pods of Amelonado and 11.34 pods of F_3 Amazon gave 0.454 kg (1 lb) dry beans while in the wet season 13.54 pods of Amelonado or 18.55 pods of F_3 Amazon were required.

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 7th international Cocoa Research Conference held at Douala, Cameroon, 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. 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 programmes of Trinitario x Amazon and Trinitario x Trinitario crosses.

Subramanian and Balasimha (1982) reported significant variation among ten hybrids studied for the seven yield components. They noted statistically significant differences between types in pod weight dry weight of peeled beans, percentage

weight of shell, wet to dry bean ratio and percentage weight of pulp. The extent of variability was the largest in dry weight of beans followed by pod values.

In a study carried out in Central Plantation Crop Research Institute, Vital, Karnataka, 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 periods. The studies on pod characters indicated that 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.

Clones are a group of plants derived from a single plant by vegetative propagation. 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 20 clones belonging to Upper Amazon, Amelonado and Trinitario types. Bean size was extremely variable, but tended to be the greatest in Trinitario types, average bean weight per 100 fermented and dried beans ranged from 212.69 for clone UF 66F (Trinitario) to 67.5 g for SCA (Upper Amazon). Bean weight decreased in successive harvest and seemed to depend partly on pod filling rate.

Nair *et al.* (1990) evaluated nine accessions for yield and related characters at Banglore, ICSI and ICS 6 performed best for number of pods/plant

(71.3 and 69 respectively) and bean yield (3.5 and 2.2 kg/plant) and had good plant height and canopy spreads. Single bean weight was greatest in IMC-67 (2g) and the accession had the best pod value.

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 Belan.

The adaptability and phenotypic stability of hybrids and a cultivar were evaluated at 6 different sites in two Brazilian states by Pinto *et al.* (1993). Traits evaluated were number of healthy pods per plant, moist seed weight per pod and moist seed weight per hectare. Variability was observed among hybrids in both adaptability and phenotypic stability over environment and good mean performance only in environments good for cocoa growing.

2.3 Correlation studies in cocoa

The development of biometrical genetics has revealed that yield and most other economic characters are being controlled by polygenes. In the genetic improvement of crop, association between major characters is of great value. Correlation studies the relationship between yield components and yield which is the most important objective of plant breeder. Alvarado and Bullard (1961) found a positive and significant correlation between bean size and fat content and a highly significant negative correlation between total size and shell percentage.

Glendinning (1963) observed a significant positive correlation between number of fruits produced and total wet weight of their seeds. It showed in some populations, number of fruits was a good estimate of yield. He also reported that the size of the seeds was relatively constant for a tree, but it was influenced positively by the size of the pod and negatively by the number of seeds per pod.

Esquivel and Soria (1967) and Atanda and Toxopeus (1969) proved that the production figure was a very reliable estimate of cocoa yield by showing a highly significant and positive correlation between wet bean weight and number of pods per tree. Soria and Esquivel (1970) showed significant correlation between precocity and potential pod production if cocoa trees.

Wessel and Toxpopeus (1969) showed various significant correlation between mean bean dry weight and the monthly rainfall cumulative totals during the development period.

Early vegetative growth measurements as well as yield attributes were taken for correlation studies by Atanda (1972). The coefficient of relationship obtained indicated that many of the factors examined eg. seedling height, leaf number, survival rate after 3rd season of field planting, canopy development, component dry weights, precocity and magnitude of pod production, wet and dry weight of beans are all reliable indices for evaluating the potential performance of a cocoa cultivar. The correlation coefficients of girth and yield however progressively decreased with age. The possible correlation between wet to dry weight conversion rates and rainfall, air temperature and relative humidity were also reported by him.

Eskes *et al.* (1977) concluded from their study that dry bean production per pod was closely related to bean number than to the average bean weight. However in fruits with a relatively high number of beans, the average bean weight is of major importance. Average bean weight is a less independent factor showing high correlations with pod weight and dry weight of pod wall.

2.4 Inheritance of characters

Variation expressed in a population can be termed, as phenotypic variation. Genotypic and environmental variations and their interaction contributes to phenotypic variation. In crop improvement aspects, the genotypic variation alone is considered since it is the only heritable component which is transferred to next generation. Heritability estimates are the true indications of the genetic potentiality of an individual which act as a tool in selection (Falconer, 1981). According to Panse (1957) the magnitude of heritable variability is the most important aspect of the breeding material which has a close bearing on its response to selection.

Some of the earlier genetic studies of cocoa carried out in Ghana revealed that occurrence of heterosis in outcrosses of Upper Amazon parents (Poinsette, 1943). A general occurrence of heterotic behaviour of outcrosses of progenies of these parents were later confirmed in Trinidad (Montserrin *et al.*, 1957).

Glendinning (1963) studied genetics of yield and yield attributes in cocoa. The results indicated that the number and size of beans in cocoa are highly heritable, traits and pod weight has a direct correlation to these characters.

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 for total weight 57 per cent indicating that these are highly transmissible characters.

Kumaran and Prasannakumari (1981) studied nine characters in twentyfive ten year old trees. Heritability estimates were high for weight of beans with pulp and cotyledon weight while it was low for number of beans per pod.

In a diallele cross among seven clones, Engels (1985) studied for eight fruit characters, GCA effects were significant for all the characters. SCA effects were significant for maximum number of seeds per fruit, total seed weight per fruit and production efficiency. There were no significant reciprocal effects and heterosis was not of importance for any of the characters studied.

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 ranged 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, which was based on a study using 20 clones.

Estimates of different genetic parameters including genetic variance (Genotypic additive and dominance variance) and heritability in narrow and broad sense were

presented by Cilas (1991) for a number of crossing schemes. He concluded that, when numerous crosses need to be studied it is therefore preferable to adopt hierarchical 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.

2.5 Prediction of yield

It has long been of research interest, particularly to breeding, that the assessment or evaluation of a cocoa cultivar can be facilitated and speed up by using early and or easily observable simple measurements, yield and yield contributing factors which accurately reflects its genetic potential. Cocoa yield forecasting also requires the understanding of the nature of correlation between environmental factors and yield factors as suggested by Ruinard (1963).

Multiple regression analysis, as suggested by Goulden (1952) has been used in many crops for formulating selection index. Anand and Torrie (1963) reported that the number of pods per plant and seeds per pod were more important than seed weight for predicting the yield in soyabean. Thamburaj (1973) carried out multiple regression analysis in ridge gourd and reported that pod weights and number of seeds per pod had a significant effect on yield per plant.

Soria and Esquevel (1968) proved that pod production figure was a very reliable estimate of cocoa yield by showing a highly significant and positive correlation between bean wet weight and number of pods per tree.

Atanda and Toxopeus (1969) found out that stem diameter the simplest field measurement, stem height and canopy score of young cocoa trees had all been shown to have a high degree of association with potential vegetative vigour as well as yield potential.

Early vegetative growth measurements as well as yield attributes were taken from various trials and experiments carried out at Gambari experimental station Cocoa Research Institute of Nigeria by Atando (1972). He reported that cumulative pod yield over the first two to five years of general fruiting suffices for predicting the yield potential of a cocoa variety.

Advanced genetic technique are now reported to be applied to cocoa crops. Sirju-Charran *et al.* (1991) attempted isozyme analysis for the identification of duplicate material in the international gene bank.

Wilde *et al.* (1991) reported characterisation of cocoa clones using DNA based markers. Randomly amplified polymorphic DNA (RAPD) were used to characterise cocoa clones representing the three main cultivated sub population criollo, Forestero and Trintario.

The crop has been now designated as a priority for conservation and characterisation by the International Board for Plant Genetic Resources because of the potential genetic diversity loss arising from the deforestation in the Upper Amazon region of South America, the primary centre of Genetic diversity of cocoa. Bekele and Bekele (1996) characterised a portion of germplasm collected in the International

Cocoa Gene Bank of Trinidad for genetic diversity with morphological descriptors. Such a characterisation and evaluation of germplasm using morphological, biochemical, agronomic and disease susceptibility characters would facilitate the work of breeders who need to obtain germplasm with desirable attributes for breeding programme.

Materials and Methods

3. MATERIALS AND METHODS

Cocoa breeding work in Kerala Agricultural University was started in 1978 when open pollinated pods from 15 different types were introduced. The germplasm collection was continued and the types collected include superior plants from populations already available in the country, from clones of several of the introductions made from time to time and maintained in various research stations in the country and from the quarantine station of the University of Reading. Utilizing these collections; breeding and crop improvement work were started in 1984.

The present investigation on `standardisation of selection criteria for cocoa hybrids' was undertaken at CCRP (Cadbury-KAU Co-operative Cocoa Research Project) farm, Vellanikkara during 1994-96. The study was based on the observations taken from 29 hybrids and their parents grown under separate trials. A brief description of the materials used and the procedures followed is given below.

3.1 Materials

KAU in collaboration with Cadburies India Ltd., launched the CCRP on 1-4-1987. Under this project, a collection of germplasm consisting of seven different sets of plants was maintained. They were categorised as Germplasm I, II, III, IV, V, VI and another earlier collection at Mannuthy was designated as 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 raised from pods of 15 selected trees introduced from the Cocoa Research Institute, Ghana in 1978 and field planted during 1979. The trees included in this study were GI 4.8, GI 5.9, GI 9.6, GI 10.3 and GI 15.5. These are open pollinated Amazonian types and are self incompatible GI 5.9 is a Scavina entry and GI 15.5 belongs to the Pound's collection obtained from Equitos.

3.1.2 Germplasm II

This collection established in 1980 includes seedling populations of cocoa collected from promising plantations of Kerala. A total of 131 plants of 26 types were included in GII. The entries used for the study include GII 19.5 and GII 20.4.

3.1.3 Germplasm VI

This is a collection established in 1983 with a total of 121 types collected from Central Plantation Crop Research Institute (CPCRI) Regional Station, Vittal, Cadbury Farm, Thamarassery, RARS Pilicode and CPCRI Station, Kannara. The plants from this group taken for the study include GVI 51, 54, 55 56, 59, 61, 64, 68 and 126. G VI 51 was raised from cuttings of `67' GVI 54 is a budded progeny of SIAL-93 and GVI 55 is from IMC-10, GVI 56 is budded from EET-272 (Equader collection) and GVI 59 from ICS 6. GVI 61 and 64 are budded progenies of accessions C_6 and C_{37} respectively maintained at Chundale, Wynad district, Kerala. GVI 68 is a budded progeny of P7C of Pound's collection. GVI 126 is derived from SCA 6.

3.1.4 Mannuthy local

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

3.1.5 Hybrids

The hybrids selected as superior based on seedling vigour during the four year period from 1984-1988 were planted in the field during the period starting from November, 1988. The total number of crosses made for screening was 119 out of which 29 were selected as superior. These 29 hybrids along with the open pollinated bulk seedlings as control were planted as a randomised replicated progeny trial, during 1988. The number of replications taken were, five and number of plants per plot, six. Two of the five replications were planted under intense shade of existing rubber and three replications in the area without shade trees and under temporary shade of banana. The crops under the shade of rubber trees appeared to grow much better where as those grown without shade in replication 3,4 and 5 showed poor growth rate. Therefore, they were not taken for the study and the investigation was limited to replication 1 and 2.

The hybrids H-22 to H-29 were field planted during August, 1989. They were only two months old when planted in the main field and hence their growth observations in nursery could not be recorded.

3.1.6 Planting of parents

To assess the comparative performance of parent plants selected for the production of hybrids, replicated field trial of parents was laid out as comparative yield trial in the CCRP Farm. Budded progeny of parents were field planted during May 1989. The number of plants per plot was six and replication three. Total number of parents included in comparative yield trial was 26. Out of these, 19 were used for the production of hybrids grown under progeny trial. The parent GVI 126 is not grown in the replicated trial. Therefore the hybrids involving that parent were eliminated from comparison of parental characters contributing to yield.

The hybrids and parents included for the study are given in Table I.

3.2 Methods

The seedling characters of hybrids at various stages of plant growth and the yield and yield attributes of hybrids and parents were used for the study. Observations on yield and yield contributing characters of hybrids and parents were recorded from April 1995 to June 1996. In addition, there were data already recorded as given below.

(1) Seedling vigour (for progeny only)

(2) Yield of pods for three years from 1992-93 to 94-95 (for both parents and hybrids)

(3) Wet bean yield of pods for three years from 1992-93 to 94-95 (for both parents and hybrids).

Table 1 Hybrids and parents of cocoa used for the study

Hybrids			Parents	
Sl. No.	Hybrid No.	Cross	Sl. No.	Name of parent
1	H1	GII 20.4 x M 9.16	1	Germplasm I
2	H2	GII 20.4 x M 16.9	1	GI 4.8
3	H3	GII 19.5 x M 16.9	2	GI 5.9
4	H4	GI 10.3 x GVI 54	3	GI 10.3
5	H5	GI 10.3 x GVI 56	4	GI 15.5
6	H6	GI 10.3 x GVI 61	5	GI 9.6
7	H7	GI 5.9 x GVI 54	II	Germplasm II
8	H8	GI 5.9 x GVI 55	6	GII 20.4
9	H9	GI 5.9 x GVI 61	7	GII 19.5
10	H10	GI 4.8 x M 16.9		Germplasm VI
11	H11	GI 4.8 x GVI 54	8	GVI 51
12	H12	GI 15.5 x GVI 55	9	GVI 54
13	H13	GI 15.5 x GVI 54	10	GVI 55
14	H14	M 13.12 x GI 5.9	11	GVI 56
15	H15	M 16.9 x GVI 56	12	GVI 59
16	H16	GI 15.5 x GVI 56	13	GVI 61
17	H17	GI 15.5 x GVI 59	14	GVI 64
18	H18	GI 9.6 x GVI 68	15	GVI 68
19	H19	GI 9.6 x GVI 51	16	GVI 126
20	H20	GI 9.6 x GVI 61		Mannuthy Local
21	H21	GI 9.6 x GVI 55	17	M 9.16
22	H22	GVI 51 x GVI 126	18	M 13.12
23	H23	GVI 59 x GVI 126	19	M 16.9
24	H24	GI 5.9 x GVI 68		
25	H25	GI 5.9 x GVI 64		
26	H26	GI 10.3 x GVI 68		
27	H27	GI 10.3 x GVI 64		
28	H28	GI 4.8 x GVI 68		
29	H29	GVI 59 x M 16.9		

The crop was harvested at an interval of two to three weeks and observations were recorded. The number of pods were estimated including pods which were fully formed but damaged by diseases, insect pests and other vertibrate pests. For all the yield components including pod and bean characters only the undamaged ripe pods were considered. The characters included for the study are detailed below.

3.2.1 Seedling characters

3.2.1.1 Height of the seedlings

Height was measured from the base of the seedlings at ground level to the tip of the upper most leaf with the help of a meter scale and recorded in cms during four, five and six months after sowing (mas) in nursery. Height of one year old seedlings was also recorded in cms in the main field.

3.2.1.2 Diameter of hybrid seedlings

As it is difficult to measure diameter accurately, the girth of the seedlings which is a measure of diameter was recorded in cms.

Girth measurements during 4 mas, 5 mas and 6 mas in nursery were taken at ground level and recorded similar data of one year old seedlings were also taken.

From the data recorded for height and diameter, HD^2 which is a measure of volume of tree was worked out.

3.2.2 Pod characters

3.2.2.1 Pod yield

The number of pods harvested was recorded for each tree in each harvest at the field itself. Total number of pods per tree per year was obtained.

From each tree five uniformly ripe pods were selected from every harvest and the following characters were recorded.

3.2.2.2 Pod length

Length of pod was measured from pedicel to apex using a scale and data recorded in cms. Average pod length for each tree was calculated.

3.2.2.3 Pod width

Width of pods was measured in cms and average for each tree was calculated.

3.2.2.4 Pod weight

Pod weight was taken in g using a weighing balance. Average pod weight for each tree was also calculated.

3.2.2.5 Pericarp thickness

Thickness of fruit wall was measured both at ridges and furrows. The thickness was measured in mm using vernier caliperse after cutting open the pod. The average of fruitwall thickness at ridges and furrows was taken as pericarp thickness. Average pericarp thickness was thus arrived at for each tree.

3.2.3 Bean characters

The beans taken from five mature pods used for observing pod character of each tree were used for further observations.

3.2.3.1 Wet bean weight

Wet beans collected from each pod were weighed separately and recorded in grams. From the data, average wet bean weight per pod per tree was calculated.

3.2.3.2 Number of beans

Wet beans collected from each pod were counted and number of beans per pod was recorded. Average number of beans per pod per tree was also computed.

In each harvest wet beans collected from the selected pods of a tree were mixed together and 20 beans were chosen at random. The testa was removed along with the mucilage and the beans were peeled off. The seeds thus obtained were taken for further observations.

3.2.3.3 Seed length

Of the 20 peeled beans, five seeds were taken at random. Length of the seeds was measured in millimetres using vernier caliperse. Average seed length for a tree was calculated from the recorded data.

3.2.3.4 Seed width

Width of the seeds was taken for those seeds which were measured for seed length in millimetres using vernier caliperse. Average seed width for a tree was calculated.

3.2.3.5 Seed thickness

Seed thickness was also measured in those seeds for which length and width were taken and average seed thickness for a tree was calculated.

3.2.3.6 Dry bean weight

The twenty seeds taken at random for seed observations were dried in hot air over until the weight of seeds recorded for two consecutive days became same. The weight of 20 seeds were recorded in mg and dry weight of a single seed was calculated.

3.2.4 Wet bean yield of a tree

Number of pods and wet bean weight of a single pod were multiplied to get wet bean yield of a tree.

The average wet bean yield for a tree was thus calculated for each year separately and cumulative yield was worked out.

3.3 Statistical analysis

The analysis was carried out using M-stat software package. Coefficient of variation with respect to each character was worked out.

The relationship between seedling characters and yield and between yield components and yield were found out by estimating the value of correlation coefficient, r.

Using the characters showing significant correlation with yield, multiple regression analysis was carried out.

The regression model can be given as:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \ldots\ldots + \beta_p X_p + E$$

where,

y = yield

x_i = i^{th} character having significant correlation with yield

α = intercept

$\beta_1, \beta_2 \ldots\ldots \beta_p$ = The partial regression coeffcients

E = the error term

Heritability was estimated by regression of offspring on mid parental value

$$h^2 = b = \frac{\text{covariance OP}}{\text{Variance P}}$$

One way Analysis of Variance was carried out wherever required.

Results

4. RESULTS

A total of 29 hybrids of specific parentage and bulk (control) have been used for the studies. These 29 hybrids were derived from 19 parents collected from Germplasm I, Germplasm II, Germplasm VI and Mannuthy Local maintained under the cadbury-KAU Co-operative Cocoa Research Project. Of these, the parent GVI 126, which was the male parent in H-22 and H-23 was not grown in comparative yield trial of parents. Therefore the parent, GVI 126 and the hybrids H-22 and H-23 were not used for parent - progeny analysis.

The following parental and progeny characters were recorded

(1) Seedling vigour in terms of height and girth

(2) Yield of pods for four years from 92-93 to 95-96

(3) Yield of wet beans for four years form 92-93 to 95-96

Of these the seedling data and pod and wet bean yields for the period 92-93 to 94-95 were previously taken under CCRP.

A number of pod and bean characters were also observed both in parents and hybrids.

The following seedling characters were analysed to find out their relationship with progeny yield. Hybrid seedlings were planted during November, 1988. Due to the poor survival of seedlings of Hybrids H-17, H-22, H-23, H-24, H-25, H-26, H-27; H-28 and H-29, they were again raised and field planted during August 1989.

They were only two months old when planted and hence their nursery observations could not be recorded. Therefore the hybrids included for the analysis of seedling characters were H-1 to H-16 and H-18, H-19, H-20 and H-21.

4.1 Height of the seedlings

Height of the seedlings during four, five and six months after sowing was recorded and analysed. The range and mean of height of the seedlings during different growth stages for 20 hybrids are given in Table 2.

Height of the hybrid seedlings ranged from 13 cm in hybrids H-9 and H-12 to 53 cm in H-1, when the observations were taken at four month after sowing (4 mas). During five months after sowing, the range was from 18 cm in H-9 to 58 cm in H-16. The seedling height, six months after sowing varied from 21 cm in H-12 to 65 cm in H-1 and H-3.

The hybrid H-1 showed a maximum mean value of height during 4 mas and 5 mas (45.83 cms and 52.08 cm respectively). During 6 mas, the hybrid H-16 recorded a maximum mean value of 59.08 cm which is on par with H-1 (58.58 cm). On the other hand the hybrid, H-12 recorded the mean minimum height during four, five and six months of nursery observations. Of the 12 plants of hybrid H-16 the plant No.7.13 exhibited the maximum height during four, five and six months after sowing and the plant No. 13.14 of H-12 recorded the lowest.

The coefficient of variation of seedling height was found to be very low during four, five and six months after sowing (13.86%, 12.46% and 12.77% respectively).

Table 2 Range and mean of height of hybrids during three nursery stages (cm)

Sl. No.	Hybrid	4 months after sowing		5 months after sowing		6 months after sowing	
		Range	Mean	Range	Mean	Range	Mean
1	1	40-53	45.83	44-57	52.08	49-65	58.58
2	2	25-39	32.33	28-45	37.50	29-48	41.58
3	3	31-46	37.25	32-52	43.33	38-65	51.33
4	4	29-43	31.92	33-46	38.33	37-48	42.42
5	5	25-38	33.00	37-46	40.83	43-54	47.92
6	6	26-47	37.42	31-56	45.58	37-61	52.33
7	7	27-40	33.67	33-54	42.42	39-59	48.75
8	8	21-35	26.67	23-38	30.08	25-56	34.75
9	9	13-36	26.50	18-42	29.08	22-43	32.25
10	10	27-43	33.75	34-50	40.83	40-54	46.00
11	11	19-31	24.75	21-35	27.33	23-38	31.92
12	12	13-29	23.67	20-33	26.50	21-37	30.50
13	13	20-33	27.08	24-37	30.67	26-42	34.92
14	14	17-29	21.50	21-32	26.92	30-39	34.92
15	15	32-41	34.92	33-45	38.92	38-51	45.08
16	16	35-51	41.58	40-58	50.75	50-64	59.08
17	18	28-37	33.25	33-41	37.17	35-48	42.33
18	19	27-44	34.75	30-49	38.33	35-50	38.08
19	20	30-46	37.08	34-48	42.17	43-52	48.42
20	21	21-30	26.83	27-36	29.58	29-38	32.17
C.V. (%)		13.86		12.46		12.77	

4.2 Girth of the seedlings

Girth of seedlings at ground level was taken as a measure of the diameter of seedlings. Range and mean of girth observations during three nursery stages are presented in Table 3. The girth ranged from 3 cm in H-12 to 10 cm in H-16 during 4 mas. The coefficient of variation estimated was very low (cv = 14%). The range of girth five months after sowing was from 5 in H_9, H_{10} and H_{12} to 13 cm in H-1. The coefficient of variation was found to be 12.62 per cent. Girth of six month old seedlings in nursery varied from 6 cm in H9, H10, H12 and H18 to 13 cm in hybrids H-I, H-3, H-16 and H-18. The low value of coefficient of variation calculated indicates less variability for that character. As in the case of seedling height, diameter at four, five and six months after sowing were largest for the hybrid H-1 (8.33 cm, 10.17 cm and 11.33 cm). At six month stage, the seedling diameter of 11.33 cm was noticed in H-3 also. Among the 20 hybrids, the lowest seedling diameter was observed for the hybrid H-12. It was 5.25 cm at 4 mas, 6.58 at 5 mas and the value increased to 7.8 cm during six month stage.

4.3 Height and girth of 0+year old seedlings

Observations of seedling height and girth taken during first year in main field, one year after sowing were used for analysis and the mean and range of these characters are presented in Table 4.

Height of the seedlings one year after sowing ranged from 43 cm in H-18 to 195 cm in H-1 with a maximum mean value of 138.42 cm for the hybrid H-1 coefficient of variation for the character was found to be 18.78 per cent. In one year

Table 3: Range and mean of girth (cm) at three nursery stages of cocoa hybrids

Sl. No.	Hybrid	4 months after sowing		5 months after sowing		6 months after sowing	
		Range	Mean	Range	Mean	Range	Mean
1	1	7-9	8.33	8-13	10.17	9-13	11.33
2	2	5-8	6.75	8-9	8.58	9-12	10.58
3	3	6-9	7.75	8-10	9.25	9-13	11.33
4	4	5-7	6.25	7-10	8.16	8-11	9.58
5	5	5-8	6.75	6-9	8.16	8-11	9.75
6	6	6-9	7.00	7-10	8.67	8-12	10.08
7	7	6-9	7.50	8-11	9.17	9-12	10.67
8	8	6-8	6.50	6-10	8.25	8-11	9.17
9	9	4-8	5.67	5-9	7.25	6-10	8.42
10	10	5-9	7.00	5-11	8.25	6-12	9.83
11	11	5-7	6.08	6-9	7.67	7-11	9.17
12	12	3-6	5.25	5-8	6.58	6-9	7.80
13	13	5-8	6.42	7-10	8.33	8-11	9.58
14	14	5-8	5.83	7-10	7.67	7-10	8.58
15	15	6-7	6.17	8-9	8.25	9-11	9.67
16	16	5-10	7.92	7-11	9.33	8-13	10.33
17	18	6-9	7.41	7-10	8.50	9-11	10.17
18	19	5-8	7.00	6-10	8.83	6-13	10.50
19	20	6-8	6.83	7-10	8.25	9-12	10.00
20	21	6-9	6.58	8-10	8.17	9-11	9.75
C.V. (%)		14.09		12.62		13.86	

Table 4 Range and mean of height and girth (cm) of seedlings - one year after sowing

Sl. No.	Hybrid No.	Range of height	Mean of height	Rang of girth	Mean of girth
1	1	90-195	138.42	6-10	8.12
2	2	83-148	117.58	5-10	7.63
3	3	106-144	124.83	6-9	7.54
4	4	92-152	120.92	7-10	8.17
5	5	107-145	119.92	7.5-10	8.37
6	6	85-135	104.67	5-9	7.87
7	7	108-169	137.00	7-11	8.42
8	8	82-147	121.17	8-11	8.96
9	9	82-149	113.08	5-8	6.87
10	10	98-129	113.33	5-9	6.54
11	11	84-137	115.83	6-10	8.00
12	12	62-144	101.58	5-8	6.58
13	13	67-130	101.75	5-9	7.30
14	14	81-142	120.42	6-9	7.67
15	15	87-154	120.33	5-10	7.83
16	16	88-154	119.50	4-9	7.00
17	18	43-148	109.33	5-10	7.42
18	19	86-132	116.25	6-9	8.00
19	20	102-129	115.67	6-10	7.87
20	21	82-128	101.83	6-10	7.75
C.V. (%)			18.78		16.58

old seedlings, girth ranged from 4 cm in H-16 to 11 cm in H-7 and H-8 with a maximum mean value of 8.6 cm in H-8. The mean seedling height was lowest for the hybrids H-12 and H-13 and the hybrids H-10 and H-12 exhibited the minimum mean value of seedling girth. The coefficient of variation, estimated for the character seedling girth, (cv = 16.58%).

4.4 HD^2 for hybrid seedlings

HD^2 which is a measure of volume of the seedling was calculated. HD^2 during four periods of observations, ie. 4 mas, 5 mas, 6 mas and one year after sowing were calculated and presented in appendix.

4.5 Pod yield of hybrids

Data on pod yield of hybrids for four years from 92-93 to 95-96 are presented in Table 5 and Table 6.

Most of the plants had come to bearing during 91-92. Data during 92-93 showed high variability of the character expressed by the high coefficient of variability (cv = 88.68%). Therefore square root transformation was done which reduced the coefficient of variation to 41.94 per cent. Number of pods varied from 0 in many hybrids to 80 pods in H-1. The average pod yield during that period was also high for H-1 (26.83 nos.) and the hybrid H-17 with an average of 1 pod recorded the lowest. The average yield of pods for bulk was 13.92. The yield of bulk is satisfactory and the hybrids, H-12,H-15, H-17, H-18, H-19, H-21, H-22, H-23, H-24, H-25, H-26, H-27, H-28 and H-29 yielded less than the bulk.

Table 5 Range and mean of pod yield of hybrids during 1992-93 and 1993-94

Sl. No.	Hybrid No.	Pod yield (No.) (1992-93)		Pod yield (1993-94)	
		Range	Mean	Range	Mean
1	1	9-80	4.81 (26.83)	9-46	4.69 (27.83)
2	2	1-32	3.62 (15.33)	2-32	3.56 (21.42)
3	3	2-30	3.58 (13.92)	15-47	4.88 (23.08)
4	4	5-49	4.54 (22.33)	8-62	5.84 (36.08)
5	5	3-35	3.77 (15.91)	16-49	5.4 (24.64)
6	6	2-39	3.91 (17.17)	7-71	5.27 (24.42)
7	7	9-32	4.41 (20.17)	2-34	4.2 (23.83)
8	8	14-37	4.61 (21.75)	5-38	4.35 (30.00)
9	9	0-29	3.54 (13.58)	2-42	4.70 (30.17)
10	10	0-34	3.71 (14.08)	9-62	5.55 (28.83)
11	11	1-40	3.32 (13.58)	6-61	4.56 (24.67)
12	12	1-27	2.68 (8.33)	4-25	3.71 (23.58)
13	13	0-44	3.33 (13.00)	6-45	4.26 (28.33)
14	14	0-43	3.96 (14.25)	0-90	4.42 (33.42)
15	15	0-29	3.32 (11.33)	4-47	4.59 (22.00)
16	16	3-33	3.45 (13.42)	1-36	3.95 (20.92)
17	17	0-5	1.00 (1.00)	0-18	2.11 (9.58)
18	18	0-29	3.12 (10.75)	6-52	3.9 (27.00)
19	19	3-28	3.00 (10.25)	4-43	4.4 (24.08)
20	20	2-41	3.87 (16.33)	10-74	5.43 (31.47)
21	21	0-24	3.26 (10.83)	4-44	4.21 (25.16)

Contd...

Table 5 contd...

22	22	0-16	2.10 (4.50)	0-37	4.09 (23.58)
23	23	0-33	3.47 (12.92)	0-48	4.48 (26.58)
24	24	0-30	2.72 (7.70)	2-29	4.45 (24.92)
25	25	0-38	3.47 (11.90)	1-74	3.85 (34.30)
26	26	0-23	2.34 (5.00)	9-65	3.98 (26.00)
27	27	1-14	2.30 (6.17)	0-29	4.5 (21.50)
28	28	0-11	2.39 (6.17)	0-29	4.51 (21.50)
29	29	0-20	2.39 (6.50)	1-36	3.46 (20.58)
30	30	0-85 Bulk	3.04 (13.92)	0-47	3.45 (16.16)
C.V. (%)			41.94		34.41

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

Table 6 Range and mean of pod yield of hybrids during 1994-95 and 1995-96

Sl. No.	Hybrid No.	Pod yield (No.) (1994-95)		Pod yield (1995-96)	
		Range	Mean	Range	Mean
1	1	10-58	5.43 (31.25)	09-88	5.37 (27.43)
2	2	11-51	4.33 (20.33)	0-59	4.49 (21.42)
3	3	15-63	5.47 (31.75)	8-54	4.60 (23.08)
4	4	18-75	5.97 (37.50)	7-84	5.72 (36.08)
5	5	7-69	5.64 (34.09	9-55	4.62 (24.64)
6	6	12-64	5.69 (34.33)	0-59	4.84 (24.42)
7	7	0-49	4.83 (23.08)	1-72	4.50 (23.83)
8	8	6-67	4.89 (26.17)	7-72	5.24 (30.00)
9	9	4-45	4.89 (25.83)	3-61	5.24 (30.17)
10	10	11-73	5.78 (35.25)	4-56	5.21 (28.83)
11	11	4-54	4.89 (26.54)	0-55	5.18 (24.67)
12	12	6-40	4.62 (22.75)	8-47	4.73 (23.58)
13	13	1-70	4.87 (26.58)	11-47	5.21 (28.33)
14	14	2-92	5.37 (33.50)	1-83	5.4 (33.42)
15	15	7-37	4.63 (23.00)	0-39	4.69 (22.00)
16	16	9-41	4.85 (24.50)	6-33	4.47 (20.92)
17	17	1-31	3.01 (10.83)	0-28	3.06 (9.58)
18	18	3-68	5.07 (28.58)	0-69	5.21 (27.00)
19	19	6-58	4.72 (24.58)	5-44	4.76 (24.08)
20	20	3-59	5.01 (27.50)	0-69	5.65 (37.75)
21	21	6-42	4.07 (18.25)	5-56	4.73 (25.17)

Contd...

Table 6 contd...

22	22	6-23	3.77 (15.50)	4-56	4.60 (23.58)
23	23	7-51	4.66 (23.67)	2-58	4.80 (26.58)
24	24	0-53	5.16 (26.75)	6-52	4.68 (24.92)
25	25	0-50	5.53 (29.00)	4-58	5.56 (34.30)
26	26	3-53	4.62 (23.09)	2-90	4.72 (26.00)
27	27	9-65	5.13 (29.00)	0-46	4.38 (21.50)
28	28	0-35	3.36 (11.60)	0-39	3.83 (14.20)
29	29	7-48	5.40 (30.50)	6-30	4.40 (20.58)
30	(Bulk)	2-56	4.06 (20.58)	1-49	3.59 (16.17)
C.V. (%)			31.54		35.53

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

The coefficient of variation for the character, pod yield during 93-94 was estimated as 67.55 per cent and that of square-root transformed data, 34.41 per cent. Number of pods per year exhibited a wide range. It varied from 'nil' in many hybrids to 90 in plant number 10.8 of H-14. The hybrid H-4 recorded the maximum value of average pod yield (36.08). The lowest value 9.58 was recorded for the hybrid H-17. The bulk produced more or less same pod yield during 93-94 also. The pod yield recorded was 16.16.

On square root transformation of the data on pod yield during 1994-95, the coefficient of variation reduced to 31.54 per cent from the original value of 59.85. The range recorded was from 0 in H-7, H-24, H-25 and H-28 to 92 in plant number 10.9 of H-14. Average pod yield was highest for H-4 (37.5) and lowest for H-17 (10.83). The bulk recorded a better average yield of 20.58 pods per year. The hybrids that yielded lower than bulk were H-17, H-21, H-22 and H-28 (Table 6).

During 1995-96, the highest average pod yield was noticed in H-20. The hybrid H-4 as during the year 93-94 and 94-95, recorded a high value of average pod yield in 95-96 also. The hybrid produced 36.08 pods on an average during that period. Number of pods exhibited a wide range and varied from 0 in a number of hybrids to 90 in plant number 7.12 of H-26. The lowest average pod yield was recorded in hybrid H-17 (9.58). The bulk produced an average of 16.17 pods during 95.96. The coefficient of variation of original data was 68.60 per cent and that of transformed data estimated as 35.53 per cent.

The average pod yield for four years from 92-93 to 95-96 was calculated for each hybrid and presented in Table 10. A total of 347 plants comprising of 29 hybrids and a bulk were used for analysis. The hybrid H-4 recorded maximum pod yield of 33.17 and the hybrid H-17 recorded the lowest (6.44). The analysis of variance for average pod yield showed significant difference of the character among the hybrids. Average pod yield recorded for the bulk was 15.54. The highest average pod yield was recorded for the plant 10.10 of H-14.

4.6 Wet bean yield of hybrids

The pulp production of a tree over a certain period can be established by multiplying the number of pods harvested in that period with the weight of their wet seed volume.

The average wet bean yield per pod of a hybrid during four years of observation is presented in Table 7. During 1992-93, the character showed a range from 23.09 g in case of H-17 to 149 g in plant number 2.8 of H-21. The average wet bean weight was also high for the hybrid H-21. The yield of wet beans of the hybrid H-12 is as good as that of H-21.

In 93-94, the wet bean yield per pod of hybrids varied from 50.8 g of plant number 10.10 of hybrid H-14 to the 171.3 g in plant number 20.16 of the H-8. The highest average wet bean yield was recorded for the hybrid H-8 and the lowest was exhibited by H-14.

Table 7 Mean of wet bean yield/pod of hybrids (g) from 1992-93 to 1995-96

Hybrid No.	1992-93	1993-94	1994-95	1995-96	Average
1	97.73	99.90	93.25	72.22	90.77
2	91.19	97.51	92.60	87.70	92.25
3	103.18	108.12	108.78	109.45	107.38
4	79.90	92.90	90.70	88.49	88.00
5	101.91	105.35	107.11	108.87	105.81
6	86.22	92.72	91.85	90.97	90.44
7	85.25	103.57	99.65	95.72	96.05
8	107.90	133.90	129.01	124.11	123.73
9	86.35	102.28	102.21	102.14	98.24
10	82.10	101.92	97.27	92.58	93.47
11	96.92	102.70	104.00	94.73	99.59
12	115.13	120.85	125.03	129.21	122.55
13	71.43	101.15	95.25	89.36	89.45
14	60.32	69.01	81.65	77.91	72.22
15	89.97	121.85	120.49	109.91	110.55
16	93.74	102.06	94.63	97.21	96.91
17	23.09	71.67	103.85	98.53	74.28
18	88.52	113.66	112.31	103.37	104.46
19	113.62	119.38	122.79	126.19	120.49
20	97.96	106.20	99.25	92.31	98.93
21	115.92	131.13	160.30	129.47	126.70

Contd...

Table 7 contd...

22	74.91	82.17	92.05	92.76	85.47
23	93.71	103.83	101.45	99.07	99.51
24	92.96	99.25	112.54	116.99	105.43
25	67.73	93.57	88.44	83.32	83.26
26	61.44	115.80	112.06	108.33	99.39
27	92.51	91.68	93.04	87.73	91.24
28	80.88	87.15	106.78	94.72	92.38
29	86.31	99.24	104.07	108.91	99.63
Bulk	82.38	79.25	97.77	91.29	87.67
C.V. (%)		37.10	28.08	18.49	27.94

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

The range of wet bean weight for a single pod during 94-95 was from 52 g in H-14 to 150 g in H-21. The maximum average of wet bean weight was shown by the hybrid H-21 and the minimum by H-14.

During 95-96, the character exhibited a wide range from 25 gm in plant number 5.20 of H-12 to 219.3 g in plant number 19.7 of H-19. The maximum average yield was recorded for the hybrids H-12 and H-21 and the lowest for H-1.

The co-efficient of variation calculated was low during years of observation. The maximum value of cv. was found to be 37.10 per cent during 92-93 and the lowest during 94-95 (18.49 per cent). The low coefficient of variation implies the less variability of that character.

On an average, highest wet bean weight per pod taken for four years was produced by the hybrid H-21 (126.7 g) and the lowest for H-14 (72.2 g). The wet bean weight of bulk was estimated to be 87.67 g.

The average wet bean weight per pod multiplied by the number of pods harvested in an year gives an estimate of pulp production of trees. The range and mean yield of wet beans per tree during four years of study starting from 92-93 to 95-96 are given in Table 8 and Table 9.

During 92-93, the average wet bean yield ranged from 0 to 88569 in H-8. The character expressed high variability. Therefore square root transformation was done which reduced the cv. to 37.03 per cent. Average wet bean yield was found to be

Table 8 Range and mean of wet bean yield of hybrids during 1992-93 and 1993-94

Sl. No.	Hybrid No.	Wet bean yield (gms) (1992-93)		Wet bean yield (gms) (1993-94)	
		Range	Mean	Range	Mean
1	1	0-8360	49.4 (2462)	740-5221	46.13 (2334)
2	2	0-6372	43.44 (1371)	95-3862	34.09 (1319)
3	3	825-6205	47.53 (1374)	224-3033	35.81 (2631)
4	4	623-7392	54.01 (1770)	400-4439	40.24 (3378)
5	5	1015-5940	48.95 (1543)	303-3430	37.47 (3163)
6	6	0-5310	44.83 (1476)	154-3705	36.14 (2709)
7	7	85-6912	43.40 (1717)	780-4285	40.35 (2080)
8	8	861-8856	57.60 (2306)	1414-3675	47.25 (2708)
9	9	334-5236	52.70 (1204)	0-2786	33.53 (2489)
10	10	0-5470	49.57 (1279)	0-3230	35.24 (3344)
11	11	976-5781	51.40 (1241)	131-3860	32.01 (2374)
12	12	356-1620	52.74 (974)	122-3294	28.82 (1747)
13	13	444-1878	48.47 (1012)	0-4498	29.36 (2083)
14	14	365-1533	46.28 (1018)	0-2812	35.63 (1552)
15	15	0-7590	51.59 (1229)	0-3538	33.26 (2914)
16	16	380-680	43.58 (1266)	285-2662	33.35 (1898)
17	17	0-2072	31.24 (90)	0-400	18.95 (406)
18	18	0-7176	55.46 (1057)	0-2764	30.68 (2001)
19	19	520-4576	53.14 (1197)	174-3934	31.68 (2493)
20	20	0-6369	54.36 (1628)	165-3965	38.46 (3421)
21	21	435-6048	54.03 (1377)	0-3370	36.49 (2771)

Contd...

Table 8 contd....

22	22	935-4816	44.17 (1038)	0-1540	19.90 (1476)
23	23	180-4700	47.60 (1266)	0-2913	34.38 (2275)
24	24	630-5512	51.04 (855)	0-3675	28.38 (2431)
25	25	460-6264	50.29 (916)	0-2236	31.00 (1546)
26	26	198-1720	48.84 (471)	0-2254	24.06 (1427)
27	27	0-4232	41.35 (568)	80-1657	21.94 (2143)
28	28	0-3549	39.69 (299)	0-1144	16.57 (1096)
29	29	570-3013	45.95 (579)	0-1716	22.83 (1327)
30	Bulk	87-4312	33.96 (1206)	0-6945	28.44 (1324)
C.V. (%)			37.03		42.21

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

Table 9 Range and mean of wet bean yield of hybrids during 1994-95 and 1995-96

Sl. No.	Hybrid No.	Wet bean yield (gms) (1994-95)		Wet bean yield (gms) (1995-96)	
		Range	Mean	Range	Mean
1	1	700-4451	46.69 (2860)	937-5221	52.07 (2402)
2	2	900-2825	36.00 (2010)	1017-4846	45.70 (1998)
3	3	1200-4335	50.16 (3510)	1545-6489	57.00 (24420)
4	4	520-7843	55.65 (3416)	1422-5995	56.75 (3256)
5	5	1190-5311	55.08 (3694)	721-7107	58.56 (2798)
6	6	571-5474	50.47 (3105)	1092-5824	54.23 (2129)
7	7	170-4640	42.99 (2227)	6-4704	47.53 (2179)
8	8	800-6544	50.21 (3128)	744-8312	53.88 (3634)
9	9	280-4849	47.02 (2580)	442-4590	49.08 (3085)
10	10	799-5880	55.90 (3463)	1023-6738	57.03 (2697
11	11	510-5720	45.96 (2705)	380-4750	49.50 (2548)
12	12	487-3250	40.38 (2960)	680-5240	52.09 (3040)
13	13	168-4464	42.86 (2584)	84-6234	47.92 (2436)
14	14	0-6300	39.50 (2542)	152-7158	47.37 (2427)
15	15	597-6190	51.17 (2844)	787-4065	51.93 (2714)
16	16	85-4500	40.13 (2446)	823-3977	48.33 (1986)
17	17	0-1306	20.46 (1082)	97-3064	30.20 (986)
18	18	622-6500	41.74 (3340)	298-7004	54.13 (3114)
19	19	488-4214	47.95 (2975)	750-7424	51.96 (3034)
20	20	1010-7622	55.98 (2733)	279-5900	49.95 (2934)

Contd...

Table 9 contd...

21	21	408-4034	48.81 (2491)	750-5418	46.94 (3328)
22	22	0-3992	38.27 (1399)	594-2320	35.89 (2212)
23	23	0-4899	45.52 (2487)	708-5508	47.03 (2718)
24	24	187-877.	46.49 (3217)	0-6201	55.26 (3054)
25	25	87-6880	37.01 (2549)	0-5450	51.93 (2784)
26	26	808-8640	31.93 (2560)	328-5830	48.66 (2824)
27	27	0-3120	43.51 (2656)	792-5720	49.15 (1854)
28	28	0-3074	32.62 (1280)	0-3325	35.02 (1567)
29	29	82-3564	34.25 (3198)	746-5184	54.96 (2326)
30	Bulk	0-3760	36.17 (2072)	188-5150	40.33 (1462)
CV (%)			36.45		37.03

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

high for H-1 (2462 g). The lowest wet bean yield of 90 g was noticed in hybrid H-17. The bulk produced an average yield of 1206 g (Table 8).

The coefficient of variation of original data for wet bean yield during 93-94 was 87.42 per cent and that of transformed data, 42.21. The yield of wet beans varied from 0 to 6945 g in the plant 9.16 of bulk. Highest average wet bean yield was given by the hybrid H-20 (3421 g) and lowest by H-17 (406 g). The average wet bean yield of bulk was found to be 1324 g (Table 8).

The range of wet bean yield was from 0 in many plants to 8877 g in plant number 623 of hybrid H-24 during the year 94-95. On an average, the hybrid H-5 exhibited a maximum wet bean yield of 3694 g where as the lowest yield was noticed in the hybrid H-17 (1082 g). The bulk reported an average yield of 2072 g. The coefficient of variation computed was 61.62 per cent for the original data and 36.45 per cent for the transformed data.

During 95-96, the wet bean yield showed a wide range of 0 - 8312 g in H-8. By transformation, the coefficient of variation reduced to 32.57 per cent. The highest value of average wet bean yield was found to be 3634 g in H-8 and the lowest yield noticed was 986 g for the hybrid H-17. The bulk recorded a wet bean yield of 1462 g.

Average wet bean yield of hybrids for four years from 92-93 to 95-96 is given in Table 10. The hybrid H-4 recorded the highest average yield, and H-17 reported the lowest. Wet bean yield taken as average of four years were high for plant number 7.21 of H-26. The bulk recorded an average yield of 1516 g.

Table 10 Average pod yield and wet bean yield of hybrid

Sl. No.	Hybrid No.	Average number of pod	Average wet bean yield
1	1	5.14 (27.29)	49.20 (2515)
2	2	3.95 (17.52)	38.40 (1674)
3	3	4.76 (23.33)	49.14 (2490)
4	4	5.69 (33.17)	53.84 (2955)
5	5	5.04 (26.23)	51.69 (2800)
6	6	5.00 (26.40)	47.50 (2355)
7	7	4.53 (21.56)	44.20 (2051)
8	8	4.85 (24.45)	53.20 (2945)
9	9	4.67 (23.62)	46.40 (2340)
10	10	5.19 (27.73)	50.80 (2695)
11	11	4.55 (22.15)	45.60 (2217)
12	12	4.13 (17.33)	42.30 (2180)
13	13	4.58 (22.08)	41.20 (2355)
14	14	4.72 (25.25)	41.25 (2340)
15	15	4.33 (19.87)	47.50 (2425)
16	16	4.31 (19.19)	42.80 (1899)
17	17	2.41 (6.44)	24.41 (641)
18	18	4.40 (20.85)	47.20 (2378)
19	19	4.40 (19.94)	48.20 (2425)
20	20	5.05 (26.85)	50.30 (2680)
21	21	4.17 (18.56)	47.63 (2492)
22	22	3.78 (15.17)	36.02 (1373)
23	23	4.47 (21.21)	43.01 (2186)
24	24	4.21 (19.94)	41.80 (2389)

Contd...

Table 10 contd...

25	25	4.66 (22.97)	43.00 (1949)
26	26	3.81 (16.77)	39.80 (1821)
27	27	4.30 (19.79)	41.12 (1805)
28	28	2.77 (9.30)	29.05 (1025)
29	29	4.17 (17.85)	42.33 (1857)
30	Bulk	3.55 (15.54)	33.26 (1516)

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

4.7 Relationship between seedling characters and yield

Data on various vegetative and yield factors were collected from 251 plants comprising of 20 hybrids and correlation coefficients of different factor combinations were worked out.

4.8 Correlation between seedling characters and wet bean yield

The figures in Table 11 represent coefficient of correlation between height measurements of seedlings taken during four, five and six months and one year after sowing with wet bean yield of hybrids. Seedling height taken at 4 mas showed significant correlation with wet bean yield during 92-93 and 94-95 ($P = 0.05$). The character exhibited a correlation coefficient, $r = 0.133$ with cumulative yield which is significant at 5 per cent level.

The height of seedlings 5 mas and 6 mas has no significant influence on wet bean yield as expressed by their correlation coefficients.

Height of seedlings taken one year after sowing from mainfield gave higher and significant correlations with yield than nursery observations. The relationship was found to be good during 92-93, 93-94 and 94-95. The correlation coefficient worked out between cumulative yield and height of seedling one year after sowing was 0.251 which is significant at one per cent level. The regression coefficient was estimated to be 0.299 which indicates, on the average a difference of 0.299 cm in height at one year after sowing results in a difference of 1 g wet bean yield.

Table 11 Correlation between seedling height and wet bean yield

Sl. No.	Variable I	Variable II	Correlation coefficient	Regression coefficient	Probability
1	Seedling height (4 months after sowing)	Yield 92-93	0.141	0.275	0.029
		Yield 93-94	0.108	0.239	0.093
		Yield 94-95	0.133	0.284	0.036
		Yield 95-96	0.012	0.028	0.048
		Cumulative yield	0.133	0.447	0.035
2	Seedling height (5 months after sowing)	Yield 92-93	0.098	0.163	0.132
		Yield 93-94	0.081	0.154	0.207
		Yield 94-95	0.094	0.172	0.141
		Yield 95-96	-0.060	-0.118	0.354
		Cumulative yield	0.074	0.213	0.244
3	Seedling height (6 months after sowing)	Yield 92-93	0.104	0.151	0.106
		Yield 93-94	0.035	0.058	0.587
		Yield 94-95	0.013	0.021	0.841
		Yield 95-96	-0.107	-0.184	0.097
		Cumulative yield	0.016	0.041	0.799
4	Seedling height (1 year after sowing)	Yield 92-93	0.332	0.230	0.000
		Yield 93-94	0.230	0.180	0.000
		Yield 94-95	0.151	0.115	0.017
		Yield 95-96	0.061	0.050	0.343
		Cumulative yield	0.251	0.299	0.000

Table 12 gives coefficient of correlation between girth measurements of seedlings and wet bean yield over a period of four years. Correlation coefficient estimated with girth observation of seedlings 4 mas showed no significant relationship with yield of hybrids.

The yield during 92-93 showed significant correlations with girth of 5 month and 6 month old seedlings (r = 0.188 and 0.126 respectively). None of the observations showed significant relationship with cumulative wet bean yield.

Girth of one year old seedling taken from main field showed a highly significant relationship with yield of hybrids during 1992-93 and 93-94 (P = 0.001) while their relationship was significant only at five per cent level during 94-95 and 95-96. The correlation coefficient was computed as 0.313 between seedling girth one year after sowing and cumulative yield. The corresponding regression coefficient was estimated to be 5.69.

The relationship between girth measurements and wet bean yield increased with age of seedlings. Correlation coefficients were estimated 0.036, 0.101, 0.119 and 0.313 between cumulative yield and girth of seedlings 4 mas, 5 mas, 6 mas and one year after sowing respectively.

The relationship between HD^2 of seedlings during different growth stages and wet bean yield is shown in Table 13. HD^2 calculated with observations of 5 month old seedlings showed significant correlation with yield of hybrids during 92-93 `r' being 0.168 which was significant at 1 per cent level.

Table 12 Correlation between girth of seedlings and wet bean yield

Sl. No.	Variable I	Variable II	Correlation coefficient	Regression coefficient	Probability
1	Seedling girth (4 months after sowing)	Yield 92-93	0.067	0.179	0.300
		Yield 93-94	0.045	0.137	0.483
		Yield 94-95	0.014	0.043	0.825
		Yield 95-96	0.005	0.015	0.942
		Cumulative yield	0.036	0.171	0.560
2	Seedling girth (5 months after sowing)	Yield 92-93	0.188	2.132	0.003
		Yield 93-94	0.075	0.974	0.241
		Yield 94-95	0.062	0.784	0.328
		Yield 95-96	0.029	0.402	0.649
		Cumulative yield	0.101	1.999	0.116
3	Seedling girth (6 months after sowing)	Yield 92-93	0.126	0.391	0.050
		Yield 93-94	0.106	0.372	0.099
		Yield 94-95	0.062	0.214	0.329
		Yield 95-96	0.095	0.352	0.138
		Cumulative yield	0.119	0.647	0.059
4	Seedling girth (1 year after sowing)	Yield 92-93	0.397	4.178	0.000
		Yield 93-94	0.298	3.543	0.000
		Yield 94-95	0.126	1.452	0.048
		Yield 95-96	0.132	1.044	0.040
		Cumulative yield	0.313	5.690	0.000

Table 13 Correlation between HD^2 of seedlings and wet bean yield

Sl. No.	Variable I	Variable II	Correlation coefficient	Regression coefficient	Probability
1	HD^2 (4 months after sowing)	Wb yield 92-93	0.043	0.000	0.512
		Wb yield 93-94	0.021	0.000	0.743
		Wb yield 94-95	-0.003	0.000	0.956
		Wb yield 95-96	0.007	0.000	0.917
		Cumulative yield	0.016	0.000	0.797
2	HD^2 (5 months after sowing)	Wb yield 92-93	0.168	0.002	0.009
		Wb yield 93-94	0.074	0.001	0.247
		Wb yield 94-95	0.083	0.001	0.191
		Wb yield 95-96	-0.010	0.000	0.873
		Cumulative yield	0.095	0.002	0.133
3	HD^2 (6 months after sowing)	Wb yield 92-93	0.102	0.000	0.116
		Wb yield 93-94	0.089	0.000	0.165
		Wb yield 94-95	0.048	0.000	0.452
		Wb yield 95-96	0.094	0.000	0.144
		Cumulative yield	0.103	0.000	0.103
4	HD^2 (1 year after sowing)	Wb yield 92-93	0.399	0.002	0.000
		Wb yield 93-94	0.293	0.002	0.000
		Wb yield 94-95	0.118	0.001	0.061
		Wb yield 95-96	0.127	0.001	0.050
		Cumulative yield	0.311	0.002	0.000

HD^2 of seedlings during 4 mas and 6 mas did not influence the yield of hybrids. But the correlations worked out with respect to HD^2 of one year old seedlings showed a high correlation coefficient of 0.311 which is significant at 1 per cent level. The regression coefficient was estimated to be 0.002. The correlation of this character with yield of individual years also was significant.

As in the case of girth of seedlings, the relationship showed an increasing trend with increase in age of seedlings.

4.9 Correlation between seedlings characters and pod yield

The extent of relationship between height, diameter and HD^2 of seedlings and their pod yield were worked out and are presented in Table 14, 15 and 16 respectively.

The seedling height taken 4 mas exhibited significant correlation with pod yield of tree during 92-93, 93-94 and 94-95. The relationship was not significant with yield during 95-96. The average yield showed a correlation coefficient of 0.14 which is significant at 5 per cent level (Table 14).

The height taken 5 mas did not influence yield in any year or cumulative yield significantly. Height of six month old seedlings was significantly correlated with pod yield during 92-93 ($r = 0.142$), but the correlation was not significant with yield on other periods of observation.

Table 14 Correlation between pod yield and seedling height

Sl. No.	Variable I	Variable II	Correlation coefficient	Regression coefficient	Probability
1	Seedling height (4 months after sowing)	Yield 92-93	0.150	0.033	0.018
		Yield 93-94	0.132	0.029	0.040
		Yield 94-95	0.137	0.028	0.037
		Yield 95-96	-0.025	-0.007	1.000
		Cumulative yield	0.140	0.025	0.015
2	Seedling height (5 months after sowing)	Yield 92-93	0.121	0.022	0.062
		Yield 93-94	0.126	0.023	0.050
		Yield 94-95	0.117	0.021	0.070
		Yield 95-96	-0.075	-0.016	0.247
		Cumulative yield	0.112	0.016	0.075
3	Seedling height (6 months after sowing)	Yield 92-93	0.142	0.022	0.026
		Yield 93-94	0.105	0.017	0.104
		Yield 94-95	0.032	0.005	1.000
		Yield 95-96	-0.082	-0.015	0.207
		Cumulative yield	0.068	0.008	0.285
4	Seedling height (1 year after sowing)	Yield 92-93	0.292	0.023	0.000
		Yield 93-94	0.179	0.014	0.005
		Yield 94-95	0.128	0.010	0.042
		Yield 95-96	0.153	0.014	0.015
		Cumulative yield	0.269	0.015	0.000

Table 15 Relationship between pod yield and seedling girth

Sl. No.	Variable I	Variable II	Correlation coefficient	Regression coefficient	Probability
1	Seedling girth (4 months after sowing)	Pod yield 92-93	0.139	0.187	0.031
		Pod yield 93-94	0.124	0.169	0.056
		Pod yield 94-95	0.058	0.079	0.368
		Pod yield 95-96	-0.047	-0.074	0.465
		Cumulative Pod yield	0.119	0.122	0.059
2	Seedling girth (5 months after sowing)	Pod yield 92-93	0.203	0.255	0.002
		Pod yield 93-94	0.097	0.124	0.134
		Pod yield 94-95	0.062	0.078	0.342
		Pod yield 95-96	0.034	0.034	0.719
		Cumulative yield	0.154	0.146	0.015
3	Seedling girth (6 months after sowing)	Pod yield 92-93	0.119	0.040	0.067
		Pod yield 93-94	0.133	0.046	0.040
		Pod yield 94-95	0.053	0.018	0.415
		Pod yield 95-96	0.058	0.023	0.371
		Cumulative yield	0.130	0.034	0.039
4	Seedling girth (1 year after sowing)	Pod yield 92-93	0.372	0.435	0.000
		Pod yield 93-94	0.264	0.314	0.000
		Pod yield 94-95	0.039	0.046	0.548
		Pod yield 95-96	0.079	0.108	0.220
		Cumulative yield	0.301	0.264	0.000

Table 16 Relationship between HD^2 of seedlings and pod bean yield

Sl. No.	Variable I	Variable II	Correlation coefficient	Regression coefficient	Probability
1	HD^2 (4 months after sowing)	Pod yield 92-93	0.033	0.000	0.604
		Pod yield 93-94	0.020	0.000	0.748
		Pod yield 94-95	0.012	0.000	0.844
		Pod yield 95-96	0.047	0.000	0.450
		Cumulative yield	0.033	0.000	0.600
2	HD^2 (5 months after sowing)	Pod yield 92-93	0.192	0.000	0.002
		Pod yield 93-94	0.122	0.000	0.054
		Pod yield 94-95	0.098	0.000	0.120
		Pod yield 95-96	-0.002	0.000	0.977
		Cumulative yield	0.149	0.000	0.019
3	HD^2 (6 months after sowing)	Pod yield 92-93	0.096	0.000	0.130
		Pod yield 93-94	0.119	0.000	0.060
		Pod yield 94-95	0.050	0.000	0.420
		Pod yield 95-96	0.070	0.000	0.260
		Cumulative yield	0.112	0.000	0.070
4	HD^2 (1 year after sowing)	Pod yield 92-93	0.383	0.000	0.000
		Pod yield 93-94	0.250	0.000	0.006
		Pod yield 94-95	0.079	0.000	0.215
		Pod yield 95-96	0.152	0.000	0.016
		Cumulative yield	0.304	0.000	0.000

Height of seedlings, taken one year after sowing exhibited significant correlation with pod yield. The relationship estimated between cumulative yield and height of one year old seedlings was highly significant (r = 0.269).

Table 15 gives coefficients of correlation of seedling girth with pod yield of hybrids. Girth of stem of 4 month old seedling exhibited significant correlation only with pod yield during the period 92-93 (r = 0.1397). Correlation coefficient with cumulative yield was very low (r = 0.119) which denotes the lack of significant influence of the character on pod yield.

Seedling girth taken 5 mas showed significant relationship with cumulative yield (r = 0.154) which was mainly attributed by its influence on pod yield during 92-93 (r = 0.203). Just like the height of seedlings taken after 6 mas, the diameter also reported no significant influence on yield of hybrids.

However, the seedling girth of 1 year old seedlings had highly significant influence on yield of hybrids during 1992-93 and 93-94. The correlation was found to be 0.301 with cumulative yield of hybrids (P = 0.001). Regression coefficient estimated was 0.264.

The correlation between HD^2 and pod yield revealed that HD^2 during 4 mas and 6 mas has no influence on pod yield (Table 16). The correlation coefficient worked out between average yield and HD^2 during 5 mas is found to be significant at 5 per cent level just as with yield during 92-93.

As in the case of height and diameter, their derivative HD^2 one year after sowing also showed significant relationship with pod yield. `r' between HD^2 of one year old seedlings and yield was estimated to be 0.304, which was significant at 1 per cent level.

4.10 Multiple regression analysis of pod yield on seedling characters

Multiple regression of pod yield on seedling characters which were significantly correlated with yield was estimated. The girth, height and HD^2 were taken as independent variables.

Among the seedling characters analysed, simple correlation was found to be significant with seedling characters during 5 mas and also with a one year old seedlings. Though girth and HD^2 of five month old seedlings had significant correlation with cumulative pod yield, multiple regression of pod yield on height, girth and HD^2 observed 5 mas was not significant (Table 17). The height and diameter alone were taken as independent variables and the analysis were resulted in a non-significant regression values for the two variables (Table 18). Both the regression analysis of variance also showed the non-significant influence of these characters.

The seedling observations taken one year after sowing expressed a highly significant relationship with pod yield when simple correlations worked out. Multiple regression analysis with all these characters reported a highly significant F-value ($P = 0.001$). But the regression coefficients were significant only in the case of seedling height (Table 19). The coefficient of determination was estimated to be 0.099 which denotes proportion of variation in pod yield explained by the regression.

Table 17 Multiple regression of pod yield on height, girth and HD^2 of seedlings five months after sowing

Sl. No.	Character	b	p
1	Height (5 MAS)	-0.00056	-0.478
2	Girth (5 MAS)	0.0896	0.608
3	HD^2 (5 MAS)	0.0000453	0.853

Coefficient of determination, R^2 = 0.021

Intercept Y = 3.82

Anova for multiple regression analysis

	SS	DF	MS	F
Regression	6.572	3	2.19	1.65
Residual	312.50	235	1.33	
Total	319.07	238		

Table 18 Multiple regression of pod yield on height and girth of seedlings - five months after sowing

Sl. No.	Character	b	p
1	Height (5 MAS)	0.0027	0.794
2	Girth (5 MAS)	0.12	0.092

Coefficient of determination, R^2 = 0.02

Intercept Y = 3.57

Anova for multiple regression analysis

	SS	DF	MS	F
Regression	6.526	2	3.26	2.46
Residual	312.55	236	1.324	
Total	319.07	238		

Table 19 Multiple regression of pod yield on height, girth and HD^2 observed on one year old seedlings

Sl. No.	Character	Regression coefficient	Probability
1	Height	0.01	0.013
2	Diameter	0.30	0.071
3	HD^2	-0.00009	0.320

Coefficient of determination, R^2 = 0.099

Intercept Y = 0.903

Anova for multiple regression analysis

	Ss	Df	Ms	F	Significance
Regression	32.90	3	10.97	9.01	0.00
Residual	286.17	235	1.21		
Total	319.07	238			

Multiple regression analysis conducted with variables height and diameter of one year old seedlings led to the conclusion that they jointly had highly significant influence on yield (Table 20). Regression analysis of variance resulted in a highly significant `F' value (P = 0.001). Regression coefficient of seedling height was 0.001 and that of seedling girth was 0.157. Both the regression coefficients were significant. Coefficient of determination, R^2 was 0.099 which was not affected when HD^2 was deleted for the regression. In other words HD^2 did not give any information on pod yield in addition to those given by height and diameter.

The estimated regression is

$$Y = 2.20 + 0.001x_1 + 0.157x_2$$

Where x_1 denotes the variable height and x_2 diameter of seedlings observed one year after sowing.

4.11 Multiple regression of wet bean yield on seedling characters

Relationship of height, girth, and HD^2 of seedlings with wet bean yield was estimated individually using simple correlations. The seedling observations taken one year after sowing exhibited significant relationship with wet bean yield.

The result of multiple regression analysis of height, diameter and HD^2 of one year old seedlings as explanatory variables and wet bean yield as dependent variable is given in Table 21. Regression coefficients of seedling height alone was found to be significant (P = 0.05). Multiple regression coefficient R^2 = 0.101 and the regression was significant. ANOVA resulted in a significant `F' value of 8.83.

Table 20 Multiple regression of pod yield on height and girth of one year old seedlings

Sl. No.	Character	Regression coefficient	Probability
1	Height	0.001	0.003
2	Diameter	0.1570	0.005

Coefficient of determination, R^2 = 0.099

Intercept Y = 2.20

$Y = 2.20 + 0.001 X_1 + 0.157 X_2$

Anova for multiple regression analysis

	Ss	Df	Ms	F
Regression	31.69	2	15.847	13.01**
Residual	287.38	236	1.218	
Total	319.07	238		

Table 21 Multiple regression of wet bean yield on height, girth and HD^2 of one year old seedlings

Sl. No.	Character	Regression coefficient	Probability
1	Seedling height	0.273	0.044
2	Seedling girth	6.191	0.104
3	HD^2	-0.001	0.490

Coefficient of determination, R^2 = 0.101

Anova for multiple regression analysis

	Ss	Df	Ms	F
Regression	13930	3	4648	8.83**
Residual	123557	235	5258	
Total	137487	238		

Since the regression coefficients were not significant for all the characters studied, analysis was conducted with height and diameter alone of one year old seedlings as independent variables (Table 22). ANOVA showed a highly significant 'F' value of 13.04. Regression coefficient of seedling height was 0.195 and that of girth 3.696. Both were significant at 1 per cent level. The coefficient of determination R^2 is found to be 0.099. Though the coefficient of determination was reduced slightly to 0.099, regression was significant at higher level and both regression coefficients were significant. The estimated model is

$$Y = 43 + 0.195x_1 + 3.70x_2$$

Where x_1 and x_2 are height and girth of one year old seedlings respectively.

4.12 Pod and bean characters of hybrids

Six pod characters viz., length of pod, width of pod, pod weight, number of beans, pericarp thickness and wet bean weight for a single pod along with four seed characters, viz., seed length, seed width, seed thickness and dry weight of seeds were recorded from 347 plants comprising of 29 hybrids and their means are presented in Table 23.

4.12.1 Pod length

Length of pods among hybrids ranged from 10 cm in plant number 2.15 of H-13 to 21.4 cm in plant number 19.7 of the hybrid H-19. Maximum mean length was also recorded for H-19 (16.7 cm) and a minimum pod length of 12.8 cm was recorded in H-13.

Table 22 Multiple regression of wet bean yield on height and girth of one year old seedlings

Sl. No.	Character	Regression coefficient	Probability
1	Seedling height	0.195	0.01
2	Seedling girth	3.696	0.002

Multiple regression coefficient, $R^2 = 0.099$

$Y = 43 + 0.195 X_1 + 3.70 X_2$

Yield = 43 + 0.2 x height + 3.7 x girth

Anova for multiple regression analysis

	Ss	Df	Ms	F
Regression	13678	2	6839.4	13.04**
Residual	123808	236	52468	
Total	137486	238		

Table 23 Mean of pod and bean characters in 29 hybrids of cocoa

Hybrid No.	Pod length (cm)	Pod width (cm)	Pod weight (g)	Bean No.	Seed dry weight (mg)	Seed length (mm)	Seed width (mm)	Seed thickness (mm)	Pericarp thickness (mm)	Wet bean weight (g)
1	14.4	7.5	334.3	35.5	0.92	19.5	10.4	6.2	9.8	90.77
2	15.1	7.3	323.8	39.7	0.82	19.0	10.2	6.4	8.8	92.25
3	15.4	7.7	370.3	39.8	0.90	20.4	10.8	7.1	9.1	107.38
4	13.1	7.2	286.4	40.9	0.77	19.4	11.1	5.9	8.7	88.00
5	13.8	7.3	313.8	44.5	0.80	19.2	10.5	5.9	8.6	105.81
6	15.3	7.1	287.6	41.7	0.76	19.1	10.1	5.7	8.5	96.05
7	13.4	7.3	277.3	39.0	0.76	19.1	10.1	5.7	8.5	96.05
8	14.1	7.8	357.5	46.2	0.79	19.7	10.1	5.5	8.2	123.73
9	14.9	7.3	277.3	40.1	0.71	18.4	9.9	6.2	7.7	98.24
10	14.7	7.4	316.4	40.8	0.77	18.5	10.1	6.4	8.6	93.47
11	13.8	7.4	320.5	41.4	0.76	19.3	10.7	5.9	9.4	99.59
12	14.5	8.1	405.5	44.3	1.83	21.7	11.1	5.7	10.7	122.55
13	12.8	10.1	293.0	38.8	0.77	19.6	10.5	5.9	8.8	89.45
14	13.8	7.6	273.0	40.6	0.68	17.4	9.6	6.2	8.2	72.22

Contd...

Table 23 contd...

15	15.2	7.8	367	43.5	0.88	20.7	10.7	6.3	8.9	110.55
16	14.2	7.7	332	43.8	0.80	20.8	11.1	5.6	8.6	96.91
17	13.7	7.7	301.3	37.2	0.93	21.3	12.0	6.9	8.5	74.28
18	14.9	7.5	348.7	42.7	0.89	19.5	11.0	6.6	9.0	104.46
19	16.7	8.1	418.0	38.3	1.18	22.3	12.8	7.1	9.1	120.49
20	14.9	6.8	286.0	39.3	0.87	18.9	10.6	6.3	7.2	98.93
21	15.0	7.7	395.3	43.2	1.02	21.5	12.1	6.6	9.0	126.7
22	16.3	7.5	334.9	40.7	0.76	18.9	7.6	6.2	8.8	85.47
23	16.0	6.7	301.9	39.7	0.79	19.8	9.9	6.4	8.4	99.57
24	14.3	7.2	316.1	42.1	0.78	19.7	10.4	6.0	7.5	105.43
25	12.9	7.1	270.1	40.0	0.66	18.0	9.4	5.6	8.7	83.26
26	15.0	7.7	339.0	43.0	0.78	19.6	10.8	6.3	8.3	99.39
27	14.4	7.8	332.9	43.2	0.75	18.9	9.6	5.7	9.6	91.24
28	14.1	6.9	298.6	45.8	0.66	17.3	9.9	5.7	9.3	92.38
29	16.0	7.6	367.6	37.4	0.95	21.0	11.7	6.7	9.9	99.63

4.12.2 Pod width

Range of width of pods was from 5.5 cm observed in the plants number 19.20 of H-6 to 12.5 cm in plant number 19.7 of H-19 as well as plant number 13.16 of H-12. A maximum pod width of 10.1 cm was noticed in H-13 and minimum was for the hybrid H-23.

4.12.3 Pod weight

Weight of single pod varied from 145 g in plant number 5.20 of H-12 to 771 g in plant number 19.7 of H-19. The hybrid H-19 recorded a highest average pod weight of 418 gms. The hybrid H-25 reported the minimum weight of pods (270 gms).

4.12.4 Number of beans

Number of beans within a pod ranged from 18-57. Highest number was observed in plant number 19.15 of H-18 and the lowest number in plants number 19-20 of H-6. Average number of beans computed for hybrids was maximum for H-8 (46.2) and the minimum, in H-1 (35.5).

4.12.5 Pericarp thickness

Pericarp thickness at ridge, ranged from 6 mm in plant number 5.13 of H-1 to 15 mm in plant number 17.11 of hybrid H-7. In furrow, thickness varied from 4 cm in plant number 5.13 of H-1 to 11.8 mm in the plant number 14.11 of H-17. The average pericarp thickness was high for the hybrid H-12. The lowest value of pericarp thickness, 7.2 mm was noticed in hybrid H-20.

4.12.6 Wet bean weight

The character exhibited a wide range of 25 gm in plant number 5.20 of H-12 to 219.3 gm in plant number 9.17 of H-19. The maximum value of average wet bean yield was recorded for the hybrids.H-21 and lowest was noticed in H-14.

4.12.7 Seed length

The range of seed length was from 13.8 cm in plant number 5.8 of H-10 to 28.5 cm in plant number 19.7 of H-19. The average seed length was also high for the hybrid H-19 (22.3 mm) where as the lowest value recorded in hybrid H-28 (17.3 mm) and H-14 (17.4 mm).

4.12.8 Seed width

The character exhibited a range of 5.8 mm in plant number 5.8 of H-10 to 15.8 mm in plant number 18.20 of H-17. The hybrid, H-19 reported a maximum seed width of 12.8 mm and the lowest observation on average seed width was for the hybrid H-22.

4.12.9 Seed thickness

Seed thickness measured in mm varied from 2.8 in plant number 5.8 of H-10 to 9.8 mm in plant number 16.20 of hybrid, H-3. Average seed thickness was maximum for the hybrids H-19 and H-3 and minimum in hybrid H-8.

4.12.10 Seed dry weight

Dry weight of single seed was calculated for each plant. It ranged from 0.505 g in plant number 21.13 of H-1 to 1.89 g in plant number 19.7 of H-19.

Average seed weight was high for the hybrid H-12 (1.83 gm). The lowest value of 0.66 g was observed in H-25 and H-28.

4.13 Pod and bean characters of parents

The mean of pod and bean characters of 18 parents grown under comparative yield trial was worked out and given in Table 24. The parent GII 20.4 showed highest length width and weight of pods (17.9 cm, 8.2 cm and 521.5 g respectively). Pod length was lowest for the parent M 13.12 (11.8 cm). The clone GI 9.6 recorded a minimum pod width of 6.5 cm as with M 9.16 and GVI 61. The lowest pod weight of 242.8 g was recorded in GI 5.9. Number of bean per pod was maximum in parent GVI 55 (50.5 nos) and the minimum bean number of 20.3 were recorded for the clone GVI 59. But that clone showed a high seed dry weight of 1.5 g and the hybrid GI 5.9 and M 13.12 exhibited the lowest (0.5 g). Seed length, seed width and seed thickness were maximum for GVI 59. A minimum of 17.2 mm in seed length was noticed in parent GI 4.8 and M 13.12. Seed width was minimum for M 16.9. The lowest mean value of seed thickness was recorded in GVI 68. Pericarp thickness was found to be highest for GII 20.4 and lowest for GI 9.6. The parent GVI 51 exhibited a maximum value of wet bean weight/pod (138.1 g) and the lowest wet bean yield was noticed for the clone M 9.16 (56.5 g).

4.14 Correlation of pod and bean characters of hybrids with those of parents

The pod and bean characters such as pod length, pod width, pod weight, bean number, dry weight of seeds, seed length, seed thickness, seed width, pericarp

Table 24 Mean of pod characters in 18 parents of cocoa

Sl. No.	Parent	Pod length (cm)	Pod width (cm)	Pod weight (g)	Bean No.	Seed dry weight (mg)	Seed length (mm)	Seed width (mm)	Seed thickness (mm)	Pericarp thickness (mm)	Wet bean weight (g)
1	GII 20.4	17.9	8.2	521.5	39.1	1.1	20.6	11.9	7.6	14.2	133.2
2	M 9.16	15.3	6.5	285.3	22.8	0.9	20.4	11.2	7.7	11.3	56.5
3	M 16.9	16.5	7.4	384.9	42.5	0.8	19.0	9.5	5.8	11.6	91.8
4	GII 19.5	15.4	7.7	402.1	36.2	1.1	20.1	11.0	7.9	10.5	126.2
5	GI 10.3	14.2	7.3	300.0	42.5	0.7	17.6	10.4	6.0	9.8	87.2
6	GVI 54	13.1	7.3	307.7	34.9	0.9	22.7	11.7	6.1	10.7	89.7
7	GVI 56	15.1	7.0	364.0	45.9	0.7	19.2	11.0	6.6	11.1	113.7
8	GVI 61	16.7	6.5	292.6	42.0	0.8	18.5	10.6	6.9	9.4	100.3
9	GI 5.9	13.1	7.0	240.6	40.8	0.5	18.3	9.6	6.1	8.1	83.2
10	GVI 55	14.4	7.6	362.5	50.5	0.7	21.0	10.6	5.7	9.6	120.8
11	GI 4.8	14.9	6.7	250.9	41.1	0.7	17.2	10.3	6.2	8.7	93.7
12	GI 15.5	12.1	7.2	281.5	41.8	0.9	20.9	11.3	5.7	9.7	83.3
13	M 13.12	11.8	7.0	254.0	34.7	0.5	17.2	10.8	6.3	10.2	61.0
14	GVI 59	15.6	6.9	297.4	20.3	1.5	25.4	14.7	11.0	7.8	77.1
15	GVI 68	15.0	7.0	343.5	43.9	0.8	19.5	9.9	5.5	12.3	110.3
16	GVI 51	17.3	7.8	407.5	36.3	1.4	25.2	14.1	9.1	9.6	138.1
17	GVI 64	12.7	6.8	304.1	41.9	0.7	20.8	11.2	6.0	11.8	92.5
18	GI 9.6	12.9	6.5	242.9	39.8	0.9	20.5	12.4	7.1	7.1	97.4

thickness and wet bean weights were recorded for both parents and hybrids and they were used for analysis. Since the number of plants constituting each treatment is different in both hybrids and parents treatment means were taken and the relationship worked out using simple correlation coefficients.

4.15 Characters of hybrid Vs. mid parental value

The parent GVI 126 which was used as male parent in H-22 and H-23 was not grown in comparative yield trial of parents. Therefore 27 hybrids and their mid-parental value were analysed to see the extent of association of pod and bean characters.

Among the pod characters studied, pod length and number of beans showed highly significant positive correlations. The coefficient `r' worked is, highly significant at 1 per cent level (r = 0.653 and 0.86 respectively). Pod weight had a correlation coefficient of 0.446 which was significant at 5 per cent level. The other pod characters such as pod width, pericarp thickness and wet bean weight did not have significant relationship between hybrids and mid parent (Table 25). Measurements on length, width and thickness of seeds exhibited significant association between parents and mid parental value (r = 0.704, 0.762 and 0.703 respectively) at 1 per cent level.

4.16 Characters of hybrid vs. characters of female parents

The pod and bean characters recorded for female parents were correlated with the averages of hybrids involving that parent and are presented in Table 26. The

Table 25 Correlation of characters of hybrids with that of mid-parental value

Sl. No.	Character selected	Correlation coefficient (r)
1	Pod length	0.653**
2	Pod width	0.360
3	Pod weight	0.446*
4	Bean number	0.860**
5	Dry weight of seeds	0.338
6	Seed length	0.704**
7	Seed width	0.762**
8	Seed thickness	0.703**
9	Pericarp thickness	0.326
10	Wet bean weight	0.319

Table 26 Correlation of characters of hybrids vs. those of female parent

Sl. No.	Character selected	Correlation coefficient (r)
1	Pod length	0.649*
2	Pod width	0.108
3	Pod weight	0.373
4	Bean number	0.606*
5	Dry weight of seeds	0.238
6	Seed length	0.501
7	Seed width	0.380
8	Seed thickness	0.130
9	Pericarp thickness	0.083
10	Wet bean weight	0.130

characters pod length and number of beans showed a significant positive (at 5 per cent level) relationship between female parent and their hybrids (r = 0.649 and 0.606 respectively). The remaining characters did not show any significant correlation between female parents and hybrids.

4.17 Heritability of pod and bean characters

Regression coefficient of offspring on midparents gives the narrow sense heritability of that character. Heritability estimates the extent of transmissibility of the character. Table 27 gives the estimate of heritability for 10 pod and bean characters. Maximum heritability was noticed for the characters pod width and seed width (h^2 = 0.7 and 0.78 respectively). The number of bean (h^2 = 0.57) and length of seed (h^2 = 0.64) had fairly good heritability estimates. The characters pod weight, dry weight of seeds and seed thickness exhibited medium heritability. The heritability in narrow sense was found to be low for the character pericarp thickness and wet bean weight of pods (estimates were 0.20 and 0.18 respectively).

4.18 Influence of pod and bean characters of parents on yield of hybrids

Simple correlation analysis was conducted to study the influence of pod and bean characters of female and male parent on hybrid yield. The correlation coefficients computed are given in Table 28. None of the characters studied showed significant influence on wet bean yield of hybrids.

Influence of male parent on hybrid yield through pod and bean characters were computed by taking the average of yield of hybrids having male parent in common.

Table 27 Heritability of some pod and bean characters

Sl. No.	Character selected	Heritability h^2
1	Pod length	0.49
2	Pod width	0.70
3	Pod weight	0.40
4	Bean number	0.57
5	Dry weight of seeds	0.48
6	Seed length	0.64
7	Seed width	0.78
8	Seed thickness	0.42
9	Pericarp thickness	0.20
10	Wet bean weight	0.18

Table 28 Correlation coefficients of pod and bean characters of male parent and female parent with wet bean yield of hybrids

Sl. No.	Character	Male parent	Female parent
1	Pod length	0.089	-0.381
2	Pod width	0.183	0.311
3	Pod weight	0.303	0.363
4	Bean number	0.482	0.315
5	Dry weight of seeds	-0.456	0.412
6	Seed length	-0.331	0.441
7	Seed width	-0.433	0.573
8	Seed thickness	-0.549	0.211
9	Pericarp thickness	0.441	-0.178
10	Wet bean weight	0.312	0.570

A total of 12 male parents were used for the hybridisation purpose,but since the data on GVI-126 was not available, correlation coefficient estimated the influence of 11 male parents on 27 hybrids of cocoa. But none of the pod and bean characters were found to be significant.

Since simple correlations estimated using the values of both male and female parents were not significant with any of the characters studied, multiple regression analysis were not carried out.

To see whether there is some influence of female parent on yield of hybrids, analysis of variance of pod yield and wet bean yield were carried out by taking mean of the average value of hybrids produced out of them against each female parent. The average values of cumulative wet bean yield and average pod yield of hybrids belonging to various female parents are presented in Table 29.

There was significant difference among the female parents with regard to pod yield and wet bean weight of hybrids (Table 30 and 31). In other words female parents do influence pod and bean yield of hybrids.

4.19 Prediction models for yield

With the seedling characters significantly related to yield, prediction models were prepared for both pod and wet bean yield using multiple regression analysis. Since relationship of seedling characters at two nursery stages (4 mas and 6 mas) with yield was not significant, they were not used in formulating prediction model. With the seedling characters taken 5 mas, multiple regression analysis conducted resulted in a non-significant F-value eventhough they showed significant simple correlations

Table 29 Mean value of cumulative wet bean yield and average pod yield for four years of hybrid having common female parent

Sl. No.	Female parent	Cumulative wet bean yield (g)	Average pod yield (No)
1	GII 20.4	8378	22.41
2	GII 19.5	9701	19.87
3	M 16.9	9961	23.33
4	GI 10.3	9394	24.57
5	GI 4.9	9392	22.50
6	GI 4.8	8142	20.34
7	GI 15.5	6749	16.26
8	M 73.12	7539	25.25
9	GVI 51	5491	15.17
10	GI 9.6	9974	21.55

Table 30 ANOVA-I for the cumulative wet bean yield of hybrids having common female parent

	Df	SS	MS	F
Between	10	508107233	50810723	
Within	331	722676028		2.327
Total	341	7734883261	21833160	

Table 31 ANOVA-I for average pod yield of hybrids having common female parent

	Df	SS	MS	F
Between	10	2770	277	2.218
Within	331	41346	124.92	
Total	341	4416		

The seedling observations taken one year after sowing expressed a highly significant relationship with pod yield. The formula derived for obtaining pod yield from height and diameter of one year old seedlings is as follows.

$$Y = 2.20 + 0.001x_1 + 0.157x_2$$

Where, Y = Pod yield

x_1 = Height of one year old seedlings

x_2 = Diameter of one year old seedlings

With the wet bean yield, the prediction model evolved is as follows:

$$Y = 43 + 0.195x_1 + 3.70x_2$$

Where, Y = wet bean yield of a tree

x_1 = Height of one year old seedlings

x_2 = Diameter of one year old seedlings

The yield can be maximised by selecting seedlings according to the equations mentioned.

Using the parental characters correlated with pod and wet bean yield of the hybrid, it was tried to formulate a prediction model for stabilized yield of hybrids. But simple correlations estimated using the values of both male and female parents were not significant with any of the characters studied. Therefore prediction model using parental characters could not be evolved.

Discussion

5. DISCUSSION

Cocoa, *Theobroma cacao* L. is an often cross pollinated species and the built in heterozygosity of the crop is high. Seedling populations therefore show a very high degree of variability in nearly all the characters including yield. The extent of variability is so high that, in a population, about 75 per cent of the yield often is recovered from about 25 per cent of the population. Such a variability also makes it difficult to rely only on the combining ability of parents as the criteria for selection. Selection at the seedling stage assumes importance as it will aid in further improvement of the quality of selected material in achieving the expected crop performance.

All crop improvement programmes need access to a stock of genetic variability which must be substantial. An insight into the magnitude of variability present in a crop species is of utmost importance as it provides the basis for effective selection for direct utilization in further genetic improvement. In perennial crops, association of characters at seedling stage and yield is of great value as the pre-bearing period is very long. Once the relationship between seedling characters with crop performance could be established, they can be used as markers/key characters indicative of final yield. This provides the breeder with reliable tools in early selection for better crop performance based on seedling characters.

The result obtained from the present investigations are discussed here in the light of available literature pertinent to cocoa and similar perennial crops.

5.1 Correlation of seedling characters with yield

Heterozygous nature of cocoa contribute to the heterogeneity of hybrid population. Variation in characters of seedling population is high which makes the selection at seedling stage inevitable for crop improvement.

Precocious varieties are of greater importance because they can attribute effectively to a faster recovery of the capital invested in perennials. The vegetative vigour measured by the diameter of the trunk was found to be correlated with precocity (Visser, 1964). In many commercially cultivated perennial trees, girth, number of leaves and height were taken as criteria for selecting superior hybrids.

Dhaliwal (1968) observed that yield was positively and significantly correlated with the circumference of the main stem at ground level in *Coffea arabica*. Yield also showed positive and significant correlation with height of the tree. Girth of the trunk indicate the general vigour of the tree and tree vigour is considered as a criteria for yield in many trees as reported by Teotia *et al.* (1970) who correlated tree vigour to yield in mango. The trunk diameter was used for ranking of clones grown in cocoa collection (Allen, 1986). Glendinning (1960) noted that the relationship between growth and yield in cocoa was positively correlated with trunk diameter during early stages of crop growth.

The present study also reveals the influence of these characters on wet bean yield of cocoa. The height of the seedlings showed significant positive relationship with yield when the observations were taken one year after sowing (Table 11). The correlation tend to be decreasing with increasing age of seedlings as expressed by the `r' value computed to be 0.133, 0.07 and 0.016 with the seedling observations taken 4 mas, 5 mas and 6 mas respectively. But a highly significant influence was noticed with the height observations taken from 1 year old seedlings ($r = 0.251$, $p = 0.001$). The regression coefficient $b = 0.299$ denotes that 0.299 unit increase in height of the seedlings resulted in one unit increase in wet bean yield.

Correlation coefficient of wet bean yield with observations on stem diameter exhibited an increasing trend with age of the seedlings, `r' estimated between wet bean yield and seedling diameter 4 mas, 5 mas and 6 mas and 1 year after sowing were found to be 0.036, 0.101, 0.119 and 0.313 respectively (Table 12). A similar study undertaken by Manoj (1992) in cashew showed a highly significant positive correlation of yield with girth of the tree ($r = 0.54$) and height of the tree (0.26).

Ascenco (1960) speculated that height measurements taken from 6 months to jorquetting upto jorquetting might form a good criterion of potential yield of a cocoa cultivar.

The relationship between seedling characters and pod yield was found to be more or less same as that with wet bean weight. But the correlation of diameter during 5 mas with pod yield was found to be significant which was not significant

with the wet bean yield (Table 15). The difference can be attributed to the high correlation exhibited by diameter with pod yield during 92-93.

The relationship was found to be significant with the observations of one year old seedlings. This is in conformity with the findings of Cilas *et al.* (1988) which established a significantly positive GCA for growth of collar diameter between 7 and 14 months after planting.

Soria and Esquivel (1970) concluded that correlation between trunk diameter and yield increases with age of the plant and concluded that highest correlation between trunk diameter and production occurs between second and third year of age. They demonstrated precocity to be dependent on the rhythm of growth of cocoa tree.

The general trend noticed in the relationship of seedling characters with yearly yield data is that with increase in age of bearing the relationship with seedling characters tend to be decreased. For example, the correlation coefficients of seedling height one year after sowing with wet bean yield during 92-93, 93-94, 94-95 and 95-96 were 0.332, 0.230, 0.151 and 0.061 respectively (Table 11). This is in accordance with the finding of Visser (1964) who demonstrated that vegetative vigour measured by the diameter of the trunk was correlated with precocity in αφρικα. It is evident from the present study too. This information will be of greater predictive value if the precocious cultivar of high productive value continue to be the better yielders for many successive years. However Bartley (1967) warns about the possibility of lack of such correlation because of the skewed distribution of production

in early ages. Soria and Esquivel (1968) also found out nonsignificant correlation after a period of five years of fruiting.

The hybrid H-1 which recorded maximum value of height and diameter during seedling stages, exhibited the highest pod and wet bean yield during second year of bearing, ie. in the first year of observation. The hybrid produced an average pod yield of 26.83 (Table 5) and an average wet bean yield of 2467 g during 92.93 (Table 8). But the average yield of four years estimated express the superiority of hybrids H-4 and H-10 in yield to the hybrid H-1.

The hybrid H-12 having a minimum value of seedling height and girth observations produced only 8.33 pods during 92-93 (Average value). This was the lowest among the 20 hybrids for which nursery observations were analysed. But the lowest yield during 1992-93 was made up with increase in age of bearing and the average yield of hybrid H-12 was found to be comparable with a number of hybrids included in the study.

The effectiveness of selection depends on the extent of variability of character studied. The variability of seedling characters height and diameter among the hybrid population were estimated to be low as expressed by the coefficient of variation, less than 20 (Table 3 and Table 4). The low variability can be due to selection carried out during planting among the hybrids for seedling vigour. Only those hybrids, which were proved to be superior in terms of seedling vigour were allowed to be planted. Low variability affects the selection for a particular character, which reflects

in the genetic correlation. The low correlation coefficients recorded between seedling characters and yield could be due to lack of substantial variability.

When a selection is applied to the improvement of the economical value of plants, it is generally applied to several characters simultaneously and not just to one, because economic value depends on more than one character. Multiple regression analysis has been used in many crops for formulating selection index. Anand and Torrie (1963) reported multiple regression analysis method for predicting the yield in soyabean.

Multiple regression analysis as suggested by Goulden (1952) has been used for finding out the joint influence of height, diameter and HD^2 of seedlings on yield. Analysis of variance conducted with height, diameter and HD^2 of one year old seedlings resulted in a significant F value. But the regression coefficients estimated for the characters were found to be significant only with the height of seedlings (Table 19).

But when regression analysis with height and diameter of seedlings alone was done, the variability was found to have better influence on yield, as indicated by the high F value (F = 3.01) which is highly significant. Regression coefficients of both characters were found to be significant at 1 per cent level.

A multiple regression fitted with these characters was

$Y = 2.20 + 0.001\ x_1 + 0.157\ x_2 \quad R^2 = 0.099$

Where, Y represents pod yield of cocoa

x_1 = the variable height one year after sowing and

x_2 = the variable diameter of one year old seedlings

The multiple regression equation of height and diameter of one year old seedlings on wet bean yield is formulated as

$$Y = 43 + 0.195\ x_1 + 3.70\ x_2 \qquad R^2 = 0.099$$

Here x_1 denotes height and x_2 diameter observed on one year old seedlings. Y represents the wet bean yield of hybrids.

The coefficient of determination was found to be 0.099 in both cases, which estimates low predictability of the regression. The low predictability can be explained by the low amount of variability of the character in seedling population (Table 2,3).

5.2 Correlation of pod and bean characters between parents and hybrids

The correlation of pod and bean characters between parents and hybrids gives a measure of transmissibility of those characters. The correlation coefficient gives the index of degree of linear relationship between two continuous variables. Taking the pod and bean characters of hybrids and female parents as two continuous variables, correlation coefficients estimated had higher value only in case of pod length and number of beans ($r = 0.649$ and 0.604 respectively). All other characters did not show any significant relationship.

The correlation of characters of hybrids with mid parental value was found to be more meaningful. The pod characters, length and weight of pods, and number of

beans found to exhibit a high `r' value (r = 0.653, 0.450 and 0.86 respectively). The characters, pericarp thickness, wet bean weight, and pod width were found to have no significant relationship between hybrids and mid parents. Seed observations namely length, width and thickness of seeds were found to have high correlation between mid parental value and hybrid value. Seed dry weight of mid parent did not have any influence on seed dry weight of hybrids (Table 25).

5.3 Heritability of pod and bean characters

Heritability estimates the proportion of total variance that is attributable to the average effect of genes and it determines the degree of resemblance between relatives. The estimate has a predictive role in the genetic study, expressing the reliability of phenotypic value as a guide to the breeding value.

Heritability values do change markedly with age, environmental changes, the type of data and the statistical approach (Nam Koong *et al.*, 1972; Lopez *et al.*, 1988). Variation in the heritability estimates of cocoa has been reported by Soria *et al.* (1974).

After an elaborate study on heritability in perennial crops (Zobel and Talbert, 1984) concluded that since heritability values are not estimated without error, the ratio obtained are only a relative indication of genetic control under a given condition and should not be interpreted as absolute invariable values.

In the present study, heritability was estimated by regressing offspring on female parent. The heritability estimated for pod length and pod weight were

49 per cent and 40 per cent respectively (Table 27). The moderate heritability of these characters were in conformity with the heritability values established by Soria *et al.* (1974). He estimated a heritability of 63 per cent and 67 per cent for these characters.

Kumaran and Presannakumari (1981) reported that the heritability of character wet bean weight was high. It was also reported by Cilas *et al.* (1985) as against the low heritability value for the character obtained in the present study (Table 27).

The number of ovules per ovary which ultimately contributes to the number of beans per pod had 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 the reason for heritability of that character. In the present study, the heritability for bean number was estimated to be 57 per cent.

Moderately high heritability has been estimated by many researchers for pod characters. 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. The present observation was in confirmity with these reports.

The measurements of seed length and seed width were found to show high heritability estimates (0.64 and 0.78) where as seed thickness and dry weight showed moderate values. Glendinning (1963) also reported similar values for heritability of these characters.

The heritability of pericarp thickness was found to be low ($h^2 = 0.2$) indicating that it was more influenced by environment. Enriquez and Soria (1966) have also made in observation to this effect. This is further supported by the study of Ramirez and Enriques (1987) observed low heritability for pod husk thickness.

5.4 Influence of pod and bean characters of parent on yield of hybrids

In perennial crops mother tree selection is as important as seedling selection. The ability of a mother tree to transmit its desirable characters to the progeny is termed as prepotency. In perennials, the selection of prepotent mother tree is an important step in crop improvement.

The heritability of pod and bean characters estimated the degree of resemblance of parents and hybrids to access their relationship with yield of hybrids. Simple correlation analysis was worked out. With the heritable characters, highly correlated with yield, the intention was to formulate a selection index which gives a clue to selection of parents.

None of the pod and bean characters of female parents were found to be significantly correlated with yield of hybrids (Table 28).

The low relationship of pod and bean characters exhibited are 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. Cheriyan (1993) in his research work in cocoa, found that dry bean weight, number of beans per pod, pod length, pod width and seed width have very

low positive direct effect on yield. Pod weight, seed length and seed thickness exhibited low degree of negative effect on yield of cocoa. In the present study negative correlations was exhibited for the characters pericarp thickness and pod length.

The low correlation estimated between yield and pod and bean characters along with low to medium heritability of character contribute to low relationship of pod and bean characters of parents with wet bean yield of cocoa hybrids.

Influence of male parent on physical and chemical characters of F_1 seed was noticed by Pereira *et al.* (1969). His study on cocoa clones in a complete diallele system revealed that fresh seed weight, fresh kernel weight, dry kernel weight, whole pod weight, husk weight and total seed weight per pod were not affected by pollen source, indicating that these traits can be evaluated on fruit from open pollination. But the character, number of seeds per pod was found to be significantly affected by male parent. The present study also established lack of influence of male parent on pod and bean characters of cocoa (Table 29).

Multiple regression equation is formulated with characters which are highly and significantly correlated with dependent variable. Since none of the correlation between pod and bean characters and parents and yield of hybrids were found to be significant, multiple regression analysis to formulate a selection index with parental characters was not attempted. However Thamburaj (1973) made multiple regression analysis in ridge gourd and reported that the pod weight and number of seeds per pod had a significant positive effect on yield per plant.

Analysis of variance conducted by taking average of hybrids having common female parent against the respective female parent resulted in a significant F value (Table 31,32). This lead to the conclusion that female parents have some influence on performance of hybrids. But the F value computed was very low and was significant only at 5 per cent level.

Based on pod and wet bean yield, ranking of hybrids have been done. Dunkan's Multiple Range Test (Duncan, 1955) was used to express the difference among hybrids. It is found that hybrid H-4 is superior to all other hybrids. It produced a mean wet bean yield of 2955 g. The yield is far superior to either of the parents or mid parental value (Table 34). This finding is an example of heterotic vigour as proved by Poinsette (1943) and Mostererin *et al.* (1957). The hybrid H-4 is established as a superior hybrid and can be recommended for commercial cultivation. The yield of hybrid H-4 is for superior to its parents (Plates 1, 2 and 3).

Also the yield of hybrids was very high compared to the yield of parents grown in same locality during the same period (Table 32, 33,34). Both wet bean yield and pod yield of parents were not comparable with that of hybrids. This illustrates ample scope for hybridisation and selection, including utilization of heterosis in cocoa. Ranking of hybrids based on pod and wet bean yield is illustrated in Fig.1 and 2.

Plate 1 Hybrid H-4

Plate 2 Parent GI 10.3

Plate 3 Parent GVI 54

Table 32 Ranking of hybrids based on wet bean yield of tree

Rank No.	Hybrid No.	Mean wet bean yield crop (g)	
1	4	2955	A
2	8	2945	AB
3	5	2800	ABC
4	10	2695	ABCD
5	20	2680	ABCD
6	1	2515	ABCDE
7	21	2492	ABCDE
8	3	2490	ABCDE
9	15	2425	ABCDEF
10	19	2425	ABCDEF
11	24	2389	ABCDEF
12	18	2378	ABVDEF
13	6	2355	ABCDEF
14	9	2340	ABCDEF
15	4	2217	ABCDEFG
16	23	2186	ABCDEFG
17	12	2180	ABCDEFG
18	7	2051	BCDEFG
19	13	2029	BCDEFG
20	25	1949	CDEFG
21	16	1899	CDEFGH
22	14	1885	CDEFGH
23	29	1857	DEFGH
24	26	1821	DEFGH
25	27	1806	DEFGH
26	2	1674	CFGH
27	Bulk	1516	FGHI
28	22	1373	GHI
29	28	1025	HI
30	17	641	I

Table 33 Ranking of hybrids based on pod yield of tree

Rank No.	Hybrid No.	Mean pod yield (No.)	
1	4	33.17	A
2	10	27.73	AB
3	1	27.29	AB
4	20	26.85	ABC
5	6	26.40	ABCD
6	5	26.23	ABCD
7	14	25.25	ABCDE
8	8	24.46	BCDE
9	9	23.63	BCDEF
10	3	23.33	BCDEF
11	25	22.98	BCDEF
12	11	22.15	BCDEF
13	13	22.08	BCDEF
14	7	21.56	BCDEF
15	23	21.21	BCDEF
16	18	20.85	BCDEF
17	19	19.94	BCDEF
18	24	19.94	BCDEF
19	15	19.88	BCDEF
20	27	19.79	BCDEF
21	16	19.19	BCDEF
22	21	18.56	CDEF
23	29	17.85	DEFG
24	2	17.52	EFG
25	12	17.33	EFG
26	26	16.77	EFG
27	Bulk	15.54	FG
28	22	15.17	FG
29	28	9.3	GH
30	17	6.44	H

Table 34 Pod yield and wet bean yield of 18 parents used for the study

Rank No.	Hybrid No.	Mean pod yield (No.)	
1	20.4	16.14	2150
2	9.16	23.99	1355
3	16.9	15.53	1425
4	19.5	11.68	1474
5	10.3	7.36	642
6	54.0	10.82	971
7	56.0	10.32	1173
8	61.0	10.28	1031
9	5.9	17.88	1488
10	55.0	3.47	419
11	4.8	10.93	1018
12	15.5	14.49	1207
13	13.12	9.30	567
14	59.0	11.06	853
15	68.0	11.22	1238
16	51.0	6.73	929
17	64.0	7.26	672
18	9.6	8.90	867

Fig.1 Average pod yield of hybrids

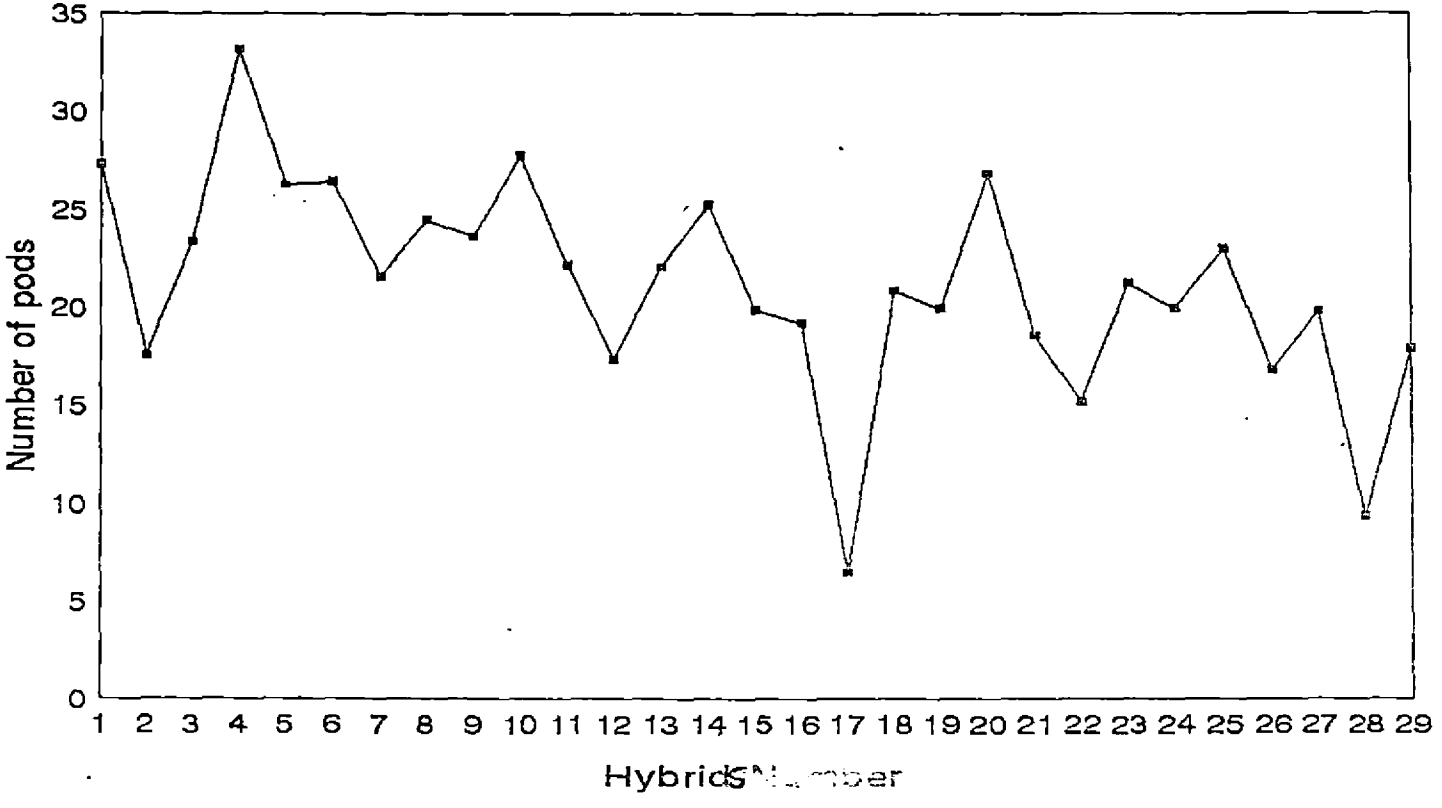
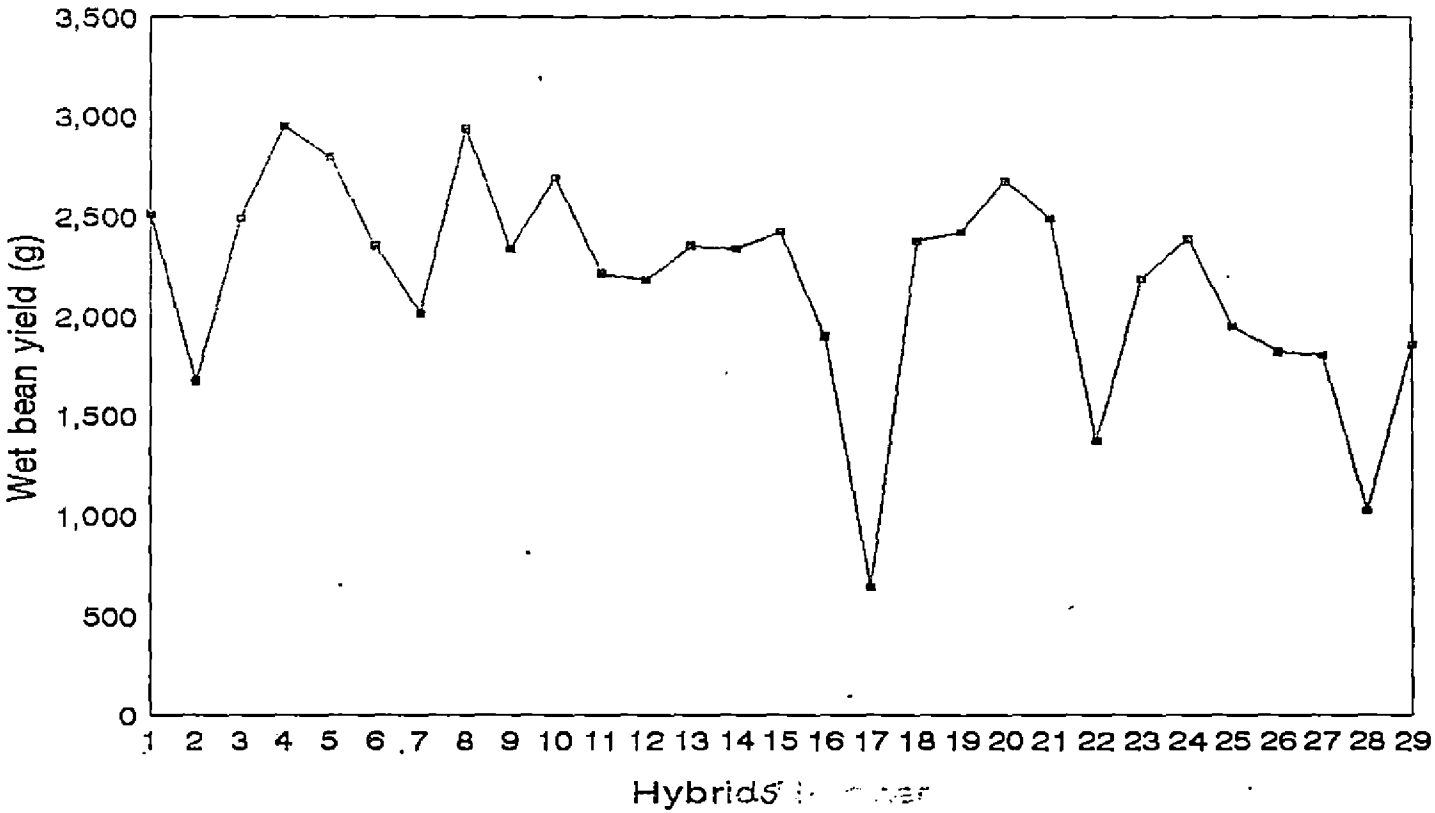


Fig.2 Average wet bean yield of hybrids



5.5 Prediction of yield

Using seedling and parental characters significantly correlated with pod and wet bean yield, separate prediction models were tried to formulate for stabilized yield. The relationship between seedling characters and yield showed a decreasing trend with the increase in age of bearing. This is in accordance with the findings of Soria and Esquivel (1970). Since the correlations were not significantly high after a period of five years of general fruiting, they suggested that cumulative pod yield from second to fifth year of general fruiting suffices for predicting the yield potential of a cultivar. The correlations worked out between cumulative yield for four years and the seedling traits were found to be significant with one year old seedlings. Multiple regression analysis carried out with pod yield resulted in the equation.

$$Y = 2.20 + 0.001x_1 + 0.157x_2$$

Where, x_1 denotes the variable height and x_2 diameter of seedlings both taken one year after sowing.

The pulp production of a tree over a certain period can be established by multiplying the number of pods harvested in that period with the average weight of their wet seed volume.

Thus taking wet bean yield as dependent variable, the equation obtained was

$$Y = 43 + 0.195x_1 + 3.70x_2$$

Where, x_1 and x_2 are height and girth of one year old seedlings respectively.

Hence by selecting seedlings having height and diameter which maximise the yield as per the equation, the production in long run can be ensured.

Summary

6. SUMMARY

Investigation on standardisation of selection criteria for cocoa hybrids was undertaken at Cadbury-KAU Co-operative Cocoa Research Project (CCRP) farm of Kerala Agricultural University, Vellanikkara during 1994-96. The study was based on 29 hybrids grown under progeny trial I and their 18 parents maintained under comparative yield trial I. Seedling observations of hybrids taken at 4 mas, 5 mas, 6 mas and one year after sowing and pod and wet bean yield of hybrids and parents for four years from 1992-93 to 1995-96 were used for obtaining seedling selection criteria. Moreover genetic components such as correlation between parents and hybrids and heritability were estimated.

Considerable variability was noted for the characters viz. pod yield and wet bean yield in hybrids. However, the variability of seedling height and diameter among the hybrid populations was estimated to be low. The low variability can be due to selection carried out during planting for seedling vigour.

From the present study, the influence of seedling characters on yield can be summarised as follows.

1. The influence of seedling characters on yield is more pronounced with observations of one year old seedlings compared to nursery observations.

2. The yield improvement can be facilitated to a certain extent by removing undesirable genotypes having poor height and diameter during first year of field planting.

3. The relationship between seedling characters and yield hold good during early stages of bearing. With increase in age of bearing the relationship tend to be decreasing.

4. The vegetative vigour measured by the height and diameter of trunk was found to be correlated with precocity.

The result of correlation and heritability studies is summarised below.

1. The correlation coefficients worked out between hybrids and female parents showed significant relationship only in the case of pod length and number of beans.

2. With the midparental value, the hybrids showed high correlation for the characters like length and weight of pods, number of beans and length, width, and thickness of seeds.

3. Heritability estimated by regressing offspring on female parent was found to be high for the character pod width, seed length and seed width. The characters length and weight of pods, bean number and thickness of seed showed moderate heritability. Low heritability was estimated for the characters wet bean weight and pericarp thickness.

4. None of the pod and bean characters of female and male parents were found to be significantly correlated with yield of hybrids.

5. The yield of hybrids was found to be exceptionally high compared to the yield of parents and mid parental values which illustrates importance of hybridisation and selection.

6. Among the hybrids studied, H-4 is found to be the most promising hybrid which can be recommended for commercial cultivation.

With the characters significantly correlated with yield, prediction models for stabilized yield was prepared. With the seedling characters taken for one year old seedlings a multiple regression equation for wet bean yield was fitted as:

$$Y = 43 + 0.195\ x_1 + 3.70\ x_2$$

Where x_1 and x_2 are seedling height and diameter of one year old seedlings.

This can be utilized as a criteria for selection of seedling with high crop performance which become a better indicative of final yield.

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Appendices

APPENDIX I

Mean HD^2 of hybrids seedlings at 4 stages of growth

Hybrid No.	HD^2 Four months after sowing	HD^2 Five months after sowing	HD^2 Six months after sowing	HD^2 One year after sowing
1	3181	5470	7534	9553
2	1519	2777	4730	7693
3	2281	3737	6684	7215
4	1276	2630	3949	8359
5	1584	2770	4598	8456
6	1900	3523	5488	6722
7	1973	3660	5650	10124
8	1148	2095	2940	9912
9	944	1633	1980	5438
10	1713	2894	4576	5180
11	947	1633	2793	7669
12	711	1216	1971	4647
13	1140	2185	3253	5779
14	753	1623	2601	7220
15	1337	2652	4244	7670
16	2715	4497	6340	6372
18	1854	2706	4395	6440
19	1775	3119	4389	7655
20	1783	2943	4882	7352
21	1182	1995	3068	7119

APPENDIX II

Mid parental value of pod and bean characters of 27 hybrids

Hybrid No.	Pod length (cm)	Pod width (cm)	Pod weight (g)	Bean Number	Dry weight (g)	Seed length (mm)	Seed width (mm)	Seed thickness (mm)	Pericarp thickness	Wet bean weight (gm)
1	16.60	7.35	403.40	30.95	1.00	20.50	11.55	7.65	12.75	94.85
2	17.10	7.80	453.10	40.80	0.95	19.80	10.77	6.70	12.90	112.50
3	15.85	7.55	393.40	39.35	0.95	19.55	10.25	6.85	12.05	109.00
4	13.65	7.30	303.80	38.70	0.80	20.15	11.05	6.05	10.25	88.45
5	14.65	7.15	332.00	44.20	0.70	18.40	10.70	6.30	10.45	100.45
6	15.45	6.90	296.30	42.25	0.75	18.05	10.50	6.45	9.60	93.75
7	13.10	7.15	274.10	37.85	0.70	20.50	10.65	6.10	9.40	86.45
8	13.75	7.30	301.50	45.65	0.60	19.65	10.10	5.90	8.85	102.00
9	14.90	6.75	266.60	41.60	0.65	18.40	10.10	6.50	8.75	91.75
10	15.60	7.05	337.80	41.80	0.75	18.10	9.80	6.00	10.15	92.45
11	14.00	7.00	299.50	38.00	0.80	20.15	11.00	6.15	9.70	91.40

Contd...

Appendix II contd.....

12	13.25	7.40	322.00	46.15	0.80	20.95	10.95	5.70	9.65	102.05
13	12.60	7.25	294.60	38.35	0.90	21.70	11.55	5.90	10.30	86.50
14	12.45	7.00	247.30	37.75	0.80	19.20	10.30	6.20	9.15	72.10
15	15.70	7.20	374.30	44.20	0.75	19.10	10.25	6.20	11.30	102.75
16	13.60	7.10	322.70	43.85	0.80	19.95	11.15	6.15	10.40	98.50
17	13.85	7.05	289.50	31.05	1.20	23.05	12.75	8.35	8.75	80.20
18	13.85	6.75	293.20	41.85	0.85	20.00	11.15	6.30	10.70	103.85
19	15.10	7.15	325.20	38.05	1.15	23.00	12.05	8.10	8.35	117.75
20	14.80	6.05	267.90	40.85	0.85	19.05	11.20	7.00	8.25	98.85
21	13.65	7.05	302.70	41.35	0.80	20.80	11.50	6.40	8.35	109.10
24	14.05	7.00	292.00	42.35	0.65	18.90	11.50	6.40	10.2	96.75
25	12.90	6.90	272.30	41.35	0.60	19.65	10.40	6.05	9.95	87.85
26	14.60	7.15	322.70	43.20	0.75	18.55	10.15	5.75	11.05	98.75
27	13.45	7.15	302.00	42.20	0.70	19.20	10.80	6.00	10.80	89.85
28	14.95	6.85	298.50	42.50	0.75	18.35	10.10	5.90	10.50	101.70
29	16.05	7.15	341.00	31.40	1.15	22.20	12.10	8.40	9.70	84.45

APPENDIX III

ANOVA for multiple regression analysis of height, girth and HD^2 of one year old seedling on wet bean yield

	SS	DF	MS	F	Significance
Regression	13930	3	4643.5	8.83	0.00
Error	123557	235	52.8	-	-
Total	137487	238	-	-	-

APPENDIX IV

ANOVA for multiple regression analysis of height and girth of seven years old seedlings on wet bean yield

	SS	DF	MS	F	Significance
Regression	13678	2	6839.4	13.04	0.00
Error	123808	236	524.6	-	-
Total	137487	238	-	-	-

APPENDIX V

ANOVA for multiple regression analysis of height, girth and HD^2 of one year old seedlings on wet bean yield

	SS	DF	MS	F	Significance
Regression	32.90	3	10.97	9.01	0.00
Error	286.17	235	1.21	-	-
Total	319.07	238	-	-	-

APPENDIX VI

ANOVA for multiple regression analysis of height and girth of one year old seedlings on pod yield

	SS	DF	MS	F	Significance
Regression	31.69	2	15.85	13.01	0.00
Error	287.38	236	1.22	-	-
Total	319.07	238	-	-	-

STANDARDISATION OF SELECTION CRITERIA FOR COCOA HYBRIDS

By
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ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
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1998

ABSTRACT

Investigation on standardisation of selection criteria for cocoa hybrids was conducted at Cadbury-KAU Co-operative cocoa Research Project (CCRP) Farm of Kerala Agricultural University, Vellanikkara during 1994-96. Twenty nine hybrids grown under Progeny Trial I and their 18 parents maintained in CYT-I were used for the study.

The influence of seedling height and girth on yield was more pronounced in the case of seedlings one year after sowing than with those of 4 mas, 5 mas and 6 mas. The vegetative vigour measured by the height and diameter of trunk was found to be better correlated with precocity.

The correlation coefficients of pod characters viz., length, width and weight of pods, number of beans, wet bean weight and pericarp thickness and seed characters viz., length, width, thickness and dryweight worked out between hybrids and female parents showed significant relationship in the case of pod length ($r = 0.649$) and number of beans ($r = 0.606$). But with midparental value, the hybrids showed high correlation for the characters pod length, pod weight, number of beans, seed length, seed width and seed thickness (0.65, 0.45, 0.86, 0.70, 0.76 and 0.70 respectively).

Heritability estimated by regressing offspring on female parent was high for the characters pod width, seed length and seed width (0.7, 0.64 and 0.78 respectively).

Among the 29 hybrids studied, the hybrid H-4 of the cross GI 10.3 x GVI 54 was found to be promising in terms of both pod and wet bean yield.

With the seedling characters of hybrids taken one year after sowing, a multiple regression equation for wet bean yield was fitted as:

$$Y = 43 + 0.195\ x_1 + 3.70\ x_2$$

Where, x_1 and x_2 are height and girth of one year old seedlings respectively.

This can be taken as a seedling selection criteria for cocoa hybrids.