POLLINATION, POD SET AND COMPATIBILITY STUDIES IN OPEN POLLINATED PROGENIES OF COCOA VAR. FORASTERO

BY

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THESIS

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the requirement for the degree

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DECLARATION

I hereby declare that this thesis entitled "Pollination, pod set and compatibility studies in open pollinated progenies of cocoa var. Forastero" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship, or other similar title, of any other University or Society.

Vellanikkara,
19-11-1984.

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CERTIFICATE

Certified that this thesis entitled "Pollination, pod set and compatibility studies in open pollinated progenies of cocoa var. Forastero" is a record of research work done independently by Sri Madhu.P. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

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We, the undersigned members of the Advisory Committee of Sri Madhu.P. a candidate for the degree of Master of Science in Agriculture with major in Plant Breeding agree that the thesis entitled "Pollination, pod set and compatibility studies in cocoa var. Forastero" may be submitted by Sri Madhu.P. in partial fulfilment of the requirement for the degree.

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Dedicated to the fond
memory of my Father

C O N T E N T S

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Introduction

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is relatively a new crop to India introduced for commercial cultivation in the latter half of the 1970's. Cocoa had received massive acclaim among the farmers of Kerala, mainly as an intercrop in coconut and arecanut gardens. Till recently the area under the crop as well as its production was increasing rapidly. But the recent fall in prices of cocoa has been causing a severe set back in the tempo of cocoa cultivation. However, ways and means are being sought out by the Government to assure reasonable prices for cocoa beans and it is expected that this may help to regain the initial tempo.

At present, the total area under cocoa in India is about 20,000 ha out of which 15,000 ha are in Kerala and the rest in Karnataka (4,400 ha) and Tamil Nadu (600 ha). During 1980, India exported 1000 tonnes of cocoa products worth Rs. 10 lakhs (Anon., 1981). The production of cocoa in India during 1981-82 was only about 3080 tonnes, out of which 2,500 tonnes were from Kerala alone. India's requirement of cocoa has been estimated to be around 5000 tonnes per year by 2000 AD (Ananthakrishnan *et al.*, 1979). But, to become self-sufficient in the requirement of cocoa and to earn a substantial foreign exchange by means of export by the end of this century, there is a long way to go. Since cocoa

can be economically grown only in Kerala, Karnataka and parts of Tamil Nadu, the scope for increasing the area is limited. Increasing the productivity *per se* is of prime importance in this regard.

The role of systematic and meaningful crop improvement programmes becomes relevant in this context. For any successful breeding programme, information on pollination, fruit set and compatibility aspects is an important pre-requisite. Literature on these aspects is available from other cocoa growing countries, but the studies on the extent to which these parameters vary in our conditions are meagre. Therefore, the present investigation was carried out at the College of Horticulture, Vellanikkara, Trichur with the following objectives.

a) To gather information on anthesis, pollination, pod set etc. in a group of Forastero trees.

b) To study the effect of controlled pollination on pod set and pod development.

c) To study the intensity and nature of self/cross incompatibility and to identify desirable clones for further utilisation.

Review of Literature

REVIEW OF LITERATURE

The literature available on cocoa relevant to the present investigations is reviewed hereunder.

A. Climate

Cocoa is strictly a tropical crop. Areas of tropical evergreen rain-forest and semi-evergreen rain-forest are the most suitable ecological zones for cocoa (Purseglove, 1974). The rainfall and temperature requirements of cocoa have been reviewed by many workers.

a. Rainfall

Cautrecasas (1948) observed that in most of the areas where cocoa flourished, the rainfall ranged between 2000 mm and 8000 mm with more or less even distribution through out the year. Adams and Mc Kelvie (1955) found that most of the cocoa growing areas had a short mild dry season while in Ghana, cocoa was limited to that areas which received not less than 250 mm of rainfall between November and March. According to Purseglove (1974) the rainfall in cocoa belt varied from 1010 mm to 2540 mm. The rainfall should be well distributed preferably with 101 mm or over per month, and with the absence of marked or intense dry season with less than 63.5 mm rainfall per month. Wood (1975) reported that the mean annual

rainfall in most cocoa growing countries of West Africa, the rainfall varied from 1150 mm to 1800 mm while in eastern Nigeria, West Cameroon and Fernando Po rainfall amounted to 2500 mm to 3000 mm per annum. Its distribution is more important than the total amount.

b. Temperature

The lower limit temperature of cocoa was a mean monthly minimum of 15°C. The optimum temperature range varied from 21.1°C to 31.2°C (Erneholm, 1948). Wood (1975) observed that a minimum temperature range of 18°C to 21°C and a maximum of 30°C to 32°C limited the cocoa belt. He also noted that the number of flowers increased as the temperature increased.

B. Flowering

Hewison and Ababio ~~et al.~~ (1929) studied the flowering pattern of cocoa in Ghana and stated that the period from March to July was the time of main flowering activity with the greatest number of flower production in April-June. Where less than a third of the tree's crop was set by the end of April, greatest flowering activity occurred during June. Alvim (1966) observed that the flowering was most intense during the early part of the rainy season, following the July-September drought. The scarcity of flowers from June to September was attributed to the indirect effects of low temperature. In a later study, Alvim (1969) found that the

non-flowering period of cocoa in Bahia was July-September. The burst of flowering at the beginning of the wet season resulted in the main crop after five to six months. Flowering was inhibited when the monthly mean temperature went below 23°C. In Cuba abundant flowering occurred from June to September and gradually decreased thereafter and under severe drought conditions flowering decreased earlier and abruptly (Delpinalrivero and Acunagale, 1967). Sale (1969) studied the flowering process of cocoa in relation to the temperature conditions in Trinidad, West Indies. As compared to plants growing in regions with a day temperature of 23.3°C, plants in the regions with a day temperature 26.6°C to 30.0°C had more active flowering cushions per plant and more number of flowers per cushion per week. Couprie (1972) opined that flowering was the greatest when the daily temperature variation was the least. Alvim et al. (1972) observed that the inhibition of flowering was due to the crop on the tree which suppressed flowering. Glendenning (1972) also found that in weather conditions suitable for growth, flowering continued until suppressed by crop development. Murray (1975) reported that a well developed cushion usually carried a large number of flowers at any one time and a full grown tree produced more than 10,000 flowers in a year. In Vittal, Karnataka the annual flower production per metre of stem varied from 168 to 2,358 (Anon., 1977). Flower production was found to be

through out the year in Kerala (Rajamony, 1981). Gregory (1983) found that the number of flowers per unit length of 50 cm on the trunk ranged from 93 to 904 with a mean of 258.04 in Trichur, Kerala.

C. Anthesis

Wellensiek (1932) found that in Java, the flowers opened at 4.30 PM. Around 6.30 PM the anthers opened and the pollens were ripe. The flower was protogynous, the stigma being ripe at the time of natural opening. From observations on 'Criollo' and 'Trinitario' trees in the Philippines Sampayan (1963) observed that anthesis started at 4 PM and the sepals and petals unfolded by 6 PM. Anther dehiscence started at 6 AM of the following morning and the pollen was accessible to insects from 8 AM to 8.30 AM onwards. In Cuba, flowers normally opened at 7 PM, but remained closed or half opened for almost the whole day at a temperature of about 15°C (Delpinalrivero and Acunagale, 1967). Rajamony (1981) observed that at Pilicode, Kerala, anthesis commenced between 2 PM and 4 PM and completed between 2 AM and 4 AM on the next day.

D. Pollen viability, germination and storage

The pollen grains removed from flowers which had remained open for more than one and a half days failed to germinate (Wellensiek, 1932). Sucrose was found to be a suitable artificial medium

for testing pollen germination. Sucrose serves as a nutrient during pollen tube growth (Ostopenko, 1956; Vasil, 1961; Singh, 1961 and Singh et al., 1961). Shapiro and Budrick (1961) observed that germination and pollen tube growth increased when boric acid and calcium were added to the sucrose medium. Varas and Soria (1962) suggested 5 to 15 per cent sucrose in the media for germinating cocoa pollen. According to them, the best germinating medium for cocoa pollen appeared to be 2 per cent agar with 10 per cent sucrose. It was also observed that 1 to 10 ppm boric acid in the medium stimulated germinatio of cocoa pollen from 22.0 to 42.3 per cent. Jacob et al.(1969) obtained good germination of cocoa pollen in sucrose solution upto a concentration of 30 per cent. Martinson (1973) noted that the best germination of cocoa pollen grains was obtained at a temperature of 28°C to 31°C. Ravindran (1977) obtained good cocoa pollen germination and tube growth in a medium containing 15 per cent sucrose. He further observed that boron or calcium was necessary for proper pollen germination and tube growth and that these nutrients enhanced tube growth considerably. He also studied the relationship of temperature with pollen germination and observed no pollen germination at a low temperature (10°C) and maximum germination and tube growth at 35°C. Increase in temperature to 40°C affected both germination and tube growth.

Wellensiek (1932) observed that cocoa pollen retained its viability in closed glass tubes for at least 12 hours. Varas (1962) found that pollen stored in a desiccator for a week germinated better in artificial medium. Cocoa pollen kept at or below 14°C for two days, germinated slowly (Delpinalrivero and Acunagale, 1967). Simmons (1976) suggested that cocoa pollen could be preserved at 5°C in sealed tubes over calcium chloride for about one week.

E. Pollination aspects

a. Pollinating agents

In Java, pollination by insects was not observed. Gross-pollination occurred only between flowers situated close together (Wellensiek, 1932). Cope (1940) found that Frankliniella parvula Hood. (Thysanoptera, Thripidae) and Wasmannia auropunctata Rog. (Hymenoptera, Formicidae) were mostly responsible for pollen transportation in Trinidad. The insects responsible for much of the cross-pollination in cocoa were identified by Posnette (1950) as Forcipomyia quasi-ingrami Macfie (Diptera, Ceratopogonidae), F. ashantii Ingram & Macfie (Diptera, Ceratopogonidae) and Lasiohelea litoraurea. Forcipomyia spp. were found to be the major pollinating insects in cocoa plantations (Saunders, 1950; Dessart, 1961; Sumner, 1962; Gerad and Saunders, 1964; and Soria et al., 1975). Ceratopogonid flies like Forcipomyia

fulginosa (Meigen), Proforcipomyia spp., Atrichopogon sp. and Dasyhelia sp. were seen to be the pollinators in the Philippines (Fontanille - Barroga, 1962). Of the 1,950 flowers examined, 45 per cent had pollen mass characteristic of midge pollination on their styles. Cautrecasas (1964) opined that pollination in cocoa was only by insects. Several kinds of flying and crawling insects (thrips, ants, midges and aphids) were found to be involved in the pollen transportation. Out of the 450 freshly opened flowers examined none contained Forcipomyia spp. while aphids were present in most of them. The thrips (Frankliniella parvula); aphids (Aphis gossypi (Glov.)); ants (Wasmannia auropunctata) and bees were identified by Hernandez (1967) as the insects most commonly associated with cocoa flowers at Turialba. Female midges of the genus Forcipomyia were identified as the most important pollinating agent in cocoa (Glendenning, 1972 and Entwistle, 1972). Mire and Mbondji Mbondji (1972) identified Drosophila triangulifer to be responsible for more than 43 per cent of fertilisations in cocoa followed by Crematogaste: and Ceratopogonids, mainly of the Stilobezzia genus.

Winder and Silva (1974) working on the population dynamics of the pollinating insects of cocoa repmrted that pollination in cocoa was exclusively due to Ceratopogonids. Leaf litter, heaps of husks, rotting jack fruit or banana stems and bromeliads were found to be the suitable breeding

sites of these insects. Their abundance in leaf litter was positively correlated with the soil moisture content, with the result that pollinations were most abundant when flowering was at a minimum and vice versa.

Studies by Kaufman (1975) revealed that not less than 50 species of Ceratopogonidae were found at Tafo, Ghana and the most abundant one was Forcipomyia squamipennis (Ingram & Macfie). Another pollinator was also identified as a species of genus Trigoria (Hymenoptera, Apidae) variously called sweet bees, stingless bees or morpane bees.

Field observations by Amponsha (1975) indicated that six rows of cocoa spaced 2.4 x 2.4 m could not prevent the transfer of pollen across that distance by pollinating insects. In an area of 31.7 x 31.7 m, 24 per cent of all pods harvested over the crop seasons were found to be the result of pollen from outside the plot, while 58 per cent could be traced to be due to pollen within the plot alone. Only seven per cent of the pods arose from mixed pollination.

Soria and Bystrak (1975) described a new species of Forcipomyia named F.(= Euforcipomyia) blantoni. E. blantoni together with F. spatulifera were considered to be the main pollinators of cocoa in Brazil.

Soria and Abreu (1976) working on the population densities of Forcipomyia spp.found that these midges were

higher from May to August, a rainy period with adventional type of precipitation. The population densities of Euforcipomyia and Forcipomyia were four and three times higher, respectively above as compared to below the canopy of cocoa trees within a shaded plantation. Euforcipomyia and Forcipomyia population densities when measured at 2 m above the soil level were 34 and 59 per cent higher respectively in the unshaded areas as compared to the shaded areas.

Massaux et al. (1976) found that several species of insects other than Forcipomyia can pollinate cocoa such as Drosophila coundo, Zapriomus spp., Toxoptera auranti B.de F., Stilobezzia sp. and Tyora tessmanni (Aulm.) (Psyllidae).

Studies conducted by Soria (1977b) in Bahia, Brazil showed significant correlation between temperature and evapotranspiration and midge populations. Heat, sunshine hours, nebulosity and water balance were significantly correlated with natural pollinations. Heat, soil-water availability and air-humidity closely interacted with Forcipomyia population and pollination. In a later study Soria (1979) found that air-temperature, soil-moisture conditions, rainfall and sunshine patterns appeared to mainly determine the population density of Forcipomyia midges.

In Cameroon, the control of mirids in cocoa plantations by the fogging or atomisation of insecticides

reduced the pollinating insect population for a period of respectively two or eight days (Lucas and Decazy, 1981). The time spent by Diptera, aphids, thrips and ants in the flowers of the cocoa tree, as well as their pollinating efficiency has been calculated by Lucas (1981). To increase the natural pollination of cocoa, the use of coloured traps was envisaged, based on the fact that the attractiveness of the flower must vary with their colour. Boussard (1981) discussed the role of insects in cocoa pollination, the role and biology of Ceratopogonids and cultural practices which lead to greater pollination.

b. Natural pollination

Fontanilla - Barroga (1962) found that pollination occurred through out the day with pronounced peak between noon and 3 PM in the dry season and a broad maximum between 9 AM and 2 PM in the rainy season. Barroga (1965) reported that the highest rate of pollination was observed from 6 AM to 11 AM and from 2 PM to 5 PM. No pollination occurred at noon. Based on hand pollination made at hourly intervals Sampayan (1966) observed that the percentage of fruit set was more when pollinations were done between 6 AM and 5 PM, reaching a maximum when pollinations were done between 10 AM and 1 PM. Widjanarko (1967) found that the extent of pollination was chiefly influenced by the morning weather

conditions and was low in rainy weather. The percentage of pistils with pollen grains was slightly higher in the flowers collected between 12 noon and 1 PM, indicating that more natural pollination took place at mid-day than in the early morning (Toxopeus and Jacob, 1970). Glendenning (1972) observed that normal fruit setting in cocoa required deposition of pollen grains in quantity. Purseglove (1974) reported that the low pollination efficiency in cocoa was compensated by the large number of flowers opened. In Ghana, two to five percentage of flowers only are pollinated and a fairly large number of these failed to set seed. Later during the season when flowers were fewer, pollination rose to 50 to 75 per cent. Fertilisation took place seven to eight hours after pollination and it could be ascertained by the swelling of the ovary. According to Murray (1975) the proportion of flowers pollinated ranged from 1 to 50 per cent, according to the season and number of flowers opening at the time. But the percentage of pollination were higher in August (57.3) followed by in July (56.2). Massaux et al. (1976) reported that under natural conditions pollen disposal was most intense at 8 AM and 5 PM with or without insects. The number of pollen collected on insects captured on the cocoa flowers indicated that all captured insects were able to ensure fertilisation. The wind, whether natural or forced by atomisation played only a small and negligible part in the transportation of pollen.

In the cocoa plants of South Karnataka (Vittal) successful pollination (stigma having 40 or more pollen grains) was only to the tune of eight per cent though the percentage of flowers pollinated was 28. The maximum successful pollination (11 per cent) was in March and minimum (four per cent) in December. Though high pollination per cent was recorded in August, there was no fruit setting (Anon,, 1977). The microscopic examination of a number of styles by Parvais et al. (1977) revealed that only a few of them carried pollen in quantities sufficient to ensure fertilisations. Pollination appeared to be a limiting factor for good yields. Pollen tends to aggregate, thus pollination depends upon the frequency of the deposition of aggregates on the style and on the size of the aggregates. Winder (1978) also observed that lack of pollination was responsible for low production in cocoa.

C. Artificial pollination

Wellensiek (1932) used a method of artificial pollination in which the pollen flowers were picked in the morning and used for pollinating newly opened flowers at 7.30 PM the same evening. This method resulted in three per cent of ripe fruits. Posnette (1950) and Jacob and Atanda (1975) observed that pod yield could be considerably increased by hand pollination. Ruinard (1963) used conical

hoods of stiff nylon cloth, attached to the bark with a couple of pins to protect the flowers used for controlled pollination in West New Guinea. Vello and Nascimento (1971) determined the percentage of hand pollinations resulting in fruit setting in four clones. It was found to be 13.5, 14.1, 21.6 and 38.8 respectively in these clones. The percentage of pollinations resulting in mature fruits were 15.1, 14.9, 11.7 and 10.2 respectively. Amponsha (1972) reported that the percentage of fruit set on hand pollination was much higher than those by natural pollinations.

Soria et al. (1975) conducted a trial to induce artificial pollination using an atomiser. The flowers were treated six times at alternating days in the early morning hours. The results showed that early harvest was tripled, but the total annual harvest was not increased.

A quantitative study on cocoa pollination based on operational research theory by Reffye et al. (1980) led to the conclusion that the distribution of the pollen on the styles can be forecast with precision if certain conditions are met and that natural pollination could be reconstructed by simulation. Under saturated mannual pollination conditions it was possible to specify the ovular fertility of the cocoa clones (Mossu, 1980). Knoke et al. (1980) observed that

mechanical pollination of cocoa using mist blowers or by brushing cocoa flowers greatly increased pod set and may have great practical application where insect population was inadequate and self-compatible cultivars were being used. Soria and Garcia (1980) also found that the technique of blowing air over the flowers of self-compatible variety to induce mechanical pollinations nearly doubled the yield in relation to untreated plots. According to Lucas and Decazy (1981) an artificially created air stream had only a little effect on pollination and only after prolonged action. The hand pollination of eight trees belonging to two clones by Paulin (1981) showed that potentially the trees were able to produce through out the year and that the number of seeds per pod is linked with the amount of pollen. Rajamony (1981) found that the percentage of fruit set and pod harvest on hand pollination increased to 52.02 and 25.76 respectively from 11.81 and 0.83 under natural pollination.

F. Pod set and development

Hewison and Ababio (1929) observed that only 0.2 to 1.5 per cent of the opened flowers developed into mature fruit. Purseglove (1974) opined that only one in 500 flowers (0.2 per cent) matured to a fruit. According to Murray (1975)

out of 10,000 flowers produced by a full grown plant in a year only 10 to 50 (0.1 to 0.5 per cent) developed as mature fruit. The fruit setting status of 23 cocoa clones had been assessed by Jacob and Atanda (1975) both with respect to use as male and female parents. The best male parent had 55.7 per cent fruit setting and 25.7 per cent pod production and the best female parent 58.2 per cent and 18.2 per cent respectively. Amponsha (1977) observed that a large proportion of flowers never produced fruits even if they were fertilised. Further, a large number of fertilised ovaries were shed before maturity. Soria (1977) found that fruit setting and yield were positively correlated with pollination level. The total productivity may be forecast from observations on flowering intensity and insect populations, instead of only on the basis of fruit setting. In Vittal, Karnataka it was found that the mean annual fruit setting was only three per cent. Lower fruit setting observed during the peak period of flowering has been attributed to insufficient number of pollinating agents (Anon., 1977).

Hewison and Ababio (1929) found that the majority of pods in cocoa ultimately reaching maturity attained maximum size in 17 to 18 weeks after fertilisation. The period

of development of cocoa pods was reported to be 16 to 21 weeks in Nigeria (Waters and Hunter, 1929), five to six months in Grenada (Toper, 1940) and in New Guinea an average of six months (Bridgland, 1953). Weekly observations on the growth rate of cocoa pods by Mc Kelvie (1954) in 'Amazon', 'Amelonado' and 'Trinitario' selections showed that the growth rate of pods was similar in these selections upto four weeks of fertilisation. Studies in Nigeria by Toxopeus and Jacob (1970) concluded that inadequate fertilisation of the cocoa flowers seemed to be the main cause of variability in the number of beans per pod. Alvim et al. (1972) presented evidences and concluded that the rate of pod development increased with increase in temperature. Pods grew more slowly in cooler climate. The time taken by cocoa pods to reach maturity stage from fertilisation was five months (Wood, 1975) five to six months (Murray, 1975) and four to six months (Anon., 1978).

Adenikinju (1978) working on the anatomical aspects of the cocoa pod observed that until a cocoa pod attained a certain stage of maturity it contained only a compact white pulpy non-mucilaginous mass, within which the outlines of the future beans were difficult to detect. Upto about 105 days from pollination the pulpy material surrounding the beans

remained in this condition which therefore made individual beans difficult to extract. As the pods matured the pulp became mucilaginous and the beans were distinct and easier to extract. At this stage the mature pod varied in age from 147 to 175 days after pollination, the rate of development depending on the prevailing climatic conditions, the cultivar, the soil and other factors. Rajamony (1981) observed that the pods took 127 to 141 days for reaching the ripening stage.

G. Cherelle wilt

The losses of immature fruits (cherelles) were the highest during the first week of growth. Another critical period was between the fourth and seventh weeks. The losses from shedding and shrivelling of immature pods ranged from 22 to 84 per cent of the fruit set (Hewison and Ababio, 1924). Cherelle wilt was generally highest between April and June in Ghana (Hamphries, 1947 and Mc Kelvie, 1955 and 1957). Naundorf and Villamil (1949) reported that the percentage of cherelle wilt was higher in large cushions, containing 10 to 30 flower buds. The occurrence of cherelle wilt in relation to the fruit development was studied by Mc Kelvie (1955) and concluded that cherelle wilt occurred in two distinct waves. The first period of wilt or 'first wilt' started a few days after fertilisation and lasted for nine to ten

weeks with a peak at the seventh to eighth week. The second period of wilt or 'second wilt' started from the eighth or ninøth week with a peak at about twelføth week. After 14 weeks (corresponding to a pod of 13 to 14 cm length) there was no further wilt. The second wilt very rarely occurred in young plantations where the first wilt could account for upto 95 per cent loss. Mc Kelvie (1956) found that the cherelles with a length of 35 mm to 60 mm were most sensitive to wilt. Nichols (1961) opined that cherelle wilt was a physiological thinning mechanism which regulated the sizes of the crop in relation to the available food reserves in the trees. The fruits wilted during the first half of their life cycle, i.e., upto 80 days from fertilisation. Reyes et al. (1969) used clonal cocoa plants in their study and showed that the percentage of prematurely wilted fruits varied during the year. Losses occurred during the dry months of March-April and again during September-October. Glendenning (1972) observed that any excess fruit set was corrected by cherelle wilt.

Couprie (1972) classified fruit set and cherelle wilt as the most important factors effecting yield. Cherelle wilt was affected by rainfall during the eighth week before fruit set and by the temperature during the second-preceeding weeks. Purseglove (1974) reported that maximum cherelle wilt

occurred at about 50 days after fertilisation when young cherelles were about 6 cm long. During the stage of further development (50 to 70 days) wilt did not occur and the fruits matured and ripened. Murray (1975) opined that the young developing fruits (during the first two to three months of their development) were subjected to cherelle wilt. Cherelle wilt was a physiological thinning mechanism. Accordin to Cobley and Steele (1976) cherelle wilt occurred mostly when the fruits were seven to eight weeks old. After three months of growth there was little risk of fruit failing to mature. Physiological wilting was found to be independent of the number and stage of development of seeds. Early shedding of fruits seemed to be the result of a defect causing their unsuitability for fertilisation. Paulin (1981) observed that the first 120 days after fruit set were critical. In Kerala, cherelle wilt was found to occur through out the year, maximum being in July (Rajamony, 1981).

4. Incompatibility

Self-incompatibility in cocoa was first reported in Trinidad by Harland in 1925 and again by Pound in 1932 (Purseglove, 1974). The modalities of the incompatibility systems in cocoa were analysed in detail by Knight and

Rogers (1955) and by Cope (1958) who concluded that self-incompatibility in cocoa was sporophytic. Their diagnosis is at variance with that of Bouharmont (1960) who claimed evidence of gametophytic control. Cope (1962a) showed that the site of incompatibility was in the embryo-sac and not in the stigma and the style. Pollen tubes in incompatible matings grew as fast as those in compatible pollinations and delivered their gametes into the embryo-sac in a perfectly normal fashion. The incompatibility was due to the failure of the male nuclei to unite with the egg and polar nuclei and was genetically controlled. In incompatible pollinations the proportion of ovules showing non-fusion averaged 25, 50 or 100 per cent. Fusion or non-fusion was controlled by a series of alleles operating at a single locus(S), showing dominance or independent relationships. They were the same in both male and female parts of the flower so that reciprocal pollinations gave the same results. Incompatible crosses involved parents with same dominant allele, or a genotype with independent alleles and another where one of these independent alleles was dominant. In addition to the S locus two other complementary loci A and B were involved, the role of which was to produce a non-specific precursor to which the S alleles imparted their specificities to prevent fusion between gametes carrying the same S allele in certain

circumstances. Genotypes homozygous for inactive alleles at one or more of the A, B and S loci would be self-incompatible.

Cope (1962 b) showed that self-compatible and self-incompatible genotypes cannot exist in equilibrium in an isolated population, and that, on theoretical grounds, the self-compatible trees would ultimately displace the self-incompatible genotypes, a process hastened by greater fruitfulness of the self-compatible trees. But, in a wild population there appears to be some strong selective descrimination against self-compatible types.

Bartley (1963) observed 39 trees and found that out of these, eight were self-compatible. Sampayan (1966) observed that Criollo - Forastero natural hybrids exhibited varying degrees of self-compatibility from 0 to 93 per cent. In Brazil, the clone UF-221 appeared to be self-compatible while the clones UF-667 and UF-613 showed high degrees of self-incompatibility (Delpinalrivero and Acunagale, 1967).

Self-incompatibility was found to be a major barrier in realising yield potential of cocoa (Toxopeus and Jacob, 1970; Jacob and Atanda, 1975). Coral and Soria (1972) proposed a genetic model to explain the mechanism of inheritance of the incompatibility system in cocoa.

In the incompatible matings flowers were shed three to four days after pollination. The self-incompatible 'Trinitario' clones were cross-incompatible also; but were compatible with self-compatible trees (Purseglove, 1974). Based on the assessment of flower setting and pod harvesting in 23 W.A.C.R.I. 'C' clones, Jacob and Atanda (1975) identified two self-compatible clones, C-26 and C-73. Murray (1975) observed that in Trinidad, the self-incompatible and cross-compatible trees required pollen from self-compatible tree to ensure fruit set but elsewhere self-incompatible trees showed cross-compatibility.

I. Pod harvest

Chat (1953) observed that in most of the countries, cocoa harvest peaked twice in a year; once during the rainy season and again during the dry season. Bridgland (1953) found that in countries with pronounced wet and dry seasons the main harvest occurred five to six months after the start of the wet season.

Alvim (1974) made detailed studies of the harvest of cocoa in Bahia and found that in regions where the rainfall was fairly well distributed, the cocoa harvest season was found to be rather long, usually starting in April and

extending until mid January. The April to August crop was called as the 'temporao' and the September to January crop as the 'safra'. The temporao crop was bigger than the safra crop depending on the rainfall pattern. January to March period was critical (with respect to rainfall) for the tempora crop and September to November for the safra. During the years with well distributed rainfall, the temporao and safra had almost the same volume. In West Africa, about 80 to 90 per cent of the crop was harvested in a relatively short period between September and December (main crop) and only 10 to 20 per cent during May-July (mid crop). The long dry season from October-November to March-April was the main factor responsible for the reduced mid-crop in West Africa.

Purseglove (1974) observed that the cocoa plants produced pods through out the year; but the main harvest usually began at the end of the wet season and continued for a period of three months. Accordingly in West Africa, the main harvest was during February-March, followed by a minor harvest in the rains. Wood (1975) opined that as in most other tropical crops, the cocoa harvest was not confined to one short period. There were peak harvest periods, one or two per year and in many countries, there was some cocoa to b harvested at all times of the year. In Ghana on an average,

25 per cent of the crop was harvested in the peak month, November, which was about six months after the commencement of the wet season. In Malaya, where there was no true dry season, the peak of harvest was less pronounced with 20-25 per cent of the crop in the peak which falls between November and March. Shanmughavelu and Madhava Rao (1977) found that there were two well defined cropping seasons in Ceylon; one from May-August and the other from September-January. Studies undertaken at the Kallar Fruit Station on the cropping and productivity of Criollo cocoa revealed that in the young plantations, the cropping was confined to November-June, with the major portion of the crop obtained during November-December.

Materials and Methods

MATERIALS AND METHODS

The studies were conducted during 1982 and 1983 at the Horticultural College, Vellanikkara, Trichur district. The experimental materials and methods used for the study are described hereunder.

I. Experimental materials

The experimental materials consisted of eight-year old bearing cocoa trees of the variety Forastero. For preliminary observations, cocoa trees planted at a spacing of 4 x 4 M at the Instructional Farm, College of Horticulture were used. The cultural practices and other operations were carried out by the Farm. For the incompatibility studies cocoa trees intercropped in coconut garden and maintained by the Kerala Agricultural Development Project at Mannuthy were used. Twenty high yielding trees were selected for the purpose based on the potential yield of the preceeding year.

II. Experimental methods

A. Field Methods

1. Flowering

a. Monthly rate of flower production

Weekly observations of the number of flowers per plant were made on five trees. During counting, older flowers

were identified by the dried appearance of the stigmatic surface, change of the petal colour from creamy white to deep yellow, the drooping character of the unpollinated flowers and by the swollen ovaries of the fertilised flowers as suggested by Purseglove (1974) and Murray (1975). All the already opened flowers including the fertilised ones were removed to avoid duplication in counting. From the observations the mean for each month and the percentage of flowers for each month were calculated.

b. Total number of flowers per tree

1) Number of flowers per cushion

To determine the total number of flowers per tree the number of flowers per cushion was first assessed. Five bearing plants were selected and on each selected plant, ten cushions were marked on the main trunk at random with aluminium foil. The marked cushions were examined daily and the number of flowers opened on these cushions was counted. The opened flowers were removed in order to avoid duplication in counting. This practice was continued until flowering was complete in all the marked cushions. Five cushions were also marked on one of the fan shoots of the selected trees and the number of flowers per cushion on the fan shoots was also determined in a similar way.

ii) Number of cushions on the main trunk

A length of 50 cm from the first jorquette downwards was marked on the main trunk of the selected trees and the number of cushions developing all around the trunk in the marked area was counted. Then the whole length of the main trunk was measured. From this the number of cushions developing on the main trunk was determined.

From the data on the number of cushions on the main trunk and the number of flowers per cushion, the number of flowers on the main trunk was determined. To determine the number of flowers on the fan shoots the number of cushions developing on one of the fan shoots was counted. From the data on the number of flowers per cushion on the fan shoots and the number of fan shoots on each tree, the number of flowers on the fan shoots was determined. The sum of the number of flowers on the main trunk and on the fan shoots gave the total number of flowers per tree.

2. Floral characteristics

The floral biology of the flower was described by examining a number of flowers under a dissection microscope and drawings were made (Fig.3).

3. Anthesis

a. Flower opening

Observations were made at two hour intervals in order to determine the time of flower opening. For this mature flower buds were marked on the previous day evening using aluminium foil. The time at which the buds started to split and the time at which the petals unfolded completely were noted. These observations were made in fifty mature flower buds each day and continued for a week. The observations were repeated in each month to study whether the factors like temperature, rainfall etc., had any influence on anthesis.

After preliminary observations the counts on splitting were done at two hour intervals between 10 AM and 8 PM and the counts on completion of flowering at two hour intervals between 12 midnight and 8 AM.

b. Anther dehiscence

The completely opened flowers were collected at 6 AM, the stamens were taken and observed under a dissection microscope. A longitudinal split on the pollen sac of the anthers was treated as a sign of anther dehiscence.

d. Stigma receptivity

Stigma receptivity was determined based on two methods.

In the first method (Heslop and Shivanna, 1977) anthers from freshly opened flowers were rubbed on the stigmatic surface and the stigmatic surface was observed under a hand lens to see whether the pollens have adhered to the stigmatic surface.

In the second method (Sampayan, 1963) hand pollinations were done using a fine forceps (the method is described under controlled pollination) at two hour intervals between 6 AM and 6 PM and the number of pods set after two weeks of pollination was determined. This was done in 50 flowers per tree at a time and continued for five days.

d. Pollen fertility

Pollen fertility was determined using the acetocarmine method as suggested by Zirkle (1937). The anthers were removed and placed on a glass slide having 0.5 per cent acetocarmine. The anthers were gently tapped with a needle and the tissue was removed. A cover glass was placed and the slide was examined under a microscope. Pollen with normal shape and size and which took up the stain was counted as fertile and those which were broken, shrivelled, small and which were not stained were counted as sterile. The observations were taken on 30 different fields.

To study the variation in the extent of pollen fertility after anther dehiscence, the above method was repeated at two hour intervals between 6 AM and 6 PM. The observations were taken on 5 days.

4. Pollination

a. Mode of pollination

To study whether natural pollination took place with the help of wind, glass slides coated with glycerine were hung vertically on different parts of the selected plants. At two hour intervals the glass slides were examined under a microscope to see whether any cocoa pollen had adhered to it.

To determine whether rain had any role in natural pollination of cocoa, drippings from the flowers were collected in a specimen tube while it was raining and examined under a microscope to see whether the drippings collected contained any cocoa pollen.

To study the role of insects in natural pollination of cocoa, close observations were made to see if any insects visited the flowers. The insects visiting the flowers were trapped and they were examined under a microscope to see whether any cocoa pollen adhered to them. The photomicrographs of the insects supposed to be associated with the cocoa pollination were taken (Plate-II).

b. Natural pollination

To determine the rate of natural pollination, five plants were selected and ten flower buds were tagged on each tree. All the other flower buds and already opened flowers from the marked cushion were removed. After two weeks the number of pods set was determined. This experiment was repeated every week through out the year.

c. Controlled pollination

Two methods of artificial pollinations were tried.

In the first method mature flower buds were covered in the morning with polythene hoods specially prepared for the purpose (Plate-I). Polythene tubes of 5 cm length and 2.5 cm diameter were taken and one open end was covered with a close mesh net kept in position by a rubber band. Then the hood was placed over the flower buds so that the sides of the tube did not touch the flower buds and the hoods were fixed on the bark with the help of plasticine. Five trees were selected and ten flower buds were thus covered with the hood on each tree. On the next day morning the hoods were removed and the opened flowers were artificially pollinated.

For artificial pollination a stamen from a freshly opened flower of a compatible tree was taken in between a

Plate - I. Protection of flower buds with polythene hoods during controlled pollination.

Plate - I

pair of fine forceps and the anthers were slightly crushed. Holding the flower in position in between the fingers of the left hand the anthers were rubbed over the stigmatic surface. To pollinate a single flower three stamens from a flower were used. Immediately after pollination the hoods were refixed and were retained for three days. The unpollinated flowers shed off within two days and the successfully pollinated flowers were identified by the swelling of the ovary.

In the second method, anthers from freshy opened flowers were taken and a suspension of the pollen was made in distilled water. The procedure followed for protecting the flower was the same as in the first method. But in this case, the suspension of pollen in distilled water was sprayed over the flowers using an atomiser. This experiment was also done on the selected trees between 9 AM and 12 Noon over ten flowers on each tree and was repeated for five days. The number of successful pollinations was noted.

5. Podset and development

Fourteen high yielding trees were selected on the basis of potential yield. Crosses were made in all possible combinations between them and the pollinated flower buds were marked. After two weeks the number of pods set was noted.

Longitudinal sections of the pods were taken and observed to note the development of ovules at weekly intervals (Plate 3). The number of days taken for maturity of the pods was also observed.

6. Cherelle wilt

The number of developing pods wilted was noted at weekly intervals. The total number of developing pods on the tree at that particular time was also noted.

7. Recovery of mature pods

The number of pods harvested from each selected tree was recorded. The rodent attacked and diseased pods were also counted as yield. From this the percentage recovery of mature pods was calculated.

8. Compatibility studies

a) Self-incompatibility

Seventeen potentially high yielding trees were selected. On the selected trees a number of flowers were selfed. For selfing, the mature flower buds on the selected trees were covered with hood on the morning. On the next day morning the hoods were removed and the stamens from the same flower or from another flower of the same tree were taken

with a pair of forceps and artificial pollination was done as described earlier. The hood was replaced immediately. Before attempting selfing on another plant, the forceps was cleaned with alcohol to remove any pollen sticking to it. After three days the number of pollinations effected was noted based on the assumption that the ovary of the fertilised flower would show swelling and that unpollinated flowers would be shed by that time. The artificial pollination was repeated for several days so that atleast fifteen flower buds were selfed on each selected tree and the compatibility status of the trees was determined.

b) Cross-incompatibility

To study the cross-incompatibility status, crosses in all possible combinations among the selected trees were made. In the trees found to be self-compatible emasculation was done before covering with the hood by removing the stamens with a pair of fine forceps. After pollination, the pollinated flowers were marked by fixing aluminium foil showing the cross combination and date of crossing. When the pods were sufficiently large the details were scribbled on the pod using a blunt end ball point pen.

B. Statistical methods

The stipulated procedures were adopted in the statistical analysis of the data. The arithematic mean of the observations were computed and tested for significance using the analysis of variance. The critical difference was calculated by the Multiple 't' test using the following formula.

$$CD = t_e \sqrt{\frac{SEm\ (1 + 1)}{r_i \quad r_j}}$$

where CD = critical difference

t_e = t value for error degrees of freedom

SEm = mean square for error

r_i & r_j = replications

The correlation between factors were computed using the following formula.

$$r = \frac{\left(\Sigma xy - n\bar{x}\bar{y}\right)}{\left(\Sigma x^2 - n(\bar{x})^2 \times (\Sigma y^2 - n(\bar{y})^2\right)}$$

where r = correlation coefficient

x and y are the observations of the two factors

n = number of observations and

$\bar{x}$ & $\bar{y}$ = the mean of the observations

The multiple correlation between the factors was worked out using the formula.

$$R_{1.\,2\,3} = \sqrt{\frac{r_{12}^{2} + r_{13}^{2} - 2 \times r_{12} \times r_{13} \times r_{23}}{(1 - (r_{23})^{2})}}$$

where

$R_{1.\,2\,3}$ = multiple correlation coefficient of the dependent variable 1 with independent variables 2 & 3

r_{12}, r_{13} & r_{23} = simple correlation coefficient between the variables

The significance of the multiple correlation coefficien was calculated using the formula.

$$F_{(M-1)\,(N-M)} = \frac{(R_{1.23})^{2} \div (M-1)}{(1-(R_{1.23})^{2} \div (N-M)}$$

where

M = the number of variables

N = the number of observations

The regression equation was obtained as follows.

$$y = a + b_1 x_1 + b_2 x_2$$

where

y = dependent variable

x_1 & x_2 = independent variables

a = constant

b_1 & b_2 = partial regression coefficients

b_1 & b_2 were obtained by solving the following equations.

$$\Sigma x_1 y - n \bar{x}_1 \bar{y} = b_1 (\Sigma x_1^2 - (\bar{x}_1)^2 n) + b_2 (\Sigma x_1 x_2 - n \bar{x}_1 \bar{x}_2) \quad \ldots \quad 1$$

$$\Sigma x_2 y - n \bar{x}_2 \bar{y} = b_1 (\Sigma x_1 x_2 - n \bar{x}_1 \bar{x}_2) + b_2 (\Sigma x_2^2 - (\bar{x}_2)^2 n) \quad \ldots \quad 2$$

The constant 'a' was obtained as follows.

$$a = \bar{y} - (b_1 \bar{x}_1 + b_2 \bar{x}_2)$$

Results

RESULTS

The results of the investigations conducted are presented in this chapter.

A. Flowering

1. Monthly rate of flower production

It was found that cocoa flowered through out the year. Data on the monthly rate of flower production are given in Table 1. There was significant difference between months in the extent in flower production. Highest flowerin was observed in December (17.31 per cent) followed by March (13.08 per cent). Lowest flower production was recorded in September (1.29 per cent) (Fig.1). There was no significant difference between the trees in the monthly rate of flower production.

a. Correlation of flowering with climatic factors

The monthly weather data of the years under study are given in Table 2. It was found that rainfall of the respective months and that of the preceeding month had significant negative correlation with flowering, while rainfall two months preceeding the month of flowering had no significant

Table 1. Monthly rate of flower production based on weekly observations

Month	Tree number					Mean for the month	%age of the total
	C_6	C_9	C_{13}	C_{25}	C_{30}		
1	2	3	4	5	6	7	8
January	326	345	279	350	302	320.4	9.33
February	402	428	399	390	412	406.2	11.83
March	468	448	439	448	443	449.2	13.08
April	327	329	286	257	279	295.6	8.60
May	289	301	318	243	240	278.2	8.10
June	99	89	118	80	88	94.8	2.76
July	255	279	289	225	225	254.6	7.41
August	234	244	273	245	193	237.8	6.92
September	60	61	34	35	31	44.2	1.29
October	85	62	84	106	75	82.4	2.40
November	364	384	387	387	362	376.8	10.97
December	501	583	629	633	626	594.4	17.31

	Between trees	Between months
F value	0.1535	170.07**
CD	-	34.94
SEm	1601.29	763.2

** Significant at 1% level

Fig.1. Monthly rate of flower production

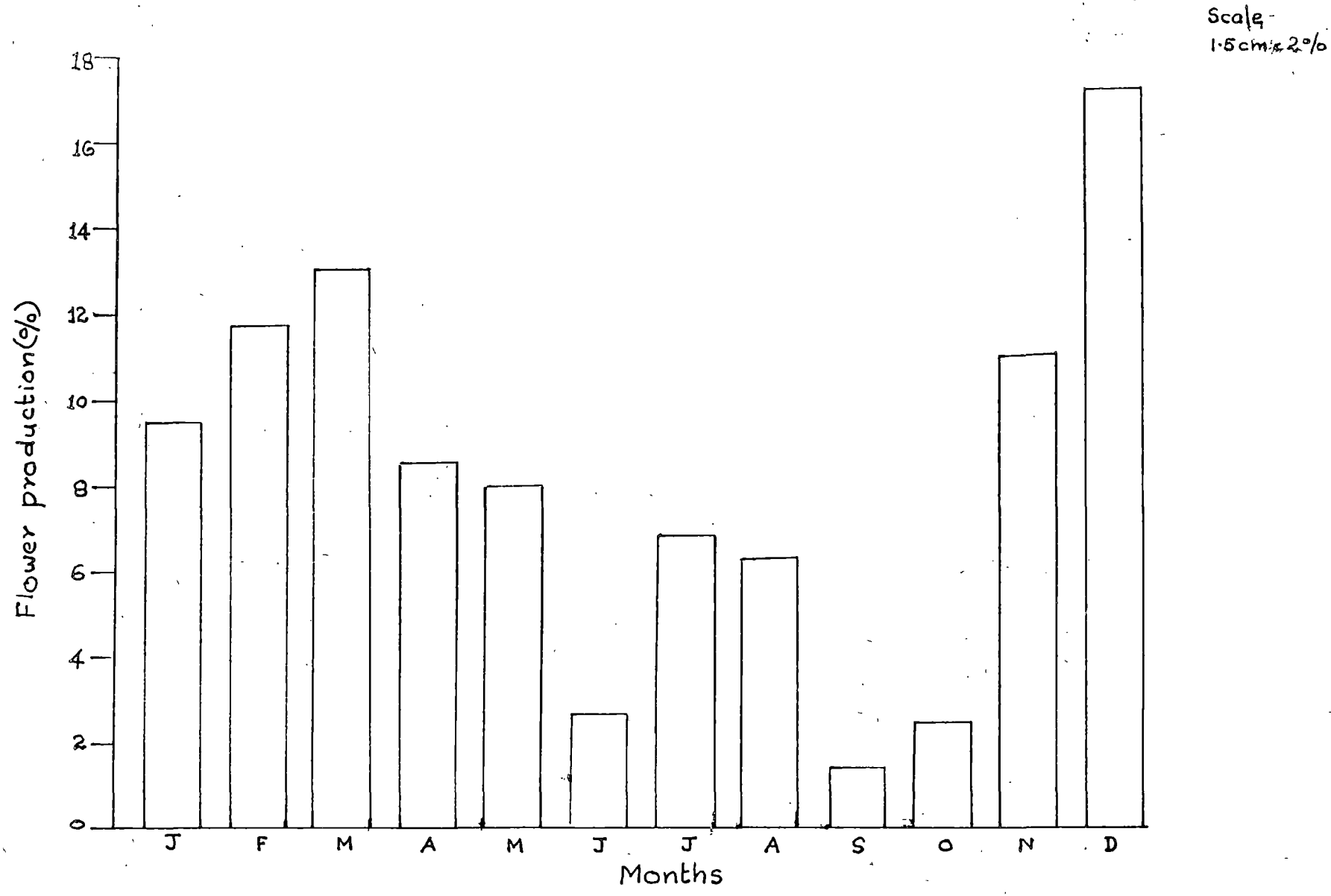


Table 2. Monthly weather data of the years under study (1982 and 1983)

Month	Rainfall mm		Maximum temperature $0^{o}C$		Minimum temperature $0^{o}C$		Relative humidity %		Sunshine hours	
	1982	1983	1982	1983	1982	1983	1982	1983	1982	1983
1	2	3	4	5	6	7	8	9	10	11
January	Nil	Nil	32.5	33.0	24.6	21.6	61.6	51.3	NA	9.24
February	Nil	Nil	36.9	34.5	21.3	22.7	57.7	64.0	NA	9.51
March	Nil	Nil	35.4	36.2	23.2	23.8	78.2	65.0	NA	9.76
April	61.4	Nil	34.7	36.2	25.4	25.8	81.7	66.0	NA	9.01
May	173.6	37.4	33.8	35.1	24.5	25.5	79.9	69.0	NA	7.76
June	657.6	387.2	30.6	31.9	23.1	24.5	79.8	79.0	NA	3.79
July	600.9	580.6	29.1	29.7	22.9	23.7	87.5	87.0	2.85	2.89
August	574.5	754.7	28.9	29.1	24.3	23.8	85.0	87.0	3.81	1.98
September	67.4	494.6	31.0	29.5	24.0	23.4	78.9	84.0	6.94	3.60
October	277.8	149.8	32.0	31.2	23.1	23.1	77.0	77.0	6.65	6.96
November	98.4	60.2	31.4	31.8	23.9	22.3	71.9	71.0	6.64	8.16
December	5.2	24.4	31.9	31.2	23.2	23.9	58.4	63.0	8.02	6.95

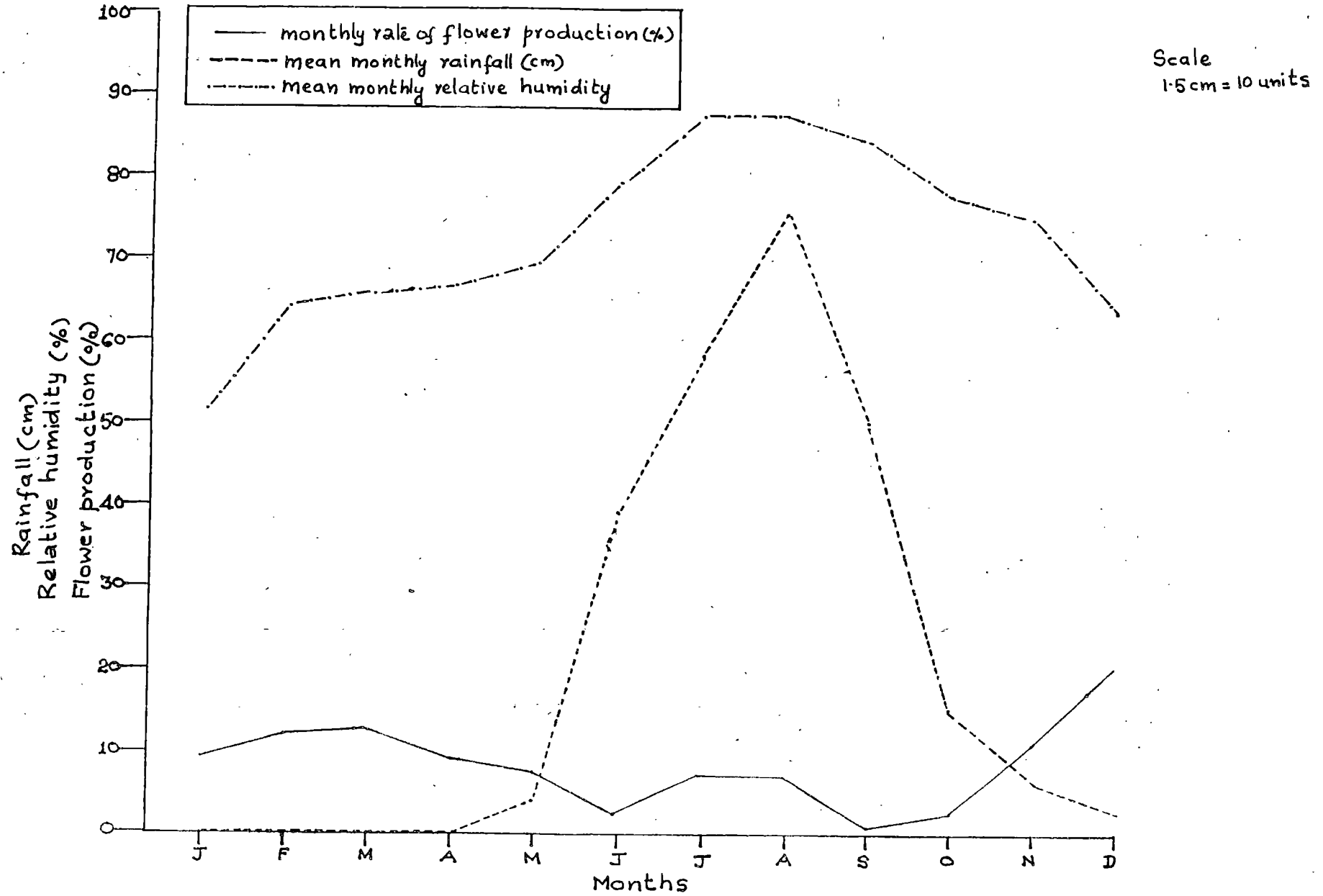
Source: 'B' class observatory, Vellanikkara

Table 3. Correlation of flowering with certain weather parameters

Weather parameter	Correlation coefficient		
	Simultaneous	One month previous	Two months previous
1	2	3	4
Rainfall	-0.5532*	-0.6698*	-0.4557
Maximum temperature	0.3934	0.2545	-0.0268
Minimum temperature	-0.0969	-0.6291*	-0.5585
Relative humidity	-0.6216*	-0.5221	-0.4029
Sunshine hours	0.5515	0.6232*	0.3859

*Significant at 5% level

Fig 2. Comparison of monthly rate of flower production with relative humidity and rainfall



correlation. Maximum temperature of the respective months, one month and two months preceeding the month of flowering had no significant correlation. However, the minimum temperature one month preceeding the month of flowering had significant negative correlation. The relative humidity of the respective months had significant negative correlation with flowering, while the relative humidity one month and two months preceeding the month of flowering had no significant correlation. The sunshine hours one month preceeding the month of flowering had significant positive correlation with flowering, while the sunshine hours of the respective months and two months preceeding the month of flowering had no significant correlation. Data on the correlation of flowering with weather factors are given in Table 3.

The multiple correlation of flowering with weather parameters was worked out (Table 4). Flowering had significant multiple correlation with rainfall of the simultaneous month and minimum temperature of the previous month, with maximum temperature of the simultaneous month and rainfall of the previous month and with relative humidity of the simultaneous month and minimum temperature of the previous month. Flowering had also significant multiple correlation with rainfall and

Table 4. Multiple correlation of flowering with certain weather parameters

Weather parameter	Simultaneous					One month previous				
	Rain-fall	Max. temp.	Mini. temp.	Relative humidity	Sun-shine hours	Rain-fall	Max. temp.	Min. temp.	Relative humidity	Sun-shine hours
1	2	3	4	5	6	7	8	9	10	11
Simultaneous										
Rainfall	..	0.5551	0.5571	0.6240	0.5584	0.5231	0.5537	0.7099*	0.5813	0.6292
Maximum temperature			0.3996	0.6726	0.5516	0.6973*	0.5432	0.6578	0.6095	0.6372
Minimum temperature				0.6228	0.5522	0.6830	0.2743	0.3123	0.5323	0.6566
Relative humidity					0.6216	0.6893	0.6446	0.7349*	0.3413	0.6606
Sunshine hours						0.5956	0.5515	0.6920	0.5775	0.4235
One month previous										
Rainfall							0.8321**	0.8785**	0.6855	0.6784
Maximum temperature								0.7936*	0.5414	0.8083**
Minimum temperature									0.7299*	0.9257**
Relative humidity										0.6255
Sunshine hours										

* Significant at 5% level
** Significant at 1% level

maximum temperature, with maximum temperature and sunshine hours, with minimum temperature and relative humidity and with minimum temperature and sunshine hours, all one month previous to flowering.

The regression of flowering on weather parameters is given in Table 5. Sixtynine per cent of the variation in flowering could be explained by rainfall and maximum temperature one month previous to flowering. Rainfall and minimum temperature, one month previous to flowering could explain 77 per cent of the variation in flowering. Maximum and minimum temperatures one month previous to flowering could explain 63 per cent of the variation in flowering. 65 per cent of the variation in flowering could be explained by maximum temperature and sunshine hours one month previous to flowering. The strongest relationship was between minimum temperature and sunshine hours, one month previous to flowering. They could explain 86 per cent of the variation in flowering.

2. Total number of flowers per tree

a. Number of flowers per cushion

1. Main trunk

There was significant difference between the trees in the rate of production of flowers per cushion on the main trunk (Table 6). The superior plant had a mean of 9.3

Table 5. Regression of flowering with certain weather parameters

Weather parameters	Regression equation	Coefficient of determination (R^2)
1	2	3
Rainfall and Minimum temperature (Simultaneous) (one month previous)	$y = 194.34 - 0.2147\ x_1 - 68.3347^{**}\ x_2$	0.5037
Maximum temperature and Rainfall (Simultaneous) (one month previous)	$y = 909.72 - 16.152\ x_1 - 0.4829\ x_2$	0.4862
Relative humidity and minimum temperature (Simultaneous) (one month previous)	$y = 2191.25 - 6.2050\ x_1 - 61.7548^{*}\ x_2$	0.5401
Rainfall and maximum temperature (one month previous)	$y = 1936.17 - 0.7065^{*}x_1 - 46.2799^{**}\ x_2$	0.6929
Rainfall and minimum temperature (one month previous)	$y = 2270.20 - 0.3319^{*}x_1 - 81.1039^{**}\ x_2$	0.7718
Maximum temperature and minimum temperature (one month previous)	$y = 1853.78 + 33.0489^{*}\ x_1 - 111.8540^{**}x_2$	0.6298
Maximum temperature and sunshine hours (one month previous)	$y = 2501.57 - 66.81^{**}x_1 - 85.90^{**}\ x_2$	0.6533
Minimum temperature and relative humidity (one month previous)	$y = 2430.89 - 74.4^{*}\ x_1 - 5.41\ x_2$	0.5328
Minimum temperature and sunshine hours (one month previous)	$y = 2310.32 - 96.99^{**}\ x_1 - 39.73^{**}\ x_2$	0.8569

* Significant at 5% level
** Significant at 1% level

Table 6. Number of flowers per cushion

Cushion number	Main trunk					Fan shoots				
	Tree number					Tree number				
	C_8	C_{11}	C_{24}	C_{32}	C_{34}	C_8	C_{11}	C_{24}	C_{32}	C_{34}
1	2	3	4	5	6	7	8	9	10	11
1	4	4	6	2	4	4	5	6	6	5
2	3	5	7	6	2	4	5	9	5	5
3	6	3	12	3	6	2	3	4	6	3
4	6	7	9	1	2	3	5	4	6	2
5	5	5	11	4	5	5	3	5	3	3
6	7	1	11	4	1	1	2	7	3	1
7	2	4	8	3	4	3	6	6	4	3
8	6	4	12	3	3	6	5	8	6	4
9	1	6	9	8	5	5	4	3	7	5
10	3	6	8	6	2	3	4	4	6	5
Mean	4.3	4.5	9.3	4.0	3.4	3.6	4.2	5.6	5.2	3.6
F value			15.32**					16.63**		
CD			1.74					1.37		
SEm			3.71					2.32		

** Significant at 1% level

flowers per cushion. It ranged between 3.4 and 9.3. On an average a cushion on the main trunk produced 5.3 flowers. The number of flowers on a single cushion ranged between one and 12.

ii) Fan shoots

The rate of production of flowers per cushion on the fan shoot varied significantly between trees (Table 6). The mean number of flowers per cushion on the fan shoot varied between 3.6 and 5.6. On an average a cushion on the fan shoot produced 4.4 flowers. The number of flowers on a single cushion on the fan shoot varied between one and nine.

b) Number of cushions

1. Main trunk

There was no significant difference between the trees in the number of cushions per unit length of 50 cm. on the maintrunk (Table 7). It varied between 125 and 134. On an average a tree had 129.8 cushions in this area. The mean number of cushions on the entire length of the main trunk was 266.94. It ranged between 237.50 and 281.60.

ii) Fan shoots

The mean number of cushions on a single fan shoot was found to be 310.8. It ranged between 285 and 346. There

Table 7. Total flower production based on number of cushions and number of flowers per cushion

Tree number	Main trunk					Fan shoots				Total
	Number of cushions in 50 cm	Height cm	Number of cushions in the entire length	Mean number of flowers per cushion	Number of flowers in the trunk	Number of cushions on a single fan shoot	Number of fan shoots	Mean number of flowers per cushion	Number of flowers in fan shoots	
1	2	3	4	5	6	7	8	9	10	11
C_8	130	108	280.80	4.3	1207.44	310	5	3.6	5580.00	6787.44
C_{11}	125	95	237.50	4.5	1068.75	285	4	4.2	4788.00	5856.75
C_{24}	128	110	281.60	9.3	2618.32	346	3	5.6	5812.80	8431.68
C_{32}	132	97	256.08	4.0	1024.32	296	5	5.2	7697.00	8720.32
C_{34}	134	104	278.72	3.4	947.65	317	4	3.6	4564.80	5512.45
Mean	129.8	102.8	266.94	5.3	1371.41	310.8	4.2	4.4	5688.32	7061.73

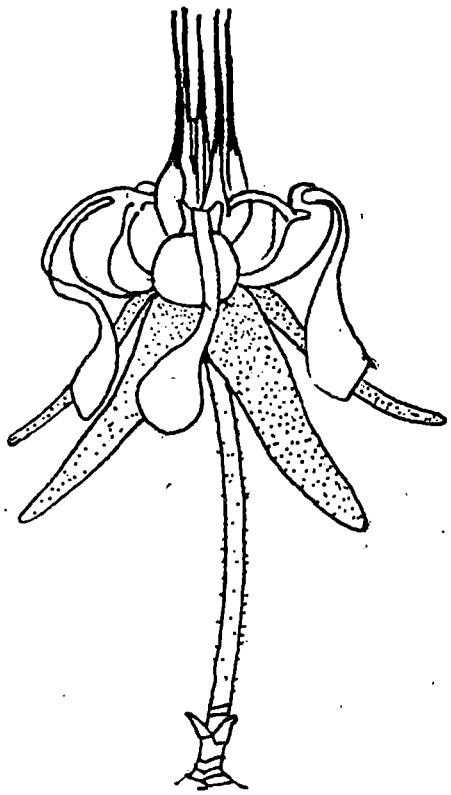
were three to five fan shoots on a single tree (Table 7).

Based on the number of flowers per cushion and number of cushions the mean number of flowers on the main trunk was 1,371.42. It ranged between 947.65 and 2,618.32. Similarly, the mean number of flowers on the fan shoots was 5,688.32. It ranged between 4,564.80 and 7,696,00. The mean number of flowers produced by a cocoa tree as a whole was 7,061.63. It varied between 5,512.45 and 8,431.68 (Table 7).

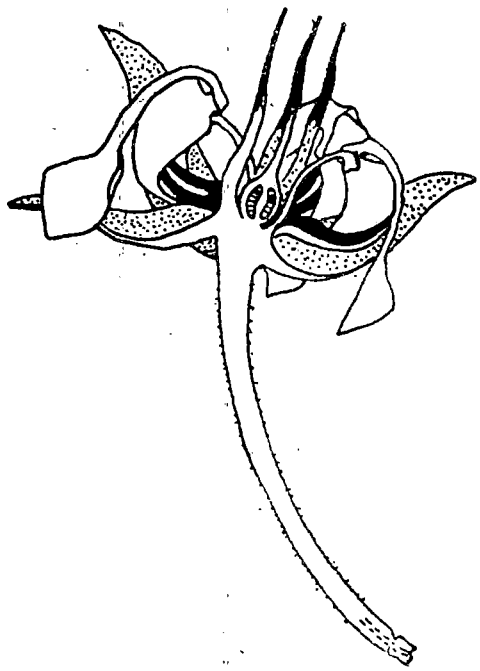
B. Floral characteristics

The long pedicelled flowers were regular and hermaphrodite (Fig.3). It had five sepals, five petals, ten stamens in two whorls, only one whorl of which was fertile and a superior ovary of five united carpels. The pink or whitish sepals were valvate in arrangement, the petals were very narrow at the base and expanded above into a cup-shaped pouch, beyond which they end in a relatively broad spatulate tip or ligule. The androecium consisted of five long pointed staminodes in the outer whorl, and five fertile stamens, which stood opposit to the petals. All ten were joined at the base into a very short tube. The filaments of stamens were bent outwards so that the anthers were concealed in the pouched portion of the corresponding petals, whilst the staminodes stood erect around the style. Each stamen had

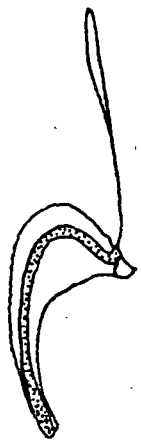
Fig 3. Floral characteristics



1. cocoa flower

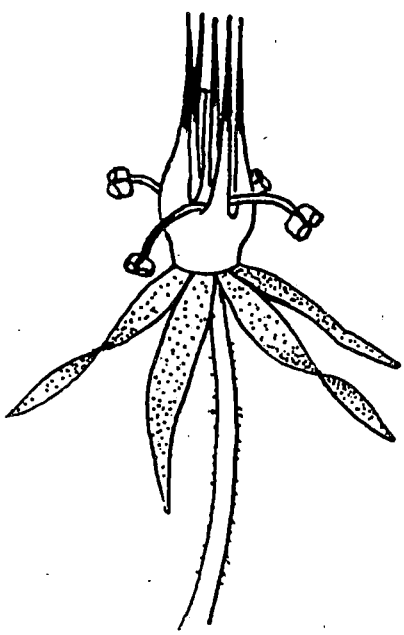


2. l.s. of a flower

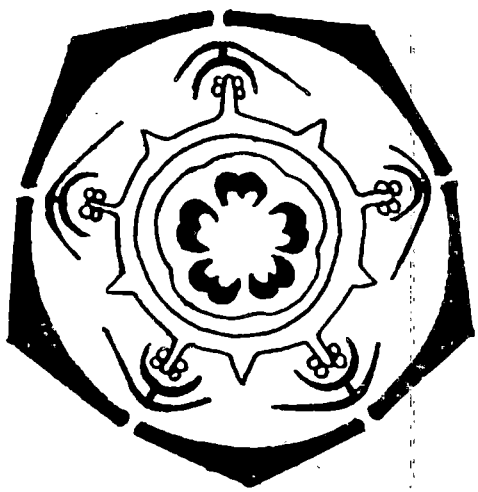


3. petal

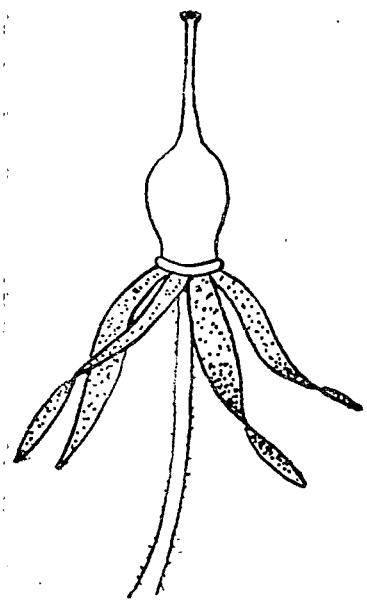
4. stamen



5. flower with petals removed



7. floral diagram
$K_5 C_5 A_{5+5} G_{(5)}$



6. pistil

four pollen sacs. The ovary was simple with five compartments containing numerous ovules arranged round a central placenta, the style was hollow, shorter than the surrounding fence of staminodes and divided at top into five stigmatic lobes which were more or less adherent.

C. Anthesis

1. Flower opening

Data on the time of anthesis based on observations at two hour intervals are given in Table 8. It was found that flower opening had two distinct stages. The flower buds at first showed the signs of splitting and remained in this condition for a long time until the sepals and petals unfolded and the flowers opened completely. The flower buds started splitting in the evening and completely opened in the next day morning. In majority of the flower buds (69.27 per cent) splitting commenced between 2 PM and 4 PM. Splitting started between 12 Noon and 2 PM and continued upto between 6 PM and 8 PM. It was observed that in the rainy months of June, July and August splitting of the flower buds started earlier between 10 AM to 12 Noon. In July and August, 68.15 per cent of the flower buds started splitting by 2 PM. 77.5 per cent of the flower buds completely opened between 2 AM and 4 AM on the next day. It commenced between 12 midnight and 2 AM

and continued upto 6-8 AM. In all the flowers examined anther dehiscence had occurred when the flowers had completely opened.

2. Stigma receptivity

When anthers from freshly opened flowers were rubbed on the stigmatic surface and observed under a hand lens adherence of pollen grains was found between 6 AM and 6 PM. The data on the number of pods set after two weeks by hand pollination at two hour intervals are given in Table 9. Maximum pod set was observed when the flowers were pollinated between 10 AM and 12 noon (70.8 per cent) followed by 12 noon and 2 PM (43.6 per cent) pollination. No pod set was observed when the flowers were pollinated between 6 AM and 8 AM and between 4 PM and 6 PM.

3. Pollen fertility

Using the acetocarmine method it was found that 61.18 per cent of the pollen were fertile. There was no significant difference in the pollen fertility between trees. The data on the variation in pollen fertility after anther dehiscence is given in Table 10. Maximum pollen fertility was found between 8 AM and 10 AM (61.12 per cent). After this, the pollen fertility decreased gradually.

Table 9. Stigma receptivity based on pod set after two weeks by hand pollination at two hour intervals.

Time	Number of pods set (out of 350 attempts)	Percentage
1	2	3
6 AM to 8 AM	-	-
8 AM to 10 AM	49	19.7
10 AM to 12 Noon	177	70.8
12 Noon to 2 PM	109	43.6
2 PM to 4 PM	32	12.8
4 PM to 6 PM	-	-

F value = 51.59**

CD = 5.49

SEm = 16.75

** Significant at 1% level

Table 10. Variation in pollen fertility after anther dehiscence (Mean of observations on five days)

Time	Pollen fertility percentage
6 AM to 8 AM	23.38
8 AM to 10 AM	61.12
10 AM to 12 Noon	37.70
12 Noon to 2 PM	16.20
2 PM to 4 PM	9.62
4 PM to 6 PM	8.20

F value = 97.56**

CD = 60

SEm = 21.098

** Significant at 1% level

D. Pollination

1. Mode of pollination

It was found that wind had no role in the transfer of cocoa pollen. The glass slides coated with glycerine did not show the adherence of any cocoa pollen.

The drippings of rain water collected from the flowers contained no cocoa pollen, ruling out the role of rain in cocoa pollination.

A variety of insects was found to visit the cocoa flowers. The insects associated with cocoa flowers are given in Table 11. The photomicrographs of the insects are given in Plate-II.

2. Natural pollination

a) Monthly rate of natural pollination

The monthly rate of natural pollination based on weekly observations are given in Table 12. There was no significant difference between the trees in the rate of natural pollination. However, between months there was significant difference in the rate of natural pollination. It was highest in September (49.0 per cent) followed by June (45.5 per cent) and lowest in February (18.0 per cent)

Table 11. Insects associated with cocoa pollination

Common name	Scientific name	Family	Order
1	2	3	4
Midges	Unidentified	Ceratopogonidae	Diptera
Midges	Unidentified	Scatopsidae	Diptera
Ants	Oecophylla smaragdina (Fabricius)	Formicidae	Hymenoptera
Ants	Plagiolepis longipes (Jardon)	Formicidae	Hymenoptera
Aphids	Unidentified	Aphididae	Hemiptera

Plate - II. Insects associated with cocoa pollination
(a) Unidentified midge of the family Ceratopogonidae (Diptera) X 25.6

Plate - II. Insects associated with cocoa pollination
(b) Unidentified midge of the family Scatopsidae (Diptera) X 28.4

Plate - II(a)

Plate - II(b)

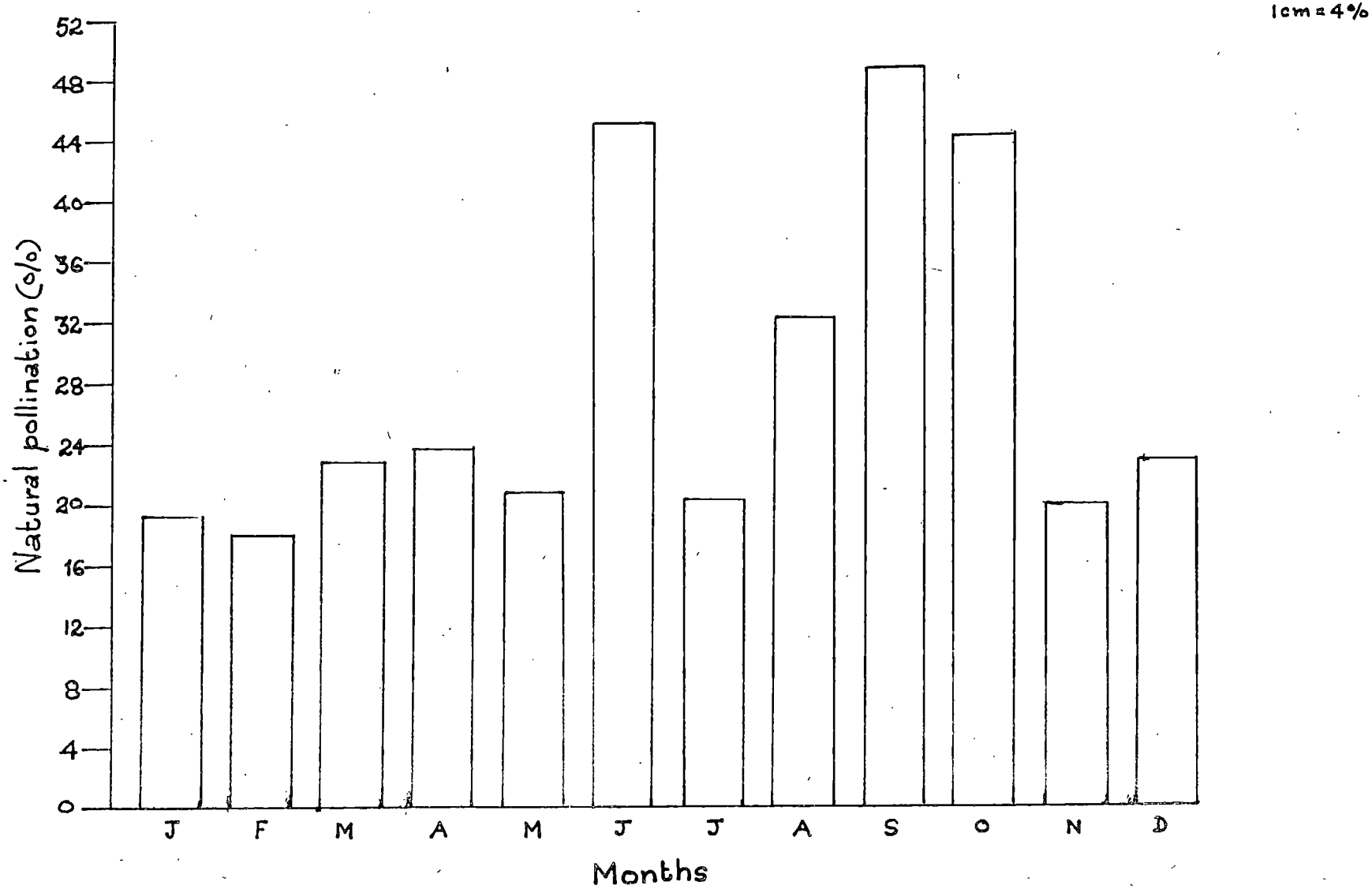
Plate - II. Insects associated with cocoa pollination
(c) Ant (*Plagiolepis longipes*);
(Formicidae, Hymenoptera) X 26·4

Plate - II. Insects associated with cocoa pollination
(d) Unidentified aphid (Aphididae, Hemiptera) X 25·6

Plate - II(c)

Plate - II(d)

Fig 4. Monthly rate of natural pollination



followed by January (19.5 per cent) (Fig.4). The mean rate of natural pollination was found to be 28.29 per cent.

b) Correlation of natural pollination with flower production and weather parameters

It was found that flower production had strong negative correlation with natural pollination. Among the weather factors rainfall, minimum temperature and sunshine hours had no significant correlation with natural pollination. However, maximum temperature had strong negative correlation and relative humidity had significant positive correlation with natural pollination (Table 13).

3. Controlled pollination

There was significant difference between the two methods of controlled pollination tried (Table 14). 76.4 per cent of the flowers pollinated using forceps was found to be successfully pollinated. The successful pollinations using atomiser was found to be only 3+ per cent.

E. Pod set and development

Out of the 382 crosses made 276 (72.25 per cent) set cherelles after two weeks (Table 17).

Table 13. Correlation of natural pollination with flowering and climatic factors.

Factor	Correlation coefficient
Flowering	-0.8001**
Rainfall	0.4950
Maximum temperature	-0.7729**
Minimum temperature	0.0878
Relative humidity	0.5777*
Sunshine hours	0.5555

* Significant at 5% level

** Significant at 1% level

Fig 5. Comparison of monthly rate of flower production with monthly rate of natural pollination.

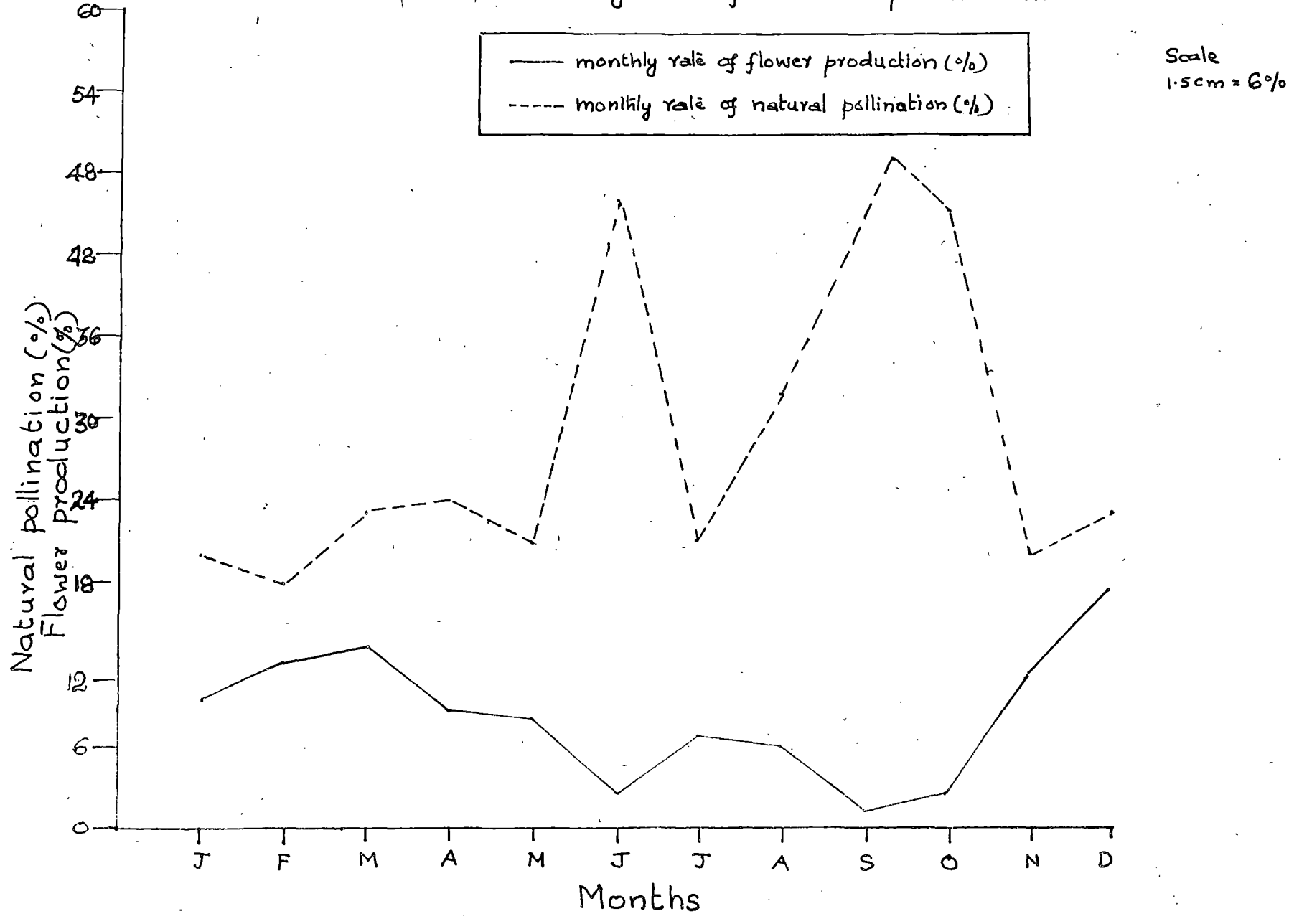


Table 14. Comparison of methods of controlled pollination (hand pollination with forceps and pollination by atomiser) based on the pod set after two weeks.

Sl. No.	Pod set after two weeks (out of 10 pollinations)									
	Tree number									
	C-20		C-22		C-30		E-32		C-35	
	Forceps	Atomiser	Forceps	Atomiser	Forceps	Atomiser	Forceps	Atomiser	Forceps	Atomiser
1	2	3	4	5	6	7	8	9	10	11
1	8	5	9	5	9	1	8	6	9	2
2	7	4	9	4	7	3	9	2	7	2
3	5	4	7	6	8	2	7	4	7	3
4	8	5	6	2	8	4	8	3	6	3
5	9	3	8	5	8	3	6	1	8	3
Total	37	21	39	22	40	13	38	16	37	13
Percentage	74	42	78	44	80	26	76	32	74	26

Mean percentage of successful pollinations using forceps = 76.4
Mean percentage of successful pollinations using atomiser = 34.0

F value = 17.67**
CD = 1.41
SEm = 56.18

** Significant at 1% level

Longitudinal sections of the developing pods showed that the individual beans could not be traced out upto four weeks after fertilisation. The pods were filled with a compact while pulpy non-mucilaginous mass. After four weeks the outlines of the future beans could be traced in the white pulpy non-mucilaginous mass. The beans gradually filled up but were difficult to separate from the cementing pulp. As the pods matured, the pulp became mucilaginous and the beans became distinct and easier to extract. At this stage the pods had a maturity of twenty weeks (Plate-III).

It took 23 to 25 weeks from pollination for the maturity of pods.

F. Cherelle wilt

The data on the weekly rate of cherelle wilt is given in Table 15. Maximum wilt (14.79 per cent) was found during the sixth week after fertilisation. The wilt continued upto 12 weeks after fertilisation and after that there was no loss due to cherelle wilt (Fig.6). Due to cherelle wilt alone 51.45 per cent of the pods were lost (Table 17). The loss due to cherelle wilt ranged from 37.04 per cent to 70.37 per cent. The total number of developing pods on the tree at the time of wilt was found to be in far excess of the

Plate - III. Longitudinal section of developing cocoa pods
1. five weeks old 2. twenty weeks old

Plate - III

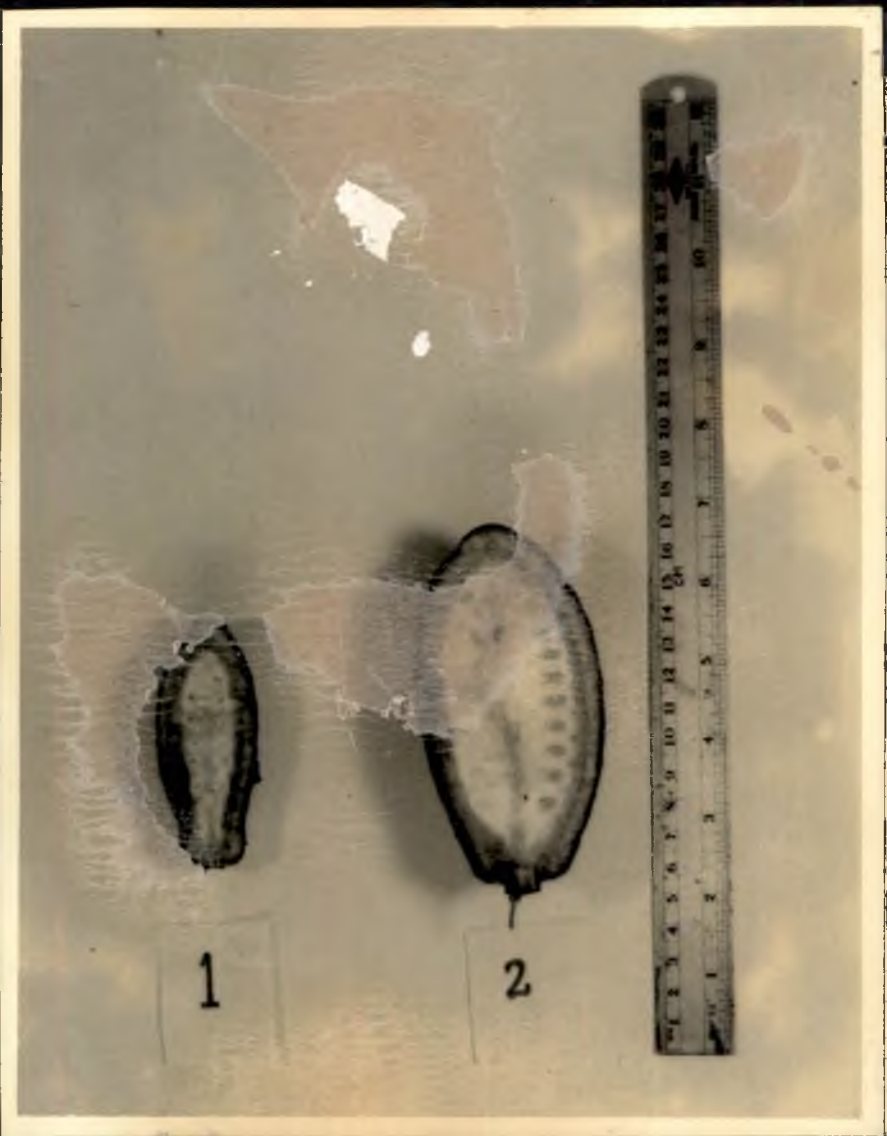


Fig 6. Intensity of cherelle wilt

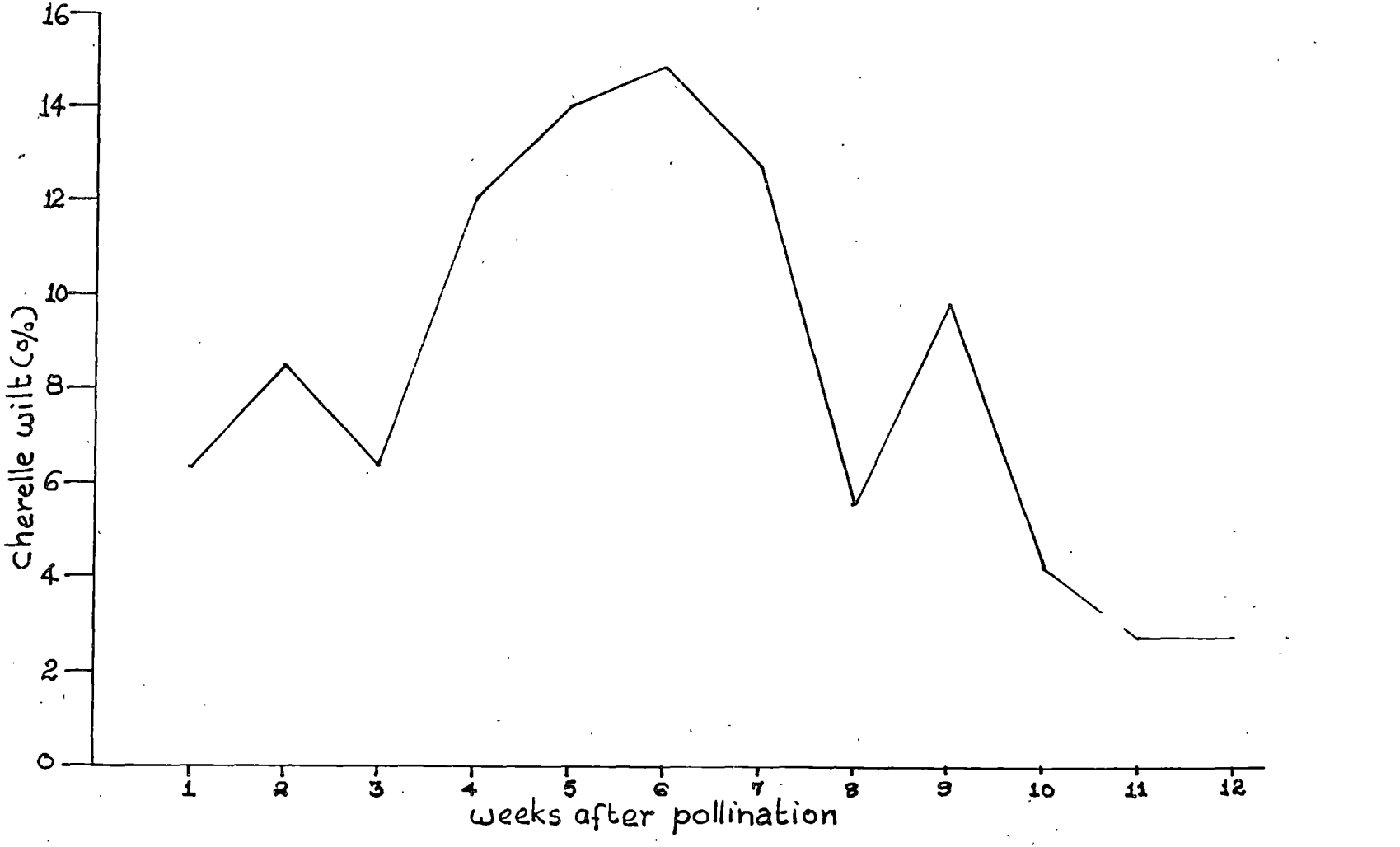


Table 16. Comparison of the pod yield in the preceding year with the number of pods developing on the tree at the time of cherelle wilt.

Tree number	Pod yield in the previous year	Number of pods developing on the tree at the time of wilt											
		1st week	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
1	2	3	4	5	6	7	8	9	10	11	12	13	14
4/18	32	35	37	39	39	30	40	42	43	44	44	44	44
5/18	35	37	40	40	41	41	42	42	44	45	46	46	46
9/16	55	53	55	57	58	58	59	60	60	61	61	61	62
13/10	41	42	42	43	43	43	43	44	44	44	45	47	48
13/12	38	37	38	38	38	39	39	39	40	41	41	41	42
16/19	69	64	64	65	65	65	66	68	70	72	73	73	74
18/10	49	52	53	53	53	53	55	57	57	58	58	58	58
19/16	33	34	36	37	38	39	39	39	39	40	40	41	42
21/4	43	45	46	48	49	50	50	50	50	51	51	52	52
29/25	46	45	45	46	47	47	47	48	48	49	50	50	51
30/14	35	38	39	39	39	40	40	41	41	41	42	42	43
33/15	26	29	29	29	30	30	32	32	32	33	34	36	36

average number of pods recovered from that particular tree in the previous year (Table 16).

G. Recovery of mature pods

From the observations it was found that on an average 48.55 per cent of the pods set were carried to maturity (Table 17). The recovery of mature pods ranged from 29.63 per cent to 62.96 per cent of the pod set. The recovery of mature pods was an average of 31.74 per cent of the number of crosses made. It ranged from 21.62 per cent to 44.74 of the crosses made.

H. Compatibility studies

Out of the seventeen trees selfed, two trees (16/16 and 21/19) were found to be self-compatible and all the others were self-incompatible. The percentage of pod set after selfing in the self-compatible trees were found to be a mean of 76.67.

All the trees tested, including the self-compatible ones were found to be cross-compatible. There was no difference in the compatibility status due to reciprocal crosses. The percentage of pod set in the different cross combinations ranged between 50 and 100 (Table 18). The cross combinations showing 100 per cent pod set were the crosses of

Table 17. Pod set, cherelle wilt and recovery of mature pods after controlled pollination in 12 selected trees.

Tree number	Number of crosses made	Pod set after two weeks		Pods lost due to cherelle wilt		Recovery of mature pods		
		Number	Percentage	Number	Percentage	Number	Percentage pod set	Percentage to crosses made
1	2	3	4	5	6	7	8	9
4/18	28	22	78.57	15	68.18	7	31.82	25.00
5/18	28	18	64.29	8	44.44	10	55.56	35.70
9/16	31	22	70.97	11	50.00	11	50.00	35.48
13/10	40	30	75.00	16	53.33	14	46.67	35.00
13/12	37	27	72.97	19	70.37	8	29.63	21.62
16/9	30	22	73.33	12	54.55	10	45.45	33.33
18/10	29	20	68.97	8	40.00	12	60.00	41.38
19/16	38	27	71.05	10	37.04	17	62.96	44.74
21/4	29	20	68.97	8	40.00	12	60.00	41.38
29/25	32	23	71.88	10	43.48	13	56.52	40.63
30/14	30	23	76.67	13	56.52	10	43.48	33.33
33/15	30	22	73.33	12	54.55	10	45.45	33.33
Total	382	276	72.25	142	51.45	134	48.55	31.74

the tree 4/18 with 5/18, 13/10, 16/16, 18/10, 30/14 and 33/15; 5/18 with 13/10, 16/9, 16/16, 18/10 and 21/19; 9/16 with 16/9, 18/10, 19/16 and 21/4; 13/10 with 4/18, 9/16, 18/10, 19/16, 21/4, 29/25 and 30/14; 13/12 with 4/18, 16/16 and 21/19; 16/9 with 4/18, 5/18, 13/12 and 21/4; 18/10 with 4/18 and 33/15; 19/16 with 13/12 and 29/25; 21/4 with 4/18, 19/16, 21/19 and 30/14; 29/25 with 4/18 and 13/12; 30/14 with 13/10, 16/9, 19/16,21/4 and 29/25 and 33/15 with 18/10.

Discussion

DISCUSSION

Investigations were carried out at the College of Horticulture, Vellanikkara, Trichur on the pollination, pod set, and compatibility aspects of cocoa, var. Forastero. The results of the investigations are discussed in this chapter.

A. Flowering

1. Pattern of flowering

Unlike most other perennial crops in which flowering was seasonal, cocoa exhibited flowering through out the year. But, there was variation in the monthly rate of flowering. In the present investigation the peak period of flowering was found from November to April (Table 1 and Fig. 1). From May to October the rate of flowering was comparatively less. However, the peak period of flowering differed from place to place. In Ghana, the peak period was from March to July (Hewison and Ababio et al., 1929), in Bahia from October to May (Alwim, 1966) and in Cuba from June to September (Delpinalrive and Acunagale et al., 1967).

The variation in the pattern of flowering in different cocoa growing regions can be attributed to the difference

in the weather conditions prevailing in those regions. The influence of weather parameters on flowering in cocoa was reported by several workers. In Bahia, Alvim (1960) found that flowering was inhibited when the monthly mean temperature went below 23°C. Under severe drought conditions flowering was seen to be less in Cuba (Delpinalrivero et al., 1967). Sale (1969) observed that in Trinidad, plants growing in regions with a day temperature 26.6°C to 30.0°C exhibited more flowering than plants growing in regions with a day temperature 23.3°C. According to Couprie (1972) flowering was the greatest when the daily temperature variation was the least. In the present investigation it was found that the mean monthly minimum and maximum temperatures, the mean monthly rainfall and the mean monthly sunshine hours, one month previous to flowering, determined the flower production. The mean monthly minimum and maximum temperatures and the mean monthly rainfall had an inverse effect on flowering while the mean monthly sunshine hours had a positive effect on flowering. Thus the peak period of flowering from November to April observed in this investigation can be due to the effect of low minimum temperature, high maximum temperature, absence of heavy showers and comparatively longer sunshine hours during the October to March period.

2. Intensity of flowering

Trees differed in their capacity to bear flowers on cushions. Purseglove (1974) opined that a fully developed cushion may bear upto 50 flowers. But in the present investigation it was found that the number of flowers per cushion ranged between one and 12 on the main trunk and between one and nine on the fan shoots (Table 6). In Vittal, Karnataka the annual flower production per metre of stem varied between 168 and 2,358 (Anon., 1977), and in Kerala, the number of flowers per 50 cm on the tree varied between 93 and 904 (Gregory, 1983). The present investigation showed that the mean number of flowers ranged between 947.65 and 2,618.32 on the main trunk and between 4,564.8 and 7,696.0 on all the fan shoots taken together (Table 7). Thus, the fan shoots on a whole had more number of flowers than the main trunk. Studies on the distribution of yield between trunk and branches of cocoa in Ghana, showed that a higher percentage of pods was produced on the branches than on the trunk (Anon., 1974). The results obtained in the present investigation is in agreement with this observation.

B. Floral characteristics

Although the flowers were bisexual, the floral parts were arranged in such a manner as to encourage

cross-pollination. The filaments of the stamens were bent outwards and the anthers were concealed in the pouched portion of the petals. The staminodes stood erect around the style as a barrier and the style was shorter than the staminodes. All these features hinder the transfer of pollen to the style from the anthers of the same flower, thus preventing self-pollination. Nevertheless, the flowers had no characteristic features typical of the cross-pollinated crops. The flowers were devoid of scent and nectar for attracting insects and the pollen was too sticky to facilitate wind pollination.

C. Anthesis

Flower opening in cocoa was observed to be a lengthy process. The flower buds at first showed the signs of splitting and remained so for a long period until the petals and sepals completely unfolded. The splitting started between 2 PM and 4 PM and the flowers completely unfolded between 2 AM and 4 AM on the next day. It took about 12 hours for the completion of flowering. In the rainy months the splitting started a little earlier between 10 AM and 12 Noon. It was found that the time of opening of cocoa flower varied from place to place. In Java the flowers opened at 4.30 PM and at around 6.30 PM the pollen grains were ripe (Wellensiek, 1932). Sampayan (1963) observed that in the Philippines

anthesis started at 4 PM, the petals and sepals unfolded by 6 PM and anthers dehisced at 6 AM on the following morning. In Cuba, the flowers opened at 7 PM, but remained closed or half-opened for almost the whole day at a temperature of 15°C (Delpinalrivero and Acunagale, 1967).

The time of natural pollination was arrived at by many workers. Barroga (1965) reported that in the Philippines the highest rate of pollination was observed from 6 AM to 11 AM and from 2 PM to 5 PM. In Nigeria, Toxopeus and Jacob (1970) observed that the percentage of pistils with pollen grains was slightly higher in the flowers collected between 12 Noon and 1 PM. Based on hand pollinations at hourly intervals Sampayan (1966) observed that in the Philippines the percentage of fruit set was more between 6 AM and 5 PM, reaching a maximum when pollinations were done between 10 AM and 1 PM. Almost a similar observation was made in the present investigation. It was found that the stigma remained receptive between 6 AM and 6 PM. By hand pollination trials it was found that stigma receptivity was the maximum between 10 AM and 12 Noon. Maximum pollen fertility was found between 8 AM and 10 AM. Thus it can be assumed that the optimum time for controlled pollination is between 9 AM and 12 Noon.

D. Pollination

1. Mode of pollination

In the present investigation, it was found that wind and rain-water had no role in the transportation of cocoa pollen. Midges of the family Ceratopogonidae and Scatopsidae were found to be associated with the cocoa flower. Many workers had identified midges of the family Ceratopogonidae, particularly Forcipomyia spp. as the major pollinating insect in cocoa (Posnette, 1950; Saunders, 1956; Dessart, 1961; Summer, 1962; Gerad and Saunders, 1964; and Soria et al., 1975). In the present investigation crawling insects like ants (Oecophylla smaragdina and Plagiolepis longipes) and aphids were also found to be associated with the cocoa flower. Hernandez (1967) too had identified ants (Wasmannia auropunctata) and aphids as the pollinating insects of cocoa at Turialba.

2. Rate of natural pollination

The rate of natural pollination was observed to be very low in cocoa. In Ghana, Purseglove (1974) reported that only two to five per cent of the flowers were pollinated, but later during the season when the flowers were fewer, pollination rose to 50 to 75 per cent. Murray (1975) found

that the proportion of flowers pollinated ranged from one to 50 per cent according to the season and number of flowers opening at the time. In the present investigation also it was found that when the monthly rate of flower production was more, the rate of natural pollination was less and vice versa (Fig.5). The highest rate of natural pollination (49.0 per cent) was observed in September and the lowest (19.5 per cent) in February (Table 12). In Vittal, Karnataka the percentage of flowers pollinated was 28 and maximum per cent of pollination was observed in August (Anon., 1977).

Natural pollination was also found to be influenced by weather conditions. When the mean monthly maximum temperature increased natural pollination decreased, and when the mean monthly relative humidity increased the rate of natural pollination also increased. This can be due to the influence of weather conditions on the population densities of the pollinating insects. Studies conducted by Soria (1977a) in Bahia had shown that there was significant correlation between temperature and evapotranspiration with the population densities of pollinating agents. Heat, soil-water availability and air-humidity also interacted with the population of pollinating insects and pollination. In a later study Soria (1979) had found that air-temperature, soil-moisture conditions, rainfall and sunshine patterns determined the population

density of the pollinating insects. Winder and Silva (1974) had reported that the abundance of the pollinating insects was positively correlated with soil-moisture content, with the result that pollinators were most abundant when the flowering was at a minimum and vice versa.

3. Controlled pollination

Several workers had tried artificial pollination in cocoa. Posnette (1950) and Jacob and Atanda (1975) observed that pod yield could be considerably increased by hand pollination. Vello and Nascimento (1971) found that in four clones they studied the percentages of hand pollinations resulting in fruit setting were 13.5, 14.1, 21.6 and 38.8. Amponsha (1972) also reported that the percentage of fruit set by hand pollination was much higher than that by natural pollination. Arevalo and Soria (1975) compared different methods of artificial pollination like individual pollination of flowers, milking, brushing and mist blowing. They found individual pollination of flowers as the most efficient method for increasing yields. In the present investigation also when hand pollination of flowers with forceps was compared with pollination using atomiser, it was found that the former one was a superior method. The percentage of fruit set on pollination by forceps was 76.4 and by atomiser was 34.0.

But, hand pollination with forceps was more time consuming and a skilled operation. However, artificial pollination significantly increased the pod set. Knoke et al. (1980) had also observed that mechanical pollination of cocoa using mist blowers or by brushing cocoa flowers greatly increased pod set. Soria and Garcia (1980) opined that the technique of blowing air over the self-compatible varieties nearly doubled the yield. From these observations it can be concluded that pollination in cocoa is a limiting factor for realising better yields and artificial pollination can be adopted for increasing the pod yield.

E. Pod set and development

The percentage of pod set observed after crossing compatible trees by hand pollination was found to be 72.25. By natural pollination the pod set was only 28.29 per cent. Jacob and Atanda (1975) while assessing the fruit setting status of 23 cocoa clones used as both male and female parents, found that the best male parent had 55.7 per cent pod setting and the best female parent had 58.2 per cent pod setting. In Vittal, Karnataka the mean annual fruit setting was only three per cent (Anon., 1977) and in Pilicode, Kerala, the fruit set under natural pollination was 11.81 per cent and under hand pollination was 52.02 per cent (Rajamony, 1981).

In the present investigation, cocoa pods took 23 to 25 weeks to reach the maturity stage. The period of development of cocoa pods was reported to be 16 to 21 weeks in Nigeria (Waters and Hunter, 1929) and five to six months in Ghana and New Guinea (Toper, 1940 and Bridgland, 1953). The time taken by cocoa pods to reach maturity stage from fertilisation was reported to be five months (Wood, 1975), five to six months (Anon., 1978), and 127 to 141 days (Rajamony, 1981). The observation made in the present investigation almost agrees with the observations made by other workers.

Studies on the development of beans in the developing pods showed that upto four weeks the individual beans could not be traced in the pod. The pod was filled with compact, white, non-nucligenous mass. After four weeks the outlines of the future beans could be traced and after twenty weeks the beans became distinct and it could be extracted easily. Similar work was done by Adenikinju (1978) and he found that at the time when the beans could be extracted easily from the pod, the pods varied in age from 147 to 175 days.

F. Cherelle wilt and recovery of mature pods

In all the trees studied cherelle wilt occurred even from the first week after pollination and continued upto

12 weeks. Maximum wilt (14.79 per cent) was observed during the sixth week after pollination (Table 15). Mc Kelvie (1955)had made a similar observation with the peak at the seventh to eighth week, but he had also identified a second peak at about twelveth week and he also observed that cherelle wilt continued upto 14 weeks. But Hewsion and Ababio (1924) observed maximum cherelle wilt during the first week of growth and another critical period between fourth and seventh weeks. According to Nichols (1961) cherelle wilt occurred upto 80 days from fertilisation and according to Purseglove (1974) maximum wilt occurred at about 50 days after fertilisation. Cobley and Steele (1976) found that cherelle wilt was maximum when the pods were seven to eight weeks old. The results obtained in the present investigation are more or less in agreement with the observation made by the other workers.

The extent of loss due to cherelle wilt in the trees in which hand pollination was made ranged between 37.04 per cent and 70.37 per cent (Table 17) of pod set. Hewison and Ababio (1924) had estimated the loss due to cherelle wilt to be ranging between 22 and 84 per cent of pod set. So cherelle wilt is a major factor limiting the yield of cocoa. In the present investigation in the trees

in which hand pollinations were made, the recovery of mature pods ranged from 21.62 to 44.74 per cent of the pollinations made and 29.63 to 62.96 per cent of the pod set. Jacob and Atanda (1975) had observed a recovery of 25.7 and 18.2 per cent of mature pods in the best male and female parents respectively in their study. The increased recovery of mature pods in the present investigation may be due to the increased pod set by hand pollination.

Many workers were of the opinion that cherelle wilt was a physiological thinning mechanism which regulated the sizes of the crop in relation to the available food reserves (Frederick, 1960; Nichols, 1961; Glendenning, 1972; and Cobley and Steele, 1976). In the present investigation also it was found that at the time of cherelle wilt the trees had a large number of pods in different stages of development on them. The total number of developing pods was in far excess of the potential yield of the trees in the previous year (Table 16).

G. Compatibility studies

Incompatibility in cocoa, particularly self-incompatibility was studied in great detail by many workers (Harland, 1925; Pound, 1932; Knight and Rogers, 1955; Cope, 1958 and 1962; Bouharmont, 1960 etc.). Self-incompatibility

was found to be a major barrier in realising the yield potential of cocoa (Toxopeus and Jacob, 1970; Jacob and Atanda, 1975). In the present investigation also only two trees out of 17 were found to be self-compatible. All the trees tested for cross compatibility, including the ones found to be self-compatible were cross-compatible and there was no difference due to reciprocal crosses. Murray (1975) had observed that in Trinidad, the self-incompatible and cross-compatible trees required pollen from self-compatible trees to ensure fruit set, but elsewhere self-incompatible trees showed cross compatibility which was also the situation in the present study.

The modalities of the incompatibility systems in cocoa was assessed in detail by Cope (1962a). He showed that the site of incompatibility was in the embryosac. Incompatibility was controlled by a series of alleles operating at a single locus (S) showing dominance or independent relationship. They were the same in male and female parts of the flower so that the reciprocal pollination gave the same results, which was true in the present investigation also.

From the present investigations, it can be concluded that, even though cocoa produced a large number of flowers, only a few of them were carried to mature pods. Pollination

was the main limiting factor. Since artificial pollination significantly increased pod set, this can be adopted as a practice for obtaining better yields. The self-incompatibility phenomenon observed in the materials investigated herein could be effectively utilised in the production of hybrid pods.

Summary

SUMMARY

Investigations were carried out at the College of Horticulture, Vellanikkara, Trichur on the pollination, pod set and compatibility aspects of a number of open pollinated progenies of cocoa, Var. Forastero. The salient results obtained in the investigation are summarised below.

1. Cocoa flowered through out the year, though the intensity varied between months. Maximum flowering was observed in December, while the minimum flowering was in September. The peak period of flowering was from November to April. The mean monthly minimum and maximum temperatures, the mean monthly rainfall and the mean monthly sunshine hours one month previous to flowering, determined the flower production.

2. The number of flowers borne on a cushion ranged between one and 12 and a single cocoa tree produced a mean of 7061.63 flowers during an year. The fan shoots taken together had more number of flowers than on the main trunk.

3. Flower opening was a slow process and it took nearly twelve hours for the completion of flowering. Flower buds started splitting between 2 PM and 4 PM and completely unfolded between 2 AM and 4 AM on the next day.

4. The stigma remained receptive between 6 AM and 6 PM, but the maximum stigma receptivity was found between 10 AM and 12 Noon. The pollen was found viable between 6 AM and 6 PM, but the maximum pollen fertility was found between 8 AM and 10 AM.

5. Natural pollination took place with the help of insects and midges of the family Ceratopogonidae and Scatopsidae were the major pollinating insects. Ants and aphids were also seen associated with the cocoa flowers.

6. Natural pollination was more when the flower production was less and vice versa. The mean monthly maximum temperature had a negative influence and the mean monthly relative humidity had a positive influence on the rate of natural pollination.

7. Controlled pollination significantly increased the pod set in cocoa. Hand pollination with forceps was more efficient than pollination by atomiser.

8. Cherelle wilt was found to be a physiological thinning mechanism. It was observed even from the first week after pollination and continued upto 12 weeks. Maximum wilt occurred in the sixth week. The loss due to this phenomenon ranged from 37.04 per cent to 70.37 per cent of pod set.

9. It took 23 to 25 weeks from pollination for the maturity of cocoa pods. The recovery of mature pods ranged from 21.62 to 44.74 per cent of the pollinations made and 29.63 to 62.96 per cent of the pod set.

10. Only two out of the seventeen trees were found to be self-compatible. All others were self-incompatible and they were found to be cross-compatible. There was no difference due to reciprocal crosses and the self compatible trees were also found to be cross-compatible.

References

REFERENCES

Adams, S.N., and Mc Kelvie, A.D. (1955). Environmental requirements of cocoa in the Gold Coast. Rep. Cocoa. Conf., London: 22-27.

Adenikinju, S.A. (1978). The selection of cocoa pods for raising seedlings. Cocoa Growers' Bull. 27: 27-3

*Alvim, P de T. (1965). The flowering of cocoa in Bahia. Cacau Atual., 2: 71-72.

Alvim, P de T. (1966). Factors effecting the flowering of the cocoa tree. Cocoa Growers' Bull. 7: 15-19.

Alvim P. de T. (1974). Physiological responses of cacao to environmental factors. Revista Theobroma, 4 (4): 3-25.

Alvim, P. de T., Mackado, A.D., and Vello, F. (1972). Physiological responses of cocoa to environmental factors. Proc. Fourth. Int. cocoa. Res. Conf., Trinidad.

Amponsha, J.D. (1972). Pollination aspects in cacao. Ann. Rep. Cocoa. Res. Inst., Ghana: 26-27.

*Amponsha, J.D. (1975). Studies in natural pollination of cocoa in Ghana. Acta Horticulturae (Netherlands), 49: 223-229.

Amponsha, J.D. (1977). Natural and hand pollination in cacao. Ann. Rep. Cocoa. Res. Inst., Ghana: 26-27.

Ananthakrishnan, S., Balakrishnan Nair, K. and Samuel, T.V. (1979). Perspective land use plan for important perennial crops in Kerala. Kerala State Land Use Board, Trivandrum.

Anonymous (1974). Distribution of yield between trunk and branches of cocoa. Ann. Rep. Cocoa. Res. Inst., Ghana: 19-26.

Anonymous (1977). Collection, evaluation and breeding of cacao. Annual Report, CPCRI, Kasaragod: 138.

Anonymous (1978). Package of practices for cacao. Extension pamphlet No.4E, Director, CPCRI, Kasaragod, Kerala.

Anonymous (1981). The cocoa of Discord. Planter's cronicle, 26 (8): 366-369.

*Arevalo, A.R. and Soria, S. de J. (1975). Evaluation de cautio methods de polinizacion artificial en cl aumento de produccion de Cacao, Theobroma cacao, L. Proc. Fifth. Int. Cocoa Res. Conf. 79-80.

Barroga, S.F. (1965). Progress report on the study of insects, particularly midges associated with pollination of Theobroma cacao. Phil. J. Plant. Ind., 29 (3-4): 113-133.

Bartley, B.G. (1963). Compatibility studies in cacao. Rep. Cacao. Res. I.C.T.A., Univ. of West Indies; Trinidad: 114-115.

*Bouharmont, J. (1960).Recherches cytologiques sur la fructification at 1'incompatibilitie chez. Theobroma cacao.Heredity, 9: 69-77.

Boussard, B. (1981). Pollination in tree fruits and cacao: a bibliographic study. Cafe Cacao The., 25 (4): 297-304.

*Bridgland, L.A. (1953). Study on the relationship between cacao yield and rainfall. Papua and New Guinea Agric. Gaz., 8 (2): 7-14.

*Cautrecasas, J. (1948). Climatic requirements of cocoa. Tropic. Agric., 32 : 84

*Cautrecasas, J. (1964). Cacao and its allies: A taxonomic revision of the genus Theobroma. Contrib. US Nat. Herb., 35 (6): 379-614.

Chat, C.M. (1953). Cocoa. Interscience Publishers, London.

Cobley, L.S., and Steele, W.M. (1976). An introduction to the botany of Tropical Crops: ELBS and Longman, 2nd Ed. pp.207-214.

Cooper St.G.C. (1940). A note on the maturation period of cacao pods in Grenada. Trop. Agric., 17: 165.

Cope, F.W. (1940). Agents of pollination in cacao. 9th Ann. Rep. Cocoa. Res. I.C.T.A., Univ. of West Indies, Trinidad: 13-19.

Cope, F.W. (1958). Incompatibility in Theobroma cacao. Nature, 181: 279.

Cope, F.W. (1962 a). The mechanism of pollen incompatibility in Theobroma cacao L. Heredity, 17: 157-182.

Cope, F.W. (1962 b). The effects of incompatibility and compatibility on genotype proportions of Theobroma cacao L. Heredity, 17: 183-195.

*Coral, F.J., Soria V.J. (1972). Different degrees of self compatibility in Theobroma cacao L. Proc. Fourth. Int. Cocoa Res. Conf. 77-81

Couprie, F. (1972). Aspects of cacao ecophysiology in relation to its productivity in Uganda. Cafe Cacao The, 16 (1): 31-43.

*Delpinalrivero, C.S., and Acunagale, J. (1967). Floral physiology of cocoa. Rev. Agric. Cuba, 1 (3): 82-111.

*Dessart, P. (1961). Contribution a uetudic des Ceratopogonidae (Diptera), les Forcipomyia pollinsateurs der cacaoyer. Bull. Agri. du. Congo, 52 (3): 525-540.

Entwistle, P.F. (1972). Pests of cocoa. Longman, London. pp. 448-473.

Erneholm, I. (1948). Cocoa production of South America. Gothenburg.

Fontanilla - Barroga, S. (1962). A progress report on the study of insects associated with pollination of Theobroma cacao with special emphasis on midges. Phil. J. Agr., 27 (3-4): 147-159.

Frederick, H. (1964). Cacao Manual, Inter-American Institute of Agri. Sciences, Turialba, Costa Rica.

Gerard, B.M., and Saunders, L.G. (1964). Pollination studies. Rep. Cocoa. Res. Inst., Ghana: 46-47.

Glendenning, D.R. (1972). Natural pollination of cacao. New Phytologist, 71 (4): 719-729.

Gregory Zachariah (1983). Genetic variability and correlation studies in cocoa (Theobroma cacao, L.) M.Sc.(Ag) Thesis. 1983. Kerala Agricultural University, pp.1-42.

Hamphries, E.C. (1947). Wilt of cocoa fruits: IV - Seasonal variation in the carbohydrate reserves of the bark and wood of the cacao tree. Ann. Bot. N.S.II: 219.

Hernandez, B.J. (1967). Insect pollination of cocoa in Costa Rica. Dis. Abstr., Sect. B., 28: 2-3.

Heslop, H.Y., and Shivanna, K.R. (1977). The receptive surface of the angiosperm stigma. Ann. Bot., 41 (176): 1233-1258.

Hewison, H.K., and Ababio, N. (1929). Flower and fruit production of Theobroma cacao. Dept. Agri., Gold Coast, Year Book: 89-94.

Jacob V.J., and Atanda, O.A. (1975). Compatibility and fruit setting in Theobroma cacao L. Revista Theobroma, CEPEC, Brazil, 5 (2): 12-18.

Jacob V.J., Toxopeus, H., and Atanda, O.A. (1969). Rep. Cocoa. Res. Inst., Nigeria: 126.

Kaufmann, T. (1975). Studies on the ecology and biology of cocoa pollinator, Forcipomyia squamipennis I and M (Dipetra, Ceratopognidae) in Ghana. Bull. Ent. Res., 65: 263-268.

Knight, R., and Rogers, H.H. (1955). Incompatibility in Theobroma cacao. Heredity, 9: 69-77.

Knoke, J.K., Soria S. de J., and Chapman, R.K. (1980). Cacao pollination with spray equipment in Costa Rica. Revista Theobroma, 10 (4): 213-224.

Lucas, P. (1981). Study of cocoa tree pollination conditions in Togo. Cafe Cacao The, 25 (2): 113-120.

Lucas, P., and Decazy, B. (1981). Influence of insecticide treatments against cacao tree mirids on pollination conditions. Cafe Cacao The, 25 (1): 29-36.

Martinson, V.A. (1973). Ann. Rep. Cocoa. Res. Inst., Ghana: 178-179.

Massaux, F., Tchiendji, C., Misse, C., and Decazy, B. (1976). Study of the cocoa tree pollen dissemination with the P^{32} labelling method. Cafe Cacao The, 20 (3): 163-172.

Mc Kelvie, A.D. (1954). Ann. Rep. West-Afric. Cocoa. Res. Inst.. 1953-54. pp.23.

Mc Kelvie, A.D. (1956). Cherelle wilt in cacao: I - pod development, its relation to wilt. J. Exp. Bot., 7: 252-263.

Mc Kelvie, A. D. (1954). Cherelle wilt in Trinidad introductions. Ann. Rep. West Afric. Cocoa Res. Inst., pp. 60

Mire, B. De., and Mbondji Mbondji, P. (1972). Insect pollinators of cacao in cross-fertilisation in the Cameroon. In: IV. Int. Cocoa. Res. Conf., Trinidad pp. 566-569.

Mossu, G. (1980). Behaviour of some clones under manual pollination: ovular fertility and early flower shedding. Cafe Cacao The, 24 (2): 113-120.

Murray, D.B. (1975). The botany of cocoa in Cocoa (Wood, G.A.R.Ed.) Longman, London: 7-18.

Naundorf, G., and Villamil, G.F. (1949). A contribution to the study of physiology of cocoa: I - Premature fruitfall and cherelle wilt of the young fruits and possible way of avoiding it. Not. Agron. Palmira. 2: 81-93.

Nichols, R. (1961). Xylem occlusions in the fruit of cacao (Theobroma cacao L.) and their relation to cherelle wilt. Ann. Bot., 25: 463.

Ostopenko, V.I. (1956). An evaluation of different methods of determining pollen viability. Bijul. nauc. techn. inform. genet. labor. Inn. I.V.Micurina, 2: 38-41.

Parvais, J.P., Reffye, P.de., and Lucas, P. (1977). Observations on free pollination in Theobroma cacao. Mathematical analysis of data and modelling. Cafe Cacao The, 21 (4): 253-262.

Paulin, D. (1981). Contribution to the study of flower biology of the cocoa tree: results of artificial pollination. Cafe Cacao The, 28 (2): 105-112.

Posnette, A.F. (1950). The pollination of cacao in Gold Coast. J. Hort. Sci., 25: 155-163.

Posnette, A.F., and Entwistle, H.M. (1958). The pollination of cocoa flowers. The cocoa choclate and confectionary alliance cocoa conference, London: 66-68.

Purseglove, J.W. (1974). Tropical Crops: Dicotyledons, Vol. I & II. ELBS and Longman, London. pp.570-598.

Rajamony, L. (1981). Studies on the floral biology and fruit set in cocoa (Theobroma cacao L.) M.Sc.(Hort.) Thesis 1981 Kerala Agricultural University, pp.1-88.

Ravindran, P.N. (1977). In vitro germination and growth of cacao pollen. J. Plant. Crops, 5 (2): 109-111.

Reffye, P.de., Parvais, J.P., Coulibaly, N., and Gervais, A. (1980). Study on pollination of cacao on the basis of insect traffic; mathematical model and simulation. Cafe Cacao The, 24 (2): 83-100.

Reffye, P. de., Parvais, J.P., Mossu, G., and Lucas, P.(1978). Influence of pollination hazards on the yields of the cocoa tree. Mathematical model and simulation. Cafe Cacao The, 22 (4): 251-274.

Reyes, E.H., Dereyes, L.C., and Armas, P.G. (1969). Observations on cherelle wilt of cacao. Agron. Trop. Maracay, 19: 19-28

Ruinard, J. (1963). A contribution to the technique of hand pollination in cacao. Trop. Agr., Trinidad, 40 (4): 285-286.

Sale, P.J.M. (1969). Flowering of cocoa under controlled temperature conditions. J. Hort. Sci., 44:163-173.

Sampayan, T.S. (1963). Flower structure and biology in cocoa. Cafe Cacao The, 13 (1): 144-148.

Sampayan, T.S. (1966). Flower biology, fruting habit and compatibility relationship in cocoa. Phil. J. Plant. Ind., 31: 193-201.

*Saunders, L.G. (1958). The pollination of cacao. Cacao, 3 (15): 1-4.

Shanmughavelu, K.G., and Madhava Rao, V.N. (1977). Spices and Plantation Crops. Popular Book Dept, Madras. pp. 143-167.

Shapiro, N., and Budrick, A.B. (1961). The effect of environment on pollen germination. Tomato Genet. Coop. Rep., 11: 26.

Simmons (1976). Cocoa production: economic and botanical perspective. Praeger Publishers, New York, pp.337.

Singh, S.N. (1961). Studies on the morphology and viability of the pollen grains of mango. Hort. Adv., 5: 121-124.

Singh, S.N., Randhawa, G.S., and Sharma, D.K. (1961). Pollen storage and pollen germination on fruit crops: a review. Indian J. Hort., 18 (1): 85-90.

*Soria, S. de J. (1975). Use of an atomiser to induce production of the cacao tree. Cacau Atual., 12 (1): 18-21.

Soria, S. de J. (1977a). Population dynamics of Forcipomyia spp. (Diptera, Ceratopogonidae) in Bahia, Brazil. e. Biotic variables related to natural cacao pollination. Revista Theobroma, 7 (1): 19-33.

Soria, S. de J. (1977b). Population dynamics of Forcipomyia spp (Diptera, Ceratopogonidae) in Bahia, Brazil. 3. Climatic variables related to cacao pollination. Revista Theobroma, 7 (2): 69-84.

*Soria, S. de J. (1979). The effect of climatic and biotic factors on the population dynamics of Forcipomyia spp. and cacao pollination in Bahia, Brazil. Cacaotero Colombiano (Colombia), 9 : 41-46.

Soria, S. de J., Abreu, J.M. (1976). Population dynamics of Forcipomyia spp. Midges (Diptera, Ceratopogonidae) in Bahia, Brazil. 1. Seasonal fluctuation of cacao pollinators related to rainfall and water balance. Revista Theobroma, 6 (2): 47-54.

Soria, S. de J. and Bystrak, P.G. (1975). A new species of Forcipomyia (Diptera, Ceratopogonidae) described in all stages, with an account of its role as a cacao pollinator. Revista Theobroma, 5 (2): 3-11.

Soria, S. de J., and Garcia, J.R. (1980). Mechanical pollination of cacao using motorised knapsack sprayers in Brazil: agro-economical assessment. Revista Theobroma, 10 (3): 135-140.

*Soria, S. de J., Tonosaki, S., and Morino, J. (1975). Pollination of cacao by Forcipomyia in vivo. Cacau Atual. 12 (3): 14-18.

Soria, S. de J., Wirth, W.W., and Besemer, H.A. (1978). Breeding places and sites of collection of adults of Forcipomyia spp. midges (Diptera, Ceratopogonidae) in cacao plantations in Bahia, Brazil: a progress report. Revista Theobroma 8 (1): 21-29.

Summer, H.M. (1962). Pollination in Agriculture and land use in Ghana. Oxford University Press, London, Wills, B.Ed. pp. 260-261.

Toper, M. (1940). Pod development in cocoa (Theobroma cacao). J. Hort. Sci., 17: 132-138.

Toxopeus, H., and Jacob, V.J. (1965). Natural pollination in Theobroma cacao. Ann. Rep. West Afric. Cocoa Res. Inst., 1964-65, pp.23.

Toxopeus, H., and Jacob V.J. (1970). Studies on pod and bean value of Theobroma cacao L. in Nigeria: II - Number of beans per pod with special reference to the natural pollination process. Neth. J. Agric. Sci., 18: 188-194.

*Varas, J. (1962). Factors affecting the germination of cacao pollen in vitro. Turrialba, 12: 220-222.

Varas, J., and Soria S. de J. (1962). Factors which affect germination of cacao pollen in vitro. Cacao 7 (3): 8-9.

Vasil, I.K. (1960). Studies on pollen germination of certain cucurbitaceae. Amer. J. Bot., 47: 239-247.

Vello, F., and Nascimento, I.F. (1971). Effect of the origin of the pollen on the yield of cacao. Revista Theobroma, 1 (1): 7-14.

Waters, H.B., and Hunter, T. (1929). Measurement of rate of development of cacao pods. Dep. Agric. Bull., Gold Coast, 16: 121-127.

Wellensiek, S.J.(1932). Flower Biological observations with (Theobroma cacao). Archief. v.d. Koffeecultur., 6: 87-101.

Widjanarko, S. (1967). Pollination of cocoa by Forcipomyia sp in relation to Endrin spraying, Menaraperk, 36 (10): 22-25.

Winder, J.A. (1978). Cocoa flower Diptera: their identity, pollinating activity and breeding sites. PANS, 24(1) 5-18.

Winder, J.A., and Silva, P. (1974). Investigation on cocoa pollination by insects in Bahia. Revista Theobroma, 2 (3): 36-46.

Wood, G.A.R. (1975). Cocoa, Longman, London, pp. 283.

Zirkle, C. (1937). Acetocarmine mounting media. Science, 85: 528.

* Originals not seen

POLLINATION, POD SET AND COMPATIBILITY STUDIES IN OPEN POLLINATED PROGENIES OF COCOA VAR. FORASTERO

BY

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ABSTRACT OF THE THESIS

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ABSTRACT

Investigations were carried out at the College of Horticulture, Vellanikkara, Trichur, to study the pollination, pod set and compatibility aspects of open pollinated progenies of cocoa, var. Forastero. It was found that eventhough cocoa flowered through out the year, maximum flower production was between November and April. The flower opening was a slow process starting from 2 to 4 PM and lasting upto 2 to 4 AM on the subsequent day. Maximum stigma receptivity was found between 10 AM and 12 Noon. Natural pollination was through the agency of insects. By controlled pollination there was 48 per cent increase in the pod set. Hand pollination by forceps was found to be the best method of artificial pollination. A large number of pods set was not carried to maturity due to the incidence of cherelle wilt. The loss due to cherelle wilt ranged from 37.04 per cent to 70.37 per cent. Most of the trees studied were self-incompatible, while two of them were self-compatible. The self-incompatibility in the materials investigated herein could be exploited for production of hybrid pods.