PHYSIOLOGICAL INVESTIGATIONS IN RELATION TO FLOWERING, FRUIT SET AND CAPSULE DEVELOPMENT OF CARDAMOM (*Elettaria cardamomum* Maton)

by

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Physiological investigations in relation to flowering, fruit set and capsule development of cardamom (Elettaria cardamomum Maton)" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Vellanikkara,
3-1-1986.

CERTIFICATE

Certified that this thesis, entitled "Physiological investigations in relation to flowering, fruit set and capsule development of cardamom (*Elettaria cardamomum* Maton)" is a record of research work done independently by Shri K.Vasantha Kumar 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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C O N T E N T S

LIST OF TABLES

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INTRODUCTION

INTRODUCTION

Small cardamom or true cardamom (Elettaria cardamomum Maton) is esteemed as the "Queen of Spices". In India, Kerala, Karnataka and Tamil Nadu account for the entire area under this crop with 58,769 ha, 292 60 ha and 8,108 ha, respectively. The three states share 61.13 per cent, 30.44 per cent and 8.43 per cent of the total area (Cherian, 1986). Current production of cardamom in India is estimated at an average of 4000 metric tonnes.

Indian cardamom is known from the time immemorial for its superior quality. It is still adjudged as the best in the international market. The bulk of the cardamom produced in India is exported to the countries in the Middle East. Although India had been earning substantial foreign exchange through the export of this high value-low volume spice, the export earnings markedly declined from Rs 58.30 crores during 1978-79 to Rs 5.44 crores during 1983-84 (Mohanachandran, 1985). The main reason attributed for this alarming situation is our low unit production (60 kg/ha) as against that in Guatemala (250 kg/ha) which was able to compete in the international market because of her higher unit productivity and lower cost of production. Added to this, the adverse climatic conditions characterized by the unprecedented and severe drought experienced during

1982 and 1983 caused unprecedented set back to the cardamom industry in the country.

The research scientists of the three State Agricultural Universities, the Cardamom Board, the CPCRI, the UPASI and the different organisations of cardamom planters have been working collectively to revive the weakened cardamom industry. To bring alive the cardamom export, it is estimated that we have to achieve a production target of 5000 metric tonnes during the VII Five Year Plan period.

Till the recent past, cardamom was either grown as a wild plant under the forest canopy or raised in a semi-wild state. The price boom of cardamom in the international market encouraged its intensive cultivation in adverse/marginal habitats. This has resulted in many of the present day problems faced by this spice of which immature capsule shedding is the most important. Though the phenomenon is common throughout the cardamom tracts, Wynad and certain pockets of the Idukki district in Kerala recorded the highest shedding of immature capsules (ranging from 20 to 60 per cent). The severity of capsule shedding in cardamom has been reported from Karnataka also (Pattanshetty and Prasad, 1972). The heavy shedding of cardamom capsules can either result from ecological disturbance, hormonal

imbalance, nutritional disorder, inadequate pollination, pests/diseases or from the combined action of one or more of these factors. Therefore, investigations were undertaken from a physiologists view point on the flowering, fruit set and capsule development in cardamom. Apart from finding the causes for capsule shedding, the studies aimed at defining the general physiological bases of flowering, fruit set and capsule development of cardamom. Since the earlier work on cardamom did not take into account the variation among the three popular cultivars (Malabar, Mysore and Vazhukka), the present studies included either typical plants of the three cultivars or their representative genotypes. The studies were carried out at the Cardamom Research Station, Pampadumpara from January, 1982 onwards. A multi-directional approach was made to the problem which included aspects like, growth and development, histology of flowering, influence of the ecological parameters, relation of endogenous and exogenous growth substances to flowering, nutrient status at different growth phases of the crop, photosynthetic rate and translocation, and development of the flavour principles of cardamom capsules with the advancement of maturity of the capsules.

REVIEW OF LITERATURE

2 REVIEW OF LITERATURE

Cardamom is a plantation crop which has substantial export potential from the Indian subcontinent to the international spice market (Reddy, 1969). The earlier researchers on cardamom gave stress primarily on crop improvement, nutrient relations, crop management and plant protection. The physiological aspects in general and the physiology of flowering in particular (of cardamom) are areas where only limited studies have been made so far. The literature pertaining to the work done on cardamom and its relatives as well as relevant work conducted on other crops have been reviewed and presented in this chapter.

2.1 Growth and development of vegetative and floral parts in cardamom

Investigations on flowering and fruiting of cardamom were conducted as early as in 1958 by Subbiah and Abraham in the Nilagiri tract of Tamil Nadu. They observed the average number of flowers borne per raceme from January to March to be 13.3, with 3.8 per cent fruit set. From April to September, on an average 150.7 flowers opened per raceme, with 30.7 per cent fruit set. From October to December 26.8 flowers per raceme opened with 19.1 per cent fruit set. Kuttappa (1969) reported that the shedding of

capsules in cardamom may be the result of improper fertilization of the flowers, injury to the flowers through spraying/dusting leading to their abscission, competition between the growing capsules, physiological factors and pest and disease incidence. Detailed investigations on the blossom biology, pollination and fruit set in cardamom were conducted at the Regional Research Station, Mudigere during 1967-1970. Pattanshetty and Prasad (1972) observed that panicles of cardamom emerged from the swollen base of the stem almost throughout the year in one or the other sucker of a plant. More than 60 per cent of the panicles were found to be produced during the post-monsoon and winter seasons. Growth of the vegetative suckers was observed to be spread over a period of 18 months from their emergence. When the suckers attained the age of one year, the reproductive buds (panicles) developed in 89 per cent of the pseudostems. These observations indicated that the suckers required about 11 to 12 months to attain maturity. According to Pattanshetty and Prasad (1972), when new panicles started developing on the mature suckers, the rate of linear growth of the suckers suddenly declined, thus indicating a sudden diversion of energy of the suckers from vegetative to reproductive needs. Fruit set was maximum during the rainy months (from June to September) because of the humid atmosphere that prevailed during the

period. During the dry months (from December to March) practically no fruit set was observed by them.

Vijayan and Zachariah (1972) determined the unit fresh weight of capsules and the percentage driage of the capsules in seven types of cardamom. The highest fresh weight obtained was 807 mg per capsule. The percentage recovery of the capsules after flue curing ranged between 20.6 and 30.6.

Parameswar (1973) observed the time taken from floral initiation to full bloom ranged between 28 and 34 days. For capsule development, it took another 106 to 113 days. Anthesis commenced at 3.30 a.m. and continued upto 7.30 a.m. Maximum number of flowers opened between 5.30 a.m. and 6.30 a.m. Anther dehiscence commenced immediately after anthesis and continued upto 7.30 a.m. Fertility of the pollen grains was found to be 85 per cent as indicated by the acetocarmine staining method. Viability dropped to 6.5 per cent after two hours of storage at 26°C. The stigma remained receptive for 12 hours on the day of anthesis, with the maximum receptivity between 8.00 a.m. and 10.00 a.m. leading to about 72 per cent fruit set. Pattanshetty and Prasad (1973) observed that honey bees played an important role in the pollination of cardamom flowers. Fruit set was obtained in 60 per cent of the

flowers marked on the exposed panicles as against in only 11 per cent in the panicles enclosed in cloth cylinders. Capsule set in the different types of cardamom was examined by Parameswar and Venugopal (1974). They found that the multiple branching type produced more flowers than the others (prostrate, erect and semi-erect); but over 80 per cent of the flowers and capsules were shed in all the types studied. They opined that almost half of the flower and immature capsule shedding might have been caused by physiological factors.

Continued investigations at the Regional Research Station, Mudigere, Pattanshetty (1980) observed that the yields from a seedling population of cardamom exhibited large variation (as much as 89 per cent). Nearly half of the plants examined by him were found to be poor yielders. He felt that by selecting clones alone, the yields could be increased from an average of 50 kg to as high as 300 kg dry capsules per hectare.

At the cardamom Research Station, Pampadumpara, Venkitaraman (1982) studied the reproductive mechanism in cardamom. He observed that the three cultivars, Malabar, Mysore and Vazhukka exhibited more or less similar panicle characters and floral morphology. A distinct peak of

flowering was not found in these cultivars. In Malabar, the period of flowering was found to be shorter than that in the other two cultivars. Self pollination occurred on a small scale with the help of crawling insects like ants and lice. The seed setting, however, was found to be low in self pollinated capsules. Venkitaraman (1982) opined that the poor seed setting observed in self pollinated capsules might have been due to the lack of sufficient pollen grains for effecting fertilization of all the ovules.

2.2 Histological studies on flower bud differentiation

Among the plant species, morphological similarities have been observed during flower bud differentiation and at the initial stages of the development of the flower buds. But at the later stages, the mode of development and the time taken for differentiation into various organs vary, depending upon the type of inflorescence produced by the plant species. It was Lang (1965) who published a thorough treatise on the physiology of flower initiation. He observed that the morphology of flower initiation in different plants exhibited many specific features. In some plants, the shoot apices, after having functioned for some time as vegetative meristems, are directly transformed into flower primordia. In others, flower primordia are initiated as lateral meristems while the terminal meristem

of the shoot remains in the vegetative phase or ceases active function. However, the principal features which distinguish flower primordia from vegetative (shoot) promordia are quite similar in all seed plants. The reproductive primordium will be usually larger (in terms of height, width and number of cell layers) than the vegetative primordium.

2.2.1 Vegetative apex

The vegetative apex had a conical shape in grapes (Chadha and Cheema, 1971) and mango (Singh, 1960). In litchi, Shukla and Bajpai (1974) found that the vegetative apex was doms shaped. In cauliflower, the young leafy plant was found to possess a small pointed shoot apex surrounded by narrow leaf primordia which arose in spiral succession around the shoot apex (Sadik, 1962). In pepper, Nalini (1983) reported three distinct stages in the development of the vegetative bud. At the beginning of initiation, the vegetative primordium was conical, undifferentiated and surrounded by leaf sheaths, which elongated in the further stages. Rajan (1985) confirmed the conical nature of the vegetative apex of pepper. He described the change of shape of the apex during a single plastochrone of leaf initiation from broadly conical just prior to initiation to sharply conical immediately afterwards.

2.2.2 Transition stage and floral differentiation

Broadening and flattening of the apical meristem just before flower bud initiation have been observed in citrus (Abbot, 1935; Randhawa and Disna, 1947), in litchi (Shukla and Bajpai, 1974) in coffee (Alvim, 1973) in jaman (Mishra and Bajpai, 1973) and in strawberry (Pathak and Singh, 1977).

In grapes, formation of bract primordium was the first indication of the formation of cluster primordium (Winkler and Shemsettin, 1937). In mango, high meristematic activity marked by the production of broad conical protuberances in the axils of the scales, was the first sign of blossom bud differentiation (Gunjate et al., 1977; Ravisankar et al., 1979).

Nalini (1983) described the appearance of two undifferentiated conical primordia surrounded by leaf sheath as the first sign of flower bud initiation in pepper. These primordia were not distinct from the vegetative primordia. Five stages were identified in the development of flower buds. During the first stage, two undifferentiated conical primordia surrounded by leaf sheaths were observed indicating the commencement of flower bud differentiation process. Towards the latter half of the first stage, one of the primordia broadened and elongated. Appearance of a

dome shaped structure at the apex of the broadened primordium in the second stage denoted the spike initiation stage. The third stage indicated floral initiation and a structure resembling pepper spike was clearly observed. During the fourth stage, differentiation of floral parts was observed. Stamen and pistil primordia developed towards the end of the fourth stage. The differentiation process was completed by the appearance of stamens and ovary during the fifth stage. Rajan (1985) also made similar observations as narrated above in pepper by Nalini (1983). He recognised the change of shape from conical to hemispherical as the transition from vegetative to floral phase. At this stage the primordial apex exhibited high meristematic activity.

2.3 Role of climatic factors (rainfall, temperature, relative humidity) and soil moisture on flowering and fruit set)

2.3.1 Climatic influence on the growth and productivity of cardamom

Abraham and Tulasidas (1958) gave a detailed account of the ecological features of the cardamom growing tracts of South India. They opined that the natural habitat of cardamom, the evergreen forests of the Western Ghats, is characterised by heavy rainfall, low to medium temperature

and high atmospheric humidity. The dense shade provided by the forest trees is peculiar to the high altitude regions of the tropical forests. That cardamom is very exacting with regard to its climatic requirement is evident from the reports of Srivastava et al. (1967). They observed the growth of cardamom in Coorg area of Karnataka and found that it flourishes well in the hot sub-mountainous regions of the tropical evergreen rain forests either on the hill slopes or valleys, and the streams running in between. Cardamom was found to thrive best on damp soils having a rich layer of vegetative mould resting on a humus layer. Virgin forest soils protected under the tall standing trees were found to be the best for cardamom. Kuttappa (1969) opined that the imbalances in the climatic factors are the causes for immature capsule shedding in cardamom. Disturbances in the micro-climatic compounents led to the improper development of pistil and weakens the stalk end of the flowers and immature capsules, favouring abscission of the capsules. George (1976) reported that dependance on the climatic conditions and the deforestation in cardamom growing tracts are the constraints in the production of cardamom. He analysed the rainfall pattern and yield of cardamom over a period of time and observed that the years of low

production were those in which timely rainfall in adequate quantities has been wanting and in which acute and prolonged dry summers prevailed. Cherian (1977) identified environmental ecology as a vital factor in cardamom cultivation. He analysed the cardamom yield figures for three decades and concluded that the productivity in 1970's was too low as compared to that obtained in the past. He was of the opinion that unless due attention is given to improve the environmental situations in such a way as to satisfy the requirements of the cardamom plants, the position would not improve with any amount of artificial tillage operations, irrigation, manuring and pesticidal application. According to Sundaram (1977) the deterioration of ecology limited the production of cardamom. The large scale denudation of forests in and around the cardamom tracts in recent years has been cited as the greatest menace to the cardamom industry (Abraham et al., 1979). This practice has upset the ecological balance which is highly essential for the successful cultivation of the crop. For better crop performance, they suggested the maintenance of a suitable microclimate in the cardamom plantations. Subbarao and Kori-Kanthimath (1983) observed the amount of precipitation, the number of rainy days and the yields from several estates of the Coorg area over a ten-year period. Their analysis indicated that the yield of cardamom was influenced more by the distribution of monthly rainfall rather than by the total rainfall and

the number of rainy days. In 10 out of the 13 estates, maximum yield was recorded when the annual rainfall was less than 2000 mm. This clearly suggested that the total annual rainfall was not the criterion deciding the production of cardamom. They concluded that a well distributed annual rainfall of 2000 mm may be the optimum for cardamom cultivation.

The effect of forest-climate on the growth and productivity of cardamom was assessed at the Indian Cardamom Research Institute, Myladumpara. Kurup (1984) opined that domestication of cardamom has not been realised to the fullest extent and the crop remains still in its wild or near wild habitat. He further stated that the unprecedented changes in the micro-climate of the cardamom growing tract is due to the large scale felling of the forest trees. As varieties tolerating these changes in micro-climate have not been developed so far, these practices have reduced the productivity of the plantations. He advised that for the rejuvenation of cardamom plantations, a secondary canopy of shade trees should be brought up, similar to that existing in evergreen tropical forests.

2.3.2 Climatic influence on growth and productivity of other crops

2.3.2.1 Rainfall

The influence of rainfall on flower initiation has been reported earlier in apple (Wiggam, 1918; Collison and

Harlan, 1927; and Degman et al., 1933) and in coffee (Pressanha, 1956; Alvim, 1960; Franco, 1962; Rees, 1964; Van der Veen, 1968; and Browning, 1971).

The flowering behaviour of coffee as related to climatic factors was examined in detail by Alvim (1973). He opined that rainfall and day length are the main external factors controlling flowering in coffee. Anthesis of the flower bud in coffee was seen associated with rain following a dry period or a transition from dryness to wetness (hydroperiodism). He postulated that rain or irrigation can effectively break the flower bud dormancy in coffee, when followed by a period of moisture deficiency (Alvim, 1977). He recognised two phases of dormancy in coffee. The first one under the control of growth inhibitors (whose concentration decreased during drought) put the bud in a ready-to grow state. The second (quiescence or imposed dormancy which persisted even after the true dormancy was over) resulted from inadequate water supply. He, therefore, concluded that a moisture stress was necessary to release the dormant phase and water uptake to release the quiescent phase. Clower (1974) investigated the physiological factors influencing irrigation and management of coffee in Rhodesia. He observed that the vegetative growth of coffee trees occurred mainly in the rainy season and the fruit

growth continued to the dry season. A six to eight week period of stress was advised for coffee, after flower bud differentiation in June, to ensure early and abundant flowering and to avoid a late crop.

Koo (1957) found that a relationship existed between the annual rainfall and the average yield per tree in Valencia oranges.

Alvim et al. (1972) observed that moisture stress inhibited flowering in cocoa. Two types of flowering were observed in cocoa, the 'normal' one in March to July and a 'crazy' flowering or lean flowering at the end of the dry period.

The influence of rainfall on the productivity of cashew was evident from the investigations of Veeraraghavan and Vasavan (1979). They stated that a well distributed rainfall during October and November months was required for the optimum flowering and fruit set in cashew.

2.3.2.2 Temperature

Temperature relations have been found to be important among the factors governing the pattern of flowering and fruit set in a wide variety of crops (Perold, 1927; Wittwer et al., 1948; Gardner et al., 1952; Koleznik, 1953; Baldwin, 1964; and Buttrose, 1969). Since the work done on cardamom on these aspects is meagre, a few pieces of work on

other crops have been reviewed and presented here.

Aoba (1966) observed that floral initiation in garlic took place in early or mid-April when a minimum temperature of 10°C was reached. Long days and high temperatures were required for floral induction.

The effect of temperature on fruit set in apple trees was studied by Grauslund and Hansen (1975). Potted apple trees of varieties, Golden Delicious and Lobo, after the commencement of flowering were kept in growth chambers at varying temperature regimes. Premature fruit drop increased when the temperature in the growth chamber was 20°C and above.

Shimamura and Okamoto (1975) studied the effect of night temperatures on flowering, fruit set and berry growth in Muscat of Alexandria variety of grapes. Three-year old vines were exposed to night temperature of 30°C, 25°C, 20°C and 15°C and today temperature of 30°C for 10 days after flowering. The highest night temperature gave the maximum berry set and berry growth. Temperature influence on flower initiation in grapes was detailed by Palma and Jackson (1981). Buds of cvs, Chasselas Dore and White Riesling were marked when the internode above the buds just began to elongate. In the following season, the number of flowers on the shoots from each marked bud was observed and related to the maximum

temperature of the day. The study revealed that the initiation of flowers in grapes was promoted by high temperatures and that this was determined well before visible changes occurred within the bud.

The influence of air and soil temperature on flowering of citrus was studied by Hall et al. (1977) The bud break was increased by warm soils at 25°C than by cool soils at 15°C. In contrast, the initiation of flowers on the new shoots was more in cooler days (20°C at day and 15°C at night) than in warmer days (30°C at day and 15°C at night).

The effect of night temperature on flowering and fruit size in Smooth Cayenne pineapple was observed by Freend (1981). Plants were grown in a green house at 25°C to 30°C and later transferred to rooms maintained at night temperatures of 15°C to 30°C. Flowering was most rapid at a night temperature of 20°C end slowest at 15°C. Flowering did not occur after three years of growth at 30°C.

2.3.2.3 Soil moisture

Soil moisture deficit influencespractically every aspect of plant growth, modifying the anatomy, morphology, physiology and biochemistry. The major effects of water stress are related to decrease in turgor pressure and water potential of the plant. Survey of the earlier literature on

these topics appeared in the papers by Huber (1956), Evenari (1960), Stocker (1960), Vaadia et al. (1961) and Kozlowski (1964). The influence of soil moisture on the flowering behaviour of some fruit plants are reviewed here.

Vannerum et al. (1966) conducted detailed investigations on the effect of soil moisture on the number of flowers produced by different varieties of strawberry. It was found that conserving the soil moisture by mulching with black polythene increased the flowering by 28 per cent and the yields upto 38 per cent as compared to the control. Benoit et al. (1984) estimated the effect of soil moisture on the yield of low bush blueberry. Plants were evaluated under greenhouse conditions at moisture regimes from 0.2 bars (about field capacity) to 5.0 bars. A significant increase in the number of flowers per stem was detected for the treatments at 0.2 and 0.6 bars than for the treatments at 1.0 and 5.0 bars. The number of flowers and the total yield of berries increased significantly with increased water availability.

Water stress was induced in nine-year old Cox apple trees, during the late spring of 1973, to assess the extent of fruit set (Powell, 1974). In one set of the experiment a soil cover was used to intercept the rainfall from entering the soil while a second set received normal rainfall. Fruit set was considerably reduced by water stress and the tree with minimal water stress retained more fruits per cluster than the stressed ones.

Rao et al. (1974) studied the effect of varying soil moisture regimes on plant growth and yield in pineapple. Irrigation was given when 80, 60, 40 and 20 per cent of the available moisture was depleted from zero to thirty cm layer; but yields were more or less similar for all the treatments. However, the TSS content of the juice was lower in the lower moisture regimes.

The influence of the environmental factors on bud burst, flowering and shoot growth of grapes was studied during a period of four years in three different localities (Alleweldt and Hofacker, 1975). Soil moisture proved to be the chief factor influencing inflorescence development and fruit shattering.

2.3.2.4 Relative humidity

The fluctuations in the water relations of a plant consequent on the fluctuations in the atmospheric humidity is of great importance in deciding the fruiting behaviour of a number of species of plants. Darwin had postulated theories in favour of this statement as early as in 1894. The problems related with pollination and fruit set of several fruit plants as influenced by relative humidity was well documented by Gardner et al., (1952). Since information on the precise role of this factor is lacking for the major

plantation and spice crops, references on a few other crops have been reviewed here.

Muhina (1955) studied the eco-physiological characteristics of photosynthesis, growth and dry matter accumulation in tea. Experiments were conducted to determine the effects of shading and changes in relative humidity on the performance of China tea. During the first year of growth, the plants showed a strong positive reaction to high humidity, but during the second year, the demand decreased and a relative humidity of 98 to 99 per cent reduced the growth and formation of dry matter, although photosynthetic activity remained high.

The effect of environment on nectar secretion was studied in flowers of nine ornamental species. (Huber, 1956). Air humidity was found to have a favourable influence on the secretion of nectar.

Hales et al. (1968) ascertained the relationship between climatic factors and growth rate of Valencia orange fruits. A high relative humidity was found to have a profound influence on the apparent growth rate of fruits and the fruit volume did not return to the normal volume dictated by soil moisture tension when relative humidity values

remained low throughout the night.

The environmental factors influencing growth and productivity of several woody perennial plants were studied by Kramer and Kozlowski (1979). They opined that relative humidity exhibited a profound influence on the transpiration rate and in turn govered the plant factors like leaf area, leaf exposure and structure, stomatal behaviour and effectiveness of the absorbing roots.

2.4 Endogenous changes of growth substances in relation to flowering and fruit set

2.4.1 Auxins

The theory that flowering requires a certain level of endogenous auxin in the leaves or meristems of a plant, was postulated by Lang (1952). Later auxins were proved to be one among the major factors that control the flowering mechanism in plants (Liverman, 1955; Salisbury and Bonner, 1956; Coombe 1960; Zeevaart, 1962 and Nitsch, 1965). The regulation of flowering of certain selected crop plants by changes in endogenic auxin levels are cited here.

The relationship between auxin content, berry growth and berry drop in Concord and Concord Seedless varieties of grapes was examined by Nitsch (1957). He observed that after

seven days of flowering, both the varieties showed a low growth rate and a low auxin content. After this growth rate and auxin content started to increase in both the varieties. In Concord variety, between 20 and 26 days of flowering, the endosperm developed rapidly in the seeds and the growth rate and auxin content of the berries were high. Changes in the auxin levels of grape berries were estimated by Nimi et al. (1977). The growth of the seeded berries showed a typical double sigmoid curve. The rapid growth rate of the berries after fruit set (Stage I) was characterised by a high activity of endogenous auxins.

Sacher (1957) conducted experiments in bean segments to examine the relationship between auxin concentration, tissue senescence and abscission. He proved that cells of the abscission zone may be sensitive to a drop in the auxin level and that below a critical auxin level, loss of membrane integrity occurs which permits displacement of cellular fluids and results in cell dissociation and abscission.

Growth substances in the flower buds and developing fruits of lowbush blueberry were assayed by Collins et al. (1966). The fruit development followed a typical sigmoid pattern. No correlation was observed between the growth of the fruits and the concentration of auxins in the fruit

tissues. The peak of auxin concentration occurred at the time of suspended growth between the two growth peaks. Dresher and Poovaiah (1983) analysed the auxin levels in strawberry fruits at various developmental stages. The levels of free and conjugated IAA were determined in achenes and receptacles of strawberry fruits (Ozark Beauty) from pollination to maturity. Free IAA was found almost exclusively in the achenes, with the maximum at 10 days after pollination (3000 ng/g dry weight). Levels of free IAA were at least ten fold lower in 3-days old fruits. Only traces of IAA could be detected in the receptacles at the advanced stages of fruit maturity.

Chacko et al.(1972) compared the concentration of growth substances present during the season of flower bud initiation in the shoots of the regular bearing variety Totapuri Red Small and the biennial bearing variety Dashehari, both in the 'on' and 'off' years. The auxin levels were found to be high in the flowering than in the vegetative shoots.

2.4.2 Inhibitors

The abscission of flowers and immature fruits is a global problem facing the cultivation of horticultural crops. The earlier proposed theories suggested a lowering of the auxin content as the major cause for fruit drop

(Luckwill, 1953). But later the occurrence of dormancy inducing substances was confirmed by Wareing (1970). These substances were subsequently named as ABA. The conclusive evidences on the increase of ABA content during the period of fruit dehiscence was reported by Davis and Addicott (1972). Some of the salient references based on the work conducted on certain fruit crops are given here.

Monselise et al. (1967) estimated the hormone-inhibitor balance of some citrus tissues. Flowers in general contained a low concentration of inhibitors and petals in particular had a high percentage of promoters. The ovaries, developing fruitlets and peel tissues at all stages of fruit development displayed considerable inhibition, but no detectable promotion.

Hormonal regulation of mango malformation was discussed in detail by Pandey et al. (1974). Endogenous growth substances were analysed in healthy and malformed mango panicles. Chromatograms of extracts from healthy buds were characterised by growth promoting activity whereas those from malformed buds had marked inhibitory zones.

Lee and Tomana (1981) observed the effect of fruit temperatures on the abscisic acid content of Delaware and Muscat Bailey grapes. Abscisic acid content in Delaware grape was not affected by temperature. But in Muscat Bailey vines grown at 30°C, the abscisic acid content was lower than that of the vines grown at 20°C.

Abscisic acid activity in the developing fruits of Florida Sun and Sharbati peaches was determined by Sandhu and Dhillon (1981). In two-year studies, ABA activity in both the cultivars were estimated, starting from one week after full bloom to maturity. In Sharbati, the ABA level remained moderate in Stage I, declined to its lowest level in Stage II and rose to a maximum in Stage III. In Florida Sun, the ABA level was highest during Stage I, moderate during Stage II and declined to a minimum in Stage III.

The inhibitory substances present in persimmon ovaries during anthesis were identified and estimated by Lu et al. (1982). The concentration of these inhibitors were related to the development of ovaries. It was found that the accumulation of ABA during and after anthesis prevented the development of the ovary, when pollination and fertilization did not occur.

Martin et al. (1982) studied the changes in ABA content of pear receptacles from anthesis to post-fertilization stages. The ABA concentration was found to decrease after anthesis in all the flowers except in the pollinated receptacles, whereas a slight increase occurred twelve days after full bloom.

2.4.3 Cytokinins

The discovery of the cytokinins was the direct outcome of tissue culture studies carried on for several years in Skoog's laboratory at the University of Wisconsin. Skoog and Tsui (1948) reported the chemical regulation of bud formation on tobacco stem segments and callus cultured in vitro. Bio-assays for the qualitative and quantitative estimation of cytokinins were standardised earlier (Richmond and Lang, 1957; McCalla, 1962; Murashige and Skoog, 1962; Miller, 1963). Though the formative effects of cytokinins on the release of buds from dormancy and inhibition of ageing have been established earlier, its precise role in flowering, fruit set and fruit growth have been published quite recently. A few work done on fruit crops like grapes, mangoes, oranges and apples are presented here.

Chacko et al. (1976) reported on the levels of cytokinin-like substances in grape berries at different

developmental stages. The concentration of cytokinins in the cv. Bangalore Blue was maximum during anthesis and at the first rapid growth period. But during the lag and subsequent rapid growth phases, the cytokinin levels markedly declined.

Endogenous cytokinins in apples during ripening was assayed by Obrenvoic (1977). Samples of growing and abscised apples (Red Delicious) were analysed at ten days intervals for cytokinin content. There was no substantial difference in the cytokinins present in growing and abscised fruits. Cytokinin concentration was very high at the start of fruit development, decreased sharply during growth and increased again at ripening.

Investigations on cytokinin-like substances in mango were conducted by Satish (1977). Cytokinin activity was estimated in Alphonso and Olour mango fruits during fruit development. In Alphonso variety, the cytokinin activity reached a maximum (197.6 /ug/g fresh weight) 32 days after flowering and declined thereafter. In Olour variety, the cytokinin activity was maximum (163.1 /ug /g) 35 days after flowering. Ram et al. (1983) studied the occurrence of endogenous cytokinins in mango, cv. Dashehari. They identified cytokinins in the pericarp and seed. It was

observed that during a period of rapid growth of the fruit and seed (42 days after pollination), the cytokinin concentration increased rapidly at two stages. The first preceded the period of rapid cell division and the second coincided with the period of rapid cell enlargement. Cytokinin deficiency in the fruit was found to be associated with fruit drop and cessation of fruit growth.

Furio et al. (1981) analysed the endogenous cytokinins in flowers, vegetative buds, leaves, ovaries and fruits of Washington Navel and Navelate oranges at different stages of development. The cytokinin content was found to be higher in vegetative than in the flower buds of Navelate oranges; but the reverse was true for Washington Navel oranges. A higher cytokinin content was observed in the ovaries of Washington Navel than in those of Navelate, suggesting that a higher flow of nutrients towards the vegetative organs occurred in Navelate, causing a low fruit set and poor productivity.

2.5 Effect of exogenous application of growth substances in enhancing flowering, fruit set and yield

2.5.1 Auxins and gibberellins

The control of flowering and fruit set by application of auxins has been the subject of numerous investigations on a large number of plant species. The wider use of

different auxins in enhancing flowering and fruit set have been published by Zimmerman and Hitchcock (1944), Avery and Johnson (1947), Wittwer (1949) and Osborne et al. (1952). Auxin applications received renewed attention in connection with the earlier theories. Lang (1952) observed that the effects of exogenous application of auxin on flowering were seen only in those cases in which the endogenous levels of auxins were below a threshold level.

References to the bolting and flowering of certain rosetted long day plants by exogenous application of gibberellins have been observed earlier (Lang, 1957; Doorenbos and Wellensiek, 1959). Since then, several workers have reported the beneficial use of gibberellin in enhancing flowering (Harada and Nitsch, 1959; Lang, 1960; Cajlachjan and Lozhnikova, 1964; Stoddart, 1966; Wareing and El-Antably, 1970; and Evans, 1971). As the work done on the role of auxins and gibberellins in enhancing flowering and fruit set of crop plants are quite laborious, some of the salient reports that are relevant to the present study are documented here.

Experiments on pineapple have proved that low concentrations of NAA would cause flowering when applied as a spray before floral differentiation (Collins, 1960). NAA would applied at low levels after the fruit initiation in pineapple,

brought about an increase in size, weight and development period of fruits. However high concentrations of NAA when applied before normal fruit formation resulted in delayed fruit initiation. Seeyave (1966) induced uniform flowering in pineapple by the application of NAA at 15 to 30 ppm at the rate of 50 ml per plant. Sharma and Randhawa (1966) studied the influence of growth substances on fruit set and fruit drop in sweet oranges. Experiments were conducted for three years with nine-year old Hamlin and Valencia trees. The trees were sprayed at full bloom with GA_3 (10,25 and 50 ppm), 2,4-D and 2,4,5-T (both at 2.5, 5.0 and 7.5 ppm). GA_3 at 50 ppm had the most marked effect on fruit set of both the varieties. The beneficial effect of GA_3 on enhancing fruit set in sweet orange was further confirmed by Agusti *et al.* (1982). A single spray of GA_3 at 5 to 20 mg/l at petal fall to the entire tree enhanced the initial set in sweet oranges. Aqueous sprays of 2,4-D (10 or 20 ppm) or GA_3 (10 or 15 ppm) reduced the fruit drop in Marsh grape fruit (Dinar *et al.*, 1977). Both GA_3 and 2,4-D increased the peel firmness, but GA_3 treated fruits were inferior in colour to 2,4-D treated fruits. Sinha *et al.* (1977) conducted experiments on the effect of plant growth regulators on fruit drop, size and quality of Nagpur Santra oranges. Studies were conducted for three years on 12-year old trees growing on *Citrus jambhiri* and treated with 2,4-D at 10 to

20 ppm, 2,4,5-T at 5 to 15 ppm and NAA at 10 to 20 ppm. The trees were sprayed at monthly intervals from early July to October. 2,4,5-T at 15 ppm was the most effective treatment for the control of fruit fall.

Attempts were made to reduce the pre-harvest drop of Jonathan and Delicious apples (Shorter and Cripps, 1966). NAA at 10 ppm plus a wetting agent applied in early February and again in late February reduced the pre-harvest drop by almost 50 per cent. Srivastava and Agarwal (1966) probed into the effectiveness of GA_3 on controlling fruit drop in Red Delicious apples. GA_3 sprays at 0, 25, 50 and 100 ppm were applied to apple trees, five to six weeks after petal fall. All the GA_3 treatments reduced the fruit drop, 25 ppm concentration being more effective.

Majumder *et al.* (1970) tried the effect of NAA on the malformation of mango. Branches of Dashehari, Chousa and Bombay Green varieties which had suffered from floral malformation on the preceding season were sprayed with 100 to 200 ppm NAA in October. The treatments considerably reduced the incidence of malformation in the following season. The effect of growth regulators on fruit retention and quality of mango was studied by Mayura and Singh (1979). Mango trees were sprayed with NAA, 2,4-D or 2,4,5-T each at 20 and 40 ppm when the fruits were at the pea stage, followed or

not by a second application one month later. Fruit retention was improved and the fruit quality enhanced by all the treatments, the best results being obtained with NAA at 40 ppm.

Weaver (1975) sprayed Zinfandel grape vines at bloom (50 per cent calyptra fall) and on the subsequent dates with KGA_3 (Potassium gibberellate). At fruit maturity, various parameters were measured. The treatments brought about a rapid increase in the cluster length, the set of berries and the weight of berries.

The effectiveness of GA_3 on the yield of Arabica coffee in Kenya was reported by Ople (1977). Foliar sprays of GA_3 at 100 ppm were given to mature trees, three times during 1974 and 1975 at various altitudes. The 1974 treatments increased the yield of the following year's crop by 12 to 26 per cent. The 1975 application increased the yield of 1976 crop by eight to nine per cent.

Experiments were conducted to find out the effectiveness of three growth regulators, IAA, GA_3 abd 2,4-D on fruit setting and yield of tomatoes (Nair et al., 1974). The maximum increase in yield was obtained with IAA at 25 ppm in four of the five varieties tested. In four

varieties, GA_3 treated plants gave maximum yield at 10 ppm concentration, while the 2,4-D treated plants showed best performance at 2 ppm concentration. A slight reduction in yield was observed at 4 ppm concentration of 2,4-D. Joseph and Peter (1981) reported on the effectiveness of 2,4-D on tomato. The trials were carried out with determinate, semi-determinate and indeterminate tomato cultivars. 2,4-D was applied at 5 and 10 ppm concentrations at 30,45 and 60 days after transplanting. 2,4-D at 5 ppm was found to enhance earliness in 16 out of 24 cultivars and increased the average fruit weight in all the cultivars.

The effect of 2,4-D on fruit development in Piper nigrum is evident from the findings of Hariharan and Unnikrishnan (1985). Pepper vines were sprayed with a sub-toxic concentration (1 ppm) of 2,4-D. Increases in the degree of cell division, fresh weight, dry weight and volume of berries were obtained in the 2,4-D treated vines over those of the untreated controls.

Gurumurthy et al.(1985) reported the results of the field experiments conducted at the Regional Research Station, Mudigere on the effect of growth substances on fruit set and fruit development in cardamom. They found that NAA at 75 ppm and 2,4-D at 2.5 ppm were effective in reducing the capsule drop. The effect of growth regulators on the weight of capsules was not found to be consistent.

2.5.2 Cytokinins

Exogenous application of cytokinins have been found to enhance fruit setting of several fruit plants (Steward and Simmonds, 1954 and Goldacre and Bottomley, 1959). A few years later the beneficial effects of cytokinins on fruit setting was observed on figs (Crane and Van Overbeek, 1965), cucurbits (Jones, 1965) and grapes (Weaver et al., 1966). A few other references on certain crop plants are presented here.

Mullins (1967) observed the morphogenetic effects of some synthetic cytokinins in grapes. Inflorescence growth was promoted by the application of 6-benzyl aminopurine. The effect of cytokinin treatments on the flower structure and berry set of the dessert variety Olimpia was studied by Jako and Szegedi (1972). Vines were sprayed with 100 ppm solutions of BA (benzyl adenine) prior to flowering at three-day intervals during the month of May. BA treatment improved the size of the pistils. There was an increase in the number of berries set per bunch and the bunches were more compact with a high proportion of seedless grapes. Takagi and Furukawa (1977) studied the effect of BA on pistil development in Muscat Bailey grapes. Pistil development was promoted by BA (applied two to three weeks before anthesis) which increased the frequency of perfect flowers and enhanced the fruit set. Srinivasan and Mullins (1980) studied the effect

of BA on Muscat of Alexandria grapes. BA promoted the formation of 'anlagen' (uncommitted primordia) and growth of the tendrils.

Development of inflorescences in tomato plants grown in adverse light conditions was stimulated by the application of BA at 10 ppm concentration (Kinet et al., 1978). It was found that on treatment with the growth substances, the soluble sugars and starch levels increased temporarily. Studies on the partitioning of the dry matter between the different plant organs suggested that the growth substances modified the distribution pattern of the assimilates within the plant, the inflorescence being favoured at the expense of the young leaves above.

2.5.3 Ethylene

Ethylene gas evolved from smoke has been known to be capable of stimulating flowering in pineapple about seven decades back (Crocker and Knight 1908). Later, it has been found to promote flowering in many plant species (Rodriguez, 1932; Van Overbeek, 1952; Burg and Burg 1966; Bleasdale, 1973 and Roberts and Tucker, 1985).

Mention is made here on the response of certain crop plants to exogenous application of Ethrel/Ethephon.

Chacko et al. (1972) induced flowering in the 'off' year of Langra mango by the spray application of Ethrel at 200 ppm. Sen et al. (1973) used Ethephon for controlling non-uniform bearing of mango. Three sprays of Ethephon at 250 ppm were given to Langra and Bombai varieties at monthly intervals during August, September and October. Shoot growth was inhibited and the percentage of shoots that flowered was doubled. In the following year however, the conditions were unfavourable for flowering and the trees remained in an 'off' condition. Pal et al. (1984) used various growth substances to tackle the problem of biennial bearing in Deshehari mango. It was seen that Ethephon at 200 ppm plus 0.1% urea, applied five times at monthly intervals gave the best results and induced bearing in the 'off' year.

The cytohistological changes in pineapple after treatment with Ethephon (400 ppm) was studied by Wee and Rao (1979). Ethephon treatment produced a broadened apex at the inflorescence initials.

Pattanshetty (1980) recommended the spray application of 250 ppm ethrel for improving the sucker production in cardamom.

2.6 Nutrient status of the plant parts and uptake by the cardamom clumps at various periods of crop growth

Earlier attempts on the nutrient analysis in cardamom

were made at Mudigere, Singampatti and Idukki. John (1967) reported that the cardamom plant contains 5.33 per cent N, 1.33 per cent P_2O_5, 6.69 per cent K_2O, 2.70 per cent CaO and 3.50 per cent MgO (on dry weight basis). He observed that a mature capsule of the variety Mysore weighed 0.5 to 0.8 g by fresh weight and the variety Malabar weighed 0.3 to 0.6 g. Raman and Khan (1967) conducted manurial experiments on cardamom at Singampatti. The results of the fertilizer trial showed that the yield increased initially with the increase in the dosage of N and K_2O. They tried the nutrients Zn, Cu, B, Fe, Mg, Mn and Mo in various combinations. The results indicated that Mn had a significant response while Mo gave only a slight response. B was found to depress the yield. Combinations of Zn and Cu, Zn and Fe, Cu and Mo and B and Mg also increased the yield significantly.

Data on soil and plant analyses were utilised by Srivastava et al. (1968) for judging the fertilizer needs of cardamom. They conducted leaf analyses for cardamom at the Citrus Experiment Station, Gonicoppal. Nutritional status of the leaves from best performing cardamom plants were worked out for macro and micro nutrients. Definite conclusions could not be drawn from this experiment since the number of samples analysed were too low for drawing any inference. George (1971) emphasised the need for conducting

trials on the nutritional requirements of the crop. He observed with regret that the favourable environment which the pioneer planters possessed when they opened the cardamom plantations on rich virgin forest soils had disappeared. The soils were under continuous cultivation for decades with the resultant depletion and exhaustion of nutrients. He pointed out the need for taking up studies to draw precise information on the nutritional requirements and to make fertilizer recommendations for young and mature cardamom clumps for ensuring thrifty growth and increased crop production.

Detailed investigations on the nutrient uptake by cardamom clumps were conducted by Kulkarni et al. (1971) at the Regional Research Station, Mudigere. The N, P and Ca content in the leaves increased from young to mature stages, whereas the K and Mg contents decreased. However at the bearing stage, while the N, P and K decreased in the leaf tissue a definite increase was observed in the case of Ca and Mg. In the case of pseudostem, there was a general reduction in N, P and K content and an increase in the Ca and Mg concentration with the advance in age of the plants. A broad pattern of the uptake of nutrients at the harvest stage revealed that the removal of K was maximum (20.01 kg/ha), followed by N (12.17 kg/ha) and Ca (8.84 kg/ha).

On the contrary, P and Mg were removed in comparatively lesser quantities (1.4 to 2.32 kg/ha). They concluded from their studies that for the production of one kg of cardamom capsules, 0.122 kg N, 0.014 kg P and 0.200 kg K were removed by the plants.

Subsequently, a series of nutritional experiments were undertaken at the Regional Research Station, Mudigere. Recently, Venkatesha (1982) observed that the foliar application of nitrogen and potassium was equally effective as the soil application on enhancing the proliferation of suckers in cardamom.

Distribution of nutrients in the different plant organs of the three popular cultivars of cardamom was estimated at the CPCRI Kasaragod by Khader et al. (1982). They found that cardamom plants accumulated major, secondary and minor elements in the order K>N>Ca>Mg>P>Na Mn>Fe>Zn>Cu. They further observed that accumulation of P, K and Mg was maximum in the panicles and flowers. The leaf blades contained the highest concentration of N and the petioles together with leaf blades also contained the highest concentration of Ca. The cultivar Vazhukka was found to absorb more P than the other two cultivars.

Dileepkumar (1983) conducted studies at the Cardamom Research Station, Pampadumpara on the nutritional status of soil and plant parts in relation to the incidence of the chenthal disorder of cardamom. His analyses indicated that the Mg content of the plant parts declined with increase in the intensity of the disorder suggesting that Mg deficiency may be a causative factor for the occurrence of the chenthal disorder. He also correlated the nutrient status of the plant and soil with the yield of the crop. Among the different nutrients, P was found to be correlated with the yield of cardamom. The correlation between the various nutrients in the soil and plant with the crop yield for the three cultivars were ranked as follows:

Malabar : P>K>N>Fe>Mn>Mg>Zn>Ca

Mysore : P>N>Ca>Mg>K>Fe>Zn>Mn

Vazhukka: P>Mg>Fe>Ca>N>K>Zn>Mn

Mohankumar and Hegde (1983) reviewed the nutritional studies conducted till date on cardamom. They indicated that the cardamom crop depletes nutrients from the soil at all the stages of growth, which necessitates the application of nutrients for restoring soil fertility. The growth habit of cardamom in relation to nutrition was studied by

Korikanthimath (1984). According to him cardamom exhibited a special growth feature whereby it produced suckers throughout the year. The initiation of panicles and the development of capsules were spread over a period of eight to nine months in an year. Thus, he concluded that a steady absorption and utilization of plant nutrients take place throughout the life cycle of cardamom. He, therefore suggested that a regular fertilizer schedule has to be followed for better fertilizer use efficiency and to realise higher yields in cardamom.

2.6.1 Carbohydrates, nitrogen and carbon/nitrogen ratio in relation to flowering

The pioneering report on the carbon/nitrogen balance as a factor governing flower bud initiation was proposed by Kraus and Kraybill (1918). Consequently, several workers have contributed to the relationship between C|N ratio and flowering (Gourley, 1915; Chandler, 1925; Archbold, 1928; Hooker, 1930; Thomas and Bernad, 1937; Shantha, 1965; Chadha and Cheema, 1971 and Chitkara *et al.*, 1972)

Some of the work done on this line in certain plantation and fruit crops are reviewed here. Gopal *et al.* (1975) made a physiological approach on the flowering of coffee under South Indian conditions. In a three-year study

of the flowering pattern of Coffea arabica cv.S-795, uniform flower bud enlargement and opening into normal flowers were found positively correlated to the starch index (reserve carbohydrate) on the wood.

The alternate bearing behaviour of Valencia orange was correlated with the carbohydrate reserves of the tree by Jones et al.(1977) who found that these reserves in the tree were reduced by an 'on' crop. In an 'off' crop followed by this, the carbohydrate levels were not found to be consistent. Bud dormancy in the spring was more prolonged in the 'on' year trees than in the 'off' year trees.

The biochemical changes associated with floral malformation in mango were studied by Pandey et al.(1977) Changes in the carbohydrate reserves, total N and the anatomy of healthy and malformed shoots of the cvs., Dashehari and Chousa were followed before and after the fruit bud differentiation. Acid hydrolysable polysaccharides and total carbohydrates remained at higher levels in the leaves, stems and panicles of malformed than in those of the healthy shoots in both the cultivars. Ravisankar and Rao (1982) studied the changes related to irregular bearing in the levels of carbohydrates, C/N ratio and mineral nutrients of Alphonso mangoes before, during and after

fruit bud differentiation. At all stages, it was found that the levels of insoluble carbohydrates were appreciably higher than those of soluble carbohydrates. The levels of insoluble carbohydrates and non-reducing sugars declined during fruit-bud differentiation, whereas the level of reducing sugars increased.

Investigations on flower bud differentiation in pepper commenced at the College of Horticulture, Vellanikkara during 1981. Nalini (1983) estimated the total soluble carbohydrate content, nitrogen content and C/N ratio of two types of laterals (those that bore the crop during the past season and those that did not) and that of the new shoots. She observed that the total soluble carbohydrates, nitrogen and C/N ratio varied considerably during different growth cycles. However, the C/N ratio exhibited two peaks the first synchronising with the differentiation of flower buds, and the second with the step up of flower bud differentiation activity. Rajan (1985) did not observe any significant correlation between the carbohydrate content and C/N ratio with flower bud differentiation in pepper. However, he recorded an accumulation of carbohydrates and a build up of C/N ratio prior to the peak differentiation period.

2.7 Rate of photosynthesis and translocation of photosynthates by $^{14}CO_2$ labelling techniques

Considerable use of isotopes have been made by plant physiologists in studies on the photosynthesis and plant productivity of several crop plants. Among the many isotopes used, the one which has been used in photosynthesis studies is ^{14}C. Some of the earlier work on rice done at the International Rice Research Institute, Philippines deserves special mention (Fujiwara and Suzuki, 1957; Ota, 1958 and Shaw and Tanaka, 1967). Of late, ^{14}C studies have been conducted on different field crops as well as horticultural crops. The work done on some major horticultural crops are reviewed here.

Austin and Longden (1967) deviced a rapid method for the measurement of the rate of photosynthesis using $^{14}CO_2$. The method consisted on interrupting the flow of air over a leaf for 15 seconds, during which time air containing $^{14}CO_2$ was passed over it. The amount of $^{14}CO_2$ assimilated by the leaf was then measured. Results obtained were comparable with those obtained using an infra-red gas analyser.

Distribution of labelled assimilates within an young apple tree after supplying $^{14}CO_2$ to a leaf or shoot was traced by radioautography (Jankiewicz et al., 1967).

It was observed that the transport of labelled assimilates from the young leaves of the leader was very meagre and was traceable only in parts of the stem and the leaves situated in the close vicinity of the treated leaves. The translocation and distribution of ^{14}C labelled assimilates within a single shoot and between two adjacent shoots were studied in one-year old Golden Delicious apple trees (Manolov et al., 1974). When $^{14}CO_2$ was introduced into an upper developed leaf the translocation of labelled assimilates was basipetal and when introduced into a lower leaf, acropetal. The major part of labelled assimilates moved from a middle leaf down the stem in a spiral. When whole shoots were exposed to $^{14}CO_2$, the labelled compounds were not translocated to an adjacent shoot, but moved into the roots.

Kriedemann (1968) investigated the translocation pattern in peach and apricot shoots, after treating them with $^{14}CO_2$ by the method of autoradiography. The terminal leaves of peach and apricot were fed with $^{14}CO_2$ from flowering till fruit maturity. It was found that in the early stages, the adjacent fruits shared the assimilates with the expanding leaves. At the later stages, only the fruits imported assimilates from the terminal leaves. The accumulation of ^{14}C continued even when the fruit was fully ripe. After

harvesting, translocation from the terminal leaves of peach was minimal, the labelled photosynthate being detected only in the main stem.

The translocation of ^{14}C photoassimilates from normal and mutant leaves to the pods of Pisum sativum was estimated by Harvey (1974). Assays of ^{14}C distribution, made 48 hours after treatment, indicated that the leaf and the pod had a well defined respective source and sink relationship that was independent of leaf morphology. Thus the pods which comprised the main ^{14}C sinks depended on the leaf that had been fed with $^{14}CO_2$. With regard to the sink activity, there was little difference between mutant and normal leaves. Lawrie and Wheeler (1974) traced the movement of photosynthetic assimilates to the nodules of Pisum sativum in relation to the fixation of nitrogen. It was seen that the accumulation of ^{14}C labelled photosynthates in the nodules of pea plants in nitrogen-free culture, reached a maximum shortly before flowering and fruit development. During the period from flowering to fruiting, accumulation of ^{14}C photosynthates in the nodules declined by 60 per cent whereas the photosynthesis of the plant was found doubled.

Uneven ripening and translocation of metabolites in 'Gulabi' grapes were studied by Vasundara (1981). Radio-

active CO_2 was fed to the leaves during the rapid growth stage of the cluster (45 days after anthesis). At this stage, there was small, medium and large sized berries within the cluster. In non-defoliated plants, the highest amount of $^{14}CO_2$ was recorded in the first two or three branches of the cluster that contained a higher sink number. When the source capacity was reduced by defoliation, the pattern of translocation from fed leaves into the sinks differed. The first branch of the cluster became the predominant sink. Hence, the total activity and the specific activity were higher in the first branches than in the other sinks.

Chacko et al. (1982) studied the relationship between leaf number, leaf area and fruit development in mango. The optimum leaf number/fruit ratio in various mango cultivars was sought by isolating individual fruits with known numbers of supporting leaves by shoot girdling. $^{14}CO_2$ feeding experiments showed a high rate of ^{14}C fixation in the leaves of the girdled shoots than in those of the control shoots. However, the translocation of ^{14}C assimilates to the developing fruits on the girdled and control shoots was comparable. Starch accumulation in the leaves was found to be reduced by shoot girdling.

Partitioning of ^{14}C photosynthates were conducted on strawberry plants by Schaffer et al.(1985). They studied the mode of ^{14}C accumulation on fruiting as well as deblossomed strawberry plants. It was observed that the total quantity of radioactivity in the unfed leaves and fruits of the fruiting plants were approximately equal to the sum of the radioactivity in the untreated leaves of the deblossomed plants. Autoradiographs showed that majority of ^{14}C was in the expanding leaves. The increased leaf production rates, which often resulted consequent to deblossoming of strawberry plants, were attributed to an increase in photosynthates that are partitioned to the expanding leaves.

The effect of CO_2 enrichment on growth and photo-assimilate transport in dwarf cucumber was assessed by Madore and Grodzinski (1985). Dwarf cucumber plants of the cv. Spacemaster were grown for six weeks in a CO_2 enriched atmosphere (1150 $\mu l\ l^{-1}$) . Source leaves of different age were pluse labelled with $^{14}CO_2$. The distribution of ^{14}C in petiole extracts and phloem exudates of the fed leaves showed an increase of the label in transport sugars whereas a decline of the label was observed in the aminoacids, particularly glycine and serine.

The import and unloading of ^{14}C assimilate into mature leaves of Coleus blumei was studied by Fisher and Eschrich (1985). $^{14}CO_2$ was fed to the apical leaves and the assimilate import ability of mature leaves (sink leaves) were estimated. Some of the sink leaves were kept exposed to light while others were kept under darkness. Autoradiographs showed that the label imported to sink leaves that were exposed to light was more concentrated in the major veins. In general, sink leaves kept under dark imported much less label. Microautoradiography of midveins of the sink leaves indicated that ^{14}C was always translocated through the phloem.

2.8 Oleophysiology of the essential oils of cardamom

The distillation technique for extracting essential oil from cardamom seeds have been standardised earlier by Clevenger (1934). He reported that seeds from green cardamom yielded more volatile oil than those from bleached cardamom. The loss of volatile oil in husk-protected seed was comparatively small after a storage period of eight months whereas the seeds removed from the husks recorded a loss in oil of approximately 30 per cent in eight months. Nambudiri et al. (1968) presented the modified knowhow for the production of cardamom oil by the distillation method originally

invented by Clevenger (1934). They advocated the establishment of a cardamom oil industry in the country, utilizing inferior varieties of cardamom which as such, did not possess an export market.

The cardamom oil of Malabar, Mysore and Ceylon varieties were analysed by Lewis et al.(1955). They identified that the three varieties have characteristically different flavours. These differences were examined by a study of their chemical composition using thin layer, column and gas liquid chromatography. The data revealed that the differences in the flavours were mainly quantitative. Nigam et al. (1965) examined cardamom oils by gas chromatography. They identified 12 compounds in the oil which included limonene, sabinene, cineole, terpeniol, terpenyl acetate and borneol. The presence of alpha pinene and cineole, reported by pioneer workers in the cardamom oil, was confirmed by Lawrence et al. (1969). In addition, they found that the oil contained 46 constituents unreported by earlier workers.

Detailed investigations on the chemistry and uses of cardamom oil were conducted by Shankaracharya and Natarajan (1971). Cardamom oil was found to contain volatile oil, fixed oil, protein, cellulose, pentosans, sugar, starch,

silica, calcium oxalate and mineral elements. The volatile oil of cardamom was described as colourless or pale yellow with an agreeable, aromatic and camphoraceous odour and a pungent, aromatic taste. Baruah et al. (1973) detected a total of 21 compounds in the oil of Alleppey strain of cardamom by gas chromatographic technique. Lewis et al. (1976) recorded that the chief constituents of cardamom oil are 1-8 cineole (25 to 40 per cent) and terpenyl acetate (35 to 50 per cent). Sayed et al. (1979) evaluated the oil percentage in different varieties of cardamom. They examined the capsules of the three popular cultivars, Malabar, Mysore and Vazhukka and eleven other types. It was seen that the cultivars Mysore and Vazhukka contained the highest oil (8.00 per cent) by dry weight.

The quality aspect of different commercial grades of cardamom were narrated by Sankarikutty et al. (1984). They attributed the major flavour constituents of cardamom to the esters, alcohols and 1,8- cineole. The fresh camphoraceous flavour in cardamom was identified as due to the presence of 1,8-cineole. The esters (alpha terpenyl acetate, linalyl acetate and geranyl acetate) contributed to the sweet, spicy, floral and fruity flavour of the spice. Among the alcohols, linalool and alpha terpeniol contributed

to the floral flavour with citrusy note. Geraniol and nerol gave a sweet rosy and fruity odour with mild lemony note. Nerolidol was found to be responsible for the woody, floral and slightly green odour. Alpha and beta pinenes accounted for the woody pine like flavour. They further found out that d-limonene was responsible for the sweet orange flavour and camphene present in traces contributed to the camphoraceous note. Mathulla et al. (1985) compared the husk and seed oils of cardamom. It was evident from the gas chromatograms obtained under similar conditions with husk and seed oils from the same lot of cardamom fruits that these oils were identical with respect to their constituents. It was further confirmed through infra-red spectroscopy that the spectra of husk and seed oils were super-imposing. This proved beyond doubt the qualitative similarity of the two oils.

Recently, gas chromatographic analysis of cardamom oils were conducted at the Regional Research Laboratory, Trivandrum. Sumathikutty et al. (1985) studied the changes of the component flavour principles at different stages of maturity of the spice. The Mysore cultivar was employed for the study. The volatile oil was distilled from flowers, and also from fruits sampled at monthly intervals after flowering till maturity. Of the thirteen constituents identified,

a higher concentration of the major constituents were found at the fourth month of fruit maturity. The per cent cineole content which gives a camphoraceous note to the oil showed an increasing trend upto three months and thereafter remained constant. Terpenyl acetate which is responsible for the fruity, mellowy flavour showed a downward trend with fruit maturation upto three months and again the values remained constant.

MATERIALS AND METHODS

3 MATERIALS AND METHODS

The studies on "physiological investigations in relation to flowering, fruit set and capsule development of cardamom (Elettaria cardamomum Maton)" were carried out at the Cardamom Research Station, Pampadumpara during the period from January, 1982 to December, 1984. The Pampadumpara station is situated in the high ranges of the Idukki district at an elevation of 1200 m above m.s.l. The laboratory analyses were conducted at the College of Horticulture, Vellanikkara.

The details regarding the experimental material, methodology of experiments, collection of the plant samples and analytical techniques adopted are presented in this chapter.

3.1 Experimental material

The three popular cardamom cultivars namely Malabar, Mysore and Vazhukka were chosen for the studies from the Germplasm Block, the Vettakanam Block and the Illimadam Block of the Cardamom Research Station, Pampadumpara as well as from the Thenammakkal Estate, Pampadumpara.

Table 1 gives the details of the experimental plants chosen for the study.

Table 1 Details of locations and plants selected for the field experiments

Location	Experiment	Year of study	Cultivar	Number of plants selected
Cardamom Research Station, Pampadumpara				
Vattakanam Block	Growth and development of vegetative and floral parts	1982 to 1984	Malabar	70
			Mysore	70
			Vazhukka	70
Illimadam Block	Nutrient status of the plant parts during the blossom and rest periods of the crop	1983	Malabar	5
			Mysore	5
			Vazhukka	5
Germ plasm Block	Histological studies on flowering	1984	PV-1 (Malabar)	10
Germ plasm Block	Rate and translocation of photosynthates	1984	PV-1 (Malabar)	12
			PR-107 (Mysore)	5
Germ plasm Block	Oleophysiology of the cardamom oils	1984	PV-1 (Malabar)	5
			PR-107 (Mysore)	5
			PV-5 (Vazhukka)	5

(contd..)

Table 1 (contd.)

Location	Experiment	Year of study	Cultivar	Number of plants selected
Thenmmakkal Estate Pampadumpara	Effect of exogenous application of growth substances on flowering, fruit set and yield	1982 to 1983	Mysore	80
Thenmmakkal Estate Pampadumpara	Endogenous changes of growth substances in relation to flowering	1984	Mysore	-
Total number of plants selected				347

The three popular cultivars were identified and selected based on their prominent morphological features.

The growth pattern of the panicles (Plates 1 to 3) was the main character (Anon., 1984) used for the selection of the experimental plants. Besides this, the plant height, pubescence on the leaves, the length of the internodes of the panicles (Plate 4) and the shape of the capsules (Plates 5 to 7) were also considered for identifying the plants belonging to the three cultivars.

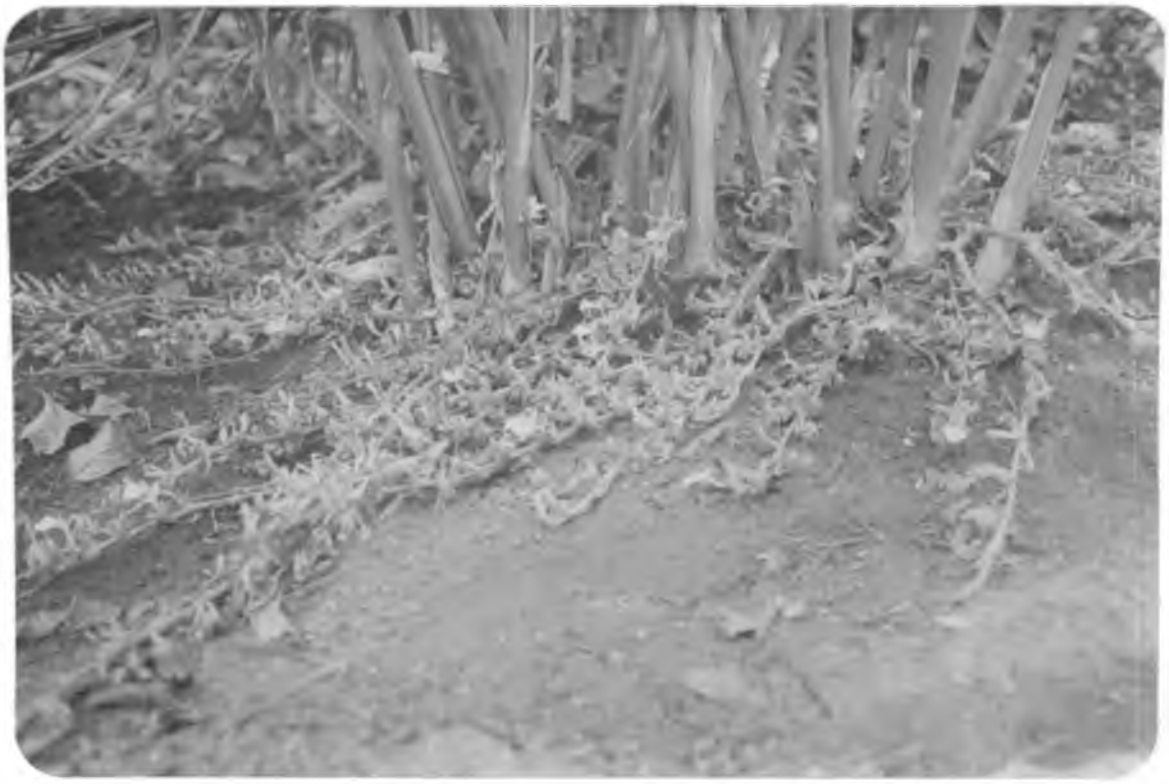


Plate 1 (×0·09)

Plate 3 (×0·11)

Plate 2 (×0·18)

Plate 4 (×0·25)

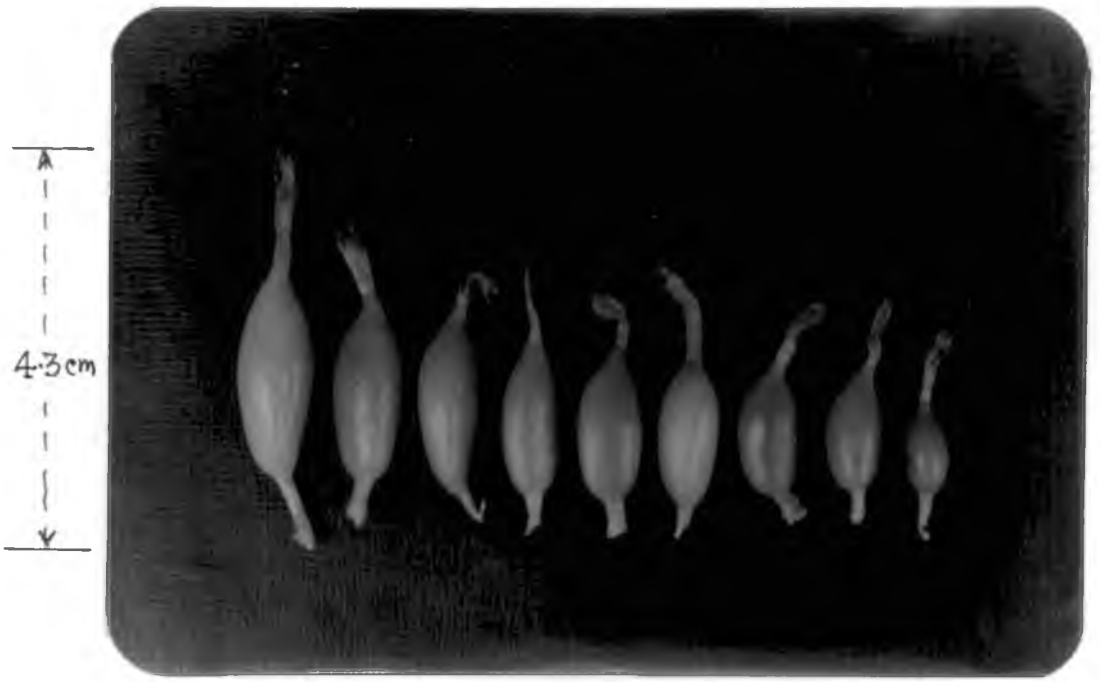


Plate 5 (×0·90)

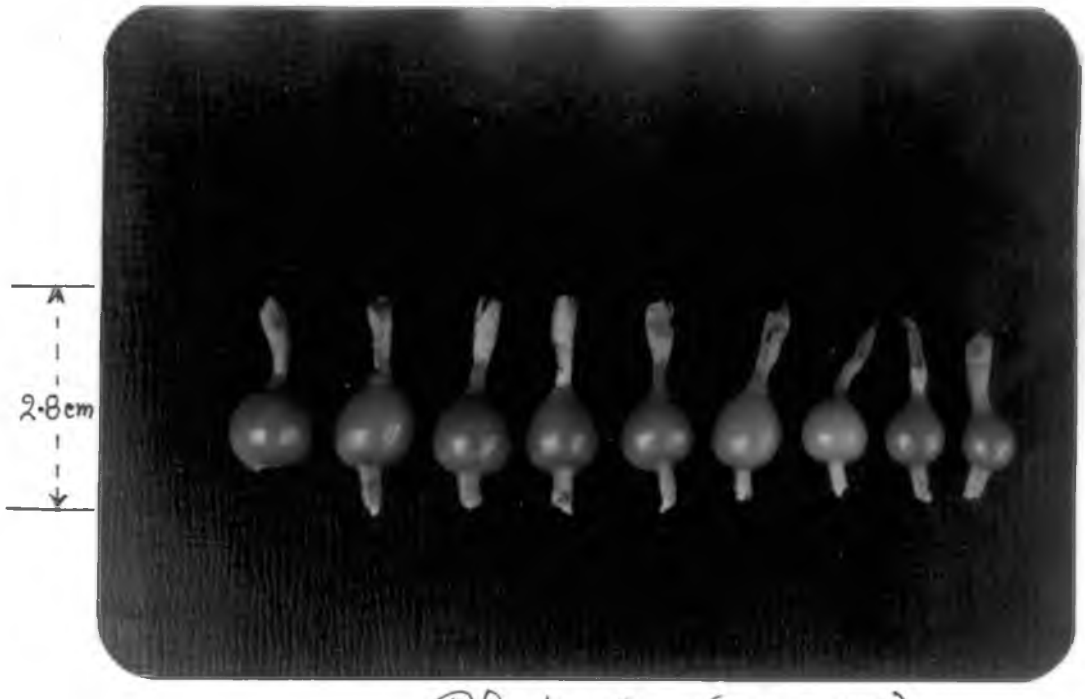


Plate 6 (×0·65)

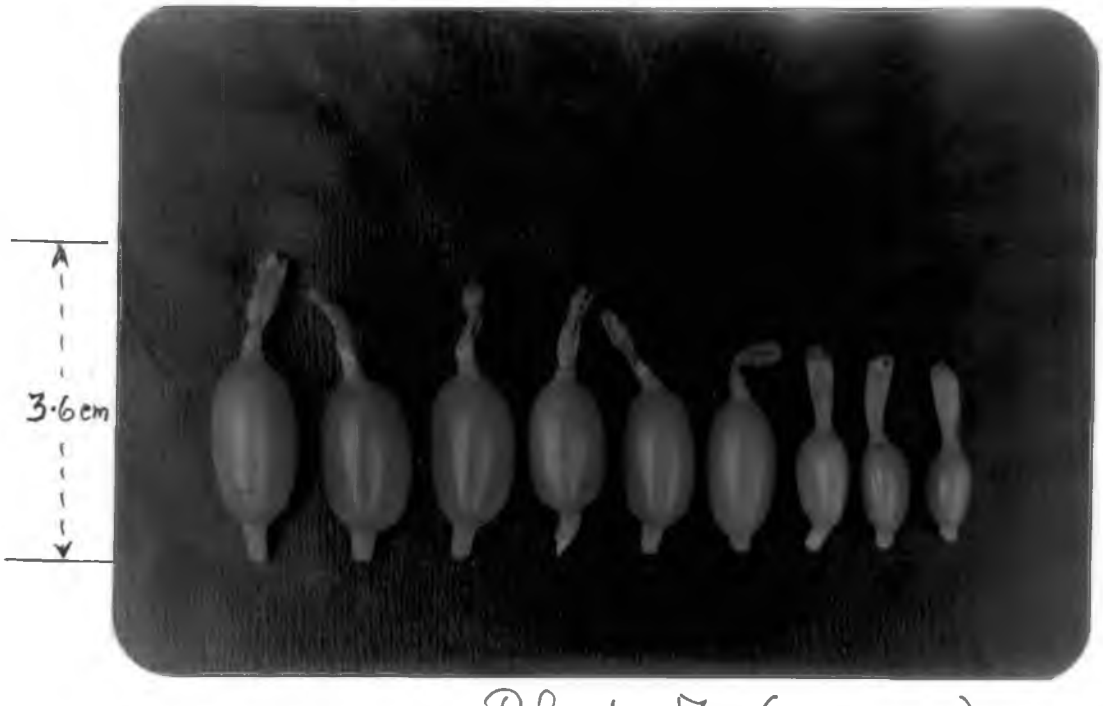


Plate 7 (×0·78)

Table 2 Characters used for classification of the cultivars

	Malabar	Mysore	Vazhukka
Vegetative characters			
Plant height	short	tall	varying
Leaf pubescence	pubescent	non-pubescent	non-pubescent
Panicle characters			
Growth pattern	prostrate	erect	varying
Internodes	closely spaced	widely spaced	varying
Capsules (Shape)	linear	oval to round	varying

Bearing clumps of uniform age (7 year-old) were chosen for the various experiments.

For the studies on flowering, rate and translocation of photosynthates, and oleophysiology of cardamom oils, monoclonal progenies of the promising selections namely PV-1 (Malabar), PR-107 (Mysore) and PV-1 (Vazhukka) were selected from the germplasm block of the Pampadumpara Research Station. The methodology adopted for the different experiments are described in the forthcoming sections.

3.2 Growth and development of the vegetative parts

This study was conducted on the plants selected from the Vattakanam Estate during the years 1982 to 1984. Seventy uniform clumps in each of the three cultivars were labelled and used for the study. Of the 70 plants in each cultivar, 50 were utilised for recording tiller counts. The experiment was laid out in randomised block design with three cultivars and five replications consisting of ten plants per replication. On the experimental plants, monthly counts of new tillers (January, 1982 to December, 1983) and yearly counts (during January, 1982, January, 1983 and January, 1984) of the panicle bearing tillers were recorded. The data were pooled.

The remaining twenty plants in each cultivar were utilized for recording the growth pattern of the tillers. On each clump, five new sprouts were labelled during the month of July, 1982. From the 100 sprouts (tillers) so labelled in each cultivar, five at random were collected at bimonthly intervals for destructive sampling and recording the observations. The observations continued for the life span of the tillers.

3.2.1 Height of tillers

The height from the ground level to the tip of the pseudostem was measured and expressed in cm

3.2.2 Number of leaves

The leaves present at each sampling period were counted

3.2.3 Plastochrone index

This was computed by noting the time interval between the production of two successive leaves on a pseudostem and expressed in days

3.2.4 Total leaf area

The leaf area was determined by measuring the maximum length and maximum breadth of leaves and applying the formula suggested by Korikanthimath and Subbarao (1983)

$A = a + bY$ (A = leaf area, a = constant -46.76, b= constant 0.77, Y = length x breadth)

3.2.5 Dry matter content of the plant parts

The suckers collected at each sampling period were separated into leaves, pseudostems, rhizomes, roots, panicles and capsules and the dry matter of each plant part was expressed in gram

3.2.6 The time taken from the initiation of a tiller to the visual appearance of an inflorescence initial on its rhizome was observed and expressed in days

3.2.7 Number of leaves present on the pseudostem at which inflorescence initiation occurred on the rhizome

3.2.8 Number of panicles borne per tiller

3.2.9 Life span of a tiller was computed from the visual appearance of the tiller initial to the death of the tiller and expressed in months

3.3 Growth and development of floral parts

Fifty clumps were employed for studying the growth and development of the floral parts. The experiment was laid out in randomised block design with the three cultivars in five replications, each replication consisting of ten clumps. The following floral characters were studied:

3.3.1 Number of panicles produced in each clump

This was observed at monthly intervals from January, 1982 to December, 1983.

3.3.2 Number of flowers opened in each clump

The flowers showing anthesis were counted during morning hours every day from January, 1982 to December 1982

3.3.3 Percentage of fruit set per clump

3.3.4 Percentage of immature capsule shedding to the set capsules as well as to the total flowers borne

3.3.5 Percentage of capsules matured to the total flowers borne

3.3.6 Yield of capsules per clump by fresh and dry weight

Apart from the floral characters studied on whole clump basis described above, observations were taken from individual panicles chosen from these clumps. Three panicles were marked at random for this study during January, 1982. From the data obtained from the three panicles, the mean values were worked out. The characters studied on individual panicles were as follows:

3.3.7 Number of flowers opened per panicle

The number of flowers borne on the panicles were estimated at monthly intervals by adding the counts of the fruits that had set and the number of barren stalks (of abscised flowers and capsules)

3.3.8 Days to 50 per cent and 100 per cent flowering

The number of days to 50 per cent and 100 per cent flowering was observed from the date of tagging the emerged panicles ie., January, 1982

3.3.9 Extension growth of the panicle at monthly intervals in cm

3.3.10 Number of racemes developed in the panicle at monthly intervals

3.3.11 Time taken in days from the visual appearance of the inflorescence initial till appearance of the first flower bud

3.3.12 Time taken in days from visual appearance of the flower bud to anthesis

3.3.13 Time taken from anthesis to fruit set

This factor was studied only in the Mysore cultivar. The flowers were hand pollinated immediately after anthesis. They were then collected at 6, 12,24,36 and 48 hours after pollination. The ovaries of these flowers were separated and the endogenous auxin contained in the ovaries were estimated by wheat coleoptile straight growth bioassay. The ovaries showing a spurt in auxin activity were considered to have attained the fruit set stage and based on this the time taken from anthesis to fruit set was computed.

3.3.14 Growth of fruits (capsules)

The fruits that had set were tagged and sampled at an interval of ten days till the maturity of fruits. The characters studied on them were length, diameter and girth of capsules in mm, volume of capsules in ml, fresh

and dry weight of capsules in mg, driage percentage of the capsules and time taken in days from fruit set to attain the various seed maturity stages namely, tender seed, greenish-yellow seed, brown seed, black seed and ripe seed.

3.4 Histological studies

3.4.1 Collection and storage of plant samples

Histological studies on flower bud differentiation were conducted on PV-1, a promising selection of the Malabar cultivar. Ten clumps of the monoclonal progenies of PV-1 were selected, each clump having more than twenty tillers. The samples were collected at fortnightly intervals starting from 1st November, 1983 to 30th April, 1984. One sucker each was collected from every clump so as to obtain ten samples at a time. The rhizome region that bears the panicles and vegetative shoots were then separated. The growing points in the nodal region of the rhizome were cut out and preserved in FAA* as suggested by Sass (1951). For studying the time taken for the development of the floral parts, samples were collected at weekly intervals, after the visual appearance of the flower buds on the developing panicles. The collection started from 1st May, 1984 and continued till 31st July, 1984. These samples were then processed and examined for the various developmental stages.

3.4.2 Processing the specimens

Killing and fixing

FAA was used for killing and also as a fixative for the specimens. The specimens could be preserved in FAA for more than six months without any cellular distortion or degradation.

Dehydration

Specimens were dehydrated after a minimum storage period of two weeks in FAA. The method adopted for dehydration was the one detailed by Johansen (1940) and standardised for pepper by Rajan (1985) in which isopropyl alcohol was used in combination with tertiary butyl alcohol (TBA) as the dehydrating agent (Table 3). The schedule followed is given below:

Specimens in FAA

↓

Decanted and flooded with 50% isopropanol (3 hours)

↓

Decanted and flooded with solution I (3 hours)

↓

Decanted and flooded with solution II (12 hours)

↓

Decanted and flooded with solution III (3 hours)

↓

Decanted and flooded with solution IV (3 hours)

↓

Decanted and flooded with solution V (12 hours)

↓

Rinsed with 3 changes of TBA and flooded in the last change (12 hours)

↓

Paraffin infiltration

---

* Formalin-Aceto-Alcohol (FAA)

Ethyl alcohol - 50 ml Glacial acetic acid - 5 ml

Formaldehyde (40%) - 10 ml Distilled water - 35 ml

Table 3 Strength of solutions used for dehydration

Grade number	95% Isopropanol (ml)	Absolute Isopropanol (ml)	TBA (ml)	Water (ml)
I	50	-	10	40
II	50	-	20	30
III	50	-	35	15
IV	50	-	50	-
V	-	25	75	-

Paraffin infiltration and embedding

The plant material, after dehydration through TBA series, were infiltrated and embedded with paraffin wax containing ceresin (m.p. 60°C).

3.4.3 Microtomy

Median longitudinal sections of the plant specimens were cut at 9 to 14 /um thickness in a 'Spencer Junior Rotary Microtome'.

3.4.4 Staining

The sections affixed to slides, after removal of the wax with xylol were stained with the nuclear dye basic fuchsin (pararosanilin) and subsequently with a safranin contrast. The method employed is a modification of the Feulgen's nucleal reaction (Feulgen and Rossenbeck, 1924) as illustrated below:

Preparation of stain

Basic fuchsin (0.5 g)
↓
Dissolved in 100 ml boiling distilled water
↓
Cooled to 50°C and filtered
↓
10 ml 1/N HCl and 0.5 g potassium metabisulphite added to the filtrate
↓
The mixture shaken thoroughly
↓
Stoppered and placed in darkness for 18 hours

Staining procedure

Slides brought down to distilled water
↓
Rinsed in cold 1/N HCl.
↓
Placed in heated (60°C) 1/N HCl (5 minutes)
↓
Rinsed in cold 1/N HCl
↓
Rinsed in distilled water
↓
Transferred to the staining solution
(basic fuchsin - 3 hours)
↓
Differentiated in 1/N HCl (10 minutes)
↓
Placed in 10% aqueous potassium metabisulphite
(10 minutes)
↓
Rinsed in distilled water
↓
Counterstained with 0.05% Safranin (1 minute)
↓
Dehydrated
↓
Mounted in canada balsam.

3.4.5 Microscopic examination and photomicrography

The slides were examined through a "Weswox" student microscope to locate the various stages of floral initiation and differentiation. The slides were examined critically and photomicrography done using a binocular research microscope (Leitz-Dialux 20) at the Kerala Forest Research Institute, Peechi. Ilford black and white negative film (125 ASA), Kodak safety colour film (100 ASA) and Ektachrome colour positive film (64 ASA) were used for taking the photomicrographs.

3.5 Endogenous changes of growth substances in relation to flowering

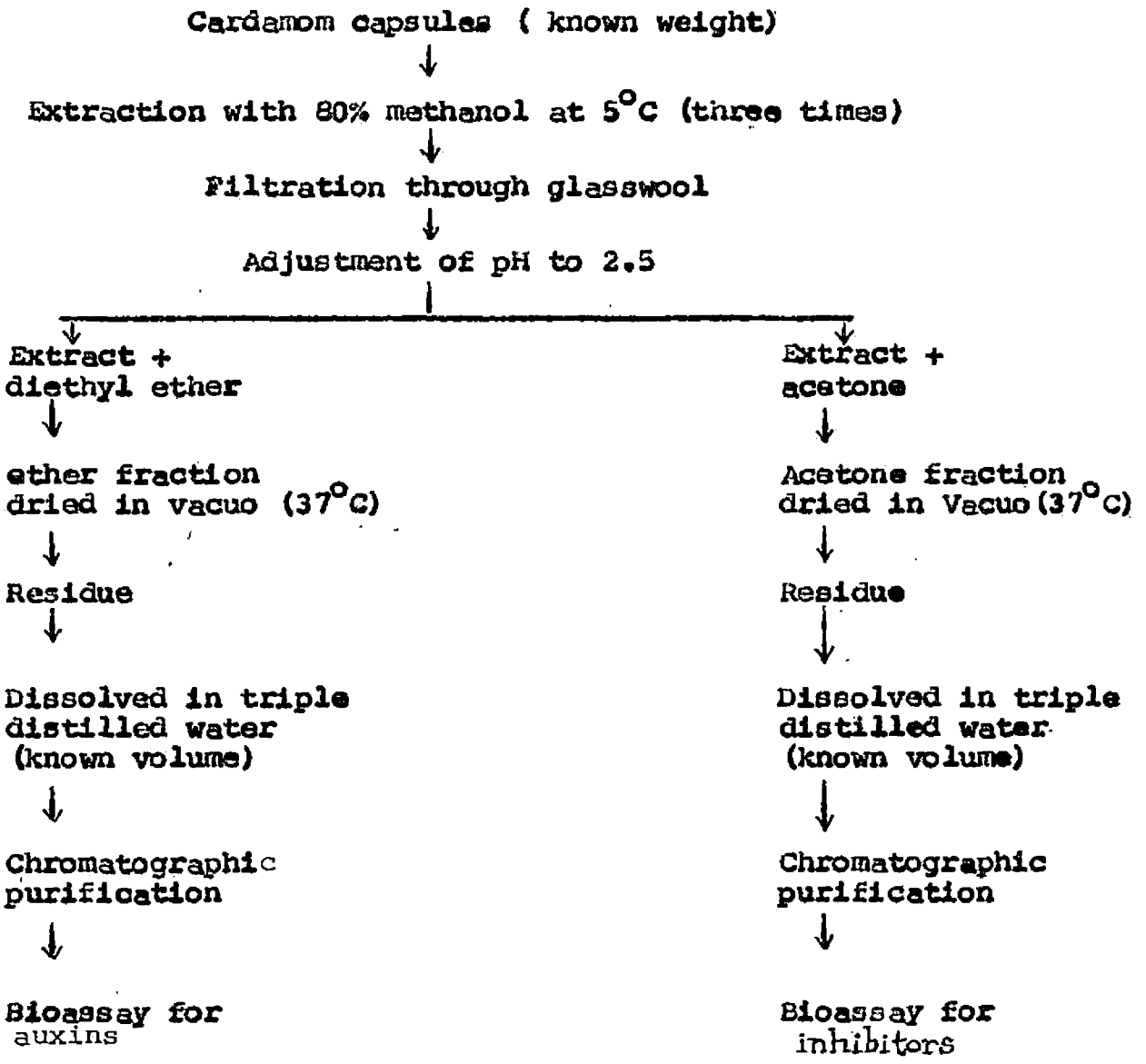
The aim of this investigation was to assess the endogenous levels of growth substances contained in the developing ovaries and fruits (capsules) of cardamom. The Mysore cultivar was selected for this experiment in which the capsule shedding has been reported to be very severe. Fifty clumps of the Mysore cultivar were chosen and utilized for this experiment. This experiment was conducted during the year 1984 and samples of cardamom capsules were quantitatively assayed for auxins, inhibitors and cytokinins. Standard bioassay techniques were followed for estimating these growth substances.

A total of 1000 flowers were pollinated and tagged during the first week of July, 1984. Twenty flowers per clump were pollinated in all the fifty plants selected for this experiment. The details of samples collected for bioassays are furnished below:

Time after pollination	Number of ovaries/fruits	Growth substances assayed
6 hours	100 ovaries	Auxins, cytokinins and inhibitors
12 "	"	"
24 "	"	"
36 "	"	"
48 "	"	"
1 week	50 fruits	"
2 weeks	"	"
3 "	"	"
4 "	"	"

3.5.1 Extraction and purification of auxins and inhibitors

The ovaries/capsules of the cardamom samples collected at the various time intervals after pollination as indicated above were processed following the methods of Murakami (1970) and Rehman et al. (1975) for the extraction of auxins and inhibitors. The procedural steps followed are schematically represented below:



Assay of auxins

The procedure standardised by Mitchell and Livingston (1968) by "wheat coleoptile section straight growth bioassay" was employed for the estimation of auxins. The quantity of auxin was calculated from individual Rf positions that showed significantly more response than the control, by referring to the standard curve obtained from the bioassay of pure IAA. The Rf position 0.3 to 0.5 was found to be

consistent for the concentration of IAA equivalent substances in the chromatograms of cardamom fruit samples. The values of auxins in the plant samples were calculated and presented as IAA equivalents in nanogram per gram fresh weight of the capsules.

Assay of inhibitors

The method deviced by Eidelnant et al. (1980) by mustard seed germination inhibition bioassay was employed for estimation of inhibitors present in the cardamom capsules. The inhibitory substances were found to be consistent at Rf regions 0.6 to 0.8 in the chromatograms of the present investigation. The inhibitors were expressed as ABA equivalents in nanogram per gram fresh weight of the samples.

3.5.2 Extraction and purification of cytokinins

Fresh capsules of the Mysore cultivar were collected in a similar manner for the assay of auxins and inhibitors. The method of extraction adopted was the one standardised by Inoue et al. (1979). The procedural steps followed are outlined below:

Cardamom capsules (known weight)

↓

Homogenisation with 80% ethyl alcohol at 5°C (three times)

↓

Debris filtered off

↓

Alcoholic extract evaporated under vacuo (37°C)

↓

Residue

↓

Dissolved in triple distilled water (known volume)

↓

Adjusted pH to 2.5

↓

Washed with equal volumes of water saturated ethyl acetate (three times)

↓

Adjusted pH of the water phase to 8.4

↓

Extracted with equal volumes of water saturated n-butanol (three times)

↓

Pooled up n-butanol phases

↓

Flash evaporated to dryness

↓

Residue

↓

Dissolved in triple distilled water (known volume)

↓

Bioassay for cytokinins

Assay of cytokinin-like substances

The method outlined by Udaykumar and Sastry (1973) employing cucumber cotyledons was adopted for this investigation. Seeds of cucumber was surface sterilized with 1% sodium hypochlorite solution. The seeds were then germinated in total darkness for 48 hours at room temperature. The seed coats were then removed and cotyledons were separated. Ten cotyledons each were weighed and they were transferred to sterilized petri dishes containing known volume of the test solutions. A set of control was run with cotyledons in pure distilled water. The petri dishes were kept under asceptic conditions and exposed to weak fluorescent light (250 lx) for 3 days. The cotyledons were then blotted dry and weighed.

The gain in fresh weight of the cotyledons was directly correlated with the cytokinin content of the plant samples. The quantity of cytokinins were worked out by referring to standard curves using kinetin and expressed as kinetin equivalent in nonogram per gram by fresh weight of the samples.

3.6 Exogenous application of growth substances for flowering fruitset and yield

3.6.1 Standardisation of the concentration of growth substance

The experiment was laid out in randomised block design.

Fifty uniform clumps of the Mysore cultivar were identified in a compact block of the estate. There were twenty-five treatments imposed for this study and each treatment was replicated twice, with one clump per replication. The growth substances were applied as liquid sprays so as to wet thoroughly the panicles and basal portion of the clumps. The frequency of spray was at fortnightly intervals from April to August, 1982 which was the peak flowering period. The concentrations of the various chemicals tried were as follows:

Treatment	Growth substances	Concentration (ppm)
T_1	2,4-D	2
T_2	"	4
T_3	"	6
T_4	"	8
T_5	2,4,5-T	2
T_6	"	4
T_7	"	6
T_8	"	8
T_9	NAA	20
T_{10}	"	40
T_{11}	"	60
T_{12}	"	80
T_{13}	BA	10

Treatment	Growth substances	Concentration (ppm)
T_{14}	BA	20
T_{15}	"	30
T_{16}	"	40
T_{17}	GA_3	25
T_{18}	"	50
T_{19}	"	75
T_{20}	"	100
T_{21}	Ethrel	25
T_{22}	"	50
T_{23}	"	75
T_{24}	"	100
T_{25}	Control	-

3.6.2 Detailed field experiment

Based on the results of the standardisation trial, the most effective concentrations for each of the growth substances were utilized for the detailed investigations in the year 1983. A separate set of thirty plants was identified in the Mysore cultivar for this experiment. There were six treatments laid out in randomised block design and for each treatment, there were five single plant replications. The growth substances were sprayed at fortnightly intervals, commencing from April, 1983 till the end of September, 1983. The experimental details are furnished below:

Treatment	Growth substances	Concentration (ppm)
T_1	2,4-D	4
T_2	2,4,5-T	8
T_3	NAA	40
T_4	GA_3	100
T_5	Ethrel	25
T_6	Control	-

3.6.3 Observations recorded

Number of panicle bearing tillers

Number of young tillers sprouted

Height of the pseudostem of productive tillers (average of ten tillers)

Total leaf area of productive tillers (average of three tillers) the leaf area was determined from length and breadth measurements of leaves making use of the formula suggested by Korikanthimath and Subbarao (1983) as given earlier in 3.2.4

Number of panicles produced per clump

Length of panicles (average of ten tillers in a clump)

Number of spikes produced per panicle (average of five panicles in a clump)

Number of flowers borne per panicle (average of three panicles in a clump)

Total number of flowers borne per clump

Percentage of capsule setting per clump

Percentage of immature capsule drop to the set fruits

Percentage of immature capsule drop to the total flowers opened

Yield of capsules per clump on fresh weight basis

Percentage of capsules infested by thrips

Essential oil content of capsules on fresh weight basis

3.7 Nutritional status of the plant parts during the blossom and rest periods of the crop

This study was carried out to estimate the mineral nutrients present in the different plant parts namely, N, P, K, Ca, Mg, S, Fe, Cu, Zn and Mn at the different phases of crop growth and their relationship with flowering. The uptake of nutrients by individual tillers of cardamom at these crop bearing periods were then computed.

3.7.1 Collection of plant samples

Five uniform clumps were identified in each of the three cultivars Malabar, Mysore and Vazhukka from the Illimadam block of the Cardamom Research Station, during the year 1983. These five clumps in each cultivar were labelled for the study in January, 1983. Three uniform tillers were marked in every clump which were at the panicle initiation phase of growth. The experiment was laid out in a factorial randomised block design with the three cultivars and five growth stages as the treatments. There were three replications consisting of one tiller in every replication. Fifteen tillers were thus chosen in every cultivar as detailed above for this experiment. There were five sampling periods

for the chemical analysis of nutrient elements contained in the various plant organs. Three tillers were sampled at random from each cultivar at one growth stage for the chemical analysis. The five stages of growth were as follows:

Visual appearance of the inflorescence initials

Flower bud development stage

Peak stages of flowering

Capsule maturation stages

Post-harvest stage

The tillers after collection were cleaned and separated into the different plant parts namely roots, rhizomes, panicles, capsules, pseudostems and leaves. The capsules were collected at five seed maturity stages namely tender seed, greenish-yellow seed, brown seed, black seed and ripe seed to determine the mineral elements contained in them.

3.7.2 Preparation of plant samples for chemical analysis

The plant samples were dried in an oven at 70°C for 48 hours to 120 hours depending on the nature of the sample. They were then ground in a Wiley mill to a fineness of 14 mesh and stored in sealed polythene covers.

3.7.3 Estimation of carbohydrates

The total soluble carbohydrates in the leaf samples were determined by the calorimetric procedure as suggested by Dubois et al. (1951). The absorbance of the test solutions were read at a wave length of 625 nm in a Spectronic 20 Spectrophotometer.

3.7.4 Total nitrogen

The total nitrogen in the plant samples were determined by the calorimetric method outlined by Snell and Snell (1967). The absorbance of the test solutions were read at a wave length of 410 nm in a Spectrophotometer.

3.7.5 Preparation of diacid extract

Diacid extract of the plant samples were used for the estimation of P, K, Ca, Mg, S, Fe, Cu, Zn and Mn which is a modification of the method outlined by Johnson and Ulrich (1959). The extract was prepared by digesting one gram of the plant sample in a 1:1 mixture of nitric acid and perchloric acid. The volume of the diacid extract was reduced from 15 ml to 3 ml, when it turned clear, the solution was then filtered and finally made upto 100 ml.

3.7.6 Estimation of phosphorus

An aliquot of the solution was taken from the diacid extract and the total P was determined, calorimetrically by the Vanadomolybdate phosphoric yellow colour method of Jackson (1967). The yellow colour was read in a Spectrophotometer at a wave length of 470 nm.

3.7.7 Potassium

Another aliquot of the diacid extract was taken, diluted 25 times and the total potassium in the extract was determined by the flame emission method using an EEL Flame Photometer.

3.7.8 Sulphur

Sulphur was determined in the diacid extract by the method of turbidimetry as detailed by Hart (1961). The principle adopted was essentially the same as for calorimetry. The turbidity developed by the precipitation of S in the plant extract as $BaSO_4$ on addition of $BaCl_2$ was read in the Spectrophotometer at a wave length of 490 nm.

3.7.9 Calcium and magnesium

Ca and Mg in the plant extract were determined after suitable dilution and a medium of strontium chloride (1000 ppm) was added to the solutions. The readings were taken by the flame atomization method in an Atomic Absorption Spectro-

photometer (make IL 257 of the Instrumentation Laboratory, USA). The wave length employed for Ca was 422.7 nm and for Mg 285.2 nm.

3.7.10 Iron, copper, zinc and manganese

Fe, Cu, Zn and Mn in the diacid extracts of the plant samples were read in the Atomic Absorption Spectrophotometer without any dilution. The wave lengths selected for reading these elements were as follows:

Fe	:	248.3 nm
Cu	:	324.7 nm
Zn	:	213.9 nm
Mn	:	279.5 nm

3.8 Rate of photosynthesis and translocation of photosynthates at various stages of crop growth

The aim of the investigation was to study the rate of photosynthesis and translocation of the photosynthates by making use of radiotracer techniques. Two promising genotypes of cardamom, namely, PV-1 (Malabar) and PR-107 (Mysore) were selected for the study.

3.8.1 Feeding of radioactive CO_2

Radioactive $^{14}CO_2$ was liberated (Vaznisensky *et al.*, 1965) in a specially fabricated leaf chamber (Plate 8).

Plate 8 (×0·05)

The reaction progressed as per the following formula:

$$Na_2{}^{14}CO_3 + 2\ HClO_4 \longrightarrow {}^{14}CO_2\uparrow + 2\ NaCl + H_2O + 4\ O_2\uparrow$$

The apparatus was a closed circuit system wherein $Na_2{}^{14}CO_3$ was allowed to react with perchloric acid 30% V/V. The specific activity of $Na_2{}^{14}CO_3$ used was 51.2 m Ci/m mole.

One ml $Na_2{}^{14}CO_3$ of 100 μCi activity was mixed with an equal volume of non-radioactive Na_2CO_3 of the same concentration. This mixture was kept at one end of the leaf chamber in a beaker. The cardamom leaves (as indicated in the respective experiments) were inserted into the leaf chamber. The leaf chamber was then made air-tight by firmly clipping the lower and upper portions together. There were two exhaust rubber tubings for purging the radioactive gases at the end of the feeding. Before commencing the experiment these tubes were closed by clips. After setting the feeding system, perchloric acid was run down into the beaker containing $Na_2{}^{14}CO_3$ through a burette firmly inserted on its top outside the chamber. Perchloric acid was added sufficiently in excess in order to insure that the reaction was complete. The leaf chamber was provided with a built-in fan (6 V capacity) to facilitate prompt circula-

tion of $^{14}CO_2$ liberated inside the chamber. The selected leaves were fed with the $^{14}CO_2$ for the time specified for that experiment. After the feeding time, the unused mixture of gases were purged through the exhaust tubes into 10% KOH absorbant solution. The light intensity that was incident on the leaf chamber was measured at intervals of 10 min. during the feeding period, by using a 'Yorco Photomet 300' luxmeter.

3.8.2 Rate of photosynthesis at different intervals of the day

This experiment was conducted on the PV-1 genotype of cardamom. Ten suckers at panicle initiation stage were identified in a single clump.From every sucker, the tips of the leaves 1 to 5 (from the apex) were removed. The leaf tips were then inserted into the leaf chamber and equilibrated in $^{14}CO_2$ atmosphere as described before. Immediately after feeding the leaves were dried and preserved for assaying the $^{14}CO_2$ activity fixed by them. Based on the radioactive counts, the relative photosynthetic rates at different intervals of a day were calculated. The feeding was done on 12th March, 1984 at half an hour intervals commencing at 8.30 a.m. and terminating at 6.00 p.m. The photosynthetic rates were correlated with the light intensities at the time of feeding periods.

3.8.3 Photosynthetic efficiency at different canopy levels of cardamom

This experiment was also conducted on the PV-1 genotype using detached leaves and intact leaves.

3.8.3.1 $^{14}CO_2$ fixation in the detached leaves

One clump of PV-1 was chosen in which four identical tillers were marked. The leaf positions 1 to 10 were marked from the apex downwards in these four tillers. The ten leaf tips of one tiller were detached on 20-4-1984, numbered and kept for feeding in the leaf chamber between 2.30 p.m. and 3.30 p.m. The leaves after the feeding time were processed for counting. The ten leaf tips from the other three tillers were utilized for the study on 21st, 22nd and 23rd April 1984.

3.8.3.2. $^{14}CO_2$ fixation in intact leaves

Ten monoclonal clumps of PV-1 (Malabar type) were chosen and from each clump, one tiller of one year growth was selected. These were serially marked as tillers 1 to 10. Leaves from these tillers were numbered and a definite leaf in a tiller was fed with $^{14}CO_2$ between 10.00 a.m. and 10.45 a.m. The leaf discs were sampled immediately after the feeding time for determining the radioactivity fixed by them.

The tiller as a whole, was detached one month after feeding, and samples of all the plant parts were dried, finely ground and the radioactivity counted in a proportional counter. The details of the feeding were as follows:

Tiller number	Position of leaf (from the apex)	Date of feeding
1	1st	18-5-1984
2	2nd	19-5-1984
3	3rd	20-5-1984
4	4th	21-5-1984
5	5th	22-5-1984
6	6th	23-5-1984
7	7th	24-5-1984
8	8th	25-5-1984
9	9th	26-5-1984
10	10th	27-5-1984

The light intensities were read at the commencement, at the middle and at the termination of the feeding time to calculate the average light intensity. Counts of the radioactivity fixed by the leaves were taken immediately after the feeding time. This count was considered as the cent per cent level. Based on the counts obtained in the organs

one month after feeding, the translocation of photosynthates to the various organs and also the relative contribution by the leaves of different positions of the various organs were computed.

3.8.3.3 Photosynthetic mobilization at different periods of crop growth

Five uniform monoclonal clumps of PR-107 (Mysore type) were selected. One tiller of panicle initiation stage was marked in each clump. $^{14}CO_2$ fixation was done on the marked tiller in each clump at five stages of crop growth, namely, panicle initiation, flower bud emergence, peak flowering, capsule maturity and post-harvest stage. Two successive feedings were given for each tiller on the same day so that radioactivity may not be a limiting factor. The leaves 1 and 2 and the leaves 3 and 4 were fed together. The experimental procedure was as follows:

Clump	Stage of growth	Date of feeding	Position of leaf	Time of feeding (hours)
1	Panicle initiation	18.2.1983	1 and 2 3 and 4	10.00 to 10.45 11.00 to 11.45
2	Flower bud emergence	21.3.1984	1 and 2 3 and 4	10.00 to 10.45 11.00 to 11.45
3	Peak flowering	18.6.1984	1 and 2 3 and 4	10.00 to 10.45 11.00 to 11.45
4	Capsule maturity	24.9.1984	1 and 2 3 and 4	10.00 to 10.45 11.00 to 11.45
5	Post-harvest stage	20.12.1984	1 and 2 3 and 4	10.00 to 10.45 11.00 to 11.45

The suckers were carefully removed from the clumps one month after every feeding and were partitioned into the different plant organs. The radioactive counts were taken and the photosynthate translocation and partitioning coefficients were calculated.

3.8.4 Radioassay

The plant material dried in an oven at 70°C to a constant weight, were finely ground in a 'Remie' grinder, taking precaution against any change of contamination. Samples (100 mg) were accurately weighed into planchets for radioactive counting. After spreading the samples uniformlly on the planchets at infinite thickness they were counted using a gas-flow proportional counter. Three counts were taken for each sample and mean of the counts computed. Back ground correction was done for every set of counting.

3.8.5 Autoradiography

The genotype PV-1 (Malabar type) was utilized for this experiment. An actively growing tiller was selected from a potted plant (one-year old) grown in the glass house. The apical four leaves were fed with $^{14}CO_2$. The plant was uprooted 120 days after feeding and separated into the different plant parts.

Specimens of the radioactive leaves, the non-fed leaves and the root system of the fed plant were dried and

pressed using a herbarium press. The specimens were then kept in contact with X-ray film in the dark. After an exposure of one month, the X-ray films were developed and positive prints taken of the autoradiographs. Based on the relative whiteness of the various areas in the positive prints, the radioactivity accumulated in the tissues tested were assessed.

3.9 Oleophysiology of the cardamom oils

The objective of this experiment was to determine the development of the flavour components in cardamom oil extracted at various stages of maturity of the capsules. Five growth stages of seeds (tender, greenish-yellow, brown, black and ripe) were recognised. Sampling of the capsules were done from five monoclonal clumps each of PV-1 (Malabar) PR-107 (Mysore) and PV-5 (Vazhukka). Initially, the fruits that had set were tagged by means of fine nylon threads. Sufficient number of fruits were tagged to yield samples required for the five stages. They were then sampled destructively at the above mentioned seed maturity phases. The essential oil was extracted from the cardamom capsules by adopting the method of Clvenger (1934) as modified by Nambudiri *et al.* (1968).

3.9.1 Extraction of essential oil

Capsules at different seed-growth stages (tender, greenish-yellow, brown, black and ripe) were utilized for

the study. A known weight of the capsules were split open, coarsely ground and fed into the round bottomed flask of a Clevenger distillation still. Distilled water was added to the flask to about five times the volume of the capsules. The condenser and the trap (for oils lighter than water) were then attached and the distillation carried out for four hours. After the distillation time, the oil was separated from the water column in the trap, collected in the glass vials and preserved in a refrigerator. The percentage recovery of oil was calculated by v/w basis of the capsules.

3.9.2 Fractionation of flavour compounds in cardamom oils by gas chromatography.

The oils distilled from the various samples of cardamom capsules were fractionated by gas chromatographic procedure to detect the important flavour constitutents present in them. This investigation was carried out at the Regional Research Laboratory of the Council of Scientific and Industrial Research, Pappanamcode.

The gas chromatograph employed was ' Hewlett Packard 5840 A' model with a built-in electronic integrator. The analysis was carried out by temperature programming from 80°C to 200°C at the rate of 5°C per minute and kept constant at 200°C for 10 minutes. A 1.828 x 0.003 m (6' x 1/8") OV-17 (10%) column was used with N_2 as the carrier gas at a flow

rate of 20 ml per minute. Flame Ionisation Detector (F.I.D) with temperature set at 300°C was used. The samples of essential oils were injected at a temperature of 250°C. Qualitative as well as quantitative characterisation of the oils were done after identifying the peaks obtained in the gas chromatogram.

3.10 The influence of climatic factors (rainfall, relative humidity, mean temperature) and soil moisture on flowering and fruit set

The meteorological data for the years 1982 to 1984 were collected from the 'B class' meteorological observatory of the Cardamom Research Station, Pampadumpara. The data on rainfall, relative humidity and temperature were collected daily and the monthly means were computed. The data on soil moisture was recorded for only one year during 1982. Soil samples were collected from the experimental plots of growth and development studies at 15 cm depth and at weekly intervals. The percentage of moisture present in the soil was calculated on oven dry weight basis and the monthly means were calculated. Path coefficient analyses were conducted between the monthly means of the climatic data and the mean data pertaining to five important aspects of growth and development, namely, production of new tillers, number of panicles produced, number of flowers opened, percentage of fruit set, and percentage of capsule maturity. Valid conclusions were drawn on the direct and indirect effects of the four climatic factors on

the behaviour of tillering, flowering, fruit set and capsule maturity in cardamom.

3.11 Statistical analysis

3.11.1 Growth and development of vegetative and floral parts

The data pertaining to the biometric characters observed were analysed statistically as a factorial randomised block design.

3.11.2 Hormonal regulation of flowering in cardamom

The experiments on the effect of exogenous application of growth substances and the changes in the endogenous levels of growth substances were analysed as randomised block designs.

3.11.3 Nutritional status of the plant parts during the blossom and the rest periods of the crop

Statistical interpretation of the data was done following the factorial randomised block design technique. This analysis aimed to investigate the extent of variability in nutrient status between the cultivars tested and the nutrient removal by cardamom tillers at the various crop bearing periods studied. The ratio of carbohydrate and nitrogen in the leaf samples were also computed for finding their effects on the floral development of cardamom.

3.11.4 Rate and translocation of photosynthates

The data on the rate of photosynthesis at different

intervals of the day, photosynthetic efficiency at different canopy levels of cardamom and the photosynthetic translocation at different periods of crop maturity were analysed as completely randomised designs. The radioactive counts obtained in the leaves and the different plant parts were compared to examine the photosynthetic efficiency of the various leaf positions in terms of $^{14}CO_2$ fixation and in turn the relative translocation of ^{14}C photosynthates to the different organs tested. Simple correlation analyses were worked out to see the relationship between immediate fixation of $^{14}CO_2$ and the light intensity that was incident on the leaf chamber during the period of the study.

The data of the parameters that were recorded in percentage were transformed into arc sin values and then interpreted statistically following angular transformation techniques. The extracts of analysis of variance tables and the meteorological data of the Cardamom Research Station, Pampadumpara for the years 1982 to 1984 are furnished in the Appendices.

RESULTS

4 RESULTS

The results of the investigations on the physiological aspects of flowering, fruit set and capsule development in cardamom conducted at the Cardamom Research Station, Pampadumpara are presented in this Chapter.

Growth of the plants was assessed in terms of production of tillers, height of tillers, number of leaves produced per tiller, plastochrone scale, total leaf area per tiller and dry matter accumulation.

4.1 Growth and development of the vegetative and floral parts

4.1.1 Height of the tillers

The progressive height of the tillers from the 2nd month (September, 1982) to the 26th month (September, 1984) for the three cultivars are presented in Table 4. The data show that the Mysore cultivar produced the tallest tillers (285.0 cm) and the Malabar the shortest (194.0 cm). Vazhukka plants were intermediate (270.0 cm). The data also reveal that the growth of the plants, in terms of the height of the tillers, ceased at the 22nd month for Malabar, 24th month for Vazhukka and 26th month for Mysore. The increment in height varied from 10.0 cm to 37.0 cm in Malabar, 11.0 cm

Table 4 Growth of the vegetative organs

Sampling intervals (months)	Height of tillers (cm)						Number of leaves						Total leaf area (sq. cm)					
	Malabar		Mysore		Vazhukka		Malabar		Mysore		Vashukka		Malabar		Mysore		Vazhukka	
	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate
2	12.60	12.6	37.00	37.0	27.00	27.0	0.00	0.0	1.00	1.0	2.20	2.2	0.00	0.00	0.00	0.00	38.90	38.90
4	16.00	13.4	57.00	20.0	70.00	43.0	1.20	1.2	2.10	1.1	3.40	1.2	15.26	15.26	20.80	20.80	78.80	39.90
6	36.00	10.0	78.00	21.0	117.00	47.0	2.20	1.0	3.40	1.3	4.20	0.8	44.70	29.44	92.70	71.90	288.80	210.00
8	68.00	32.0	92.00	14.0	130.00	13.0	4.50	2.3	4.70	1.3	5.50	1.3	228.10	183.40	182.50	89.80	522.20	233.20
10	80.00	12.0	137.00	45.0	167.00	37.0	5.30	0.8	5.90	1.2	6.40	0.9	411.50	183.40	600.50	418.00	1601.00	1079.00
12	117.00	37.0	152.00	15.0	187.00	20.0	7.10	1.8	7.60	1.7	8.20	1.8	1279.50	868.00	1257.56	657.00	2133.00	532.00
14	138.00	21.0	174.00	22.0	203.00	16.0	9.40	2.3	9.80	2.2	11.40	3.2	1694.51	415.01	2847.06	1589.50	3139.00	1006.00
16	151.00	13.0	201.00	27.0	211.00	8.0	10.40	1.0	11.50	1.7	13.80	2.4	2490.74	796.23	3633.32	786.26	3915.00	776.00
18	166.00	15.0	230.00	29.0	228.00	17.0	11.30	0.9	13.80	2.3	14.20	0.4	2429.69	-61.05	3872.00	238.68	4784.00	869.00
20	183.00	17.0	248.00	18.0	233.00	5.0	11.80	0.5	14.50	0.7	14.40	0.2	2256.35	-173.34	4897.00	1025.00	4738.00	-46.00
22	194.00	11.0	260.00	12.0	257.00	24.0	12.70	0.9	15.20	0.7	14.50	0.1	2240.58	-5.77	5213.00	316.00	3329.00	-1409.00
24	-	-	271.00	11.0	270.00	13.0	-	-	15.20	0.0	14.70	0.2	-	-	4844.00	-369.00	2775.00	-554.00
26	-	-	285.00	14.0	-	-	-	-	15.30	0.1	-	-	-	-	3080.00	-1764.00	-	-
Mean	106.51	17.64	170.92	21.92	175.00	22.50	6.90	1.15	9.23	1.18	9.41	1.23	1190.08	204.60	2349.26	236.92	2278.48	231.25
@ F test for growth increments			NS Cultivars		NS Sampling intervals				NS Cultivars		NS Sampling intervals				NS Cultivars		NS Sampling intervals	

@ Statistical comparison was made only for the growth increments

NS: Not signficant

required shorter periods (a mean of 34.9 days) as compared to Malabar (37.55 days) and Mysore (35.75 days).

The leaf production was found to be slightly faster in the three cultivars during the summer months. Considering the three cultivars together the plastochrone scale was 34.46 days for the period from January to March and 34.60 days for the period from April to June. During rains and winter, longer periods (36.86 days and 38.33 days respectively) were needed for a single plastochrone.

4.1.4 Total leaf area of the tillers

The leaf area was greater in the cultivar Mysore than in the other two (Table 4). The maximum leaf area values observed in the three cultivars during the entire span of growth were 5213 cm^2 (for Mysore at the 22^{nd} month), 4784 cm^2 (for Vazhukka at the 18^{th} month) and 2490.74 cm^2 (for Malabar at the 16^{th} month). A decline in leaf area was observed beyond the 16^{th}, 22^{nd} and 18^{th} months in Malabar, Mysore and Vazhukka respectively. The mean rate of expansion in leaf area for the cultivars as well as growth periods were not significant.

FIG. 1 PROGRESSIVE GROWTH OF CARDAMOM TILLERS
HEIGHT (cm)

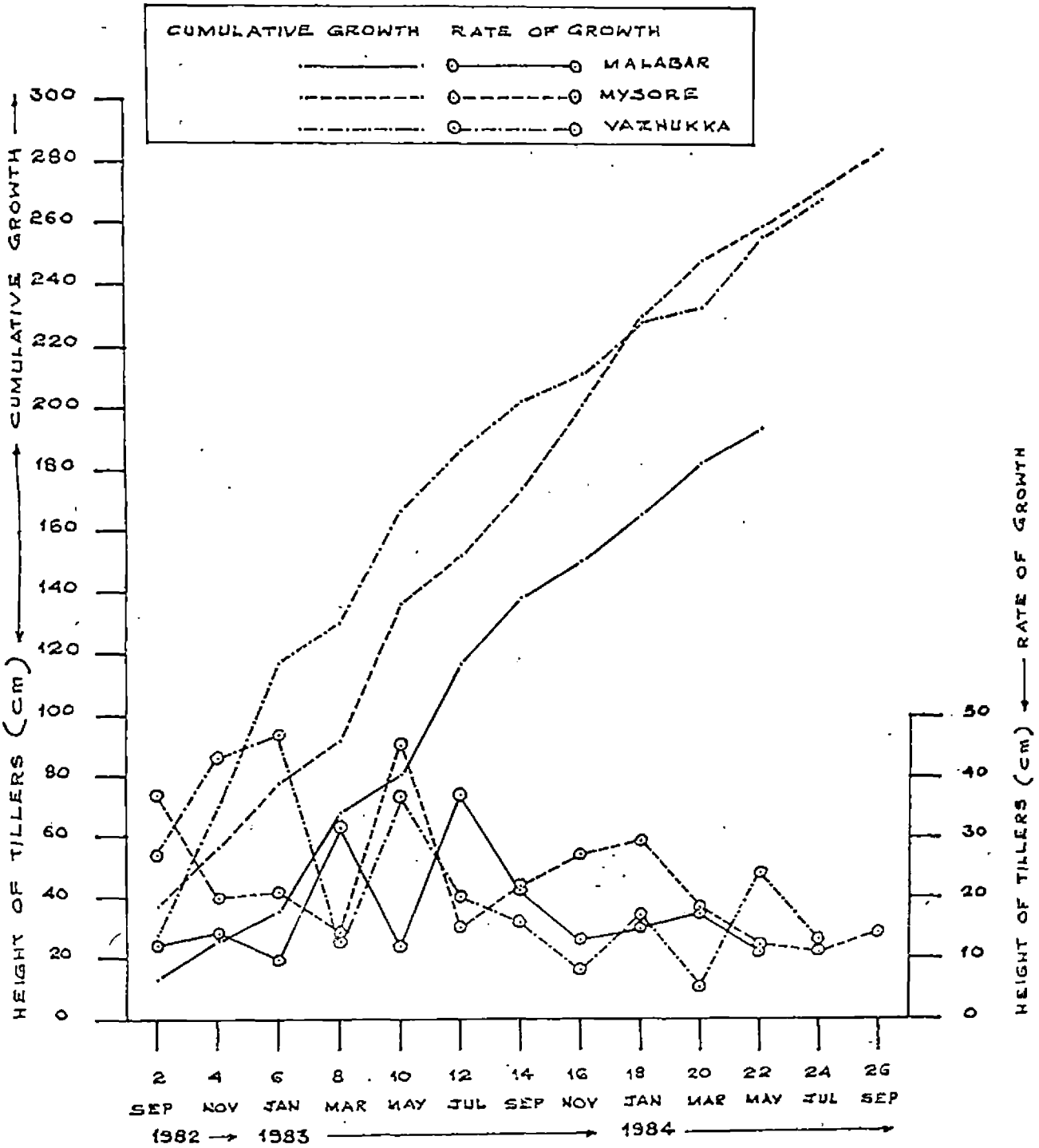


Table 5 Growth of the vegetative organs

(Dry matter content)

Sampling intervals (months)	Dry matter of leaves (g)						Dry matter of pseudostems (g)						Dry matter of rhizomes (g)					
	Malabar		Mysore		Vazhukka		Malabar		Mysore		Vazhukka		Malabar		Mysore		Vazhukka	
	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate
2	0.00	0.00	0.00	0.00	0.26	0.26	0.22	0.22	0.44	0.44	0.28	0.28	0.15	0.15	0.18	0.18	0.11	0.11
4	0.11	0.11	0.24	0.24	0.71	0.45	0.78	0.56	1.15	0.71	1.64	1.36	0.45	0.30	0.41	0.23	0.93	0.82
6	0.41	0.30	0.76	0.52	2.03	1.32	2.10	1.32	2.44	1.29	11.95	10.31	0.79	0.34	1.56	1.15	2.78	1.85
8	1.70	1.29	1.51	0.75	3.77	1.74	5.70	3.60	6.96	4.52	13.42	1.47	1.90	1.11	2.84	1.28	3.35	0.57
10	3.80	2.10	6.43	4.92	13.28	9.51	12.20	6.50	13.14	6.18	18.65	5.23	3.10	1.20	3.17	0.33	3.96	0.61
12	13.50	9.70	12.25	5.82	19.00	5.72	28.00	15.80	22.42	9.28	30.50	11.85	4.50	1.40	3.68	0.51	5.00	1.04
14	18.50	5.00	23.00	10.75	29.00	10.00	31.00	3.00	56.00	33.58	46.00	15.50	5.80	1.30	5.00	1.32	6.00	1.00
16	22.00	3.50	32.50	9.50	35.25	6.25	59.00	28.00	68.00	12.00	56.00	10.00	6.50	0.70	6.50	1.50	9.60	3.60
18	24.80	2.80	36.00	3.50	43.00	7.75	75.00	16.00	73.00	5.00	81.00	25.00	8.00	1.50	7.30	0.80	11.50	1.90
20	28.00	3.20	45.00	9.00	41.00	-2.00	86.00	11.00	97.00	24.00	107.00	26.00	14.00	6.00	12.00	4.70	21.25	9.75
22	30.50	2.50	51.00	6.00	30.25	-10.75	94.00	8.00	121.00	14.00	116.00	9.00	21.50	7.50	22.50	10.50	25.00	3.75
24	-	-	42.00	-9.00	23.60	-6.65	-	-	88.50	-32.50	83.00	-33.00	-	-	27.00	4.50	27.00	2.00
26	-	-	38.00	-4.00	-	-	-	-	82.00	-6.50	-	-	-	-	32.00	5.00	-	-
Mean	13.03	2.77	22.21	2.92	20.10	1.97	35.82	8.55	48.62	5.54	47.12	6.92	6.06	1.95	9.55	2.46	9.71	2.25
@F test for growth increments		NS		**				NS		*				NS		**		
C.D(0.05)		-		4.25				-		14.62				-		3.17		
		Cultivars		Sampling intervals				Cultivars		Sampling intervals				Cultivars		Sampling intervals		

@ Statistical comparison was made only for the growth increments

NS: Not significant

* Significant at 5 per cent level

** Significant at 1 per cent level

contd...

Table 5 Growth of the vegetative organs (contd.)

Sampling intervals (Months)	Dry matter of roots (g)						Dry matter of panicles and capsules (g)						Total dry matter of a tiller (g)					
	Malabar		Mysore		Vazhukka		Malabar		Mysore		Vazhukka		Malabar		Mysore		Vazhukka	
	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate
2	0.11	0.11	0.12	0.12	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.48	0.74	0.74	0.73	0.73
4	0.24	0.13	0.29	0.17	0.14	0.06	0.00	0.00	0.00	0.00	0.00	0.00	1.58	1.10	2.09	1.35	3.42	2.69
6	0.42	0.18	1.27	0.98	1.05	0.91	0.00	0.00	0.00	0.00	0.00	0.00	3.72	2.14	6.03	3.94	17.81	14.39
8	1.20	0.78	2.13	0.86	1.38	0.33	0.00	0.00	0.00	0.00	0.00	0.00	10.50	6.78	13.44	7.41	21.92	4.11
10	1.80	0.60	2.44	0.31	1.44	0.06	0.00	0.00	0.00	0.00	0.00	0.00	20.90	10.40	25.18	11.74	37.33	15.41
12	4.00	2.20	2.60	0.16	1.50	0.06	0.50	0.50	0.00	0.00	0.15	0.15	50.50	29.60	40.98	15.80	56.15	18.82
14	4.50	0.50	3.00	0.40	3.50	2.00	2.00	1.50	0.10	0.10	1.05	0.90	61.80	11.30	87.10	46.12	85.55	29.40
16	6.20	1.70	7.00	4.00	4.00	0.50	5.50	3.50	0.25	0.15	1.50	0.45	99.20	37.40	114.25	27.15	106.35	20.80
18	8.50	2.30	8.50	1.50	7.50	3.50	12.60	7.10	1.20	0.95	2.10	0.60	128.90	29.70	126.00	11.75	145.10	38.75
20	13.50	5.00	9.00	0.50	10.50	3.00	21.50	8.90	2.50	1.30	5.00	2.90	163.00	34.10	165.50	39.50	184.75	39.65
22	9.75	-3.75	14.00	5.00	15.75	5.25	24.60	3.10	14.00	11.50	16.00	11.00	180.35	17.35	222.50	57.00	203.00	18.25
24	-	-	15.30	1.30	14.20	-1.55	-	-	19.00	5.00	28.00	12.00	-	-	191.80	-30.70	175.80	-27.20
26	-	-	13.50	-1.80	-	-	-	-	21.50	2.50	-	-	-	-	187.00	-4.80	-	-
Mean	4.57	0.89	6.09	1.04	5.09	1.09	11.12	2.24	8.36	1.65	7.69	2.33	65.54	16.10	90.97	14.38	86.49	14.60
@ F test for growth increments		NS		**				NS		*				NS		**		
C.D. (0.05)		-		1.84				-		4.70				-		18.97		
		Cultivars		Sampling intervals				Cultivars		Sampling intervals				Cultivars		Sampling intervals		

@ Statistical comparison was made only for the growth increments

NS: Not significant

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 6 Plastochrone scale (time interval in days for successive leaf emergence)

Seasons	Cultivars			
	Malabar	Mysore	Vazhukka	Mean
January to April	35.20	34.40	33.80	34.46
April to June	36.20	34.20	33.40	34.60
July to September	38.00	36.60	36.00	36.86
October to December	40.80	37.80	36.40	38.33
Mean	37.55	35.75	34.90	36.06

@ Every observation a mean of five tillers

F test: Not significant

4.1.5 Dry matter accumulation by the various plant organs

The data on dry matter accumulation by the various plant organs are presented in Table 5.

The leaf dry matter accumulation followed a trend similar to that of the leaf area. The cumulative dry matter accumulation by the leaves reached the maximum at the 22nd month for the cultivars. Malabar and Mysore (30.5 g and 51.0 g respectively) and at the 18th month (43.0 g) for the Vazhukka cultivar. The data indicated that the mean increment in dry matter accumulation by the leaves were of the order 2.92 g, 2.77 g and 1.77 g respectively for the cultivars Mysore, Malabar and Vazhukka. Statistical analysis showed that significant difference existed only between the growth periods of sampling.

The highest dry matter accumulation by the pseudostems (Table 5) was for the Mysore cultivar (121.0 g). The Vazhukka cultivar (116.0 g) and the Malabar cultivar (94.0 g) recorded low dry matter accumulation when compared to the Mysore cultivar. The mean incremental rate of pseudostem dry matter accounted to 8.55 g, 5.54 g and 6.92 g respectively in Malabar, Mysore and Vazhukka. The mean differences between the cultivars did not reveal statistical significance.

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The dry matter accumulation by rhizomes (Table 5) showed the highest values at the 22nd month for Malabar (21.5 g), 26th month for Mysore (32.0 g) and 24th month for Vazhukka (27.0 g). The mean increment in dry matter accumulation by the rhizomes were 1.95 g, 2.46 g and 2.25 g respectively for the three cultivars.

The cumulative dry matter accumulation by the roots (Table 5) exhibited the maxima at the 20th month in Malabar (13.5 g), 24th month in Mysore (15.3 g) and 22nd month in Vazhukka (15.75 g). The data indicated that the mean increment in dry matter accumulation by the roots were 0.89 g, 1.04 g and 1.18 g respectively for the three cultivars.

The data presented in Table 5 also show that the maximum dry matter accumulation by the panicles and capsules were for the three cultivars, Malabar, Mysore and Vazhukka (24.6 g, 21.5 g and 28.0 g respectively) at the 22nd, 26th and 24th months. The incremental rate for dry matter accumulation by the panicles and capsules varied from 0.00 g to 8.90 g in Malabar, 0.00 g to 11.50 g in Mysore and 0.00 g to 12.00 g in Vazhukka. The mean increment in panicle dry matter accumulation for the three cultivars were 2.24 g, 1.65 g and 2.33 g respectively.

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The total dry matter accumulation (Table 5) was highest in all the three cultivars at the 22nd month (180.35 g by Malabar, 222.50 g by Mysore and 203.00 g by Vazhukka). The data further showed that the mean rate of total dry matter accumulation were of the order 16.40 g, 14.38 g and 14.60 g respectively for the three cultivars. A decline in total dry matter accumulation occurred beyond the 22nd month in the cultivars, Mysore and Vazhukka wereas a sharp decline was not observed in the Malabar cultivar (Fig.2).

Statistical analyses of the data for the dry matter accumulation by rhizomes, roots, panicles and the total dry matter gave significant difference only between the sampling periods of the study. The mean incremental rates of dry matter accumulation by the cultivars in all these cases were not significant. Based on the growth parameters studied, it is evident that growth continued upto 22 months in Malabar, 26 months in Mysore and 24 months in Vazhukka.

4.1.6 Production of tillers

The data presented in Table 7 denote the frequency of production of new tillers, observed at monthly intervals during the years 1982 and 1983. The number of new tillers

FIG. 2 TOTAL DRY MATTER OF A TILLER (CUMULATIVE TOTAL)

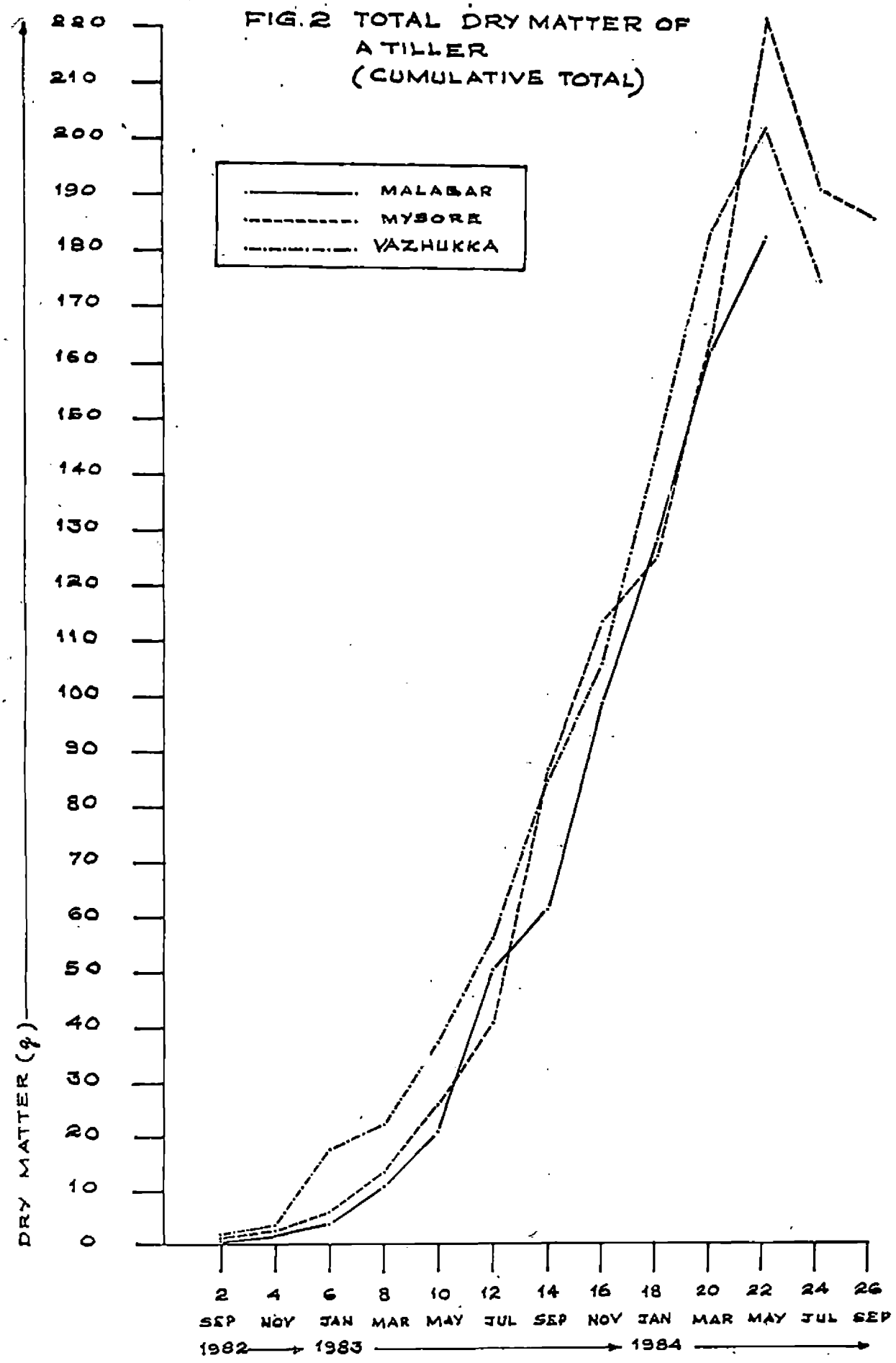


Table 7 Frequency of production of new tillers

Months	1982			1983		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka
January	5.04	1.62	3.54	1.56	1.12	3.24
Feburary	2.62	1.12	2.62	1.42	0.54	2.70
March	3.34	0.90	3.30	0.80	0.36	1.68
April	4.54	2.54	6.22	2.18	1.82	2.90
May	6.22	3.78	9.80	4.50	2.52	4.86
June	11.36	5.10	17.20	4.88	2.70	9.92
July	22.38	6.68	28.62	7.16	3.00	16.14
August	15.30	4.96	21.30	9.26	3.72	18.34
September	6.68	3.78	12.00	6.94	1.94	14.16
October	4.24	3.56	6.50	3.08	2.64	9.02
November	9.16	5.12	10.56	3.86	3.12	9.90
December	4.12	2.42	4.24	2.02	2.08	5.30
Mean	8.86	3.47	10.49	3.97	2.13	8.18
F test	**	**	**	**	**	**
C.D (0.05)	0.92	1.83	3.17	0.60	1.21	2.08
	Cultivars	Months	Interaction	Cultivars	Months	Interaction

** Significant at 1 per cent level

produced was maximum during the month of July for the three cultivars studied during the year 1982 (22.38, 6.68 and 28.62 respectively for Malabar, Mysore and Vazhukka).

Least tillering was observed in February in the three cultivars during the year 1982 (2.62, 1.12 and 2.62 respectively). During the year 1983, maximum tillering was recorded in August (9.26, 3.72 and 18.34 respectively) and the minimum in March (0.80, 0.36 and 1.68 respectively) for the three cultivars.

Two distinct peaks in tillering were seen in the three cultivars studied (Figs.3 and 4). During 1982, July and November were the peak months of tillering, whereas August and November months showed peak tillering during 1983.

The data presented in Table 8 show the number of panicle bearing or productive tillers during the January months of 1982, 1983 and 1984. The number of panicle-bearing tillers registered an increase during the year 1983 for the cultivars, Malabar and Mysore. During 1984, a decline in the number of productive tillers was observed for the two cultivars. The Vazhukka cultivar also exhibited

FIG. 3 FREQUENCY OF PRODUCTION OF NEW TILLERS

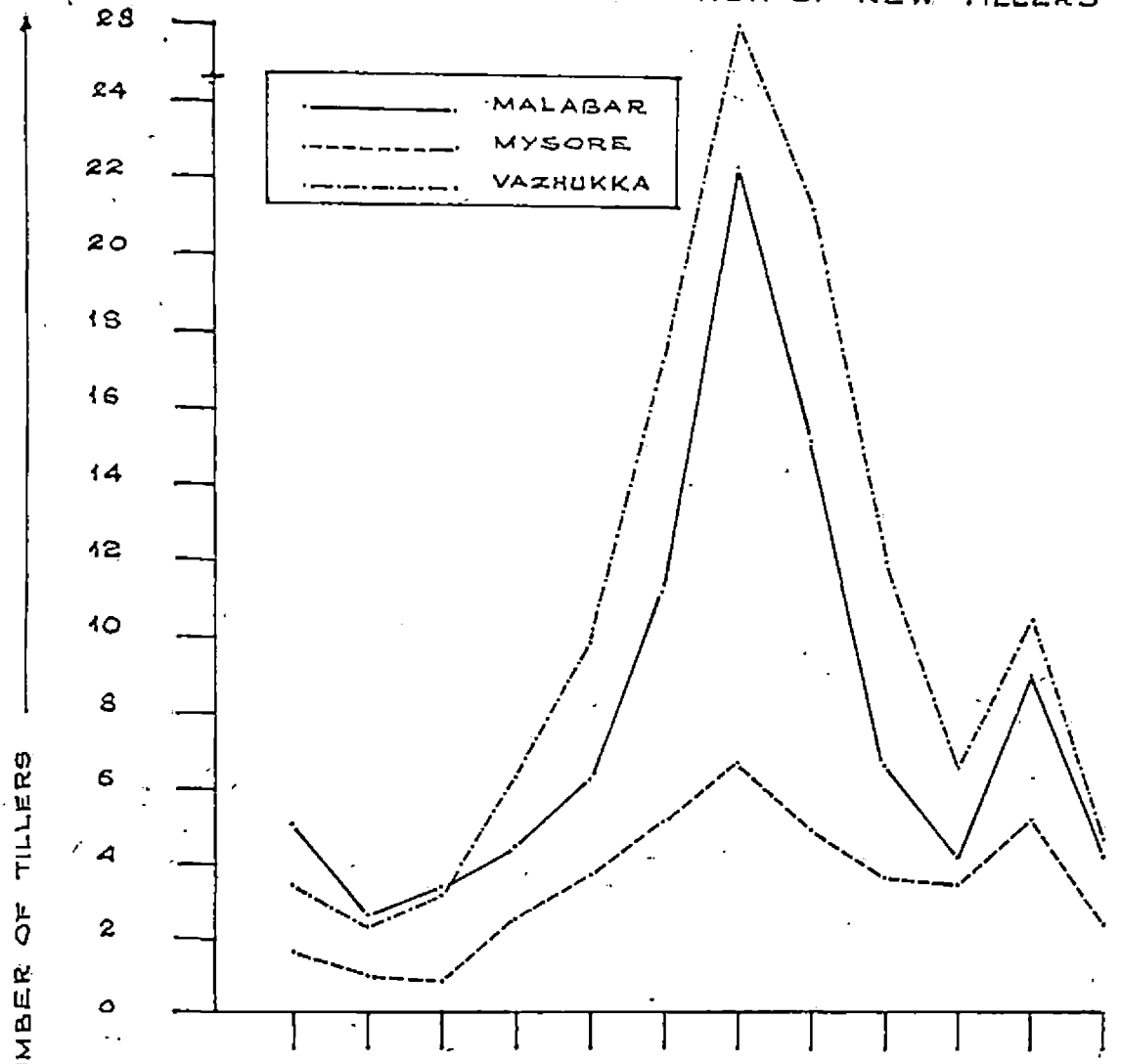


FIG. 4 FREQUENCY OF PRODUCTION OF NEW TILLERS

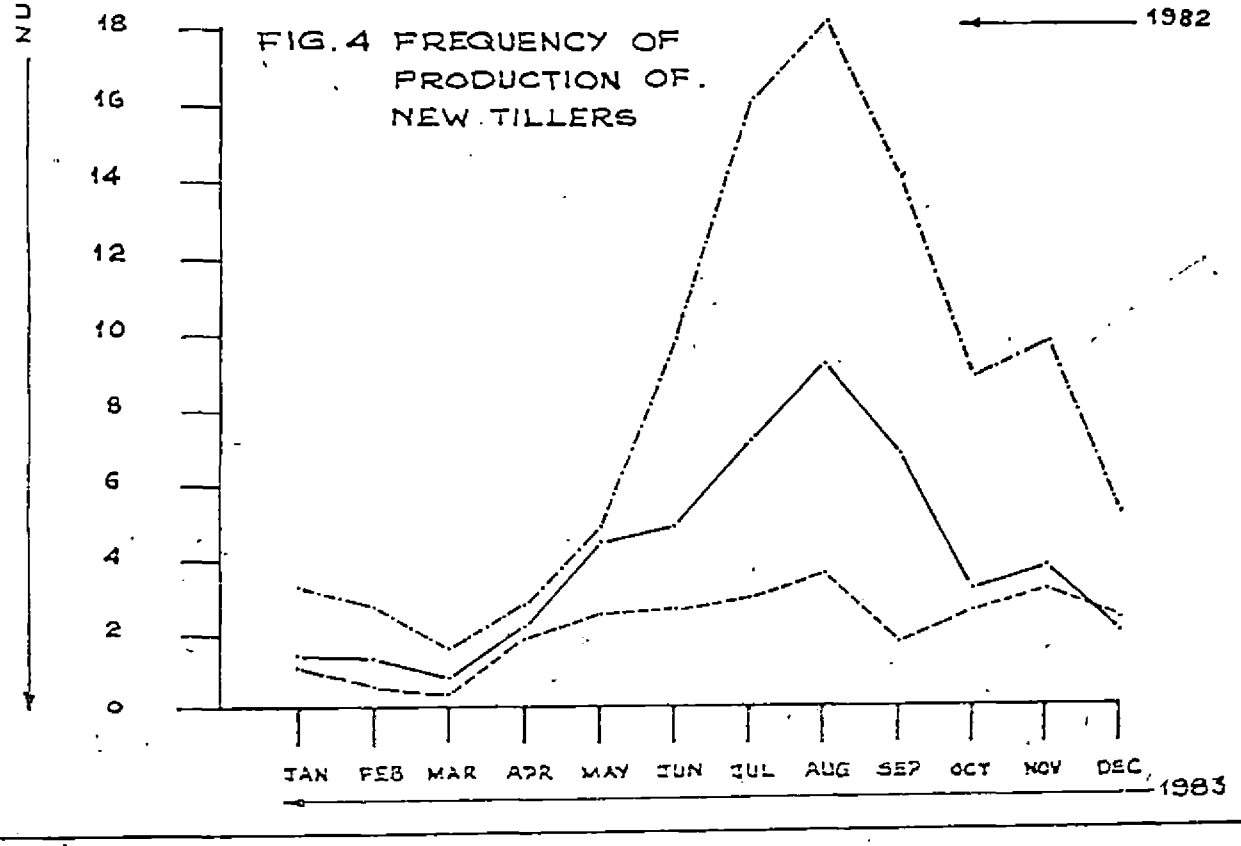


Table 8 Production of panicle bearing tillers

@ Replications	Cultivars								
	Malabar			Mysore			Vazhukka		
	January 1982	January 1983	January 1984	January 1982	January 1983	January 1984	January 1982	January 1983	January 1984
1	29.40	35.20	27.50	24.50	30.30	26.30	41.20	46.10	42.90
2	33.20	43.30	29.20	18.00	25.70	26.00	32.50	39.00	40.70
3	26.80	33.80	34.40	23.70	28.90	23.60	33.80	37.90	40.10
4	27.30	35.00	32.10	17.70	30.50	21.80	30.80	37.40	36.10
5	26.60	37.70	26.50	20.10	26.80	30.10	31.90	37.40	31.20
Mean	28.66	37.00	29.94	20.80	28.44	25.56	34.04	38.80	38.20
F test		**			**			**	
C.D (0.05)		4.75			4.18			3.05	

@ Every observation, a mean of ten plants.

** Significant at 1 per cent level

an increase in the number of tillers during January, 1983. However, the number remained the same during 1984 also. The differences in tiller counts recorded in the cultivars as well as during the periods of counting were statistically significant. The Vazhukka cultivar produced the maximum tillers (38.8 and 38.2 during the years 1983 and 1984 respectively) followed by the Malabar cultivar (37.0 tillers) during the year 1983. The least number of productive tillers was in the Mysore cultivar (20.8) during January, 1982.

4.1.7 Life span of a tiller

The average life span of a tiller was 22.98 months for Malabar, 26.37 months for Mysore and 24.88 months for Vazhukka (Table 9). The range of variability was from 21.8 to 24.4 months in Malabar, 25.1 to 28.2 months in Mysore and 23.8 to 26.0 months in Vazhukka. Statistical analysis of the data revealed that the Mysore cultivar was significantly superior to the other two cultivars in this respect.

4.1.8 Number of panicles produced per tiller and per clump

The number of panicles produced during the life span of the tiller was more in the tillers of Malabar (mean of 2.2), followed by in Vazhukka

Table 9 Life span (months) of a tiller

Replications	Cultivars			Mean
	Malabar	Mysore	Vazhukka	
1	23.70	28.20	23.80	25.23
2	23.10	25.10	24.30	24.17
3	22.60	26.60	25.60	24.93
4	24.00	25.80	24.80	24.87
5	22.20	27.30	24.20	24.57
6	22.00	26.00	25.10	24.37
7	23.20	25.40	25.50	24.70
8	21.80	25.80	24.40	24.00
9	24.40	26.10	26.00	25.50
10	22.80	27.40	25.10	25.10
Mean	22.98	26.37	24.88	24.74

F test **

C.D(0.05) = 0.82

** Significant at 1 per cent level

(2.1) and Mysore (1.7). When the three cultivars were considered together a range of one to four panicles were produced by a tiller (Table 10). Statistical analysis of the data revealed no significance.

The data presented in Table 11 indicate the pattern of panicle production per clump. More number of panicles initiated during January, 1982 in the Malabar and Vazhukka cultivars (9.84 and 12.42 respectively). The Mysore cultivar showed three peaks (Fig.5) of panicle production during February, April and August 1982 (6.18, 7.20 and 4.86 respectively). The mean number of panicles produced were 4.14 (Malabar), 3.56 (Mysore) and 5.90 (Vazhukka). Statistical analysis revealed that the Vazhukka cultivar was significantly superior to the other two cultivars in this respect. The panicle production declined in the three cultivars beyond August, 1982.

During 1983 also, a similar trend in panicle production was observed (Table 11 and Fig.6). The differences observed between the two year's were that in the Mysore cultivar, the peak period of panicle initiation was confined to four months (May to August, 1983) and that in all the three cultivars, December was also a peak month for panicle initiation (3.78, 6.94 and 5.50 respectively for Malabar, Mysore and Vazhukka).

Table 10 Number of panicles produced per tiller

Replications	Cultivars		
	Malabar	Mysore	Vazhukka
1	1	1	4
2	4	1	2
3	1	2	1
4	2	2	3
5	2	2	2
6	3	3	3
7	2	1	1
8	1	1	1
9	4	2	3
10	2	2	1
Mean	2.0	1.7	2.1

F test : Not significant

Table 11 Number of panicles produced per clump

Months	Malabar		Mysore		Vazhukka		Means	
	1982	1983	1982	1983	1982	1983	1982	1983
January	9.84	6.68	3.22	0.88	12.42	4.48	8.49	4.01
February	6.38	1.80	6.18	0.54	7.60	2.21	6.72	1.52
March	5.88	1.20	3.28	1.00	8.44	1.24	5.87	1.15
April	8.42	1.18	7.20	1.64	10.56	0.76	8.73	1.19
May	6.92	4.24	4.80	8.10	9.24	3.80	6.90	5.38
June	4.98	3.36	3.04	6.18	5.98	6.30	4.67	5.28
July	3.78	4.02	2.54	5.64	4.56	3.86	3.63	4.51
August	1.68	1.44	4.86	4.12	3.46	4.36	3.33	3.31
September	0.40	0.72	2.86	1.34	1.90	2.86	1.72	1.64
October	0.42	0.52	2.04	2.58	1.80	2.24	1.42	1.78
November	0.30	1.18	1.60	4.76	1.72	4.90	1.21	3.61
December	0.64	3.78	1.12	6.94	2.88	5.50	1.55	5.41
Means	4.14	2.49	3.56	3.65	5.90	3.54	4.53	3.23
1982 F test		**		**		**		
C.D.(0.05)		0.61		1.22		2.12		
1983 F test		**		**		**		
C.D (0.05)		0.40 Cultivars		0.80 Months		1.39 Interaction		

** Significant at 1 per cent level

FIG. 5 NUMBER OF PANICLES PRODUCED PER CLUMP

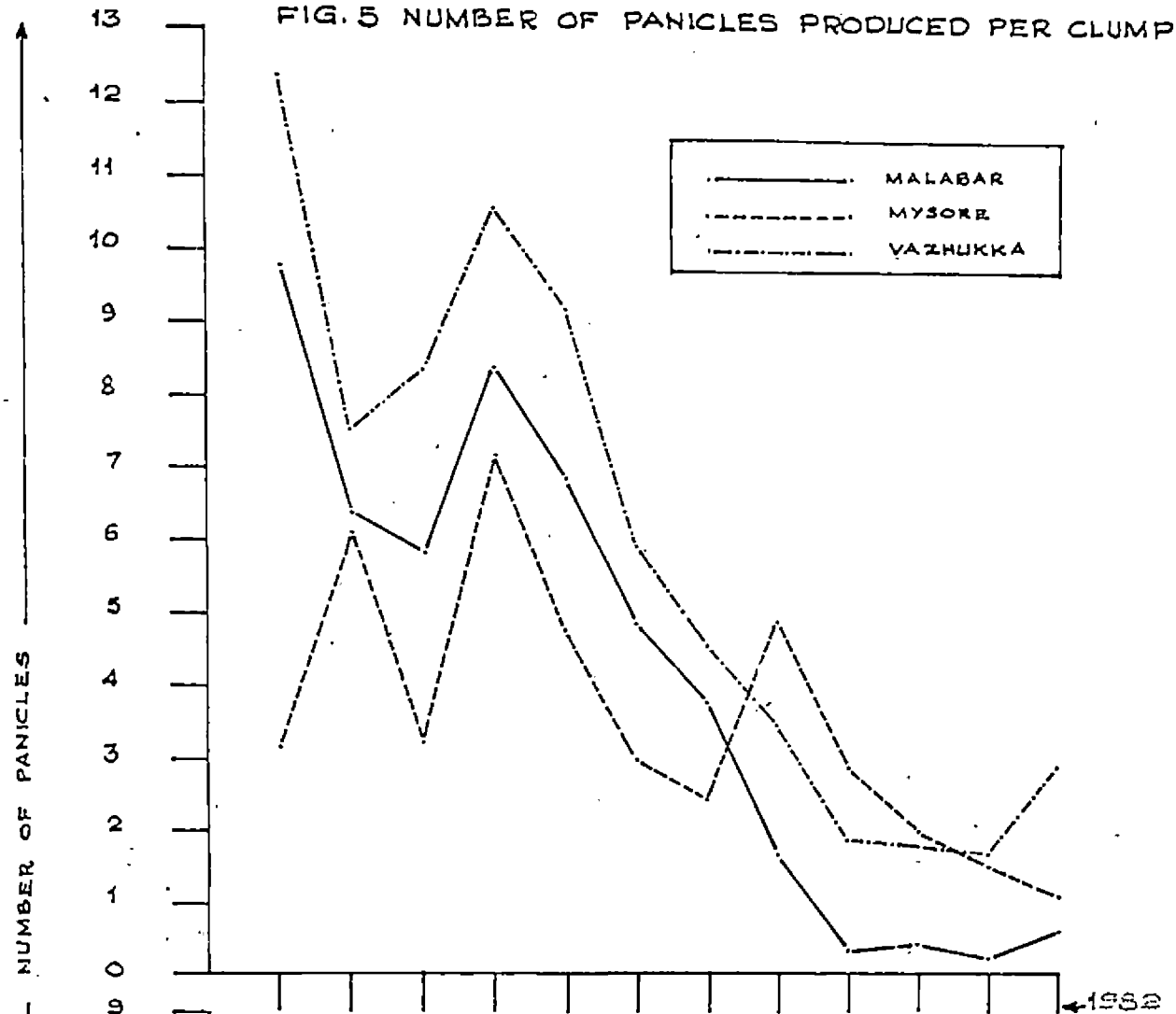
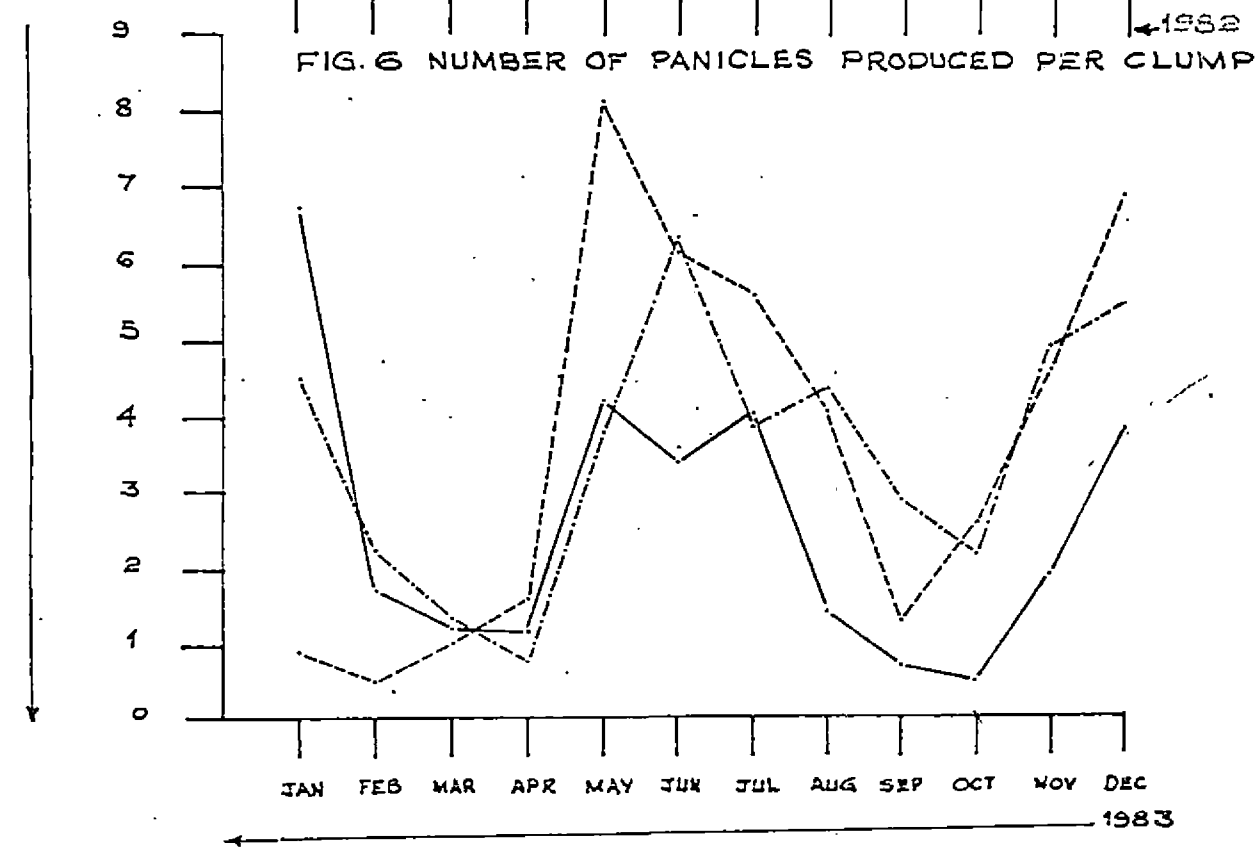


FIG. 6 NUMBER OF PANICLES PRODUCED PER CLUMP



4.1.9 Number of leaves at the time of panicle initiation

At the time of panicle initiation a tiller of Malabar had 6.8 leaves while those of Mysore (9.4) and Vazhukka (8.7) had more number of leaves (Table 12). The extent of variability ranged from 6 to 8 leaves in Malabar, 8 to 11 leaves in Mysore and 8 to 10 leaves in Vazhukka.

4.1.10 Time taken for the visual appearance of panicle initials

In order to subtend a panicle on its rhizome, a growing tiller of Malabar cultivar took 335 days. The tillers of Mysore and Vazhukka took 387 days and 347 days (Table 13). The difference between the Malabar and Vazhukka cultivars was not statistically significant and they were inferior to the Mysore cultivar. The data revealed a spectrum of variability from 318 days to 353 days in Malabar, 369 days to 414 days in Mysore and 322 days to 405 days in Vazhukka.

4.1.11 Extension growth of the panicle at monthly intervals

Studies conducted on the growth of the panicles that initiated during January 1982 indicated that growth continued upto 13 months in Malabar, 14 months in Mysore and 15 months in Vazhukka (Table 14 and Fig.7). The cumulative growth was maximum in Vazhukka (74.90 cm) followed by in Malabar (68.27 cm)

Table 12 Number of leaves at the time of panicle initiation

Replications	Cultivars		
	Malabar	Mysore	Vazhukka
I	6	10	10
II	7	8	8
III	8	11	8
IV	7	9	9
V	6	8	9
VI	6	10	10
VII	8	10	8
VIII	7	9	9
IX	6	9	8
X	7	10	8
Mean	6.8	9.4	8.7

F test *

C.D(0.05) = 0.82

* Significant at 5 per cent level

Table 13 Time taken (days) for the visual appearance of panicle initials

Replications	Cultivars		
	Malabar	Mysore	Vazhukka
I	341	407	346
II	353	381	405
III	326	384	331
IV	318	392	344
V	330	385	322
VI	327	414	360
VII	344	380	329
VIII	349	381	366
IX	320	377	340
X	342	369	327
Mean	335	387	347

F test **

C.D. (0.05) = 15.33

** Significant at 1 per cent level

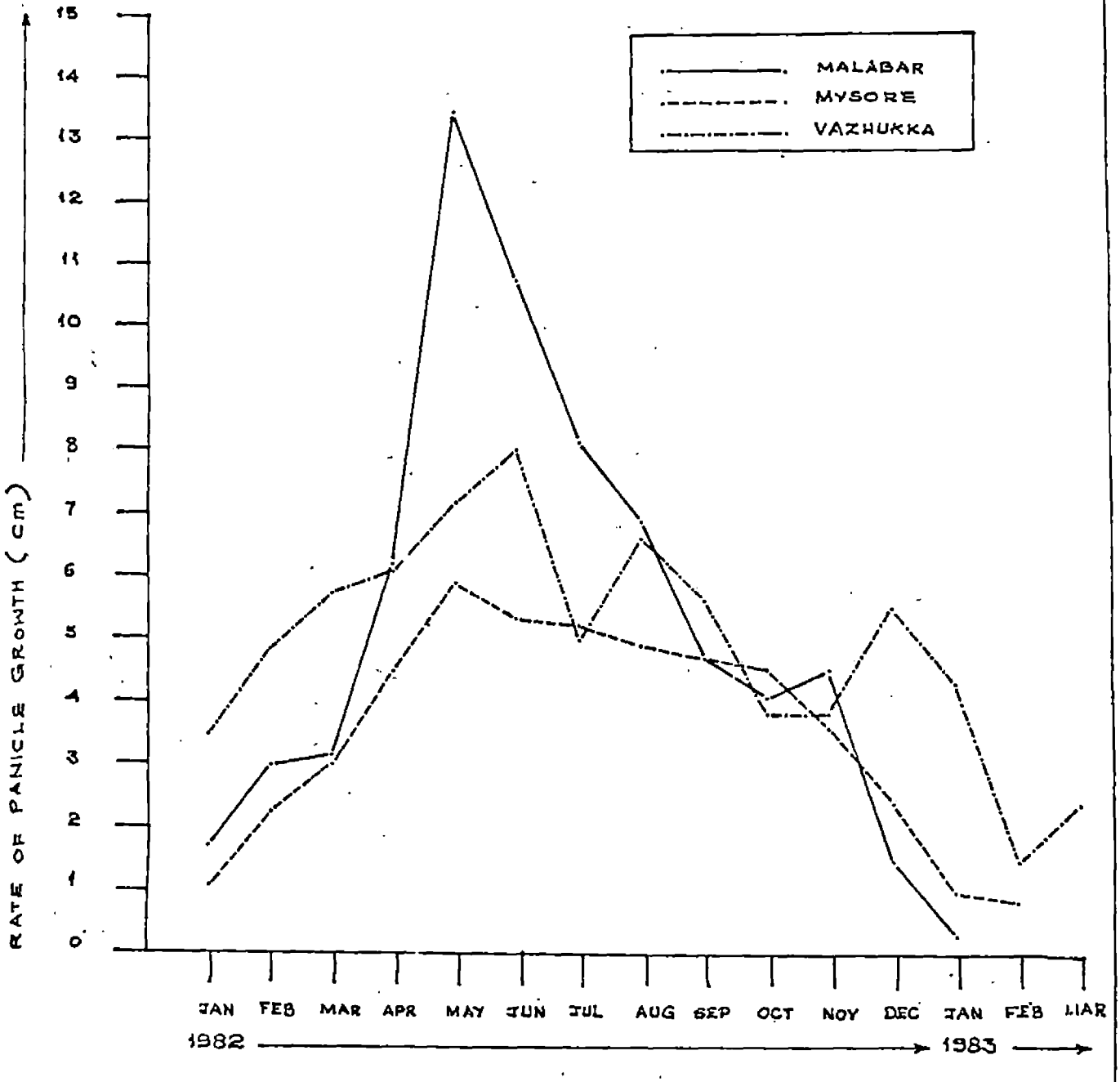
Table 14 Extension growth of the panicles (cm)

Month & year	Cultivars					
	Malabar		Mysore		Vazhukka	
	cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate
January, 1982	1.73	1.73	1.11	1.11	3.47	3.47
February "	4.77	3.04	3.37	2.26	8.33	4.86
March "	8.00	3.23	6.40	3.03	14.00	5.67
April "	14.20	6.20	10.93	4.53	20.13	6.13
May "	27.60	13.40	16.80	5.87	27.33	7.20
June "	38.27	10.67	22.07	5.27	35.33	8.00
July "	46.33	8.06	27.33	5.26	40.33	5.00
August "	53.13	6.80	32.20	4.87	46.87	6.54
September "	57.87	4.74	36.93	4.73	52.47	5.60
October "	62.00	4.13	41.47	4.54	56.33	3.86
November "	66.53	4.53	45.13	3.66	60.13	3.80
December "	68.00	1.47	47.53	2.40	65.67	5.54
January 1983	68.27	0.27	48.67	1.14	69.93	4.26
February "	-	-	49.53	0.86	71.47	1.54
March "	-	-	-	-	74.90	3.43
Mean	39.75	5.44	27.82	3.54	43.11	4.99
@ F test for incremental growth		**		**		**
C.D.(0.05)		1.48 Cultivars		2.56 Months		3.18 Interaction

@ Statistical comparison was made only for the growth increments

** Significant at 1 per cent level.

FIG. 7 EXTENSION GROWTH OF PANICLES
RATE OF GROWTH



and in Mysore (49.53 cm). The mean incremental rate of panicle growth per month was high in Malabar (5.44 cm) followed by in Vazhukka (4.99 cm) and in Mysore (3.54 cm). Significant difference was found only between the Malabar and Mysore cultivars.

The rate of extension growth of panicles was faster in the cultivars, Malabar and Vazhukka during the first six month period after emergence (Fig.7). The Mysore cultivar exhibited a slow and steady growth without revealing a distinct peak.

4.1.12 Number of racemes per panicle

The production of racemes by the panicles continued upto 12 months in Malabar, 13 months in Vazhukka and 14 months in Mysore (Table 15 and Fig.8). The maximum number of racemes were in the panicles of Vazhukka (24.43), closely followed by in Malabar (24.16). The minimum number was in Mysore (15.00). The rate of raceme production per month was faster in Malabar (1.99), followed by in Vazhukka (1.88) and in Mysore (1.11). Statistical analysis revealed that the Malabar and Vazhukka cultivars were on par and both of them excelled the Mysore cultivar in this respect.

Fig.8 illustrates that the Malabar and Vazhukka cultivars were precocious in raceme production whereas

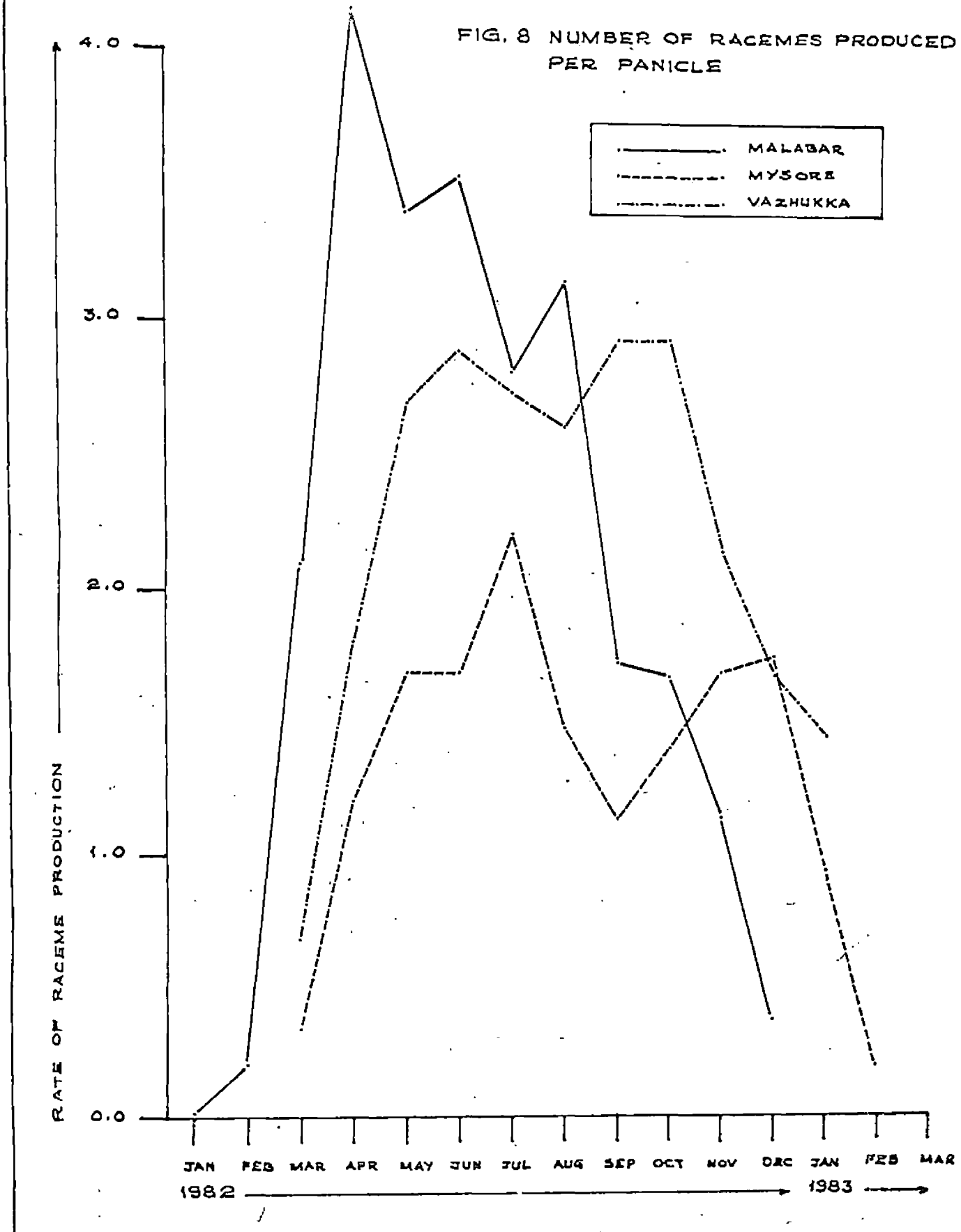
Table 15 Number of racemes per panicle

Month and year	Cultivars					
	Malabar		Mysore		Vazhukka	
	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate
January, 1982	0.00	0.00	0.00	0.00	0.00	0.00
February "	0.20	0.20	0.00	0.00	0.00	0.00
March "	2.27	2.07	0.33	0.33	0.67	0.67
April "	6.40	4.13	1.53	1.20	2.47	1.80
May "	9.80	3.40	2.60	1.67	5.14	2.67
June "	13.33	3.53	4.27	1.67	8.01	2.87
July "	16.13	2.80	6.47	2.20	10.74	2.73
August "	19.26	3.13	7.94	1.47	13.34	2.60
September "	20.99	1.73	9.07	1.13	16.27	2.93
October "	22.66	1.67	10.47	1.40	19.20	2.93
November "	23.79	1.13	12.14	1.67	21.33	2.13
December "	24.16	0.37	13.87	1.73	23.00	1.67
January, 1983	-	-	14.80	0.93	24.43	1.43
February "	-	-	15.00	0.20	-	-
Mean	13.25	1.99	7.04	1.11	11.12	1.88
@ F test for incremental growth		**		**		**
C.D (0.05)		0.62 Cultivars		1.07 Months		1.10 Interaction

@ Statistical comparison was made only for the growth increments

** Significant at 1 per cent level

FIG. 8 NUMBER OF RACEMES PRODUCED PER PANICLE



the Mysore cultivar exhibited a protracted nature for the production of the racemes.

4.1.13 Time taken from visual appearance of the panicle initials till the appearance of the first flower bud

For the appearance of the first flower bud in an inflorescence, the Mysore cultivar took 49.4 days (range 41.0 to 64.0 days), Vazhukka, 44.8 days (range 34.0 to 55.0 days) and Malabar 40.8 days (range 31.0 to 48.0 days). Statistical analysis of the data (Table 16) indicated that significant difference existed only between the Malabar and Mysore cultivars.

4.1.14 Time taken from visual appearance of the flower bud to anthesis

The data presented in Table 17 indicate that the three cultivars took more or less a month's time from the visual appearance of the flower bud to anthesis. The mean number of days required was 28.8 in Malabar, 32.0 in Vazhukka and 34.0 in Mysore.Significant difference existed only between the Malabar and Mysore cultivars. The range of variability was from 26 to 31 days in Malabar, 27 to 38 days in Vazhukka and 27 to 40 days in Mysore. The different stages of development of flower buds till anthesis are shown in Plate 9.

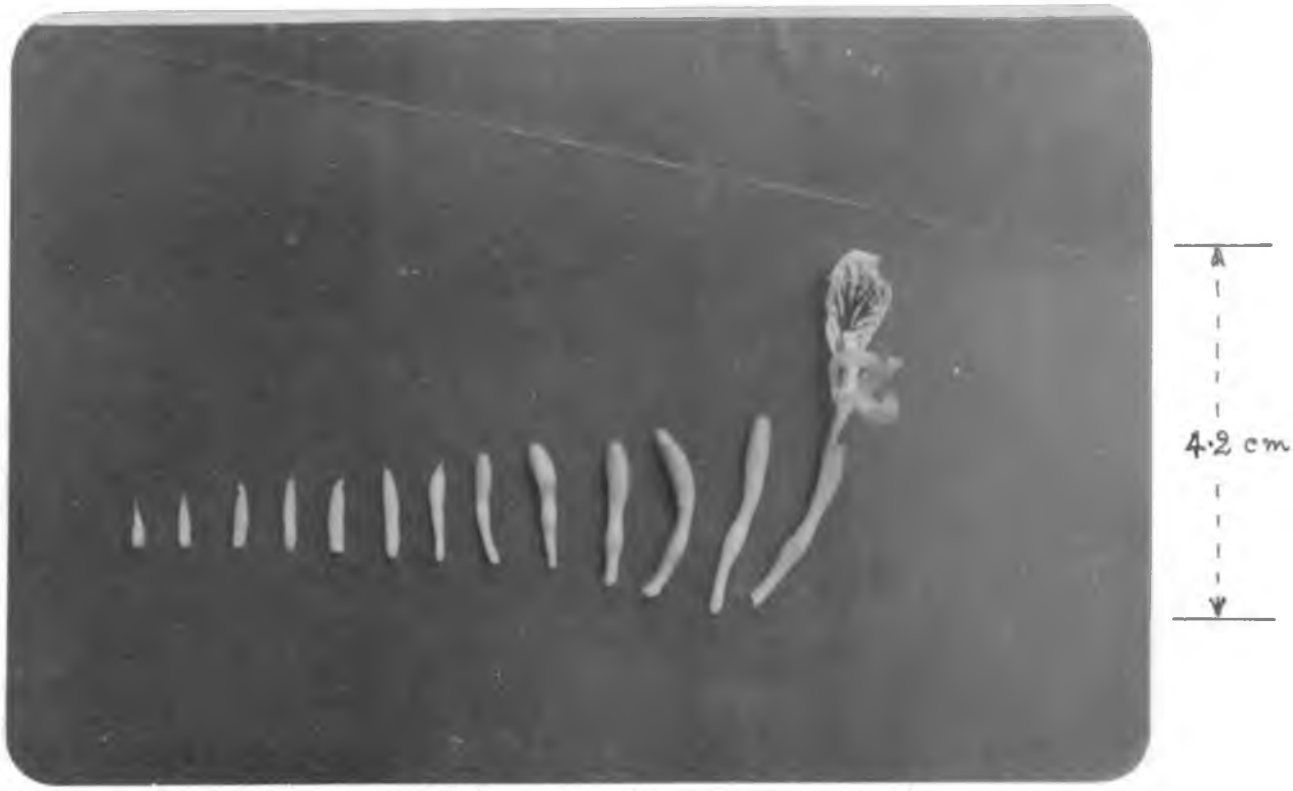


Plate 9 (×0·92)

Table 16 Time taken (days) from the visual appearance of the panicle initial till the appearance of the first flower bud

Replications	Cultivars		
	Malabar	Mysore	Vazhukka
I	40	48	39
II	47	64	55
III	31	42	51
IV	42	58	48
V	38	53	34
VI	35	45	47
VII	46	52	44
VIII	44	48	51
IX	37	43	41
X	48	41	38
Mean	40.8	49.4	44.8

F test *

CD (0.05) 5.28

* Significant at 5 per cent level

Table 17 Time taken (days) from the visual appearance of the flower buds to anthesis

Replications	Cultivars		
	Malabar	Mysore	Vazhukka
I	29	30	38
II	30	36	36
III	31	38	30
IV	28	35	27
V	30	27	31
VI	29	31	29
VII	30	38	28
VIII	28	36	31
IX	26	29	32
X	27	40	38
Mean	28.8	34.0	32.0

F test *

C.D(0.05) = 3.34

* Significant at 5 per cent level

4.1.15 Number of flowers opened per panicle

The data on the pattern of flowering on individual panicles of a clump are presented in Table 18. The mean number of flowers opened per panicle per month was 7.77 in Vazhukka, 5.86 in Malabar and 4.56 in Mysore. The differences were found to be statistically significant among the cultivars as well as the months. Flowering attained a faster rate from April in Malabar and Vazhukka cultivars (Fig.9) flowering continued till August in Malabar and till October in Vazhukka. The peak flowering in Mysore cultivar was from May to October.

4.1.16 Number of flowers opened per clump

The data presented in Table 19 reveal that the mean number of flowers opened per clump in one month was highest in Malabar (118.40), closely followed by in Vazhukka (115.20) and lowest in Mysore (75.56). Statistical analysis of the data showed that the Malabar and Vazhukka cultivars (which were on par) were significantly superior to the Mysore cultivar.

Fig.10 indicates the pattern of flowering in the three cultivars. The cultivars exhibited a protracted nature of flowering. The peak flowering was from March to

Table 18 Number of flowers per panicle

Month and year	Cultivars							
	Malabar		Mysore		Vazhukka		Means	
	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate	Cumulative growth	Incremental rate
January 1982	0.82	0.82	0.10	0.10	1.02	1.02	0.65	0.65
February "	3.00	2.18	0.50	0.40	2.90	1.88	2.13	1.49
March "	7.88	4.88	1.24	0.74	6.94	4.04	5.35	3.22
April "	17.14	9.26	2.96	1.72	13.72	6.78	11.27	5.92
May "	29.94	12.80	8.72	5.76	23.16	9.44	20.61	9.33
June "	45.18	15.24	20.02	11.30	34.82	11.66	33.34	12.73
July "	57.66	12.48	31.36	11.34	51.62	16.80	46.88	13.54
August "	65.18	7.52	40.24	8.88	68.64	17.02	58.02	11.14
September "	68.42	3.24	47.26	7.02	80.64	12.00	65.44	7.42
October "	69.52	1.10	51.28	4.02	89.86	9.22	70.22	4.78
November "	70.00	0.48	53.96	2.68	92.44	2.58	72.13	1.88
December "	70.26	0.26	54.74	0.78	93.22	0.78	72.74	0.61
Mean	42.08	5.86	26.03	4.56	46.58	7.77	38.23	6.06
@ F test for growth increments		**		**		**		
C.D.(0.05)		0.55 Cultivars		1.10 Months		1.91 Interaction		

@ Statistical comparison was made only for the growth increments

** Significant at 1 per cent level

Table 19 Number of flowers per clump

Months	Cultivars			
	Malabar	Mysore	Vazhukka	Mean
January	10.68	6.58	10.50	9.25
February	29.56	13.08	25.64	22.76
March	100.84	31.36	49.44	60.55
April	112.8	51.04	100.92	88.25
May	178.88	167.64	168.60	171.71
June	233.10	152.28	232.62	206.00
July	277.66	113.9	254.00	215.19
August	247.16	119.82	209.94	192.31
September	128.76	113.46	153.20	131.81
October	57.48	61.68	97.90	72.35
November	17.68	49.16	55.0	40.61
December	26.52	26.90	24.2	25.87
Mean	118.40	75.56	115.20	103.05
F test	**	**	**	
C.D (0.05)	9.32 Cultivars	18.63 Months	32.28 Interaction	

** Significant at 1 per cent level

FIG. 9 NUMBER OF FLOWERS OPENED PER PANICLE

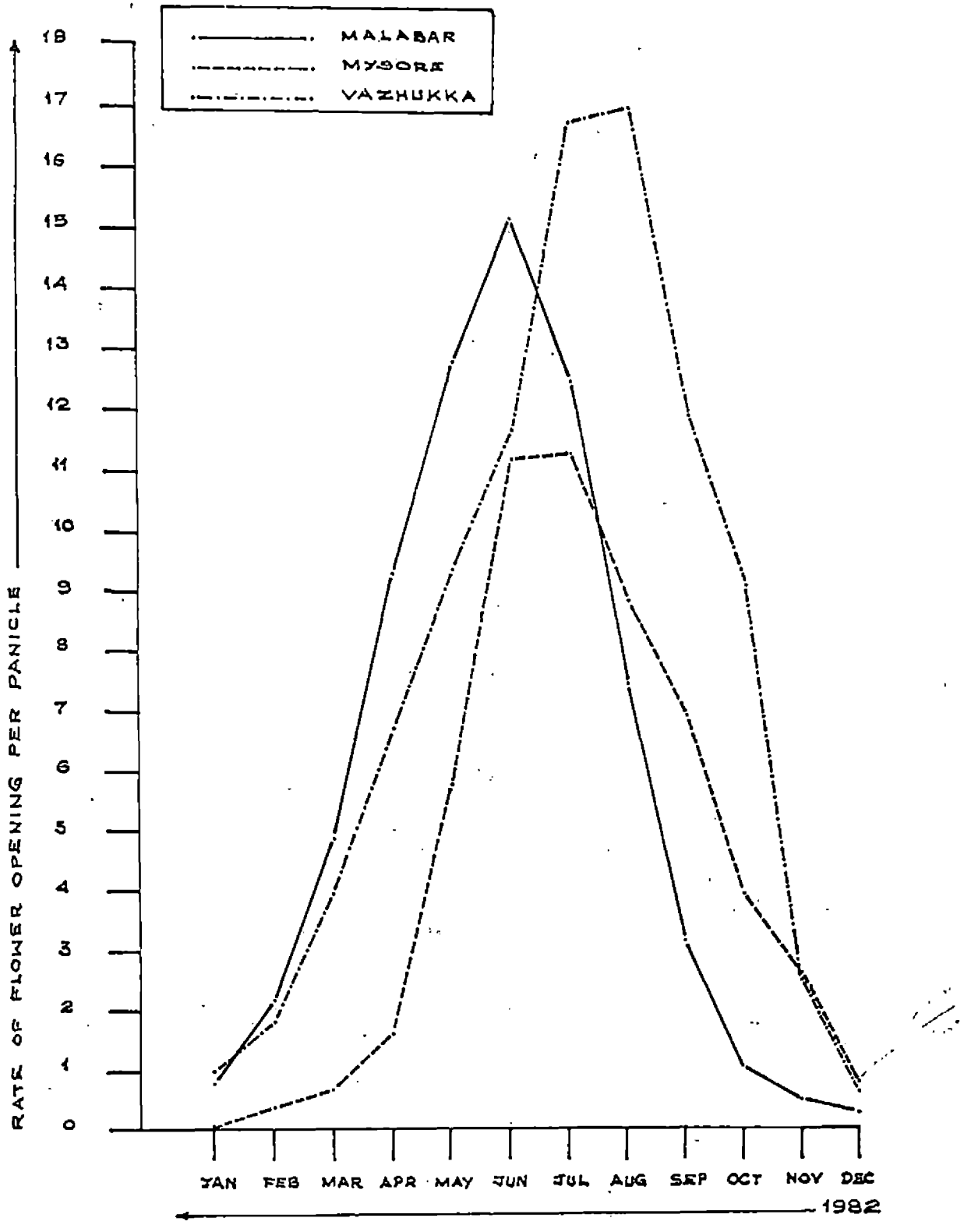
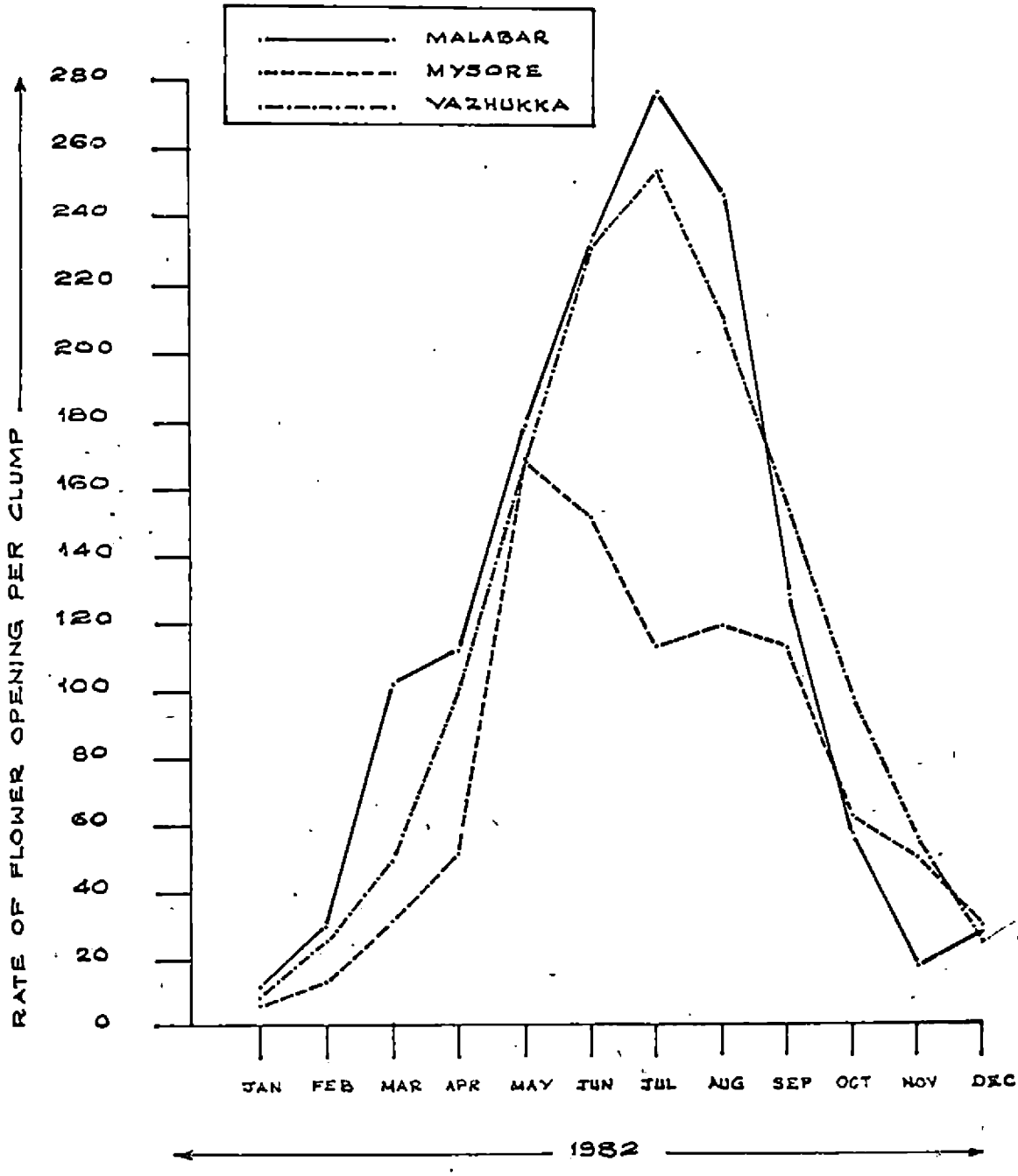


FIG. 10 NUMBER OF FLOWERS OPENED PER CLUMP



September in Malabar, My to September in Mysore and April to September in Vazhukka.

4.1.17 Days to 50 per cent and 100 per cent flowering

On the panicles initiated during January 1982, 50 per cent flowering was observed in 170 days for Malabar, 192 days for Mysore and 204 days for Vazhukka (Table 20). Statistical analysis of the data did not reveal significant difference between Vazhukka and Mysore cultivars which were superior to the Malabar cultivar. The data revealed the variation to be from 151 to 188 days for Malabar, 173 to 208 days for Mysore and 166 to 234 days for Vazhukka.

Hundred per cent flowering was observed in the cultivar Malabar in 317.8 days, in Mysore in 385.0 days and in Vazhukka in 380.8 days. The difference between Mysore and Vazhukka was not statistically significant. The range of variation observed in Malabar was from 247 to 372 days, in Mysore from 338 to 422 days and in Vazhukka from 312 to 442 days.

When the above parameters of flowering were compared it was evident that the extent of variability was high in Vazhukka followed by in Malabar and low in Mysore.

Table 20 Days to 50 per cent and 100 per cent flowering

Replications	Cultivars					
	Malabar		Mysore		Vazhukka	
	50 per cent	100 per cent	50 per cent	100 per cent	50 per cent	100 per cent
I	157	308	185	338	208	421
II	168	277	173	375	226	356
III	182	358	191	346	231	408
IV	174	247	208	395	193	387
V	188	281	181	385	205	442
VI	151	344	206	381	166	345
VII	175	335	183	422	183	330
VIII	181	372	192	406	210	370
IX	155	305	205	411	184	312
X	169	351	196	391	234	437
Mean	170	317.8	192	385.0	204	380.8
F test		**		**		
C.D(0.05)		15.89		39.03		
		50 per cent flowering		100 per cent flowering		

** Significant at 1 per cent level

4.1.18 Time taken from anthesis to fruit set

This parameter was studied only in the Mysore cultivar of cardamom, Biological assay of endogenous auxin was conducted in the ovaries after pollination at periodical intervals. The peak point of auxin activity was taken as the time of fruit set. The data presented in Table 37 indicate that the activity of endogenous auxins expressed as equivalents of indole acetic acid was maximum (315 ng/g), 36 hours after pollination. The higher auxin activity observed at this point indicated that fruit set had occurred within 36 hours of pollination.

4.1.19 Time taken from fruit set to the different seed maturity stages

Five distinct seed maturity stages were observed in the developing capsules. They were the tender seed, the greenish-yellow seed, the brown seed, the black seed and the ripe seed as shown in Plate 10. The Vazhukka cultivar attained the tender seed stage in 19.0 days (Table 21), the Malabar cultivar in 20.0 days and the Mysore cultivar, in 22.2 days. The period required to attain the greenish-yellow stage also followed a trend as above. The cultivar Vazhukka took a mean of 47.3 days,

Malabar, 57.5 days and Mysore, 65.6 days to reach this stage. The brown seed stage was reached in Malabar (78.5 days) earlier than in Vazhukka (81.0 days) and Mysore (85.4 days). The mean duration required for reaching the black seed stage was 113.2 days for Malabar, 124.4 days for Vazhukka and 126.2 days for Mysore. The ripe seed stage was attained in 128.6 days (Malabar), 136.5 days (Vazhukka) and 139.1 days (Mysore). Statistical analysis of the data did not reveal significant difference among the cultivars for the brown and ripe seed stages.

4.1.20 Growth and development of ovaries / fruits

The data given in Table 22 and Figs. 11 to 17 show the growth of the ovaries before anthesis as well as the growth and development of the capsules (fruits) after fruit set. The maximum length of the capsule was in the Malabar cultivar (28.0 mm), followed by in Vazhukka (26.50 mm). The Mysore cultivar had the shortest (16.20 mm) capsules. The difference in the mean length of the capsules among the three cultivars was statistically significant.

The diameter of the capsules at maturity was more in Vazhukka (13.8 mm) than in Mysore (13.3 mm) and Malabar (11.5 mm). The differences among the cultivars were not

Table 21 Time taken (days) from fruit set to attain the different seed maturity stages

Replications	Tender seed stage			Greenish-yellow seed			Brown seed			Black seed			Ripe seed		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka
I	19	25	24	44	59	42	75	82	86	124	126	131	131	138	151
II	20	23	23	62	70	55	83	80	98	114	119	129	127	144	145
III	23	21	17	70	67	49	78	84	92	105	133	125	124	128	138
IV	22	20	15	64	66	40	71	91	77	108	128	136	137	136	129
V	18	26	16	51	50	51	80	88	61	117	146	141	130	149	129
VI	23	24	14	46	82	46	74	83	66	121	131	132	141	145	118
VII	18	20	20	48	68	43	85	86	85	118	128	117	133	139	146
VIII	19	22	24	55	71	56	88	81	80	102	120	108	128	126	137
IX	21	20	19	67	58	42	73	94	93	126	113	122	120	134	130
X	17	21	18	68	65	49	78	85	72	97	118	103	115	152	142
Mean	20.0	22.2	19.0	57.5	65.6	47.3	78.5	85.4	81.0	113.2	126.2	124.4	128.6	139.1	136.5
F test		*			**			NS			**			NS	
C.D (0.05)		3.04			7.62			-			7.35			-	

NS Not significant

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 22 Growth and development of ovaries/ capsules

Growth stages (days)	length (mm)			diameter (mm)			girth (mm)		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka
Pre-anthesis									
10	1.2	0.8	1.0	0.6	0.5	0.5	1.8	1.5	1.6
20	2.8	1.0	2.5	1.1	0.8	1.0	3.1	2.0	3.3
30	3.6	1.6	3.1	1.9	1.2	1.7	7.4	2.4	5.2
Post anthesis									
Fruit set	8.5	4.7	6.1	4.8	2.8	4.6	16.6	9.5	13.0
10	14.2	8.4	11.0	6.0	5.8	5.5	23.4	18.0	21.0
20	15.0	8.9	12.4	6.9	7.0	6.6	25.8	22.6	24.2
30	16.4	9.8	15.2	7.8	7.3	6.9	27.0	24.8	25.0
40	19.0	10.2	18.6	7.8	7.5	7.7	28.0	25.4	26.8
50	21.4	10.9	20.8	8.0	7.8	8.5	28.8	26.0	30.0
60	24.5	11.0	21.0	8.6	8.2	9.2	29.5	27.0	31.5
70	24.8	11.0	22.2	9.7	8.6	9.7	31.8	28.0	32.0
80	25.5	11.3	23.6	10.0	9.5	10.1	32.0	32.5	32.2
90	26.0	12.5	24.2	10.5	10.2	11.7	32.2	33.0	33.4
100	26.7	13.3	24.5	10.8	10.8	12.2	32.6	33.7	34.7
110	27.0	14.7	25.1	11.0	11.5	12.4	32.9	34.1	36.1
120	28.0	15.1	25.8	11.5	13.0	13.0	33.5	35.8	27.4
130	-	16.2	26.5	-	13.3	13.8	-	35.8	38.0
Mean	17.8	9.5	16.7	7.3	7.4	7.9	24.1	23.1	25.0
F test		*			NS			*	
C.D. (0.05)		1.05						1.30	

NS Not significant

* Significant at 5 per cent level

(contd..)

Table 22 Growth and development of ovaries/ capsules (contd.)

Growth stages (days)	Volume (ml)			fresh weight (mg)			dry weight (mg)			drisge (%)		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhu-kka
Pre-anthesis												
.10	0.011	0.008	0.009	7.0	4.0	8.0	0.5	0.2	0.7	7.14	5.00	8.75
.20	0.022	0.012	0.014	11.1	7.3	12.0	1.0	0.5	1.5	9.09	6.82	11.67
.30	0.028	0.015	0.017	14.2	8.8	16.4	1.5	1.0	2.0	10.50	11.29	12.20
Post anthesis												
Fruit set	0.050	0.042	0.038	17.5	24.5	20.5	2.0	3.0	3.0	11.42	12.24	14.63
.10	0.057	0.053	0.060	60.0	65.0	54.0	7.0	8.0	8.0	11.66	12.30	14.81
.20	0.100	0.075	0.140	60.0	82.0	68.0	9.0	12.0	11.0	15.00	14.63	16.18
.30	0.170	0.140	0.230	110.0	95.0	103.0	17.0	16.0	17.0	15.45	16.84	16.50
40	0.220	0.140	0.380	175.0	123.6	146.0	31.0	25.0	25.0	17.71	20.22	17.12
.50	0.240	0.220	0.430	223.0	176.6	255.0	43.0	37.0	45.0	19.28	20.95	17.65
.60	0.380	0.280	0.480	335.0	241.0	340.0	66.0	52.0	62.0	19.70	21.57	18.24
.70	0.440	0.310	0.520	425.0	256.0	410.0	88.0	57.0	85.0	20.70	22.26	20.73
.80	0.470	0.370	0.590	455.0	312.0	520.0	98.0	71.0	110.0	21.54	22.76	21.15
.90	0.570	0.410	0.730	514.0	374.0	600.0	114.0	88.0	135.0	22.18	23.52	22.50
100	0.680	0.440	0.760	602.0	442.0	640.0	135.0	105.0	150.0	22.42	23.75	23.44
110	0.740	0.500	0.810	685.0	517.0	680.0	156.0	123.0	160.0	22.77	23.79	23.53
120	0.820	0.560	0.860	730.0	590.0	705.0	170.0	142.0	170.0	23.28	24.06	24.11
130	-	0.640	0.880	-	620.00	760.0	-	150.0	185.0	-	24.19	24.34
Mean	0.312	0.248	0.409	276.5	231.6	313.9	58.7	52.4	68.8	16.87	18.01	18.09
F test		NS			*			*			NS	
C.D. (0.05)		-			35.6			6.1			-	

NS - Not significant

* Significant at 5 per cent level

FIG. 11 GROWTH AND DEVELOPMENT OF OVARIES/CAPSULES

LENGTH OF CAPSULES (mm)

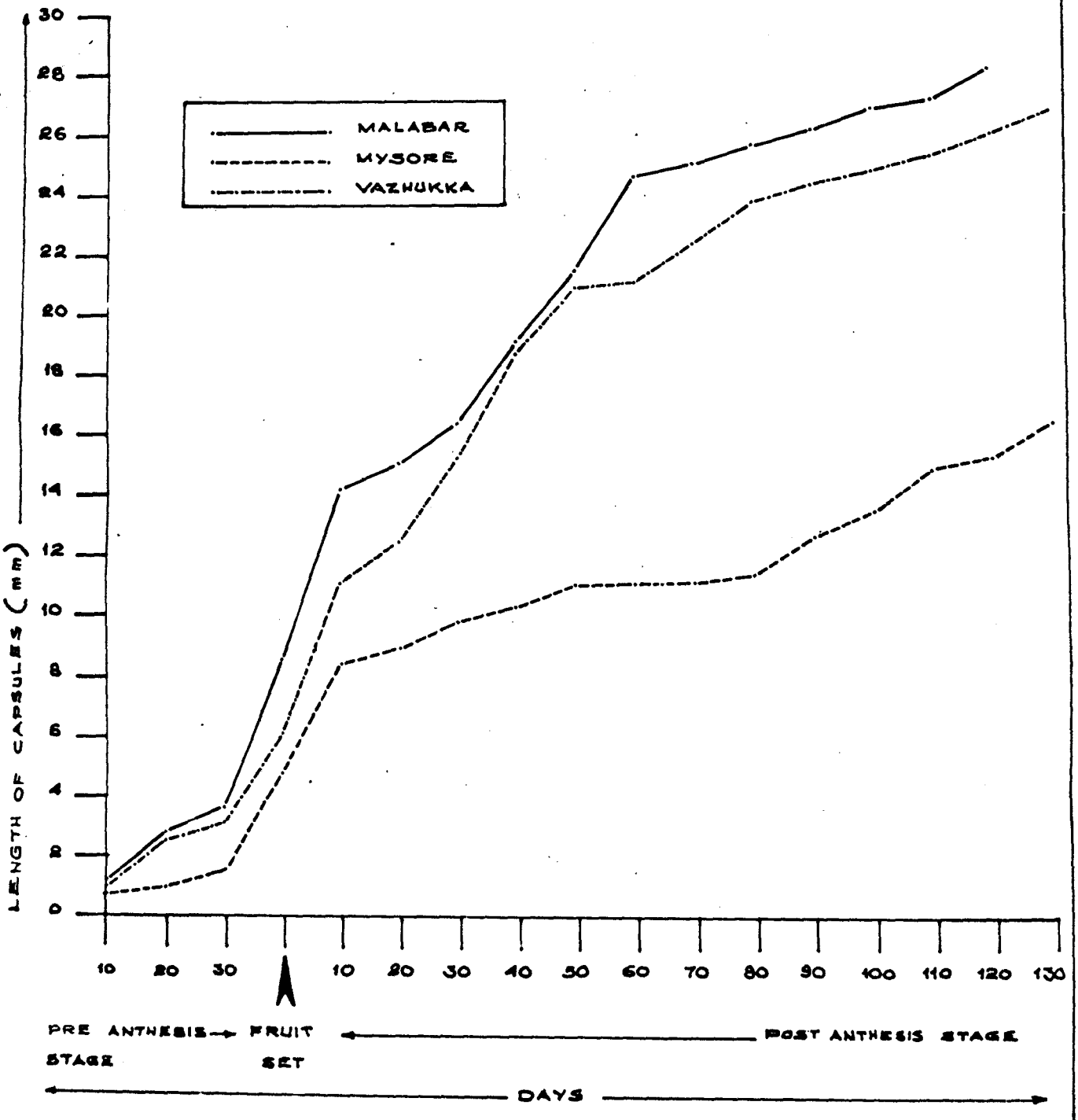


FIG. 12 GROWTH AND DEVELOPMENT OF OVARIES/CAPSULES
DIAMETER OF CAPSULES (mm)

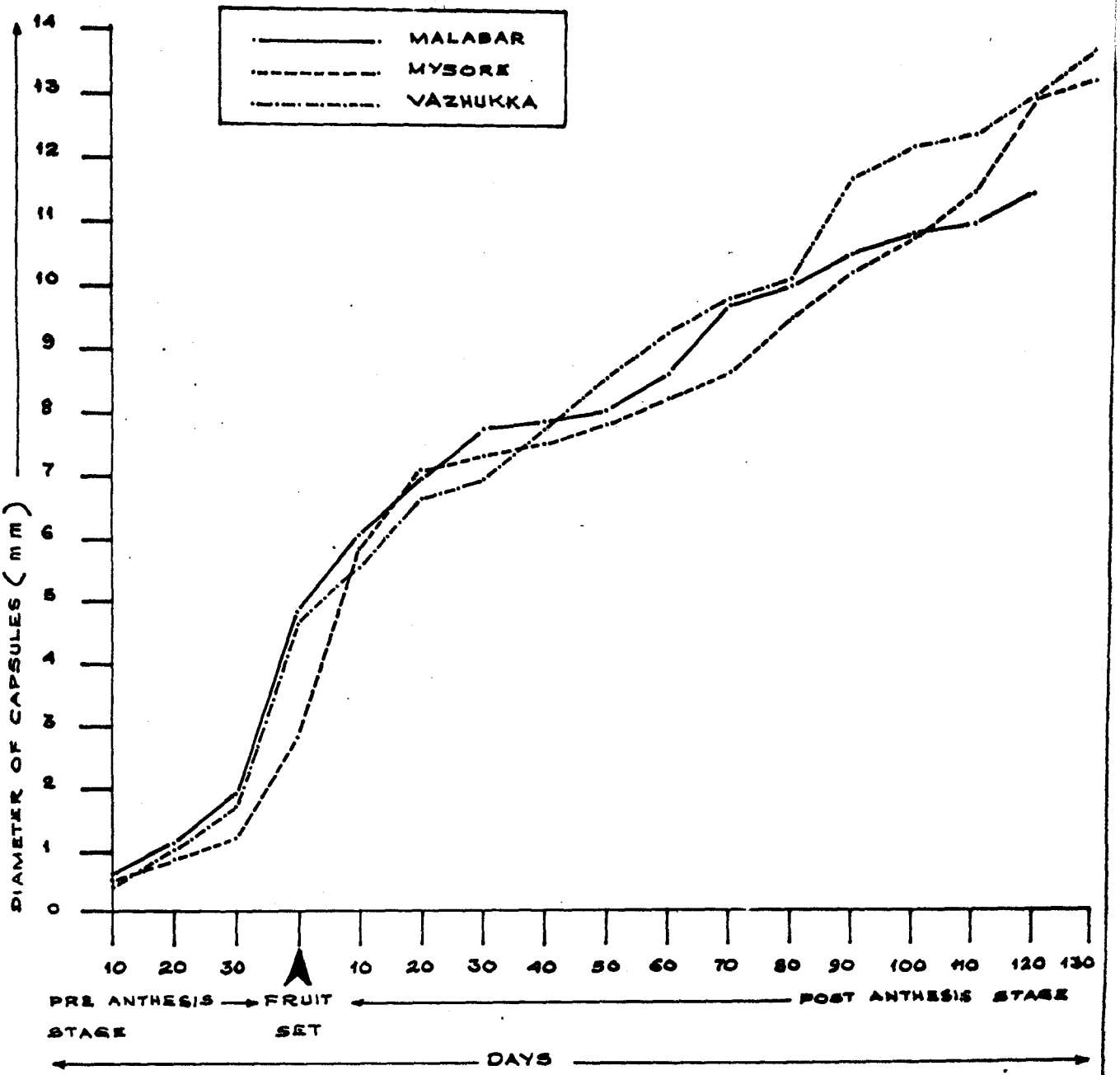


FIG. 13 GROWTH AND DEVELOPMENT OF OVARIES / CAPSULES

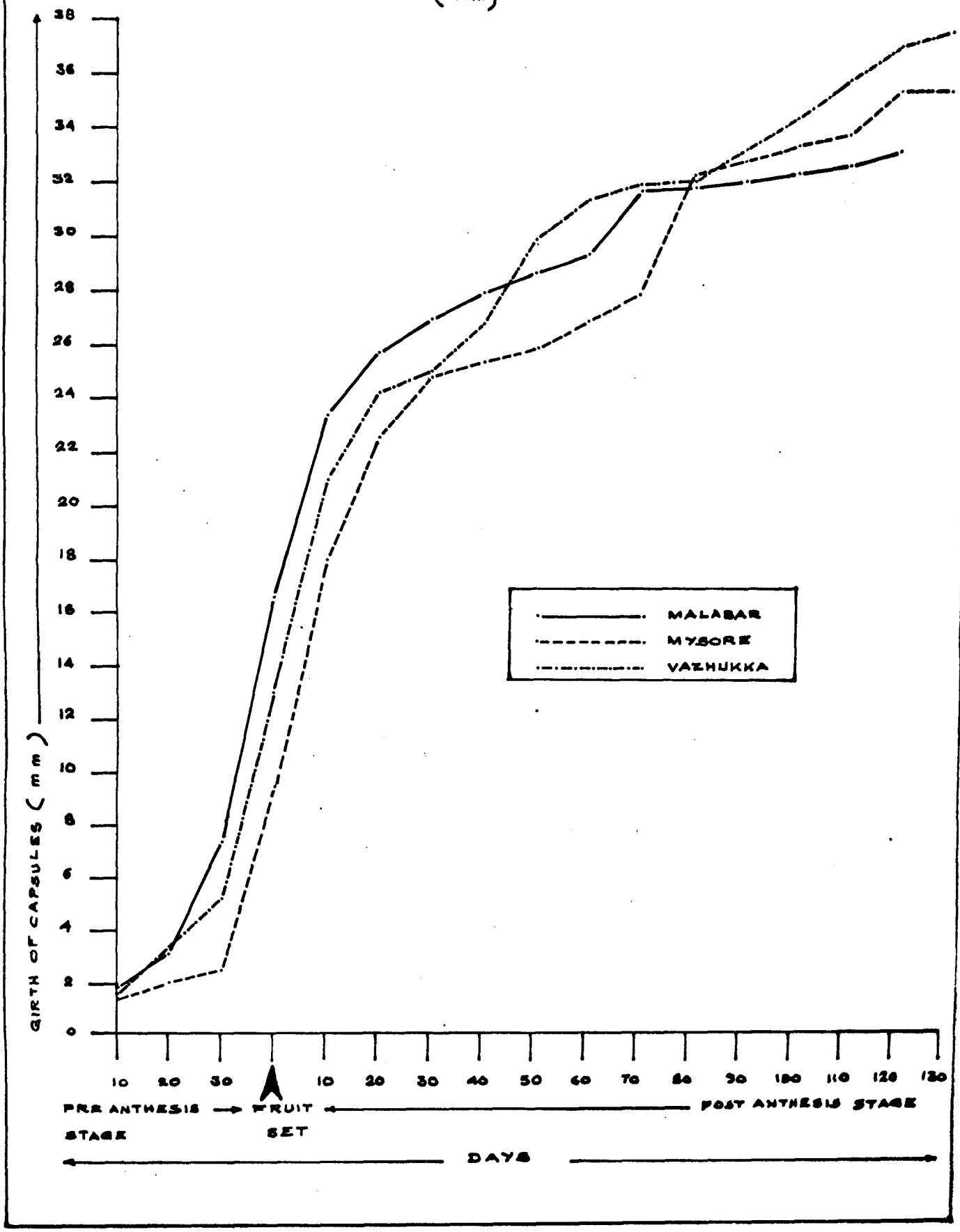


FIG.14 GROWTH AND DEVELOPMENT OF OVARIES/CAPSULES

VOLUME OF CAPSULES (ml)

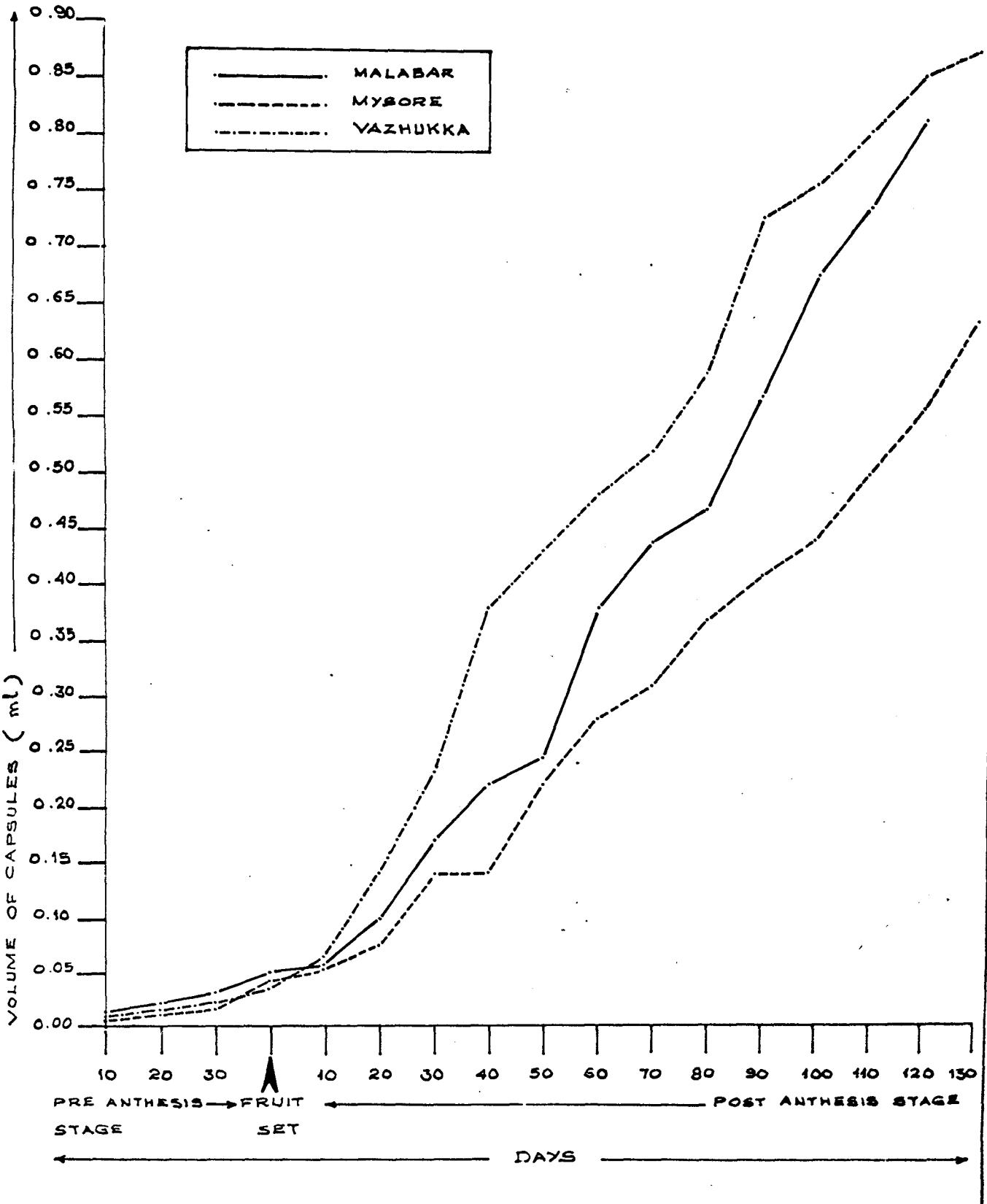


FIG. 15 GROWTH AND DEVELOPMENT OF OVARIES/CAPSULES

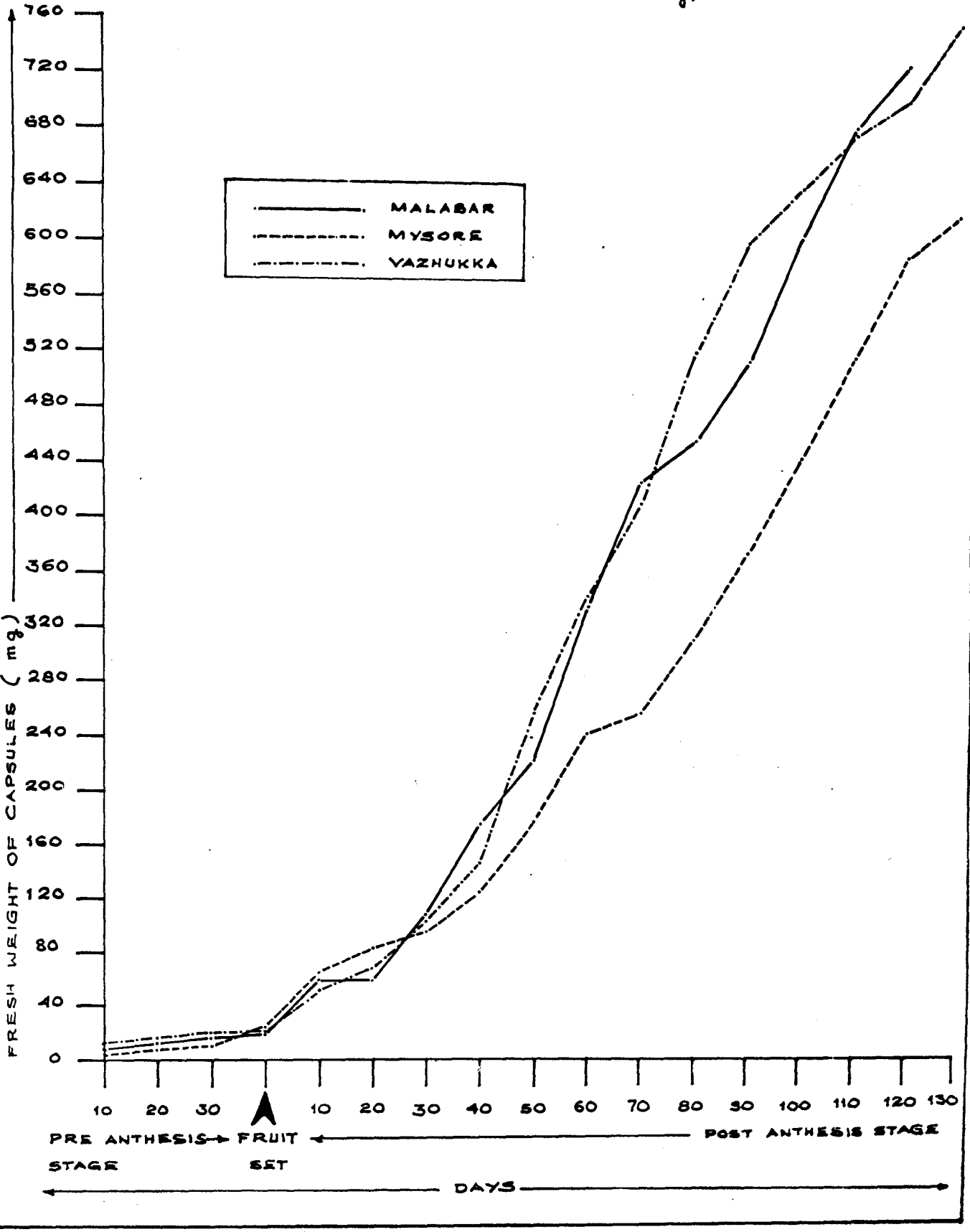


FIG. 16 GROWTH AND DEVELOPMENT OF OVARIES/CAPSULES

DRY WEIGHT OF CAPSULES (mg)

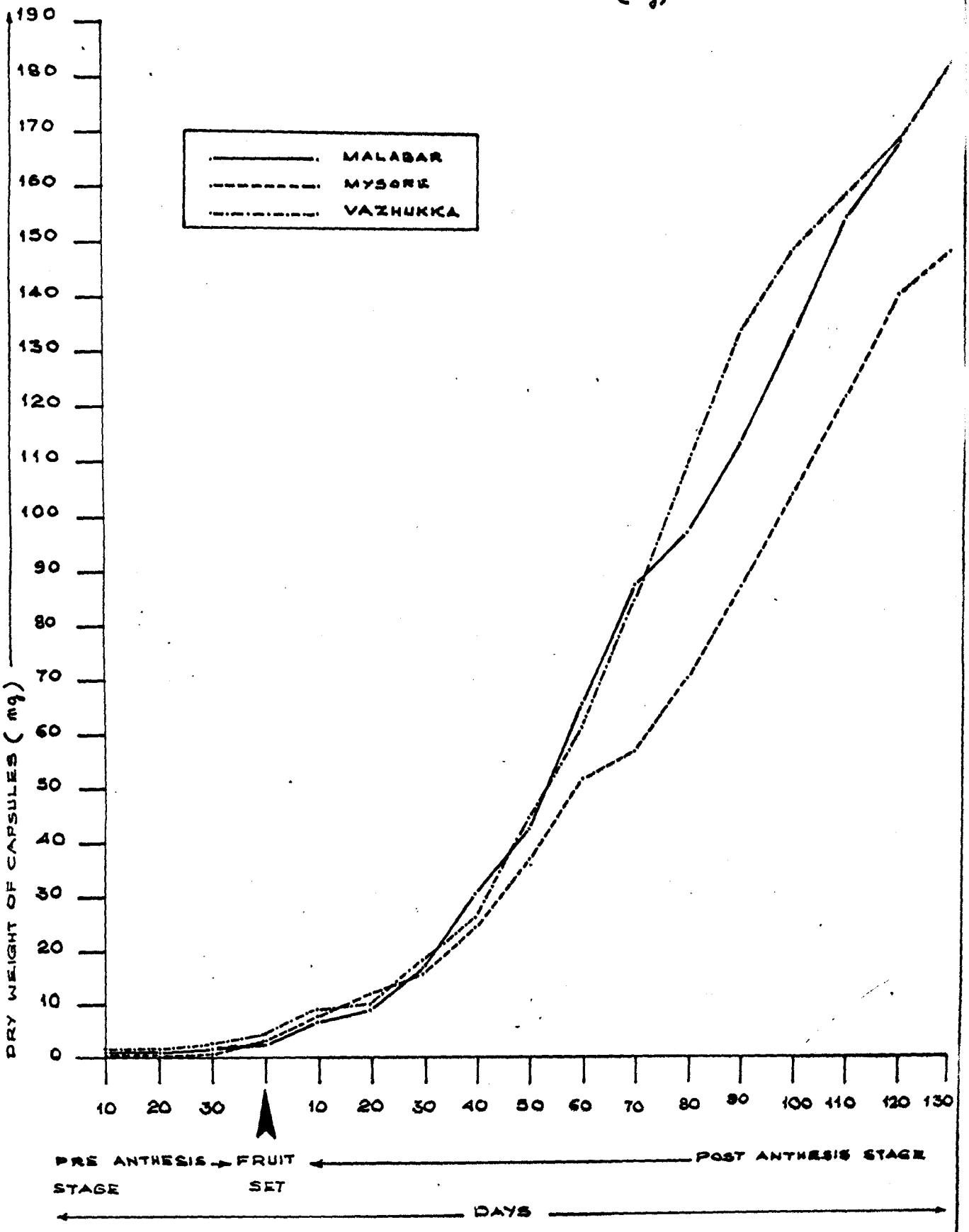
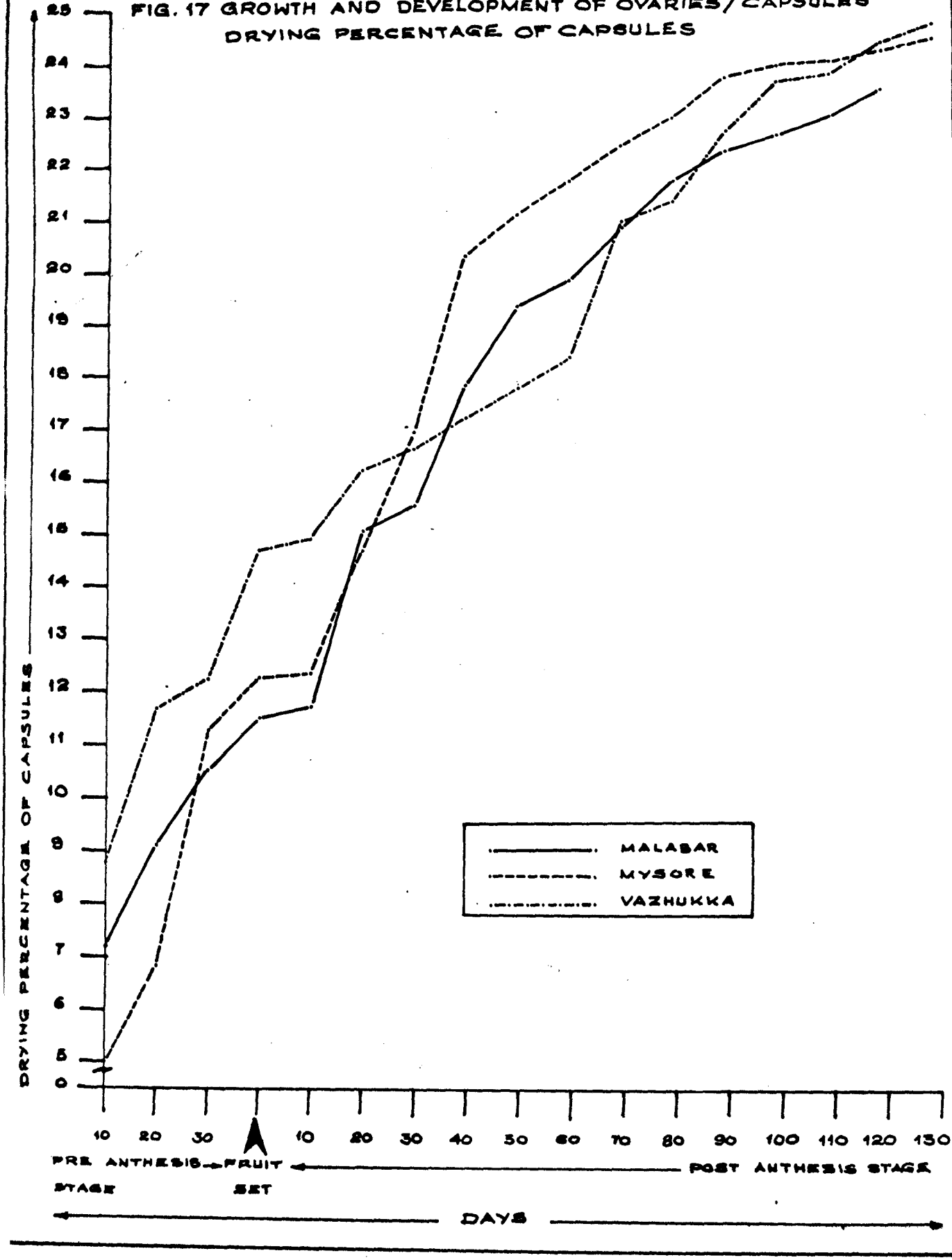


FIG. 17 GROWTH AND DEVELOPMENT OF OVARIES/CAPSULES
DRYING PERCENTAGE OF CAPSULES



statistically significant.

The girth of capsules also exhibited a growth pattern similar to that of the diameter. The girth was more in Vamboika at maturity (36.00 mm) than in Mysore (35.00 mm) and Malabar (33.50 mm). Significant difference existed only between the Mysore and Vamboika cultivars.

At maturity, the capsules of Vamboika were the largest (0.98 ml volume). Malabar (0.81 ml volume) and Mysore (0.64 ml volume) had significantly smaller capsules. Significant difference was not found among the three cultivars.

The length, girth and volume of the capsules exhibited a double sigmoid growth pattern in the three cultivars (Figs. 11,12 and 13). Two peaks of capsules growth were distinguished in the three cultivars. The first peak was common for all the cultivars which lay between 10 and 20 days of fruit set. The second peak was observed in Malabar between 60 and 70 days, in Mysore between 70 and 120 days and in Vamboika between 80 and 100 days of fruit set.

The fresh weight as well as the dry weight of the capsules at maturity were high in Vamboika (760 mg and

165 mg respectively) followed by in Malabar (730 mg and 170 mg) and in [illegible] 650 mg and 150 mg). The differences among the [illegible] cultivars were statistically significant. The dry matter content of the capsules as indicated by the drying percentage was maximum at the final maturity stages in the three cultivars. The Vanbukka cultivar ranked [illegible] (24.34 per cent) followed by Mysore (24.19 per cent) and Malabar (23.26 per cent). Statistical analysis did not reveal any significant differences among the cultivars with respect to this parameter. The data have been depicted in Figs.15 to 17. It can be observed from [illegible] 30 days of fruit set the per cent dry matter accumulation was more in the Mysore cultivar [illegible] in the other two. However, after 120 days of fruit [illegible] the Vanbukka cultivar surpassed the Mysore cultivar in this character.

4.1.21 Percentage of fruit [illegible] per clump

Table 23 shows that the [illegible] percentage of fruit set per clump was of the order of 52.98 in Vanbukka, 51.27 in Malabar and 47.96 in Mysore. The differences among the cultivars as well as among the dates of observations were found to be statistically significant. The fruit set was observed to be less during the months of

Table 21 Fruit [illegible] mm clump

Months	Cultivars							
	Malabar		[illegible]		Vazhukka		Mean	
January	14.97	(21.98)	[illegible]		28.96	(32.29)	20.48	(26.27)
February	18.02	(24.46)	[illegible]		34.01	(35.35)	23.98	(28.73)
March	33.96	(35.96)	[illegible]		32.42	(46.40)	40.15	(38.94)
April	57.78	(49.49)	53.19	(46.68)	52.51	(46.47)	54.48	(47.61)
May	74.87	(60.22)	69.96	(56.86)	77.29	(61.82)	70.71	(57.63)
June	45.82	(67.64)	76.41	[illegible]	85.38	(67.73)	81.60	(65.81)
July	83.60	(66.23)	73.78	[illegible]	86.42	(68.53)	81.27	(64.69)
August	78.57	(62.65)	66.78	[illegible]	81.47	(64.64)	76.28	(61.20)
September	69.38	(51.13)	57.82	[illegible]	69.37	(56.54)	62.86	(53.40)
October	45.26	(42.02)	34.46	[illegible]	62.14	(52.35)	48.44	(47.32)
November	41.62	(40.07)	37.46	[illegible]	62.61	(52.32)	47.23	(43.20)
December	21.26	(26.86)	24.15	[illegible]	39.34	(38.64)	28.25	(31.45)
Mean	51.27	(45.68)	47.96	[illegible]	60.98	(51.92)	53.48	(47.04)

The values given in parentheses are transformed by arc-sin conversion

F test	**	**	*
C.D. (0.05)	2.34	4.68	8.10
	Cultivars	[illegible]	Interaction

* Significant at 5 per cent level

** Significant at 1 per cent level

January and February 1982 (Fig.18). The peak period of fruit set was from May to August 1982 in all the three cultivars.

4.1.22 Percentage of immature capsule shedding to the total flowers borne in a clump

When the immature shedding of the capsules was considered on the basis of the total flowers borne per clump, 18.92 per cent shedding was observed in Malabar, 16.82 per cent in Vamboliha and 16.80 per cent in Mysore (Table 26). The difference between Malabar and Vamboliha cultivars was not statistically significant.

Fig. 20 denotes that the immature capsule shedding prevailed through out the year and more severely during the summer and winter periods.

4.1.23 Percentage of immature capsule shedding to the set capsules in a clump

Table 25 reveals that the immature shedding of capsules was high in the Malabar cultivar (46.80 per cent) followed by in Mysore (43.10 per cent) and Vamboliha (34.96 per cent).

Fig. 19 illustrates that the periods from January

to April and from [redacted] to December were highly conducive for [redacted]. Three distinct stages of immature capsule [redacted] are depicted in Plate 11.

4.1.24 Percentage of [redacted] carried to maturity (to the total [redacted] borne in a clump)

The data given in Table 25 and Fig.21 indicates that 42.94 per cent of the total number of flowers borne in a clump was carried to [redacted] in Vanbukka, 32.30 per cent in Malabar and [redacted] per cent in Mysore. The difference between Malabar and Mysore was not statistically significant. It is further evident that a larger proportion of the flowers that were produced from April to September in the three [redacted] were carried to maturity, with a peak from June to August.

4.1.25 Yield of capsules per clump

The data tabulated in Table 27 reveals that the Vanbukka cultivar ranked first for the yield of capsules per clump both on fresh weight and on dry weight basis (719.02 g and 175.40 g respectively) followed by Malabar (650.8 g and 150.46 g respectively) and Mysore (312.24 g and 78.14 g respectively). The difference between the Malabar and Vanbukka cultivars was not statistically significant.

Plate 10 Seed maturity of cardamom capsules (from left to right: tender, greenish-yellow, brown, black, and ripe seed stages)

Plate 11 Three distinct stages of immature capsule shedding in cardamom

Plate 10 (×0·65)

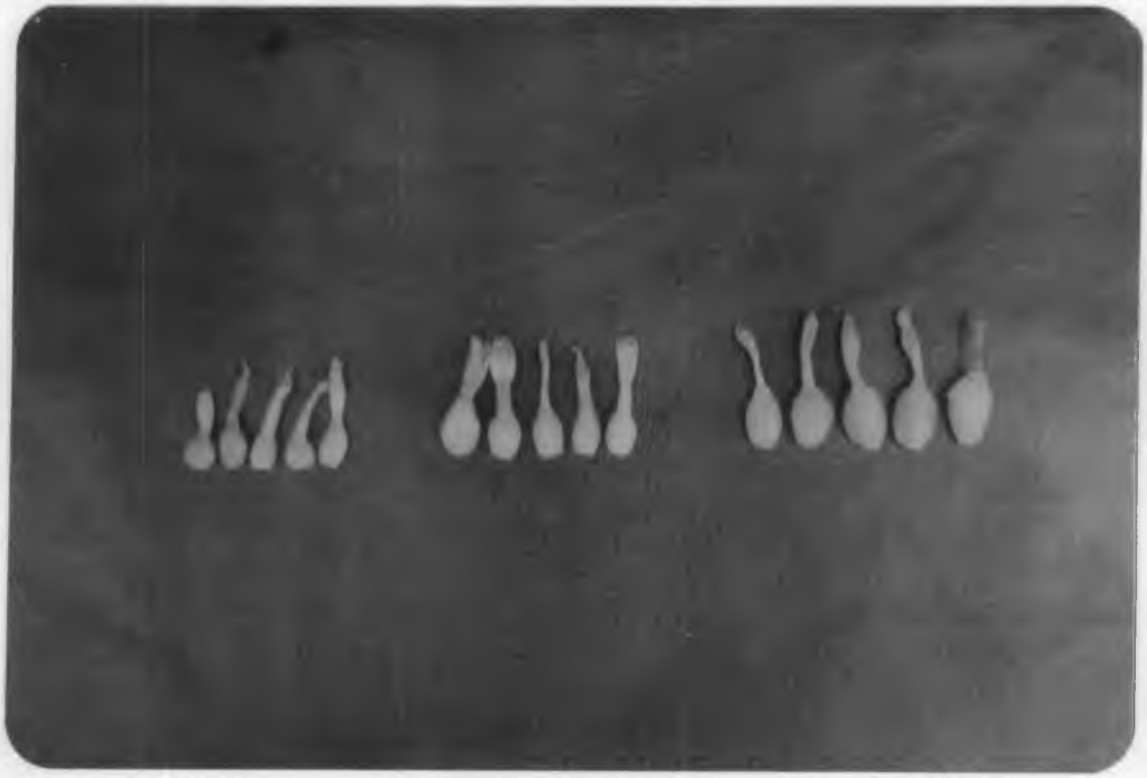


Plate 11 (×0·83)

Table 24 Percentage of immature capsule shedding to the total flowers borne in a clump

Months	cultivars Malabar		Mysore		Vashukka		Mean	
January	11.87	(19.19)	20.18	(26.07)	16.85	(23.36)	16.3	(22.87)
February	13.48	(20.68)	14.18	(21.89)	17.11	(24.17)	14.92	(22.51)
March	21.50	(26.70)	20.13	(26.18)	23.51	(28.97)	21.71	(27.28)
April	23.65	(29.05)	19.06	(25.69)	17.36	(24.58)	20.02	(26.44)
May	16.87	(24.23)	12.75	(20.80)	15.22	(22.46)	14.95	(22.49)
June	16.96	(24.27)	18.29	(25.31)	12.21	(20.12)	15.82	(23.23)
July	16.05	(23.53)	16.52	(23.89)	10.79	(19.07)	14.45	(22.16)
August	14.00	(21.84)	17.27	(24.45)	12.57	(20.54)	14.61	(22.28)
September	24.63	(29.08)	14.79	(22.49)	16.58	(23.81)	18.67	(25.06)
October	23.16	(28.08)	23.31	(28.82)	21.39	(27.27)	22.62	(28.05)
November	30.20	(32.60)	14.69	(22.40)	29.08	(32.61)	24.65	(29.20)
December	14.69	(21.70)	11.62	(19.40)	23.62	(28.79)	16.64	(23.30)
Mean	18.92	(25.08)	16.90	(23.93)	18.02	(24.64)	17.95	(24.52)

The values given in parentheses are transformed by arc-sin conversion

F test	**	**	**
C.D (0.05)	0.45	1.92	3.84
	Cultivars	Months	Interaction

** Significant at 1 per cent level

Table 25 Percentage of immature capsule shedding to the set capsules in a clump

Months	Cultivars						Mean	
	Malabar		Mysore		Vazhukka			
January	74.92	(63.23)	86.82	(67.62)	55.83	(48.26)	72.52	(59.70)
February	71.42	(58.29)	69.90	(56.90)	54.94	(47.10)	65.42	(54.09)
March	59.64	(50.74)	60.54	(51.34)	46.12	(42.74)	55.43	(48.27)
April	41.20	(39.89)	35.42	(36.48)	33.97	(35.55)	36.86	(37.31)
May	22.93	(28.93)	21.13	(27.31)	19.59	(25.79)	21.22	(27.21)
June	19.98	(26.50)	24.59	(29.72)	14.16	(21.81)	19.58	(26.01)
July	19.13	(25.87)	22.77	(28.32)	12.43	(20.56)	18.11	(24.92)
August	17.86	(24.91)	23.68	(29.96)	15.45	(22.91)	19.00	(25.93)
September	39.63	(38.68)	23.24	(29.90)	24.93	(29.53)	29.93	(32.70)
October	50.41	(45.24)	43.32	(41.14)	35.23	(36.16)	42.98	(40.85)
November	69.26	(56.99)	43.16	(40.82)	46.34	(42.90)	52.92	(46.89)
December	65.63	(54.61)	48.64	(44.18)	60.58	(51.12)	58.28	(49.97)
Mean	46.00	(42.78)	42.10	(40.30)	34.96	(35.36)	41.02	(39.48)

The values given in parentheses are transformed by arc-sin conversion

F test	**	**	*
C.D(0.05)	3.12	7.23	10.79
	Cultivars	Months	Interaction

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 26 Percentage of capsules carried to maturity to the total flowers borne in a clump

Months	Cultivars						Mean	
	Malabar		Mysore		Vashukka			
January	3.10	(8.80)	2.65	(6.97)	11.68	(20.59)	5.81	(12.12)
February	4.54	(11.94)	5.85	(12.81)	16.89	(22.75)	9.09	(15.83)
March	12.44	(20.38)	13.95	(21.04)	28.91	(32.24)	18.43	(24.55)
April	34.09	(35.66)	34.13	(35.68)	35.15	(36.19)	34.45	(35.84)
May	57.99	(49.69)	47.22	(43.30)	62.07	(52.10)	55.76	(48.39)
June	68.05	(55.64)	56.11	(48.51)	73.18	(58.89)	65.78	(54.34)
July	67.54	(56.29)	57.26	(49.22)	75.63	(60.49)	66.81	(55.32)
August	64.47	(53.46)	52.65	(46.57)	68.90	(56.20)	62.01	(52.07)
September	35.67	(36.53)	43.03	(40.98)	52.80	(44.60)	43.83	(41.37)
October	21.70	(27.09)	31.12	(33.77)	40.76	(39.48)	31.19	(33.44)
November	11.42	(19.08)	22.75	(27.69)	33.53	(35.38)	22.56	(27.38)
December	6.60	(14.39)	12.52	(20.12)	15.74	(22.98)	11.62	(19.16)
Mean	32.30	(32.42)	31.60	(32.23)	42.94	(40.32)	35.61	(34.99)

The values given in parentheses are transformed by arc-sin conversion

F test	**	**	**
C.D.(0.05)	2.46 Cultivars	4.93 Months	8.54 Interaction

** Significant at 1 per cent level

Table 27 Yield of capsules per clump (g)

Replications	Cultivars					
	Malabar		Mysore		Vazhukka	
	Fresh weight	Dry weight	Fresh weight	Dry weight	Fresh weight	Dry weight
I	658.5	148.16	331.2	78.16	917.8	219.0
II	793.0	187.15	303.5	73.14	621.0	154.0
III	554.5	133.65	390.0	95.55	922.8	223.0
IV	585.5	127.64	272.0	67.45	595.5	147.0
V	662.5	155.69	314.5	76.42	538.0	134.0
Mean	650.8	150.46	322.24	78.14	719.02	175.40
F test			**		**	
C.D.(0.05)			182.17		42.01	
			Fresh weight of capsules		Fresh weight of capsules	

FIG. 18 PERCENTAGE OF FRUIT SET PER CLUMP

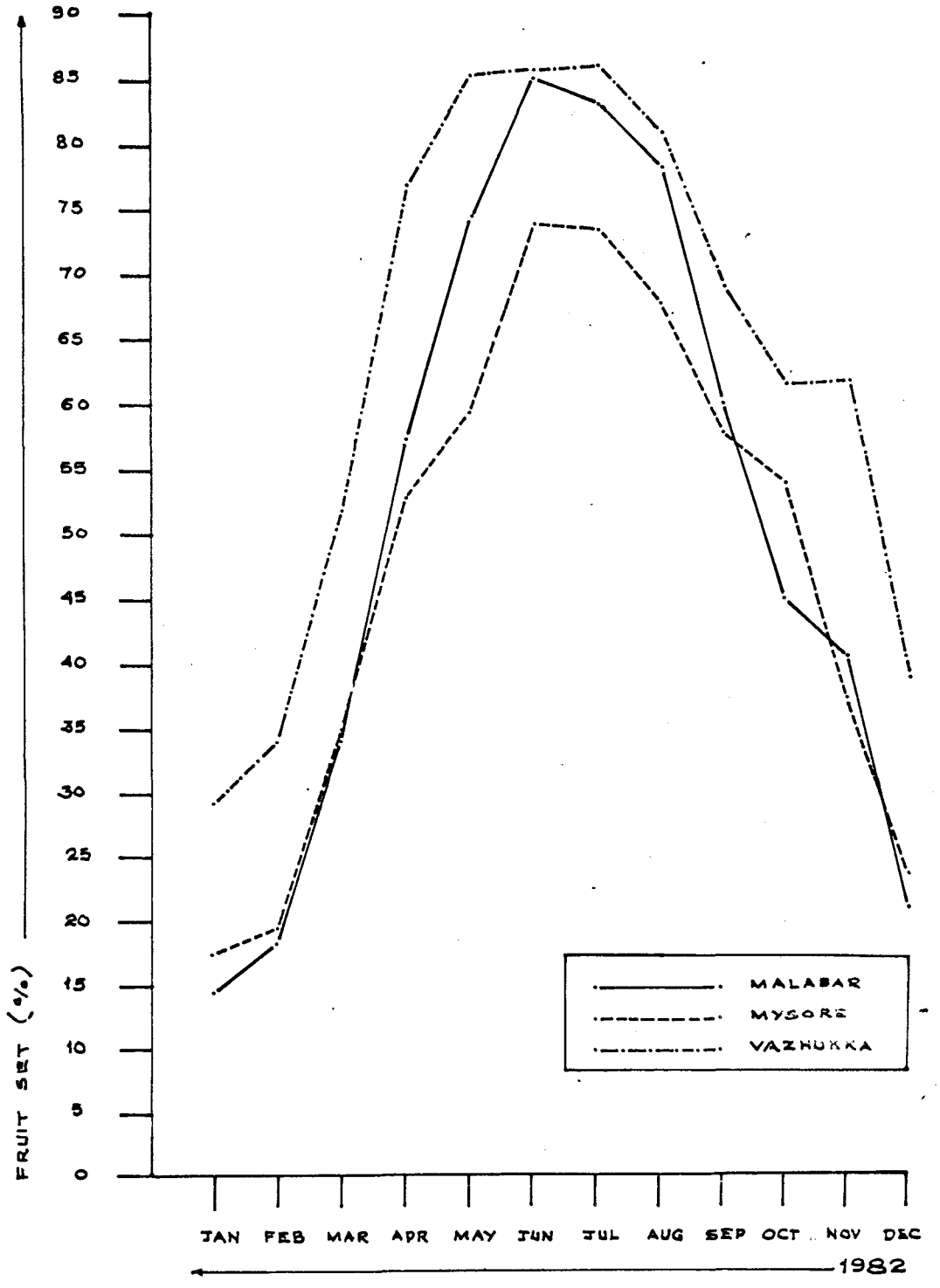


FIG. 19 PERCENTAGE OF IMMATURE CAPSULE SHEDDING TO THE SET CAPSULES IN A CLUMP

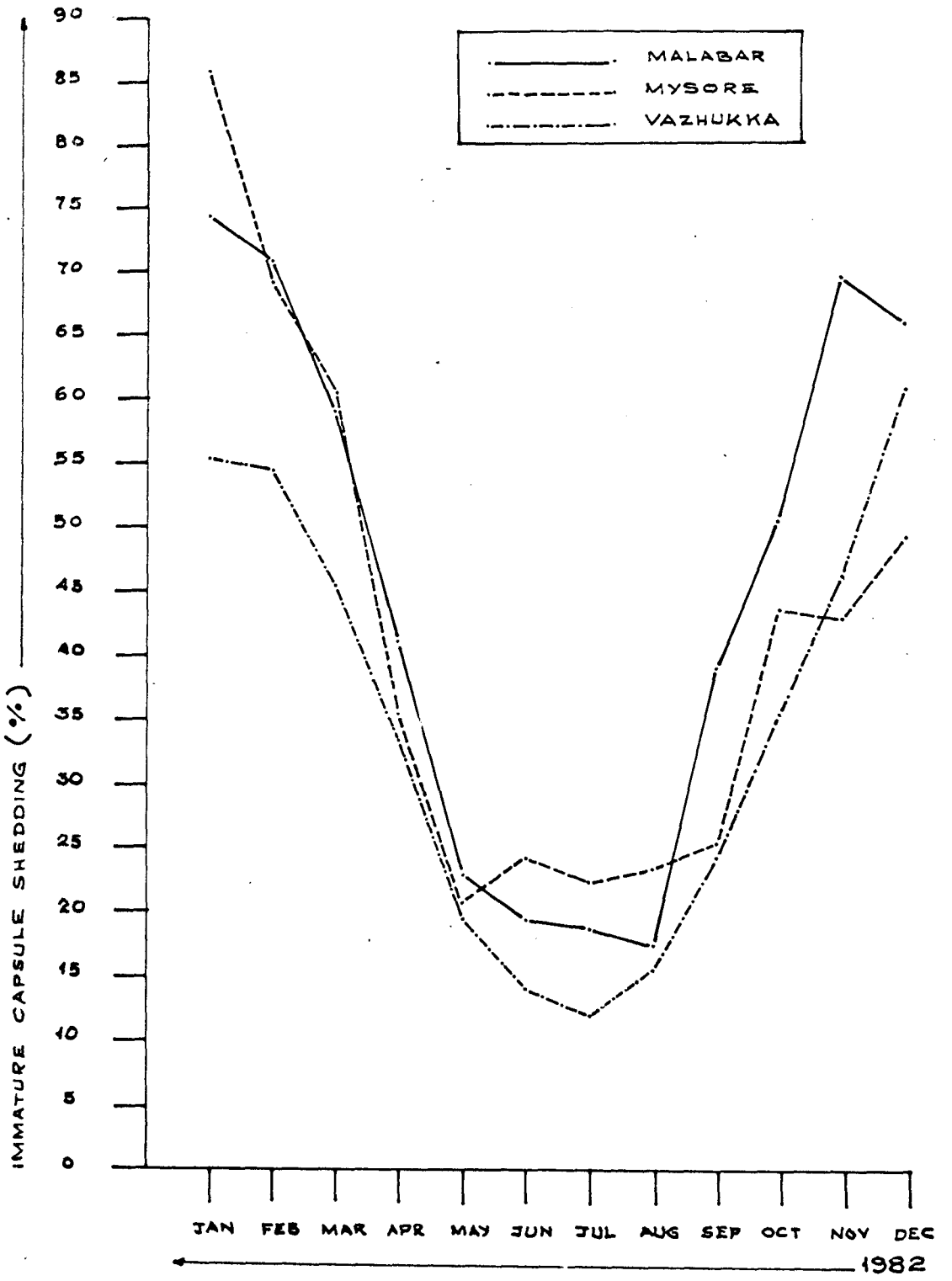


FIG. 20 PERCENTAGE OF IMMATURE CAPSULE SHEDDING TO THE TOTAL FLOWERS BORNE IN A CLUMP

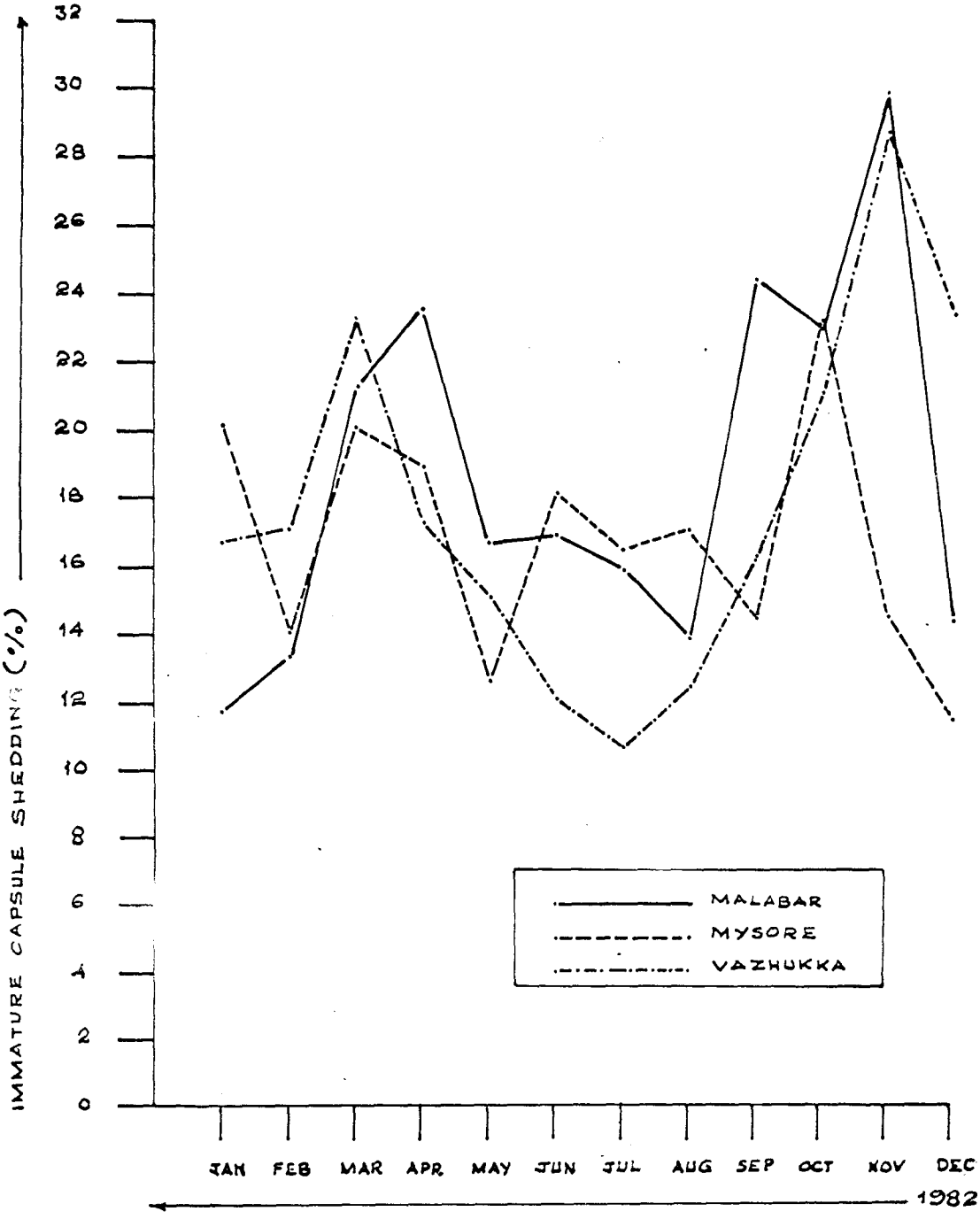
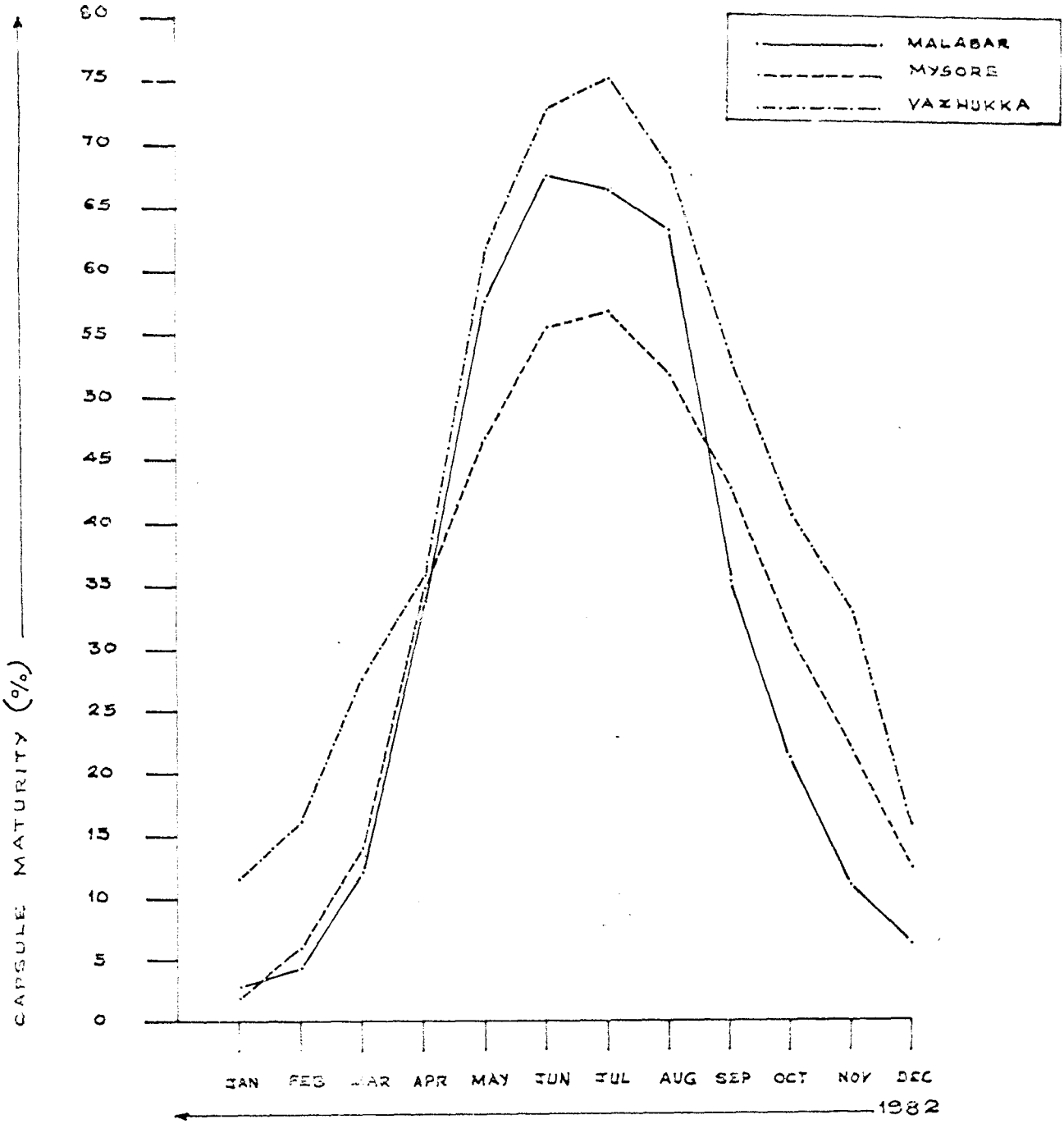


FIG. 01 PERCENTAGE OF CAPSULES MATURED TO THE TOTAL FLOWERS BORNE IN A CLUMP



4.2 Histological studies on flowering

4.2.1 Differentiation of flower buds in the genotype, PV-1

The study was carried out during a six-month period from 1st November, 1983 to 30th April, 1984 on PV-1, a promising selection of the Malabar cultivar. The buds were sampled at fortnightly intervals to examine the percentage of floral differentiation and also to study the internal morphology of the developing buds.

The data pertaining to the differentiation of flower buds presented in Table 28 show that differentiation of flower buds increased from November, 1983 and attained a peak during the second fortnight of December, 1983 (86.6 per cent). Thereafter, flower bud differentiation steadily decreased.

4.2.2 Histology of the apical meristems

Median longitudinal sections of the buds were examined under microscope to observe the histological features of the differentiating shoot and floral meristems of the PV-1 genotype of cardamom.

Differentiation of the shoot meristem

The apical meristem appears broadly conical during the initial stages, with prominently nucleated cells

Table 28 Differentiation of flower buds in the genotype, PV-1 (Malabar)

Date of observation	*Flower bud differentiation (per cent)
1-11-1983	60.6
15-11-1983	66.6
1-12-1983	70.0
16-12-1983	86.6
1-1-1984	80.0
16-1-1984	70.0
1-2-1984	66.6
15-2-1984	73.3
1-3-1984	53.3
16-3-1984	36.6
1-4-1984	33.3
15-4-1984	23.3

* Data based on 30 buds examined at every observation

(Plate 12). The meristem has a broad base and the inner core of cells in the meristem constitute the corpus which can be seen lined by a single cellular layer, tunica. The primordium is seen wrapped up with several scale leaves in succession.

Plate 13 shows that the meristem has lost the sharpness at the periphery and appeared buldged at the sides. Just below the tunica, the corpus region appear deeply stained, indicating the localisation of DNA at the primordial site. The primordial cells are with large nuclei. The high quantum of DNA in these nuclei might have reacted with basic fuchsin (the nuclear stain used in this investigation) to give the dark colour to the meristematic apex.

With continued growth, the meristem loses its conical shape and attains a hemispherical shape (Plate 14). The meristem together with the young scale leaves arching over it, appear deeply stained. The old scale leaves can be seen stained to a lesser degree when compared to those of the meristematic primordial zone.

The hemi-spherical apex pushes upward and distinct notches are recognizable on the periphery of the primordium,

Plate 12 L.S. of the shoot meristem at the initiation stage (X 100)

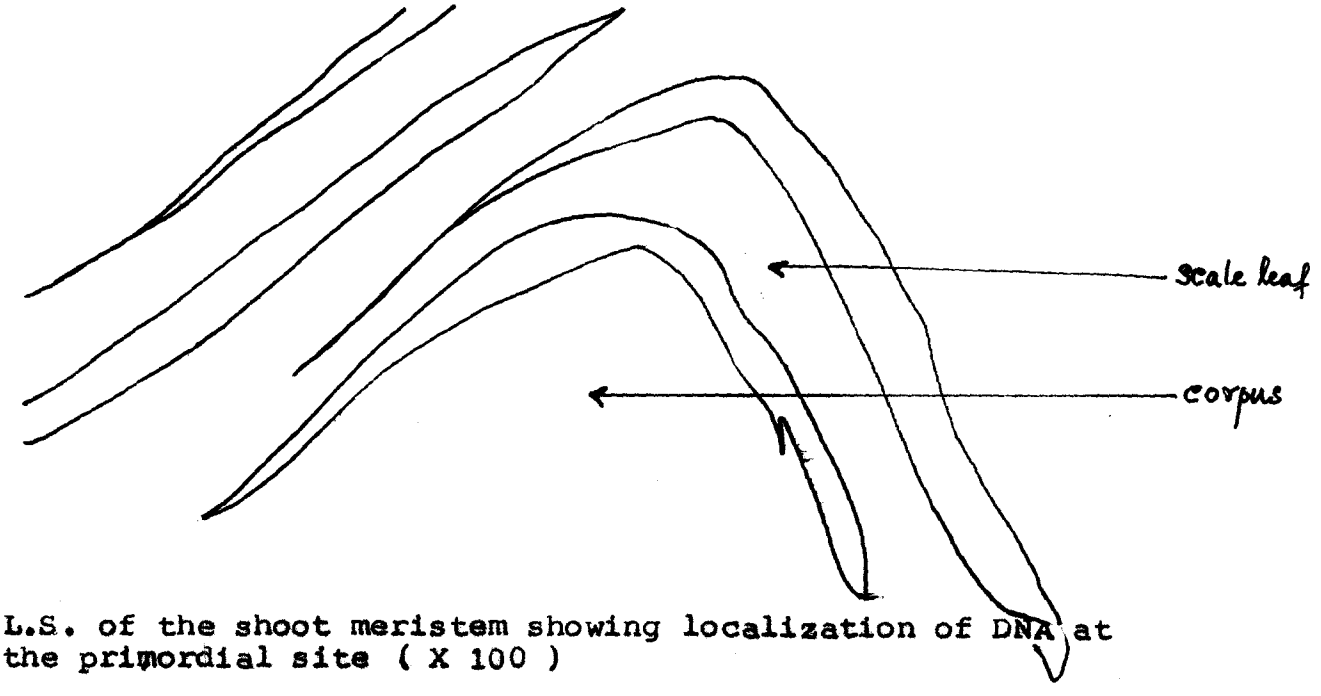


Plate 13 L.S. of the shoot meristem showing localization of DNA at the primordial site (X 100)

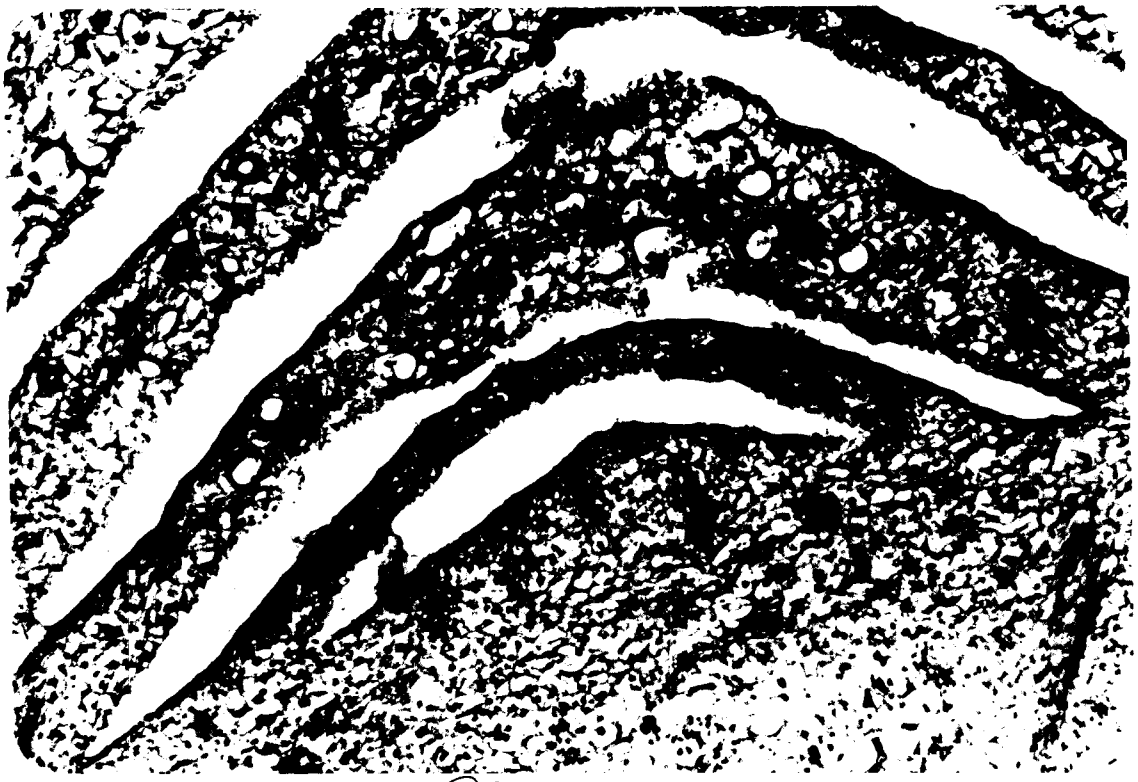


Plate 12

Plate 13

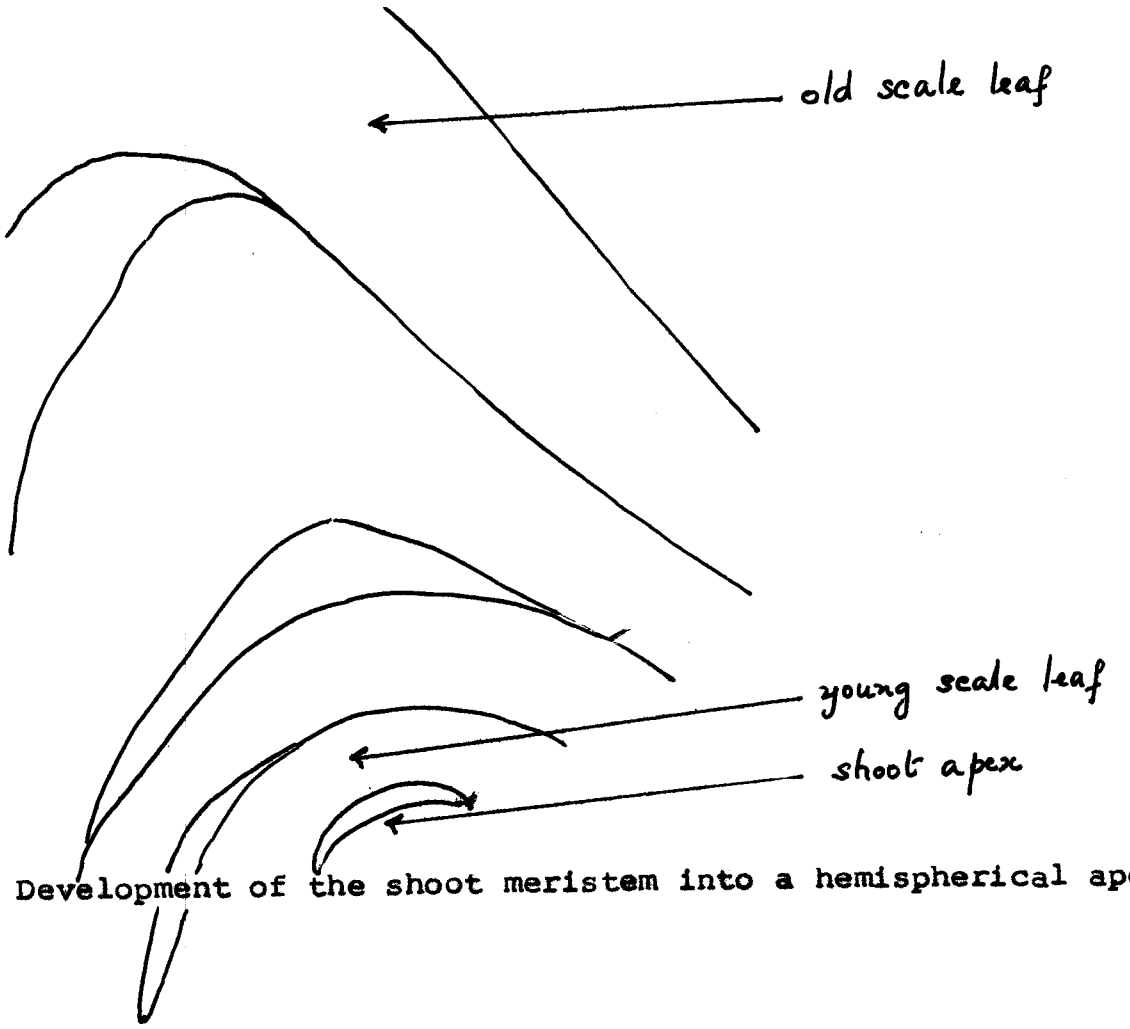


Plate 14 Development of the shoot meristem into a hemispherical apex (X 100)

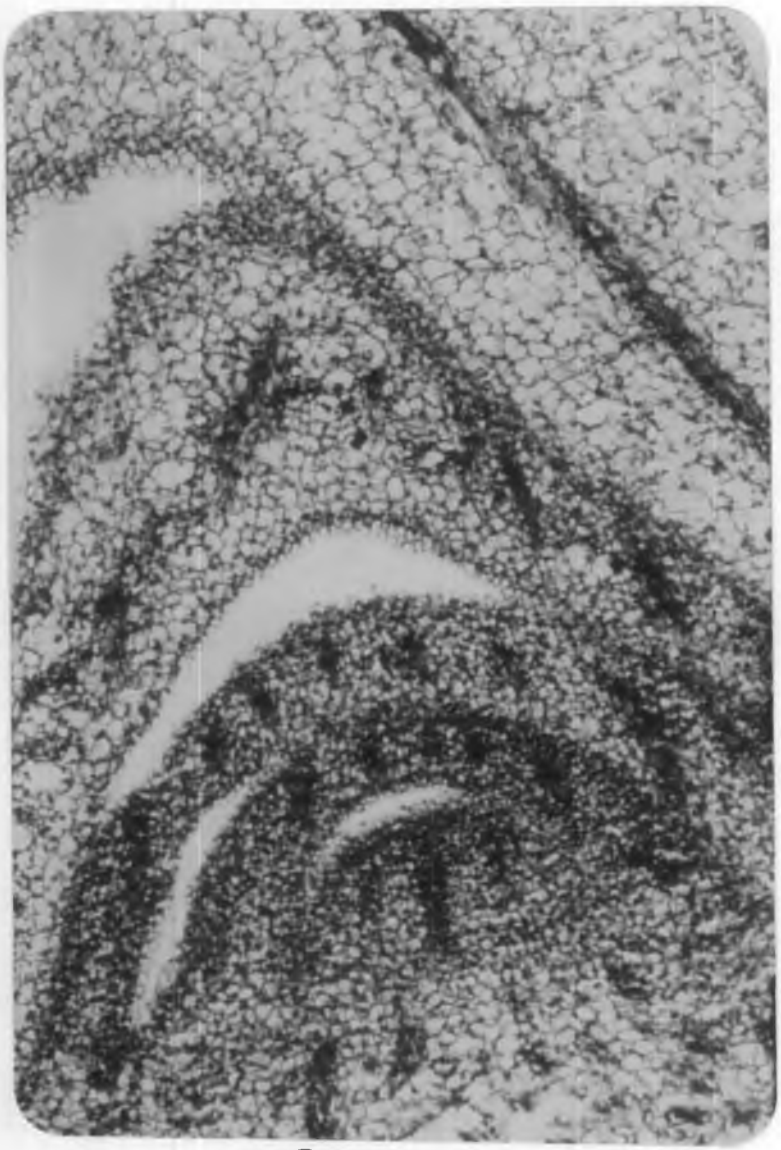


Plate 14.

which would later develop into leaf primordia (Plate 15). Wedge like protuberances can be seen on either side of the primordium, which might be the primordia of the enveloping scale leaves. At this stage, the primordium is identifiable as a shoot meristem.

These morphological features were observed only in the buds collected from the fourth to the lowest nodes (counted from above) of the rhizome where normally only vegetative tillers developed.

In Plate 16, the notches that appeared on the apical meristem (Plate 15) have deepened further. The primordium shows elongation, pushing forward the scale leaves arranged as a series of cones one over the other in succession.

The apical meristem is seen developed into a cylindrical structure which can be identified distinctly as a shoot primordium (Plate 17). The outer tunica and the nuclei of the inner corpus layer are seen deeply stained. The leaf primordia can be numbered from the apex downwards in a series, L_1, L_2, L_3, L_4 etc. The exact numbering was not possible because of the spiral nature

Plate 15 Appearance of notches on the shoot apex and emergence of wedge like protuberances on either side of the shoot meristem (X 100)

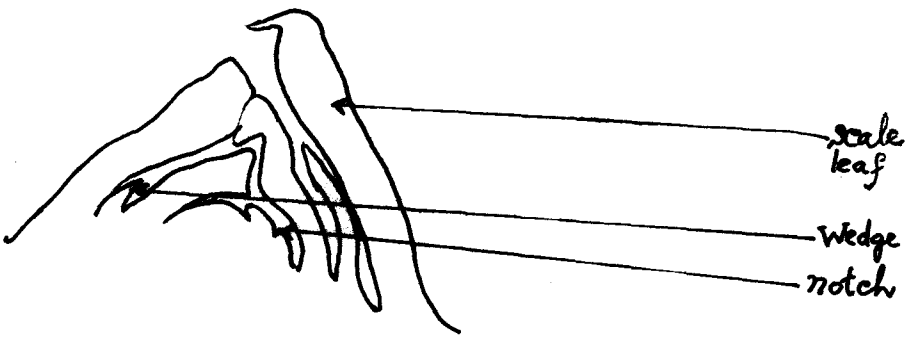


Plate 16 Elongation of the shoot meristem and deepening of notches at the meristematic apex (X 50)

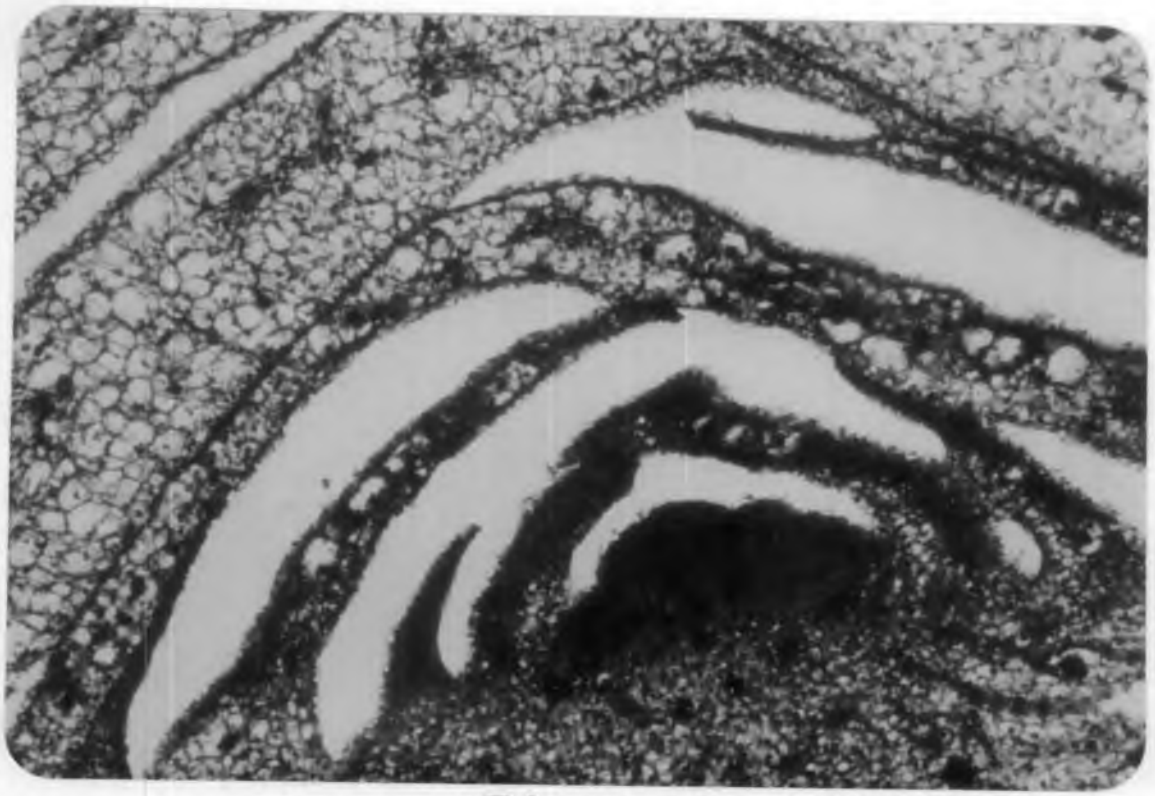


Plate 15

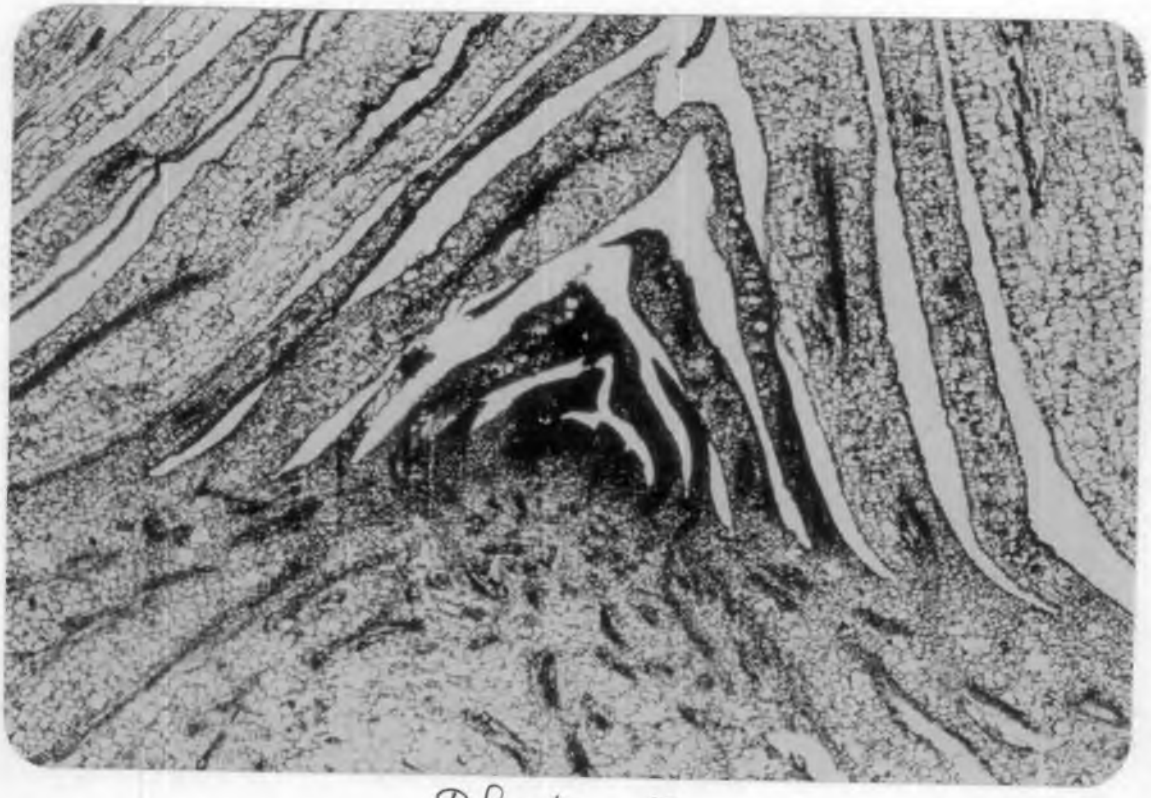


Plate 16

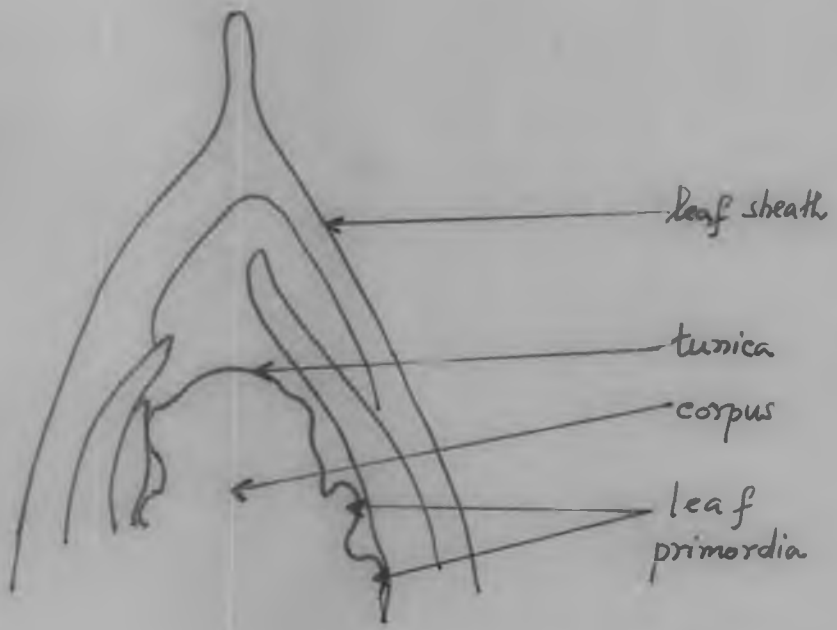


Plate 17 Development of leaf primordia on the shoot meristem (X 100)

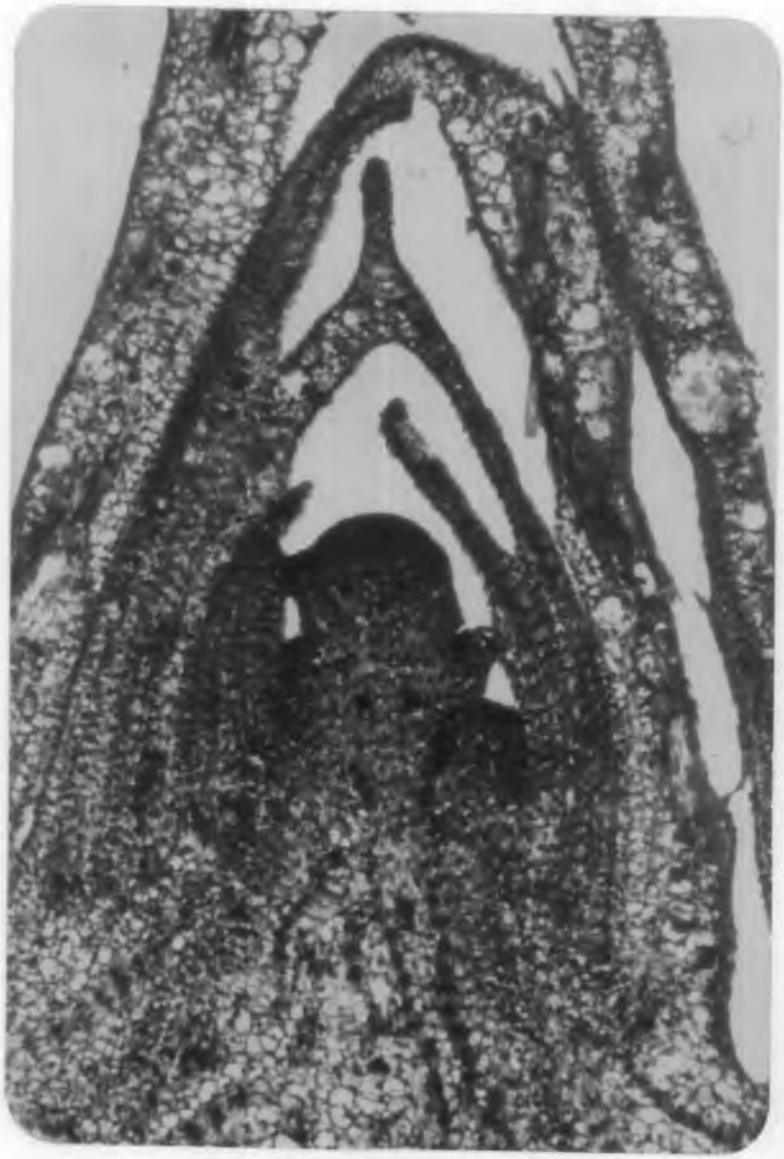


Plate 17

Plate 18

Plate 19 L.S. of the nodal region of rhizome, preparatory to the initiation of inflorescence (X 100)

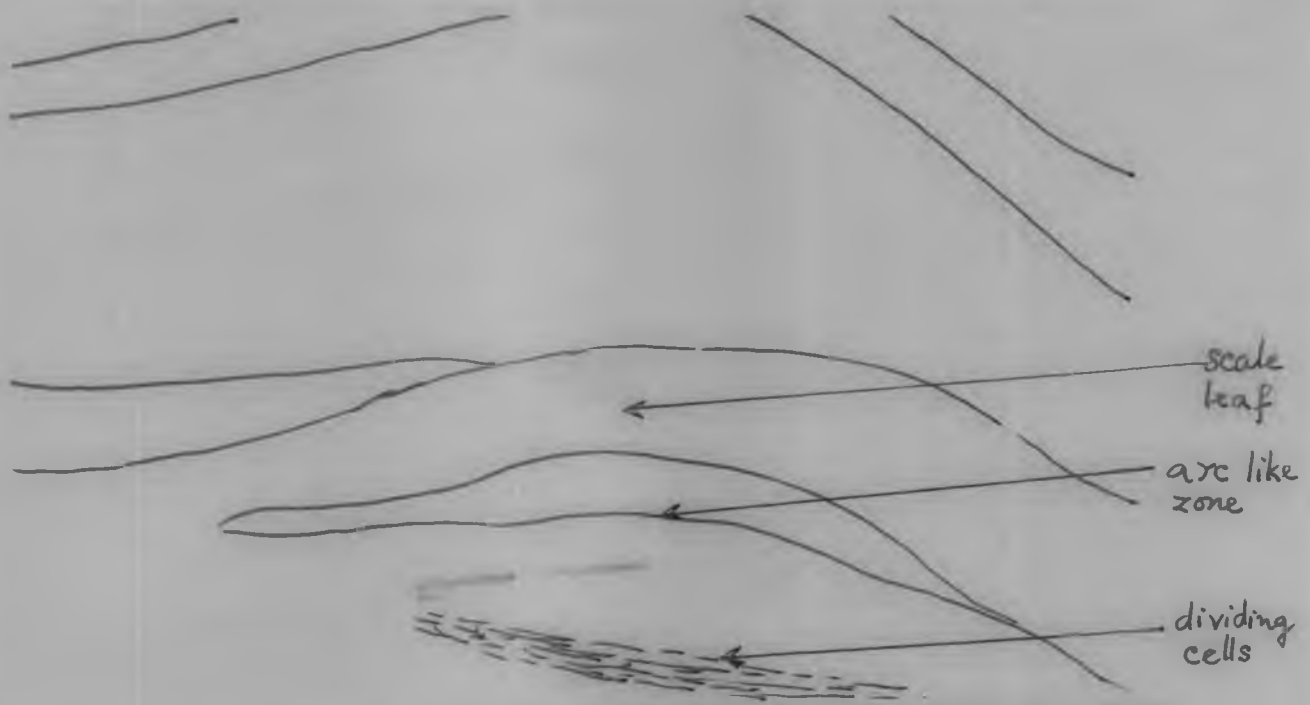


Plate 20 L.S. of the site of inflorescence initiation showing an arc like zone and dividing cell layers beneath (X 100)

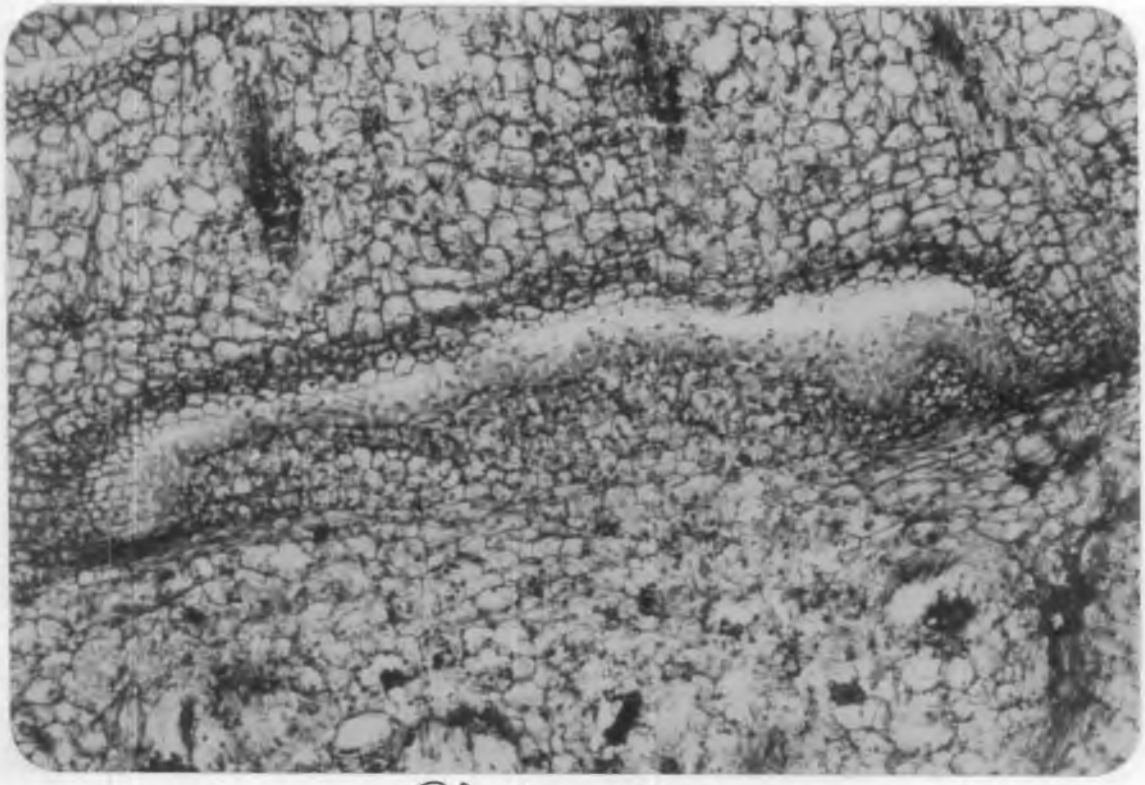


Plate 19

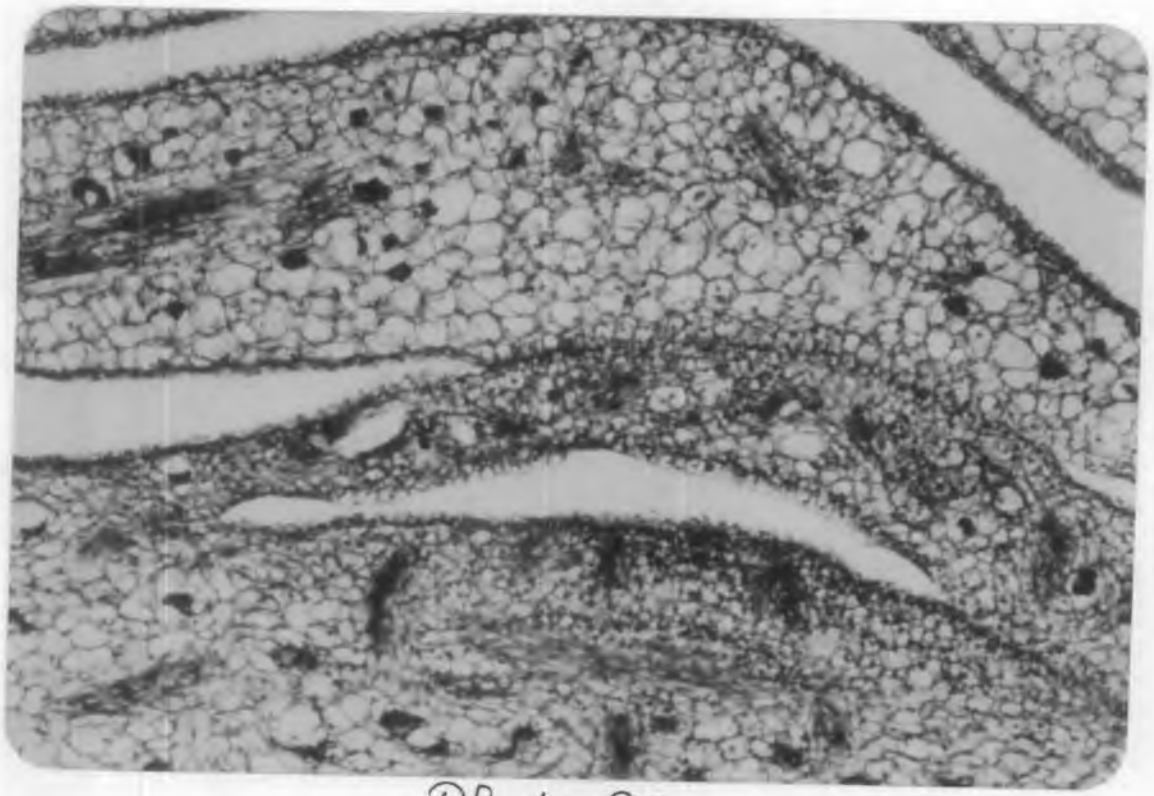


Plate 20

Subsequently, the inflorescence primordium has assumed a pyramidal shape (Plates 21 and 22). Like the shoot primordium, the inflorescence primordium is seen enveloped by a series of scale leaves (Plate 21). A notch can be seen on one side of the inflorescence primordium which could be the initial of a floral bract (Plate 22).

In Plate 23, the elongating primordial zone can be distinguished from the rest of the ground tissue by its dark stained appearance. Under higher magnification (Plate 24). DNA localization can be easily observed in the large nuclei prominently stained with basic fuchsin.

The structure depicted in Plate 25 marks the transition of an apical meristem from its vegetative to the floral phase. Like the vegetative primordia showing primordial leaves initiating in whorls around a shoot apex, floral initials appear on the axils of bracts in a spiral manner around the inflorescence apex. Unlike the shoot primordium which has a hemisperical apex, the inflorescence apex is rather flattened and individual flower primordia are large and blunt.

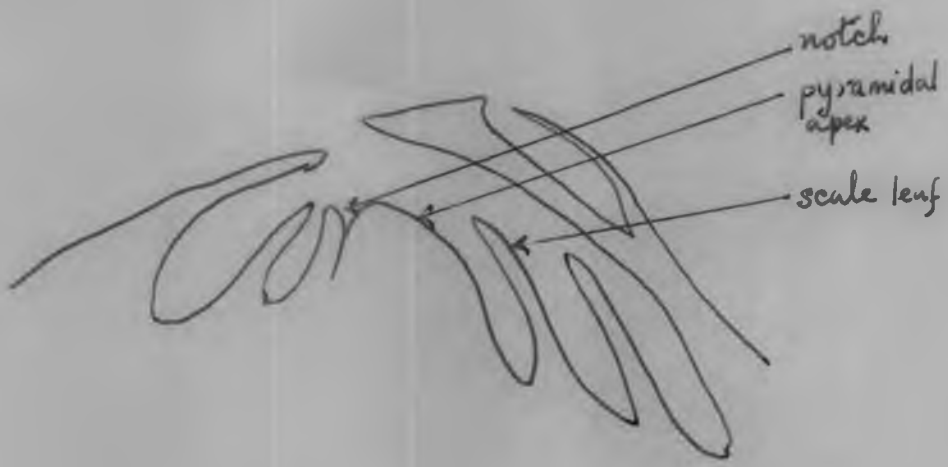


Plate 21 Inflorescence primorium showing its characteristic pyramidal shape enveloped by scale leaves (X 100)

Plate 21

Plate 22 The inflorescence primordium in Plate 21 magnified, showing a notch- the initial of a floral bract (X 320)

Plate 23 Elongation of the infloreseence primordium showing dark stained cells (X 100)

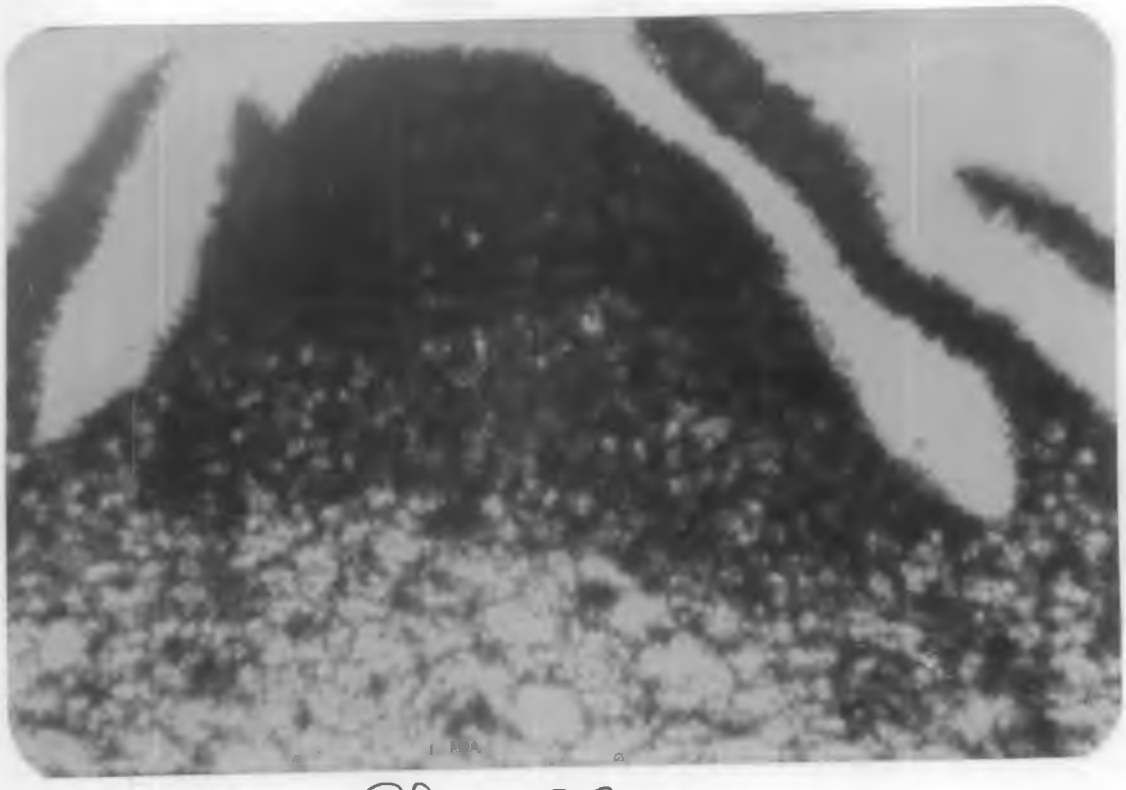


Plate 22

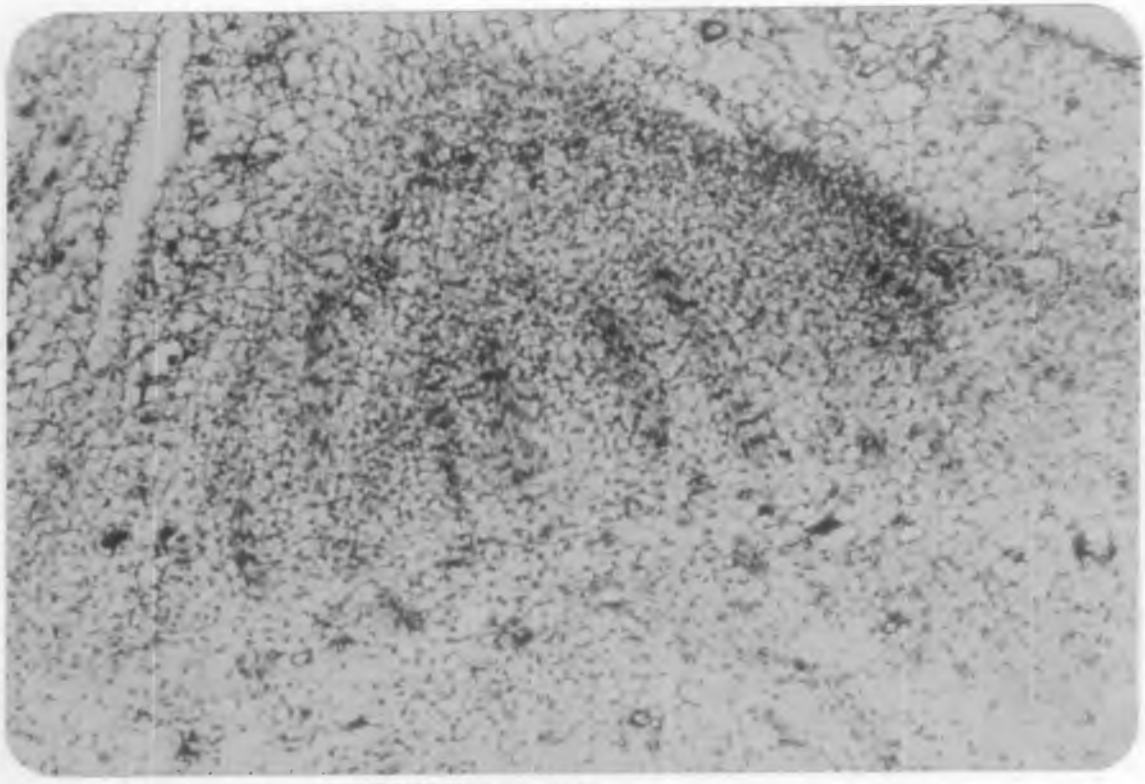


Plate 23

Plate 24 The inflorescence primordium in Plate 23 magnified showing localization of D NA in the large nuclei (X 200)

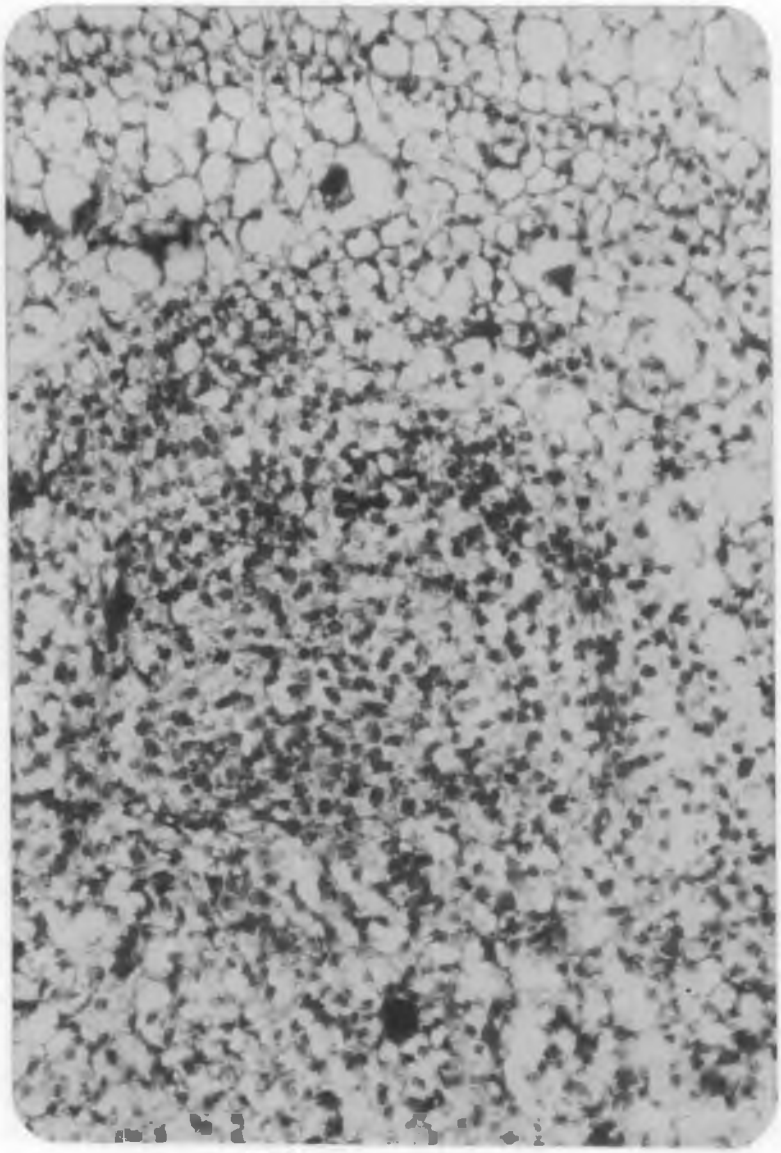


Plate 24

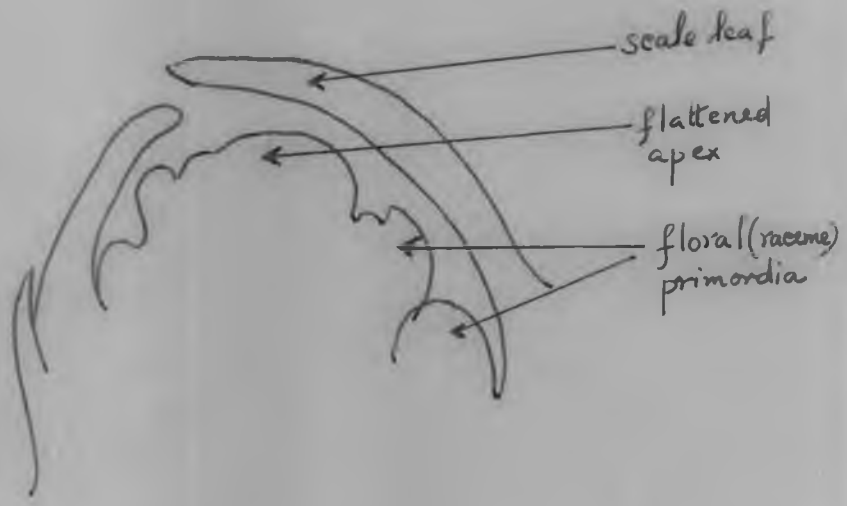


Plate 25 Transition of an apical meristem from vegetative to reproductive phase: floral initial appearing in spiral succession (X 100)

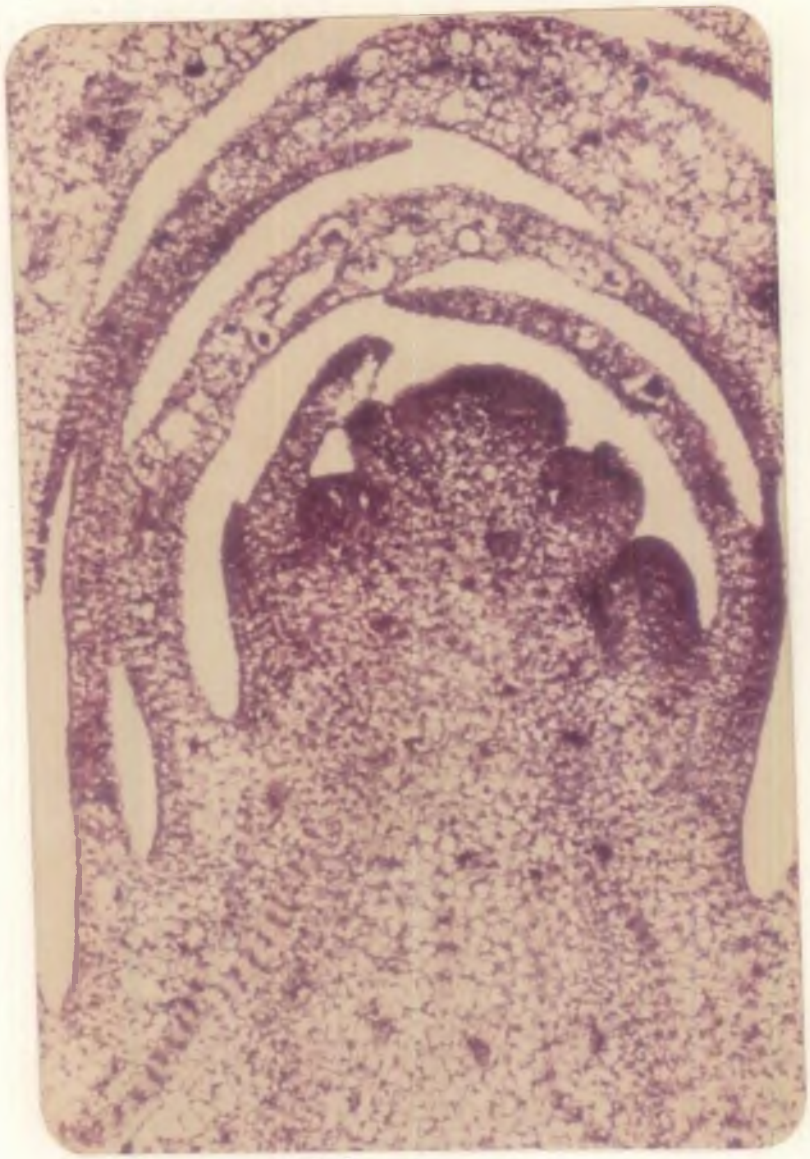


Plate 25

The panicle primordium shows marked elongation and individual flower primordia appear as round protuberances encircled by bracts (Plate 27). These flower primordia can be numbered from the apex downwards as F_1, F_2, F_3, F_4 etc., in a manner similar to what was indicated in the case of leaf primordia initiated on shoot apices (Plate 27). Several scaly bracts have arisen from the central cylindrical axis immediately behind the floral initials, which are seen running parallel to one another in a series (Plate 26).

The individual floral initials show further development in Plate 28. They have assumed ovoidal to dome shapes. The initials are seen subtended at the axil of every floral bract. The central axis has lost its cylindrical shape consequent on the invaginations caused by the developing floral primordia.

Individual flower buds are seen differentiated in Plate 29. Four flower buds can be identified on the raceme and floral bracts appear at the peripheral regions which envelope the developing floral primordia. In normal course, a single raceme of the cardamom panicle produce five to eight flowers.

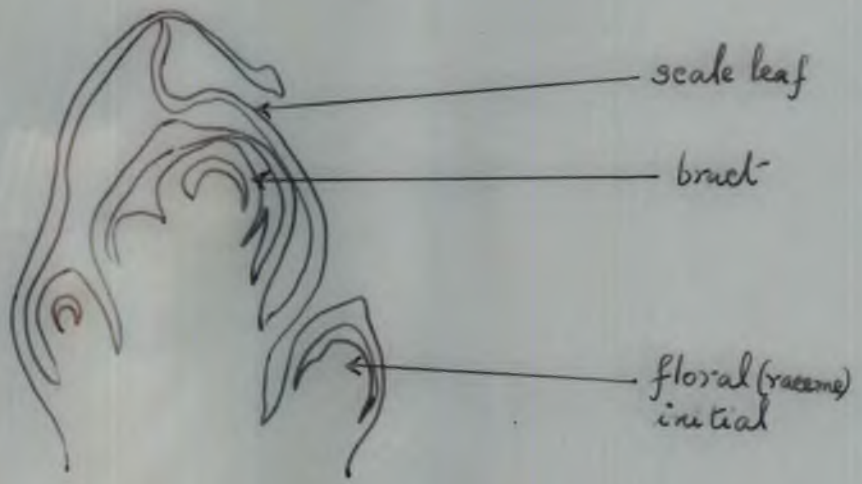


Plate 26 Elongatiof inflorescence primordium with flower primordia encircle bracts (x 50)

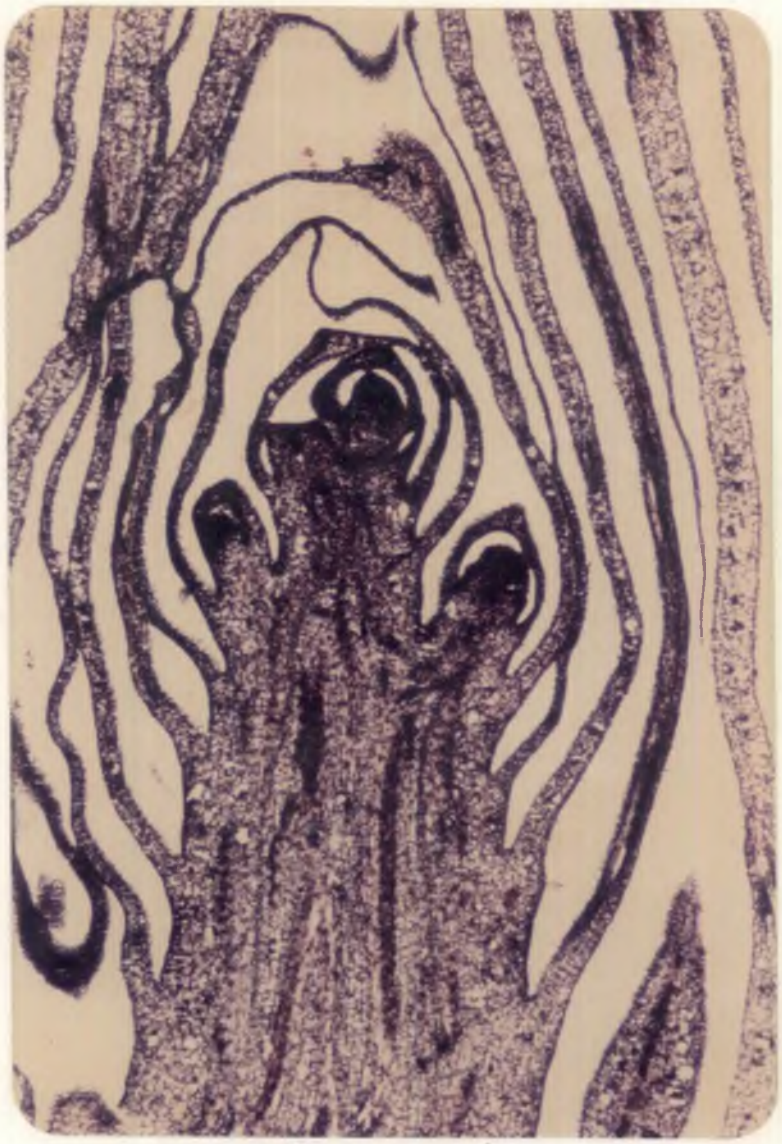


Plate 2.6

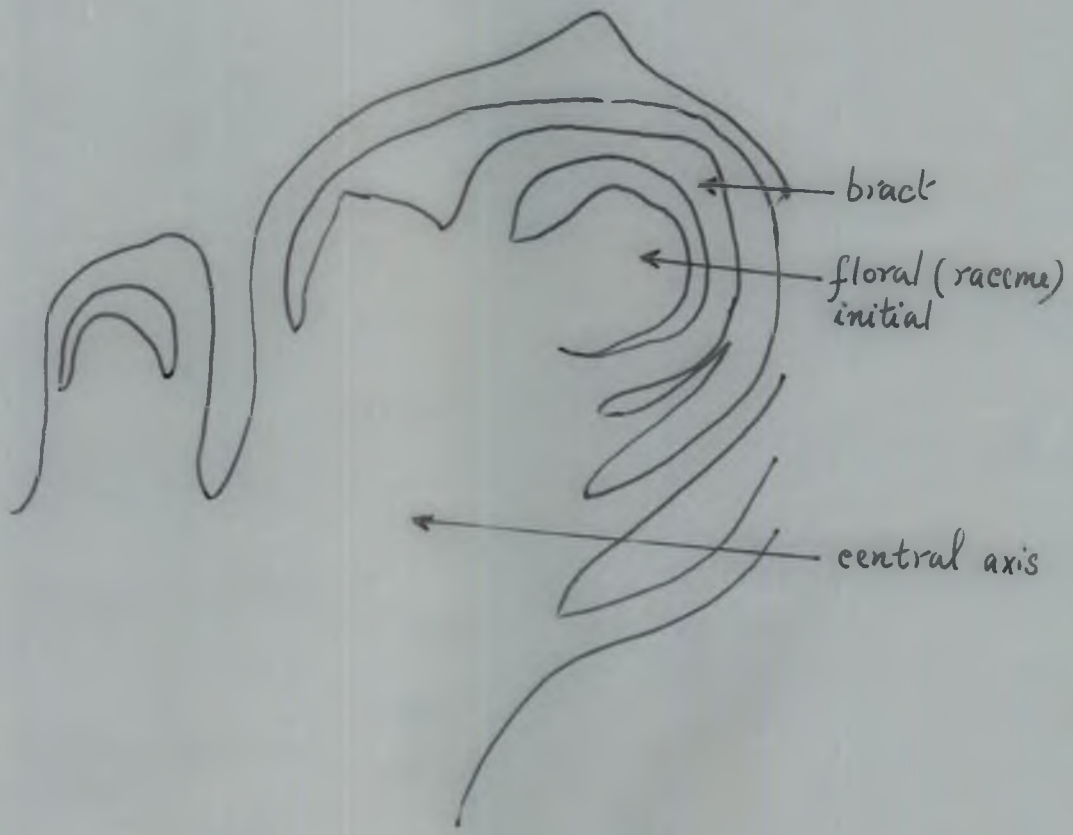


Plate 27 A portion of the inflorescence primordium in Plate 26 magnified, showing initiation of flower (raceme) primordia in succession (X 100)

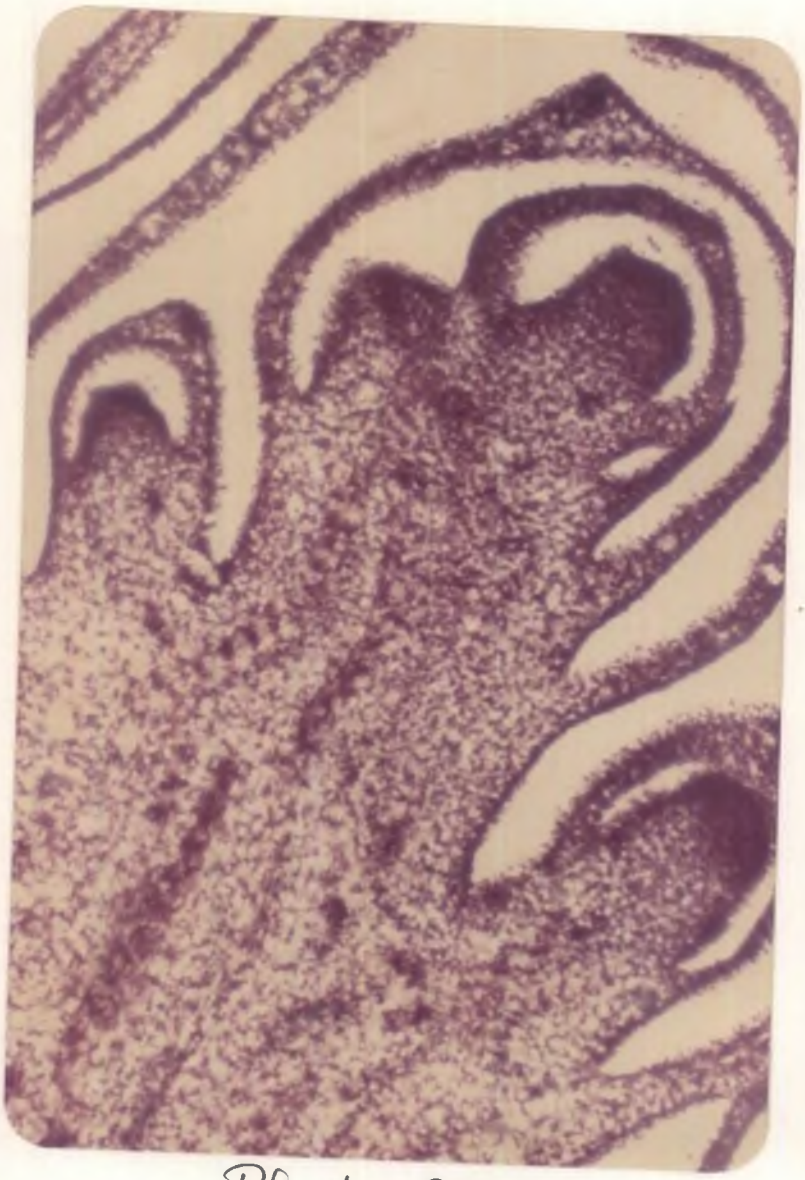


Plate 27

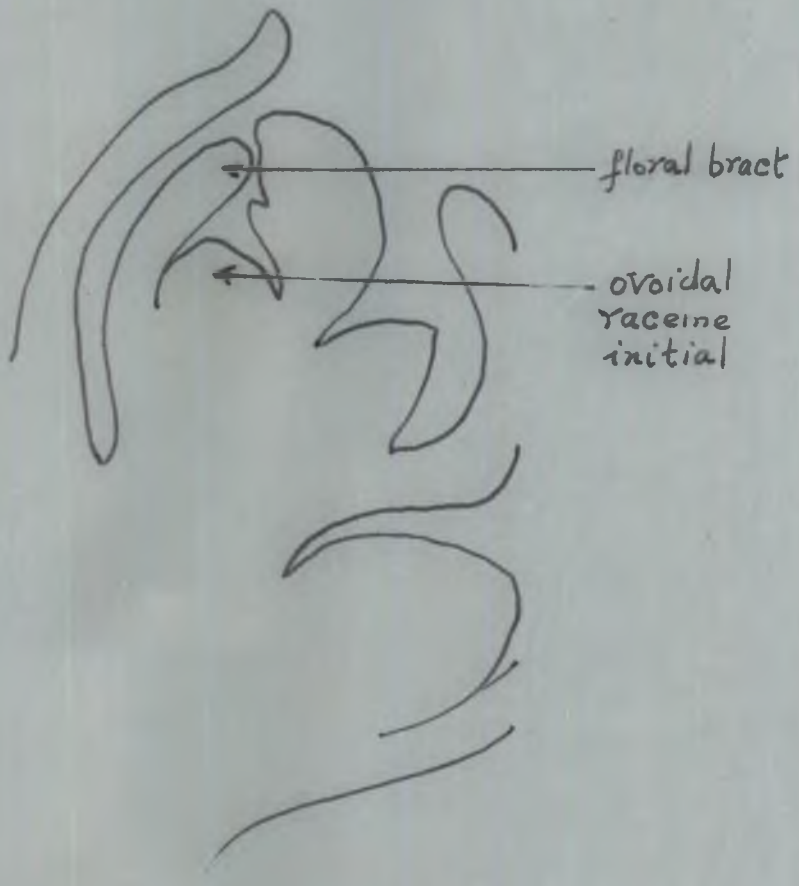


Plate 28 Development of the floral (raceme) initial into ovoidal structures subtended at the axils of floral bracts (X 50)

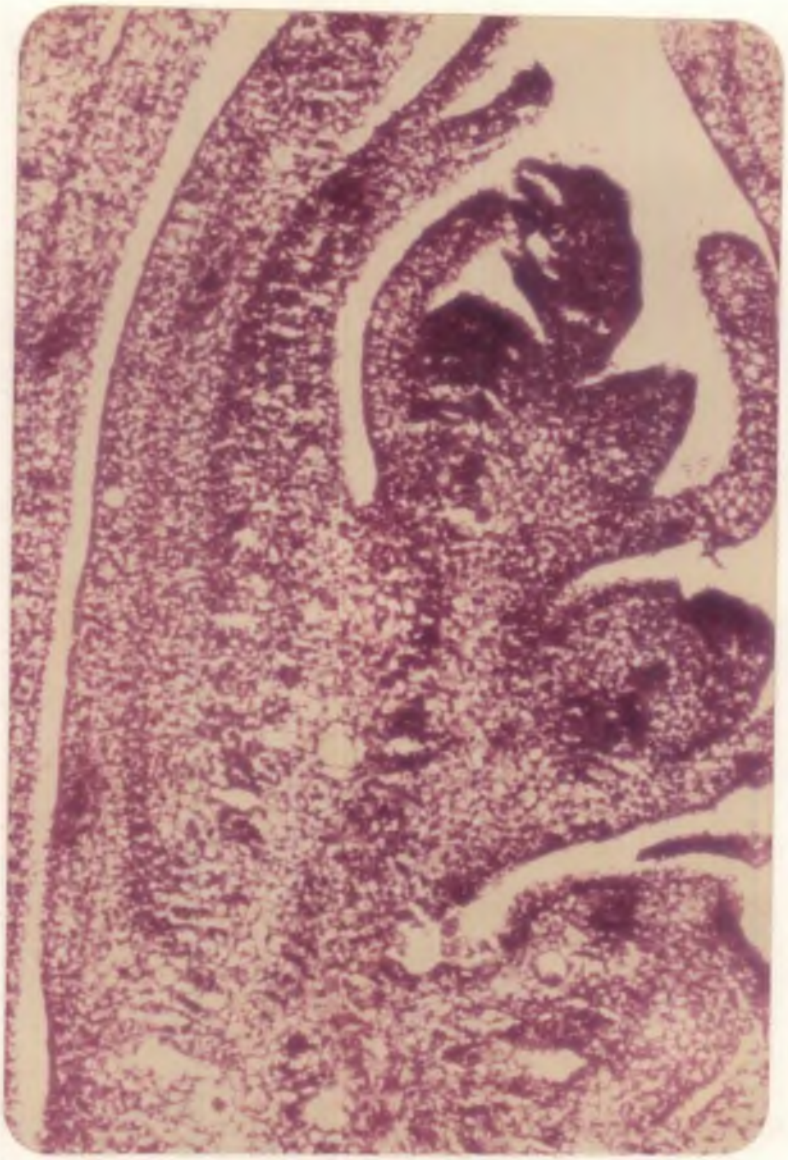


Plate 28

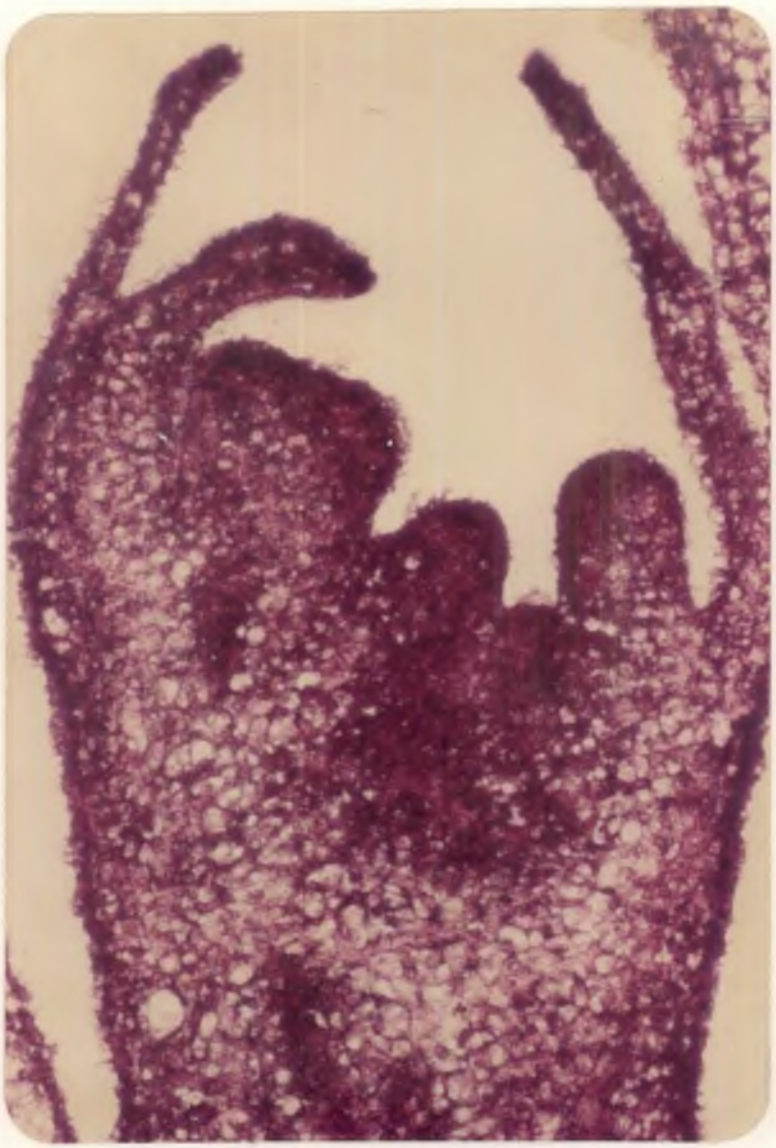


Plate 29

Plate 30

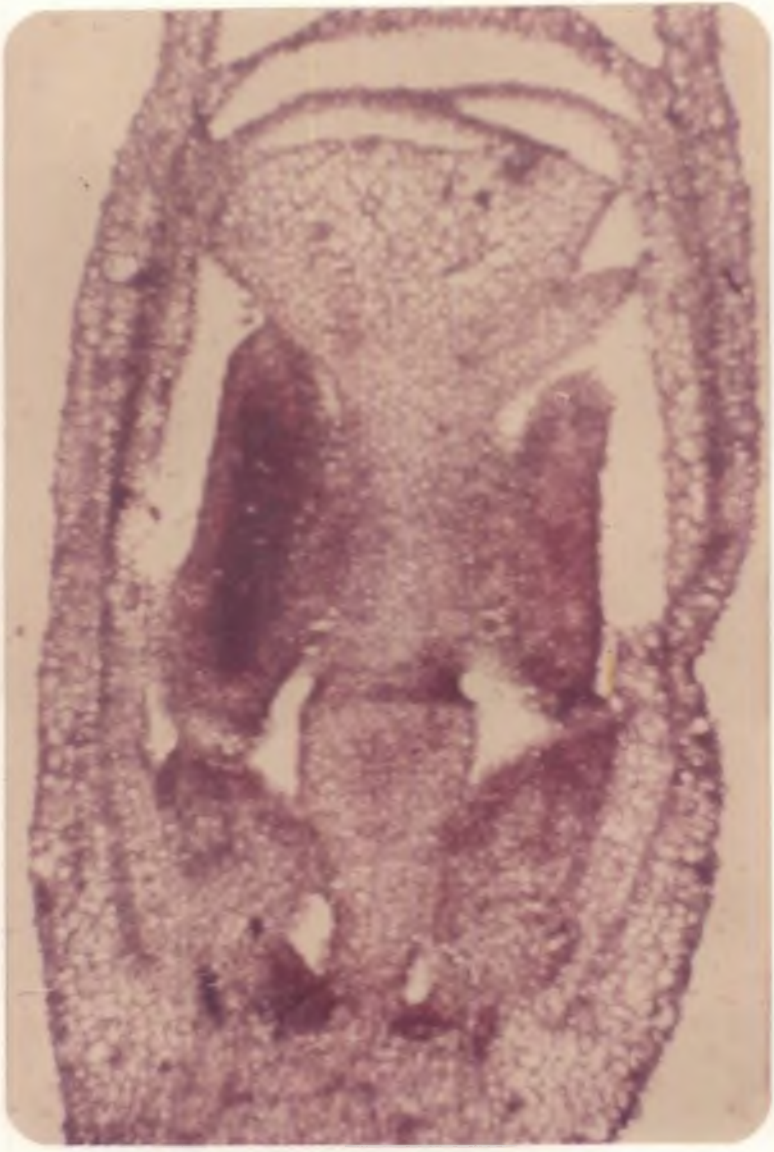


Plate 31

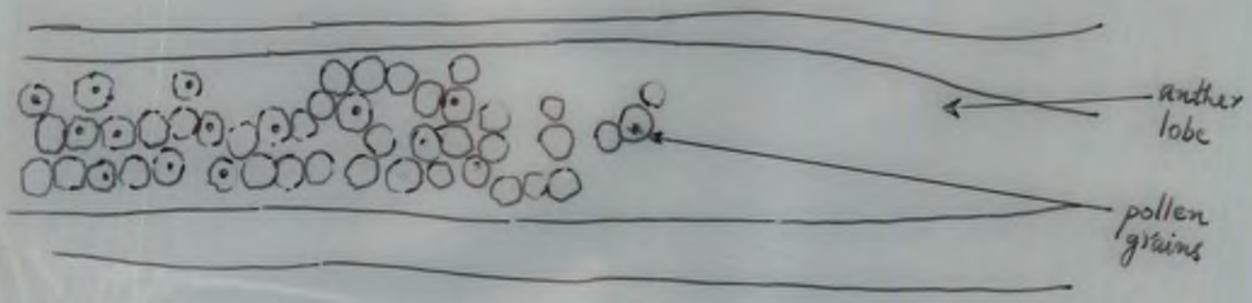


Plate 32 L.S. of the anther lobes showing pollen grains (X 100)

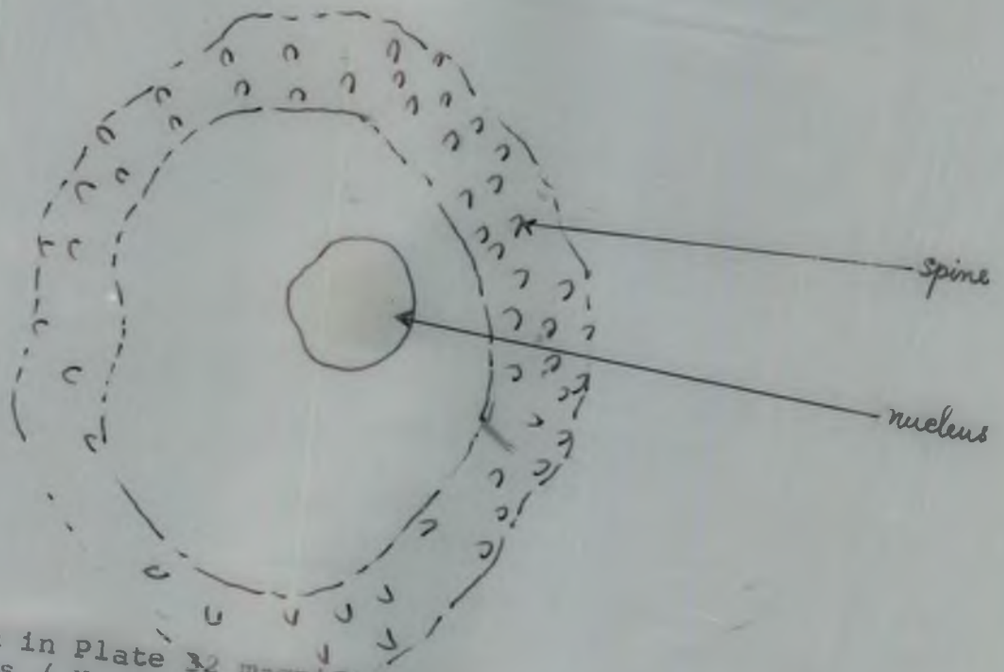


Plate 33 A pollen grain in Plate 32 magnified showing the deeply stained nucleus (X 640)

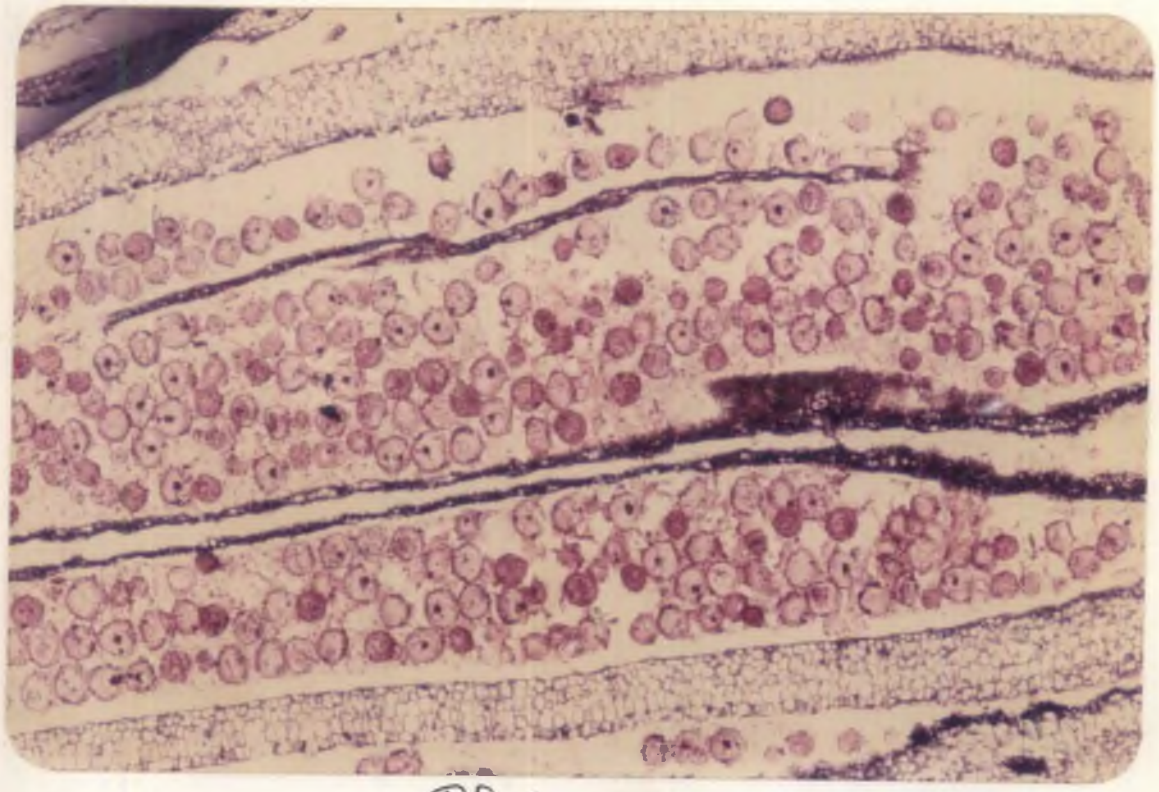


Plate 32

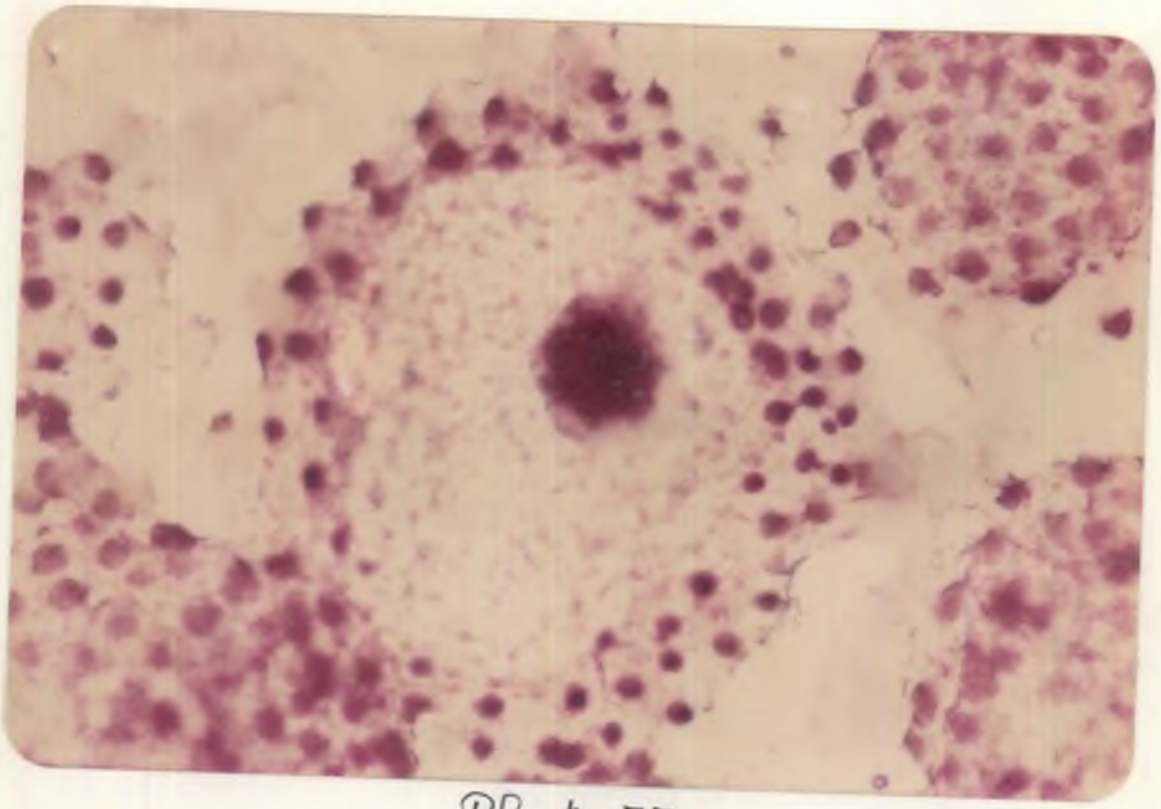


Plate 33

4.2.3 Time taken for the flower bud differentiation in cardamom

The genotype PV-1 was employed for this study also. For obtaining information on tho time taken for the different developmental phases, buds were collected at weekly intervals commencing from 1st July, 1984. To avoid any chance of variation in the basic morphological features, buds were sampled from a single clump of PV-1.

The details of the time taken for various morphological events are presented in Table 29. Anatomically, the panicle primordium was recognisable at the 2nd week from the pre-primordial phase (Plates 21 and 22). When morphogenesis of the other floral parts were also considered, the transition of an apical meristem from vegetative to reproductive phase (with distinct floral primordia) occurred at the 5th week (Plate 25). The panicle primordium elongated considerably at the 6th week (Plates 26 and 27) and a series of rather round primordia (of the racemes) developed on the panicle primordium. This stage that marked the elongation of the panicle primordium coincided with the visual appearance of panicle initials on the nodal region of rhizomes.

Table 29 Time taken for the development of floral parts in the genotype, PV-1 (Malabar)

Serial number	Details of development of the floral part		Time taken
1	Panicle initiation	Primordial stages	2nd week
2	Transition to panicle primordium		5th week
3	Elongation of panicle primordium and initiation of primordia of individual racemes		6th week
4	Development of raceme primordia		7th week
5	Differentiation of bracts and flower buds in a raceme		9th week
6	Development of anther		12th week
7	Development of pistil		13th week
8	Development of microspores		15th week

The raceme primordia continued development and by the 7th week from the pre-primordial stage, the raceme primordia were easily identifiable (Plate 28). Differentiation of bracts and flower buds occurred at the 9th week (Plate 29). Upto this phase, the inflorescence could be considered as if in its primordial phase of development.

Development of anther took place at the 12th week and that of the pistil, at the 13th week (Plates 30 and 31 respectively). Microspores developed inside the anther lobes at the 15th week (Plate 32).

4.2.4 Histology of the fruit abscission zone

A narrow horizontal zone was observed in the fruit stalks when examined prior to the immature fruit (capsule) shedding. Plate 34 shows that the cells of abscission zone differ structurally from the cells above and below it. A three-layered abscission zone can be observed which possess denser cytoplasm.

4.2.5 Histology of the rhizome

The section through the nodal region of a rhizome (Plate 35) prior to the initiation of panicle

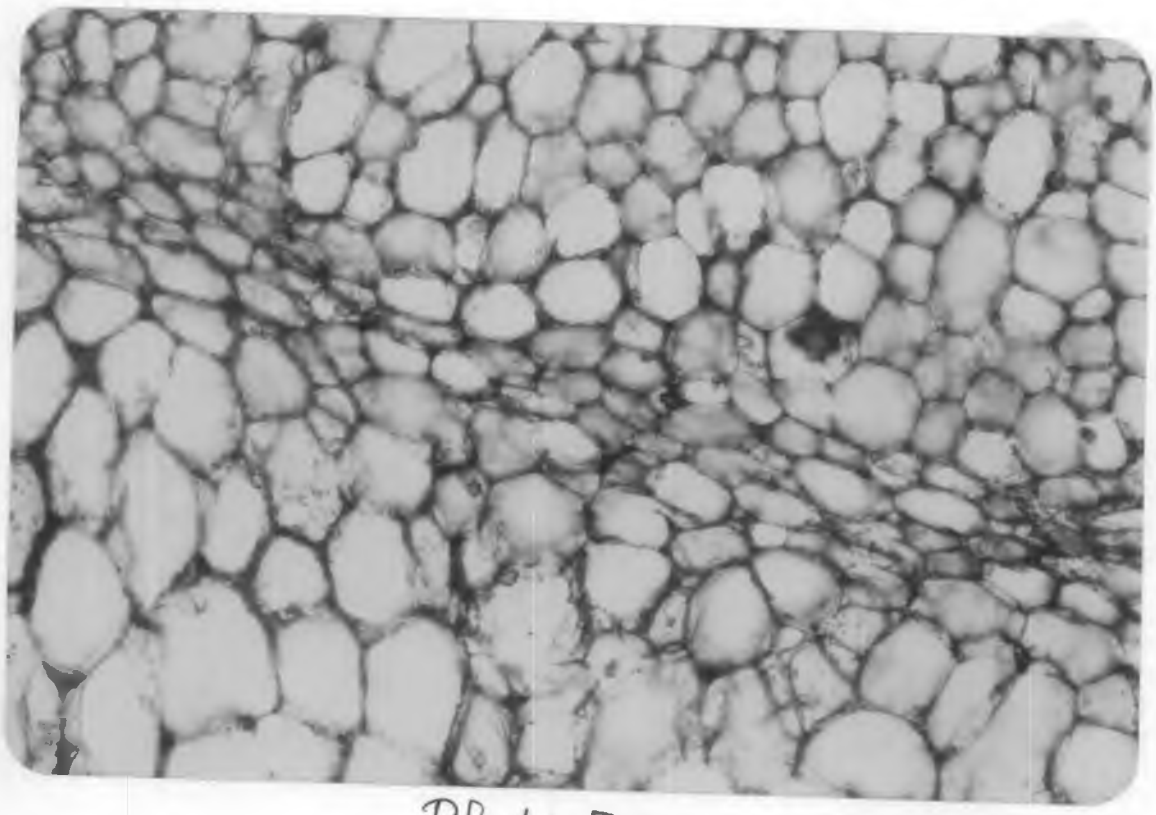


Plate 34

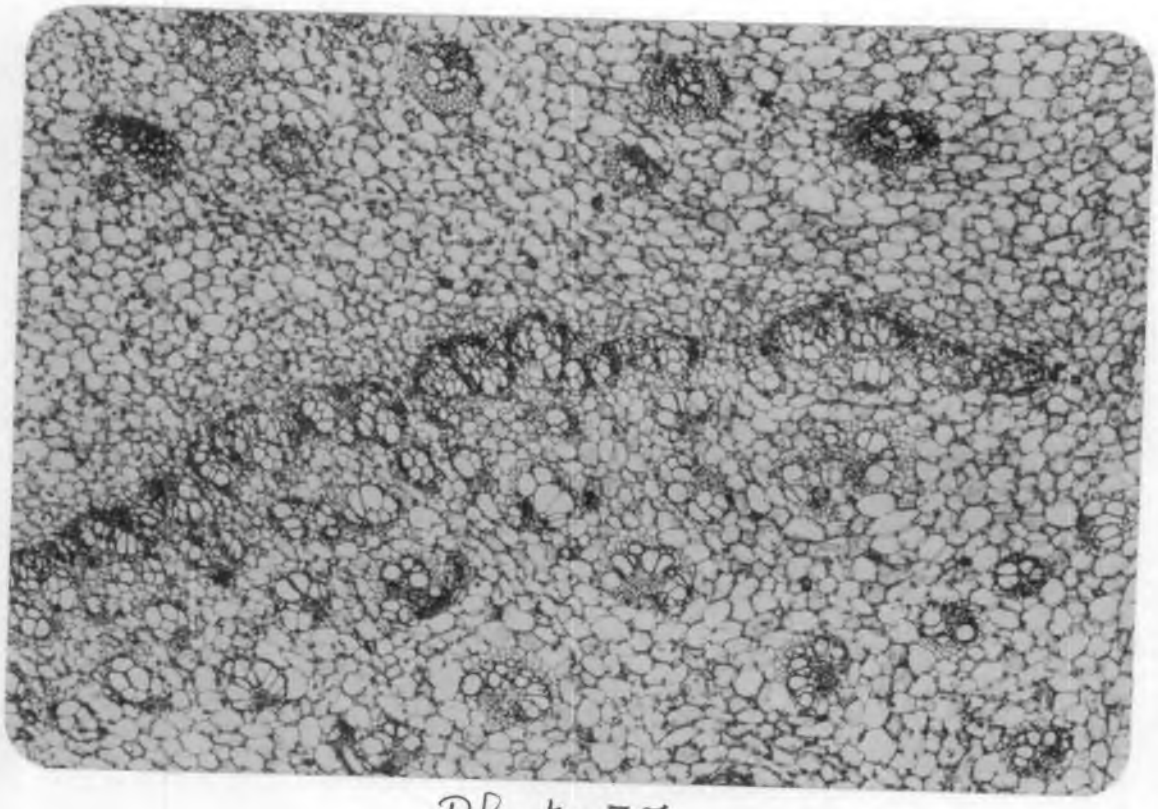


Plate 35

shows a prominent zone with severe vascularisation at the node. Bundles can be seen distributed throughout the stelar region. The endodermis is lacking and the limiting boundaries of cortex, pericycle and pith are indistinguishable.

Plate 36 shows two metaxylem vessels each on either side a protoxylem engulfing it. The phloem parenchyma is prominent and the companion cells appear deep stained. The vascular bundles are seen covered by a group of cells (the bundle sheath).

4.2.6 Histology of the leaf

A transverse section of a mature leaf of cardamom (Plate 37) shows an outer epidermis that formed the limiting boundary of cells on the adaxial side. A row of palisade mesophyll is seen which has closely packed cells that are vertically arranged. A central core of mesophyll can be recognised with irregularly arranged cells which contain abundant number of chloroplasts. The spongy mesophyll, seen beneath the central mesophyll, shows only a few chloroplasts. The abaxial side of the leaf is limited by a single layer of the cells, the lower epidermis.

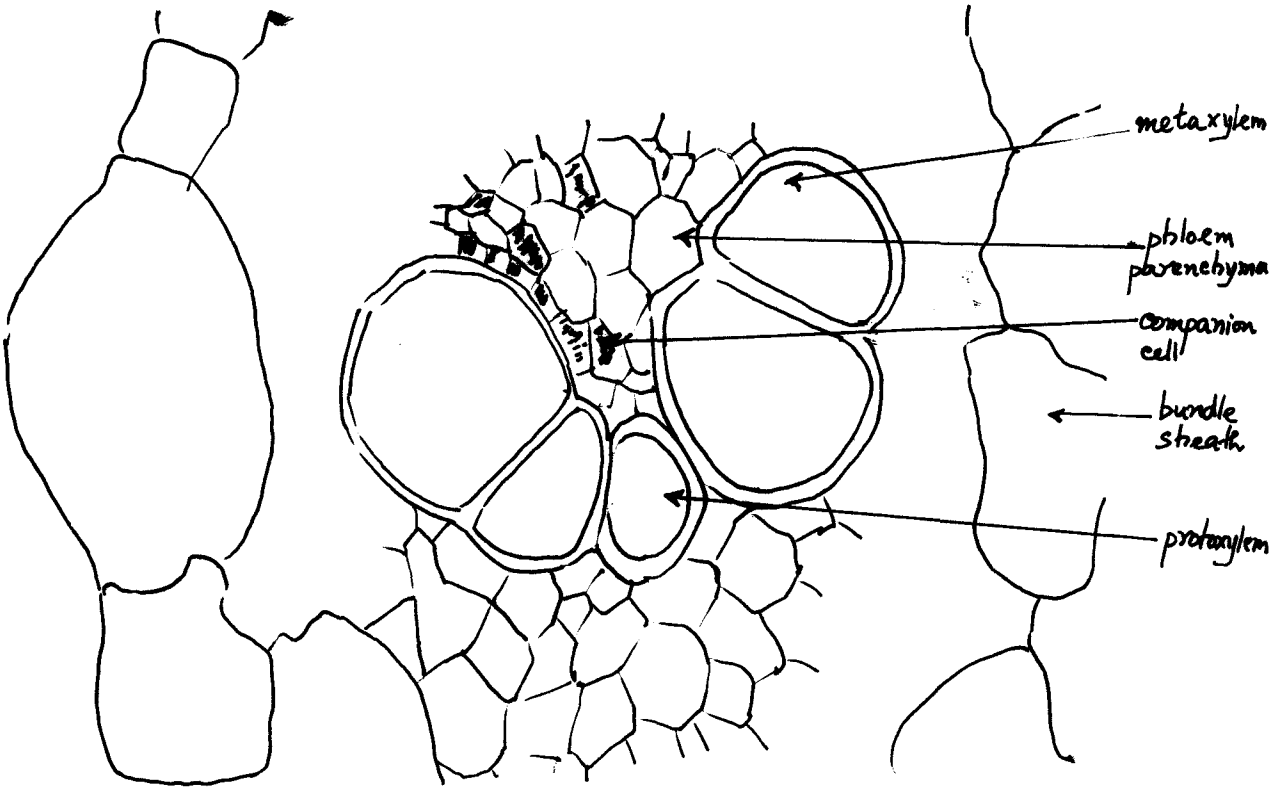


Plate 36 A portion of Plate 35 magnified showing a single vascular bundle (X 400)

Plate 37 T.S. of cardamom leaf (X 320)

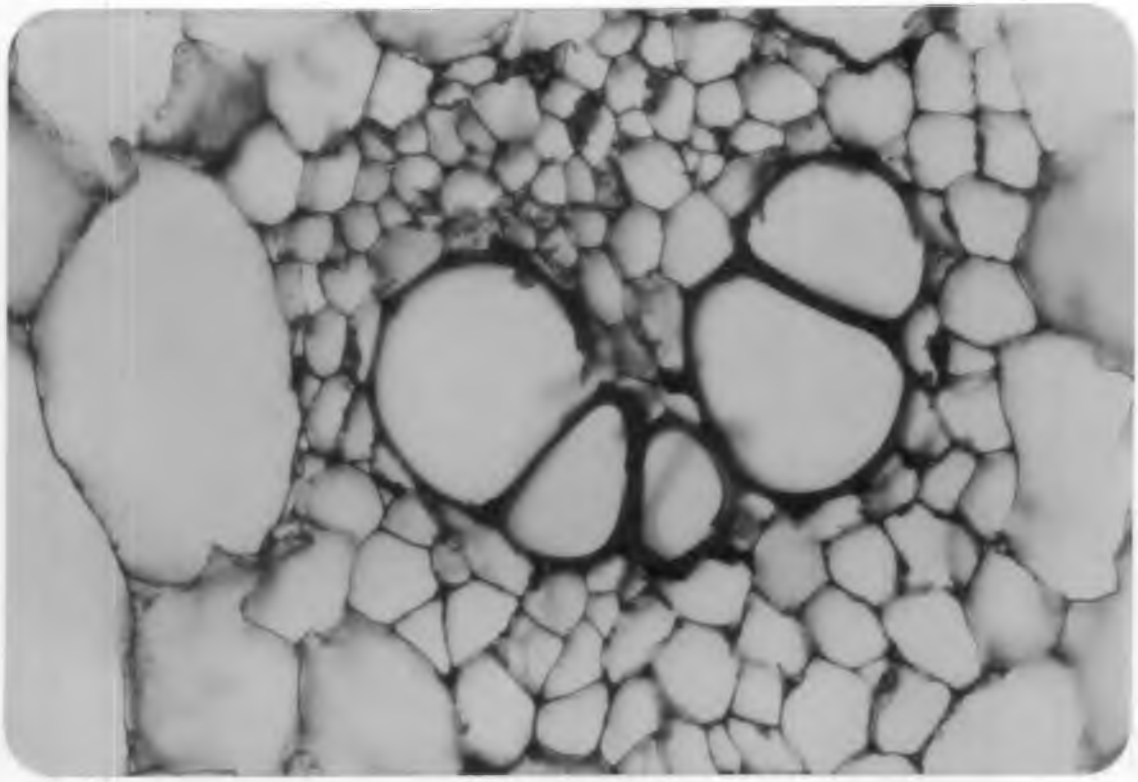


Plate 36

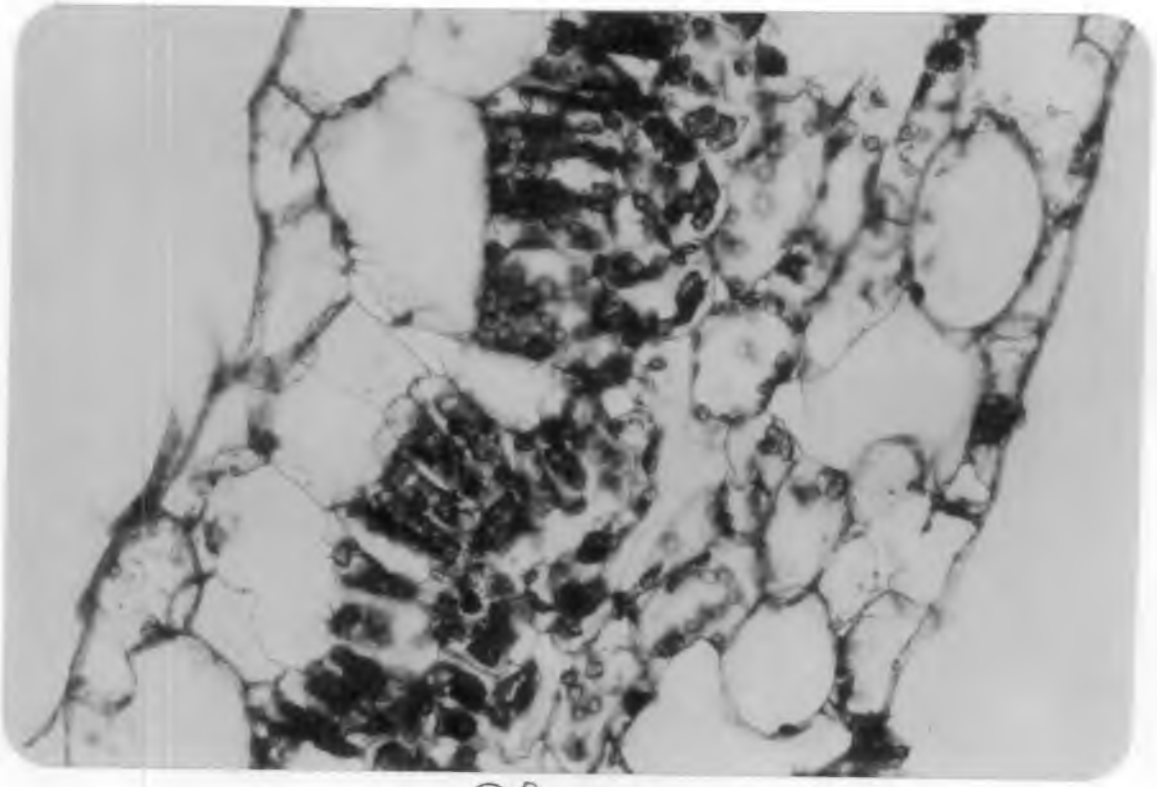


Plate 37

4.2.7 Histology of the seed

A portion of the transverse section of a seed at its "tender stage" is shown in Plate 38. The seed coat or testa can be identified as having three layers of cells. An inner core of endosperm can be seen developing with thin-walled parenchymatous cells.

Plates 39 and 40 reveal the structural peculiarities of the seed at the greenish-yellow stage. The innermost layer of the integument (testa) appears slightly more stained than the outer layers (Plate 39). The inner core of endosperm cells indicate the onset of the development of starch grains which appear as blackish bodies (Plate 40). The middle layer of teste shows thin walled vertical cells arranged parallel to one another.

The 'brown seed' stage (Plate 41) shows lignification of inner testa layer and a heavily stained mass of endosperm cells with diffused starch grains.

The 'black seed' stage illustrated in Plates 42 and 43 shows the development of starch grains in almost all the cells of the endosperm. The inner layer of testa appears heavily lignified. A layer of warty mucilaginous

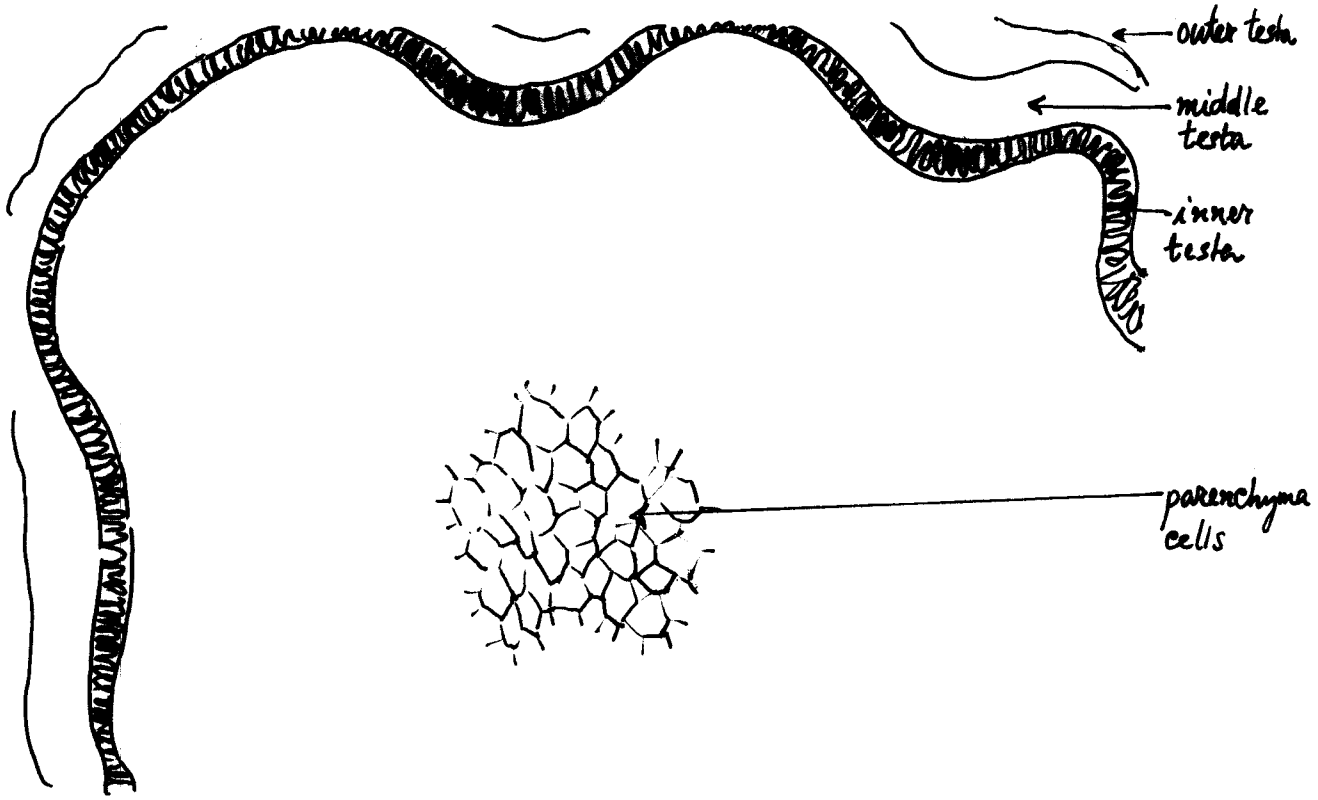


Plate 38 T.S. of tender seed of cardamom (X 100)

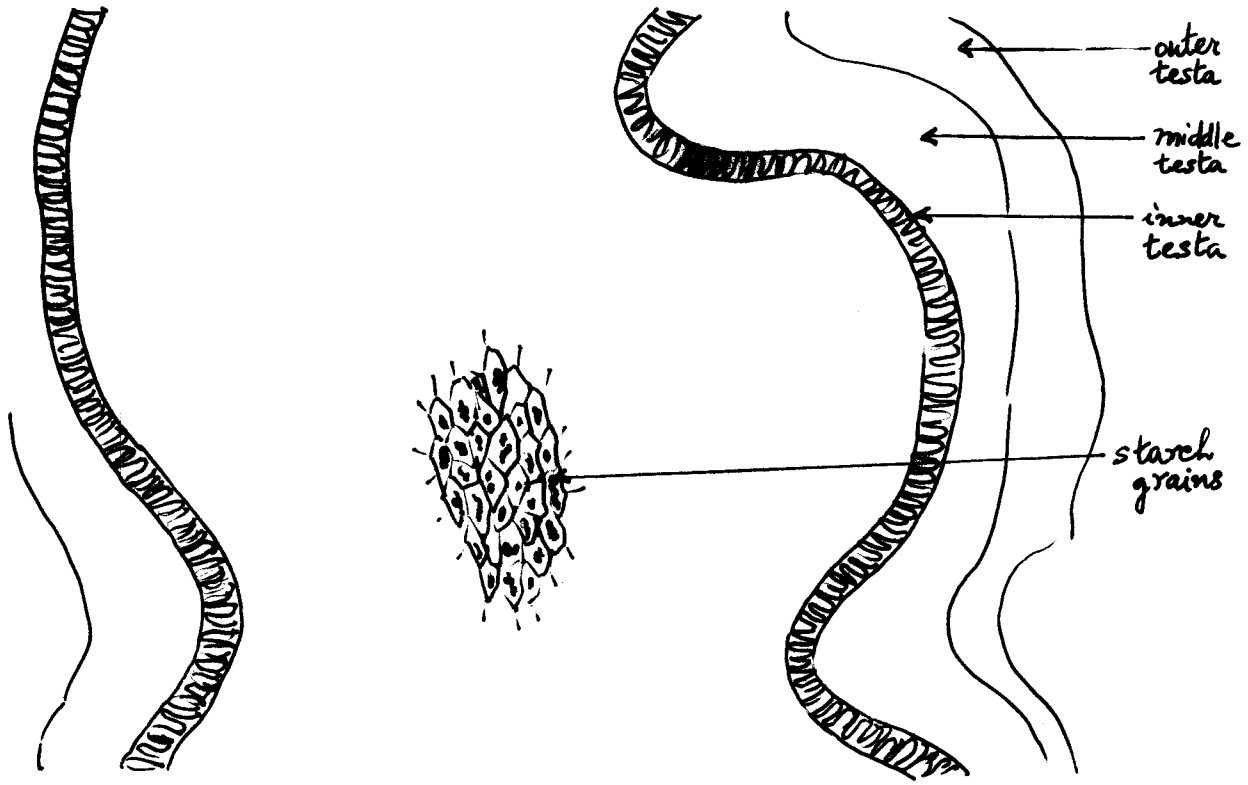


Plate 39 T.S. of greenish-yellow seed of cardamom (X 100)

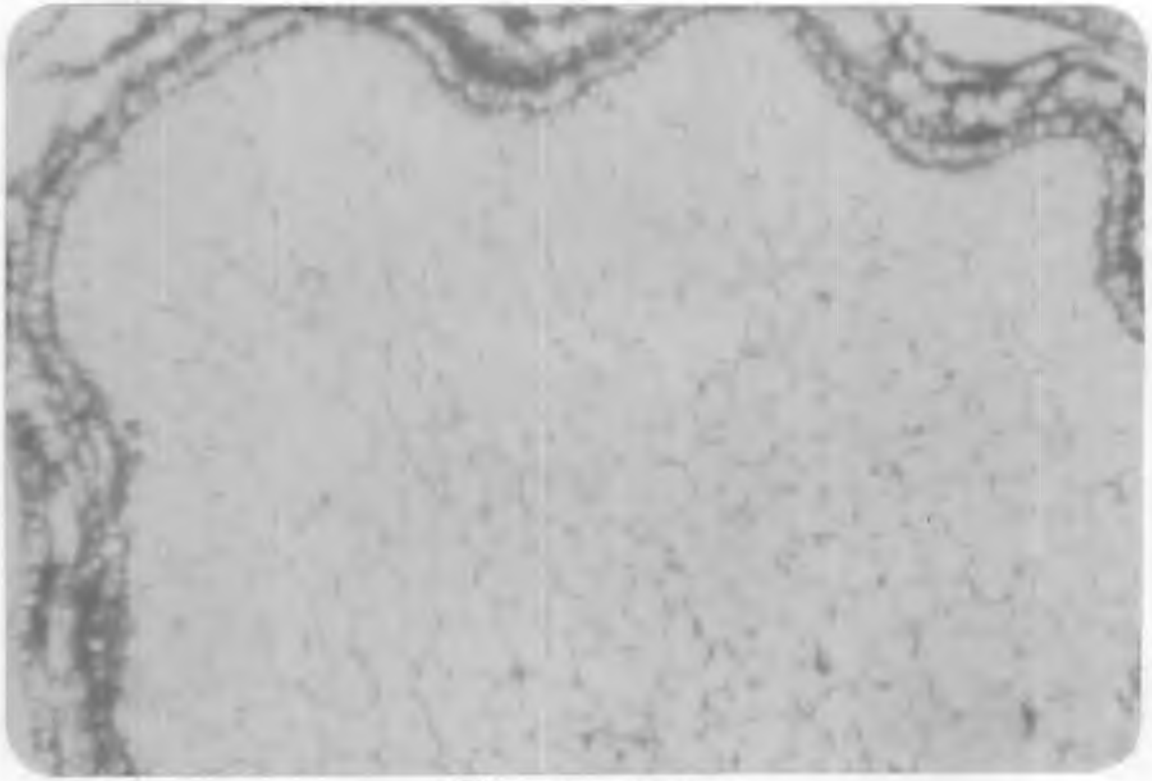


Plate 38

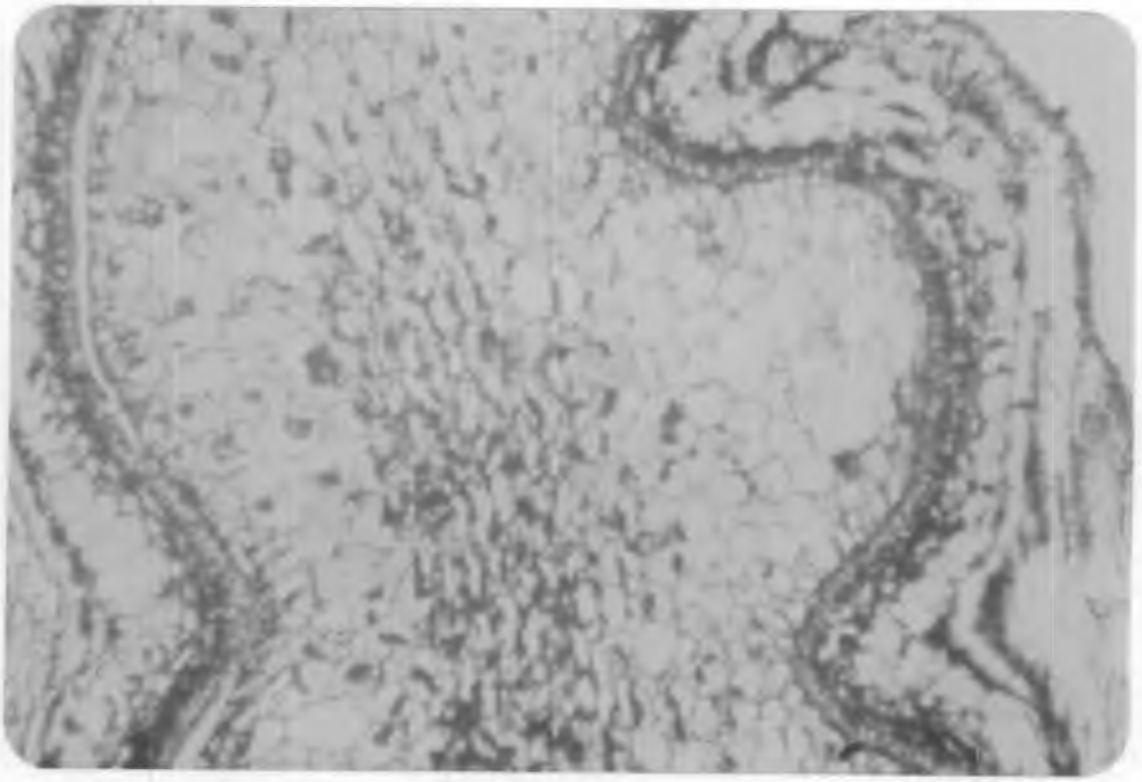


Plate 39

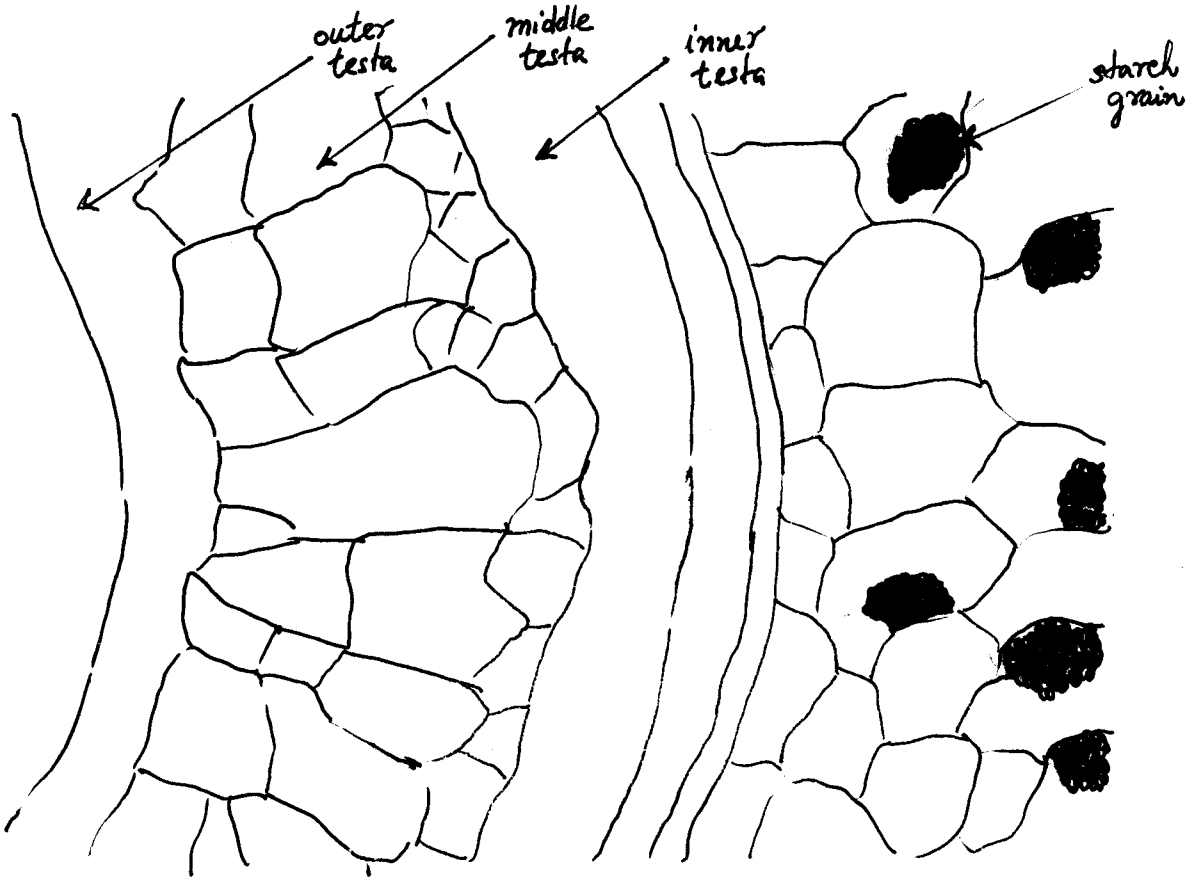


Plate 40 A portion in Plate 39 magnified showing the development of starch grains (X 200)

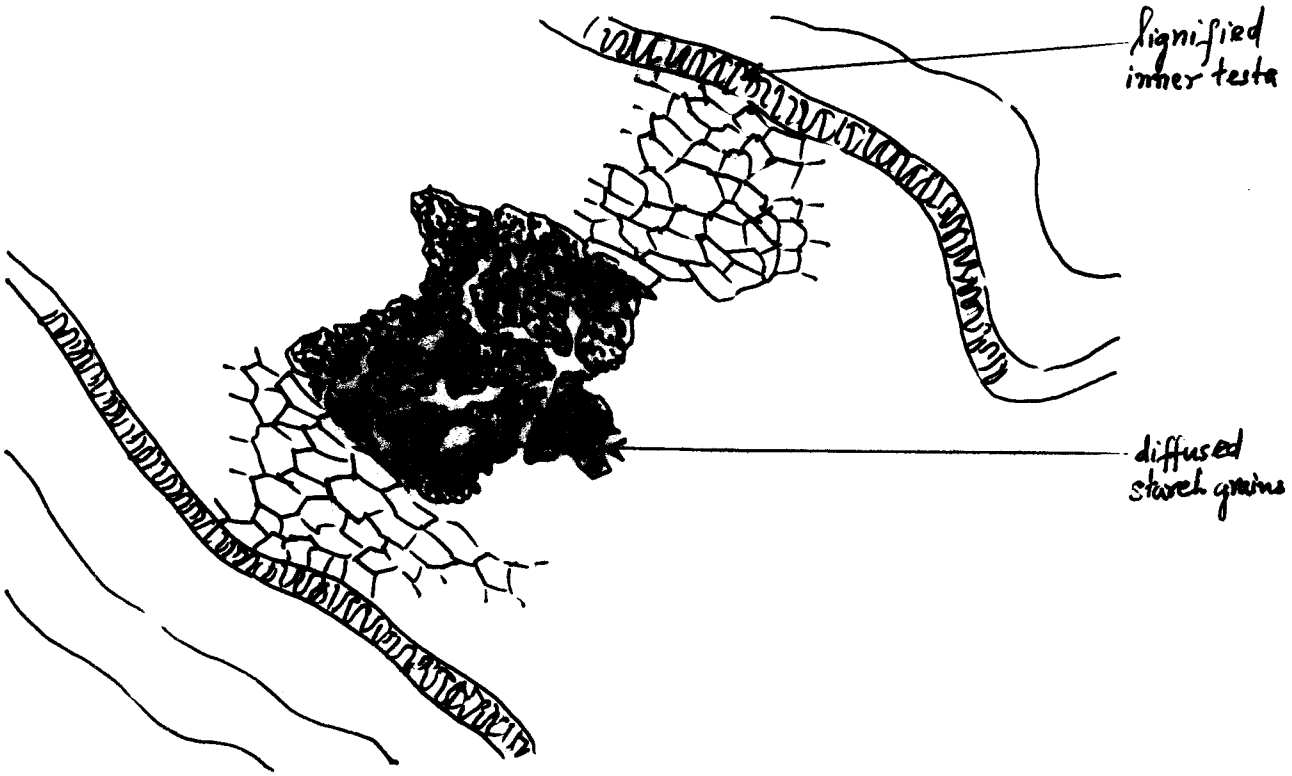


Plate 41 T.S. of brown seed of cardamom (X 100)

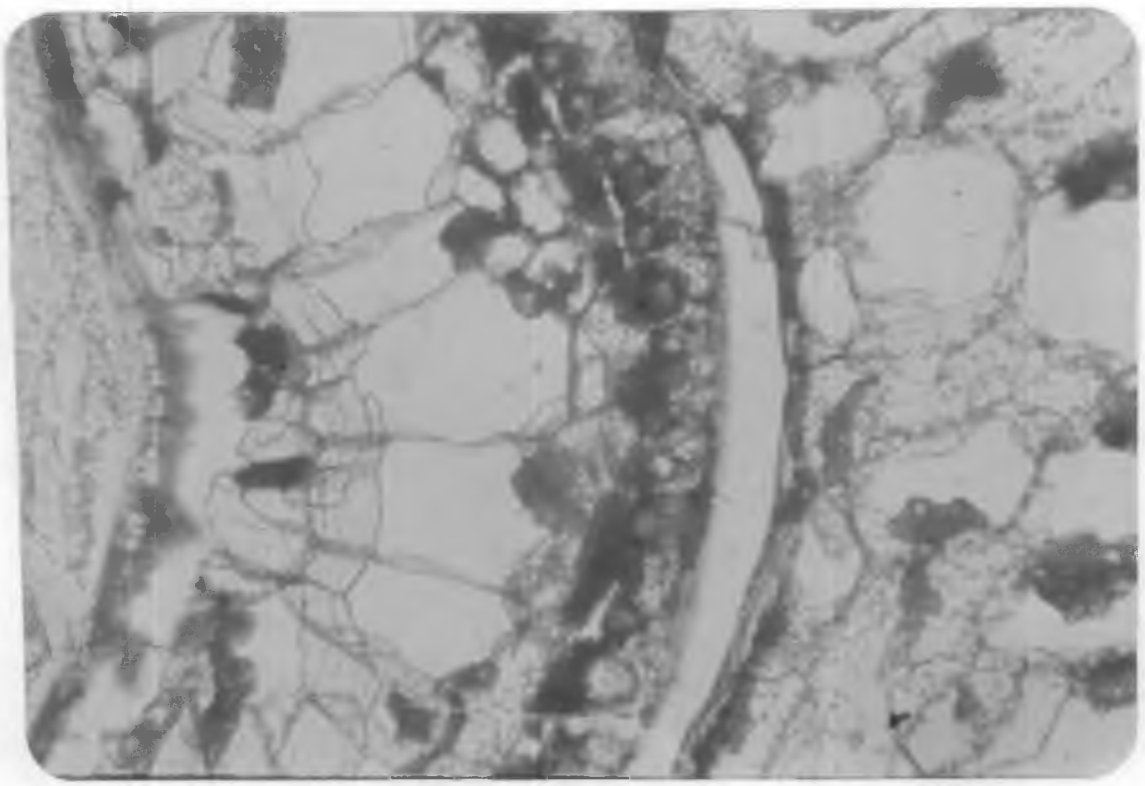


Plate 40

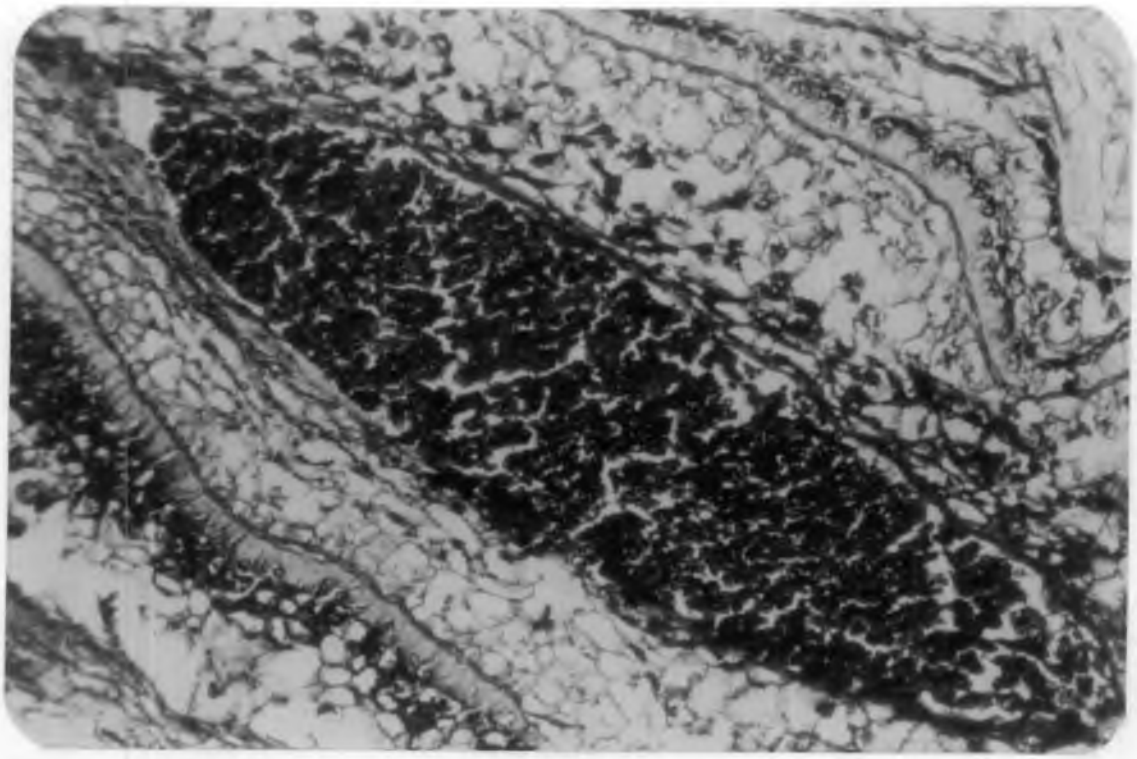


Plate 41

Plate 43 T.S. of black seed of cardamom (X 100)

Plate 44 A portion in plate 43 magnified showing differentiation of cells and development of starch grains in all the cells (X 500)

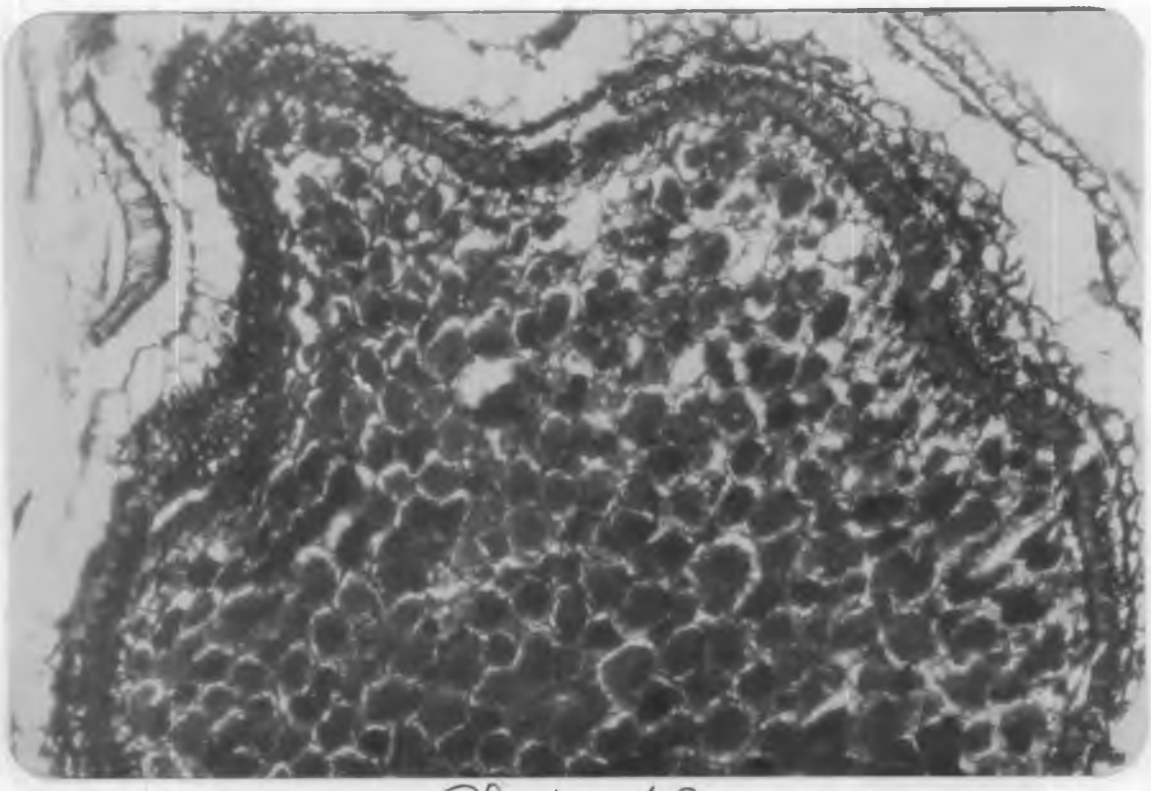


Plate 42

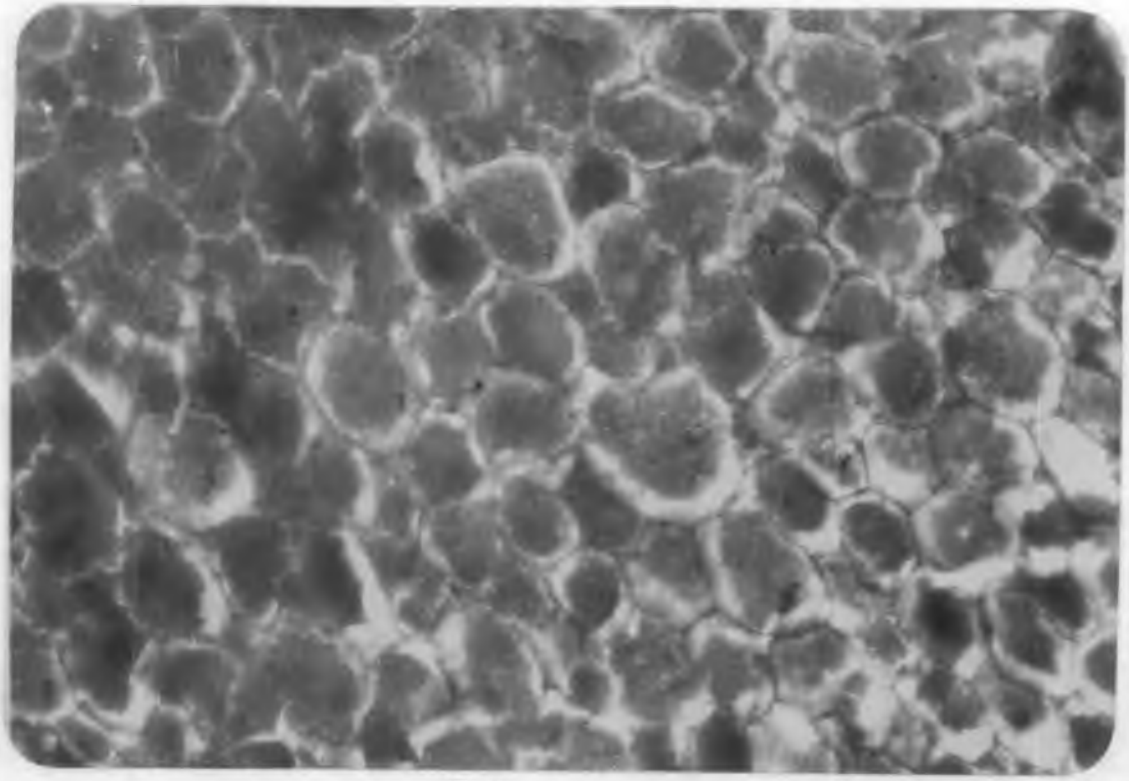


Plate 43

cells can be seen developed above the outer testa. The starch grains show angular configuration and have filled almost the entire space of the endosperm cells (Plate 43) but are separated from the cell walls.

4.3 The influence of climatic factors (rainfall, relative humidity, mean temperature) and soil moisture on flowering and fruit set

The data on the meteorological factors during the period of the present investigations (January, 1982 to December, 1984) are presented in Appendices I to III.

A perusal of the weather data of 1982 indicated that the total rainfall received during the year was 1411.80 mm with a mean of 117.65 mm par month. The monthly rainfall varied from nil during January and February, to 265 mm during June. The lean rainy months were January, February and March while the heavy rainy months were June, July and August.

The relative humidity ranged from 68.10 per cent in February, 1982 to 91.30 per cent in July 1982.

The period from June to August, 1982 was marked by high relative humidity with a pattern similar to that of the rainfall distribution. Comparatively low relative humidity was recorded for the periods from January to May and September to December.

The mean monthly temperature varied from 18.45°C in December, 1982 to 24.29°C in April, 1982. The period that recorded high temperature was from February to May. The temperature recorded during the other months exhibited rather an erratic pattern.

Soil moisture estimated at 15 cm depth of the soil, gave an average monthly mean value of 18.42 per cent. The monthly mean ranged from 9.24 per cent in March, 1982 to 33.60 per cent in June, 1982. Soil moisture attained a peak during June to August,1982. The moisture percentage of the soil was low during the months from January to April,1982 and again from October to December, 1982.

4.3.1 Direct and indirect effects of climatic factors on the frequency of production of new tillers per clump

Table 30 shows the influence of the climatic factors on the tillering ability in cardamom.

The climatic factors studied contributed 77.95 per cent variation in Malabar, 86.89 per cent variation in Mysore and 82.98 per cent variation in Vazhukka.

Table 30 @ Direct and indirect effects of climatic factors on the frequency of production of new tillers in a clump

30.1. cv. Malabar

	Rainfall	Relative humidity	Mean temperature	Soil moisture	Correlation
Rainfall	-0.3968	0.8779	-0.0006	0.2216	0.7020*
Relative humidity	-0.3321	1.0488	-0.0812	0.2285	0.8640**
Mean temperature	0.0013	-0.4531	0.1879	-0.0701	-0.3340
Soil moisture	-0.3186	0.8684	-0.0477	0.2759	0.7780**

Residual effects = 0.4695

30.2 cv. Mysore

Rainfall	0.6412	0.2789	0.0004	-0.0194	0.8940**
Relative humidity	0.5367	0.3248	0.0465	-0.0200	0.8880**
Mean temperature	-0.0021	-0.1403	-0.1077	0.0061	-0.2440
Soil moisture	0.5148	0.2689	0.0274	-0.0242	0.7870**

Residual effects = 0.3621

30.3 cv. Vazhukka

Rainfall	-0.2876	0.6708	-0.0007	0.3866	0.7690**
Relative humidity	-0.2407	0.8014	-0.0953	0.3986	0.8640**
Mean temperature	0.0009	-0.3462	0.2205	-0.1223	-0.2470
Soil moisture	-0.2309	0.6635	-0.0560	0.4814	0.8580**

Residual effects = 0.4126

@ The diagonal values (underlined) are the direct effects and the horizontal values are the indirect effects.

* Significant at 5 per cent level

** Significant at 1 per cent level

Relative humidity had the highest direct effects in the case of Malabar and Vazhukka cultivars (1.0488 and 0.8014 respectively). In the Mysore cultivar, rainfall had the maximum direct effect (0.6412). The second highest direct effects were for rainfall in Malabar (-0.3968), relative humidity in Mysore (0.3248) and soil moisture in Vazhukka (0.4814). The direct effects of relative humidity were positive in the three cultivars whereas that of rainfall was positive in Mysore and negative in Malabar and Vazhukka.

The indirect effect of rainfall on tillering ability was more through relative humidity in the three cultivars (0.8779, 0.2789 and 0.6708) respectively). The mean temperature also had the maximum indirect effect on tillering through relative humidity in the three cultivars (-0.4531, -0.1403 and -0.3462 respectively) and in this case the effects were negative. The indirect effect of soil moisture on tiller production was highly influenced by the relative humidity, in the cultivars, Malabar and Vazhukka (0.8684 and 0.6635 respectively) and by the rainfall in the Mysore cultivar (0.5148).

The correlation between tiller production and the climatic factors (relative humidity and soil moisture)

were highly significant for the three cultivars ($P<0.01$). Rainfall also exhibited a significant correlation at one per cent level with the tillering ability of Mysore and Vazhukka cultivars and at five per cent level with Malabar cultivar. The tiller production did not indicate any significant correlation with the mean temperature.

4.3.2 Direct and indirect effects of climatic factors on the number of panicles produced per clump

The results of the above analysis are presented in Table 31.

With respect to panicle production per clump, the four weather parameters together accounted for 32.25 per cent variation in Malabar, 56.03 per cent variation in Mysore and 35.30 per cent variation in Vazhukka.

Rainfall had the maximum direct effect in Malabar and Vazhukka cultivars (-0.6031 and -0.6384 respectively) the effects being negative. In Mysore cultivar, the direct effect was maximum for relative humidity (-1.0544) and this effect was also negative. In the three cultivars, the second highest direct effect was for soil moisture (0.5867, 0.7510 and 0.5345 respectively for Malabar,

Table 31 @ Direct and indirect effects of climatic factors on the number of panicles produced per clump

31.1 cv. Malabar

	Rainfall	Relative humidity	Mean temperature	Soil moisture	Correlation
Rainfall	-0.6031	-0.1656	-0.0014	0.4712	-0.2990
Relative humidity	-0.5049	-0.1979	-0.1882	0.4859	-0.4050
Mean temperature	0.0019	0.0855	0.4356	-0.1490	0.3739
Soil moisture	-0.4843	-0.1638	-0.1106	0.5867	-0.1720

Residual effects = 0.8231

31.2 cv. Mysore

Rainfall	0.2032	-0.8822	-0.0010	0.6030	-0.0769
Relative humidity	0.1701	-1.0539	-0.1369	0.6219	-0.3990
Mean temperature	-0.0006	0.4553	0.3171	-0.1908	0.5810*
Soil moisture	0.1632	-0.8727	-0.0081	0.7519	-0.0390

Residual effects = 0.6634

31.3 cv. Vaishakha

Rainfall	-0.6384	-0.1583	-0.0014	0.4292	-0.3690
Relative humidity	-0.5344	-0.1892	-0.1840	0.4426	-0.4650
Mean temperature	0.0021	0.0817	0.4259	-0.1358	0.3740
Soil moisture	-0.5127	-0.1566	-0.1082	0.5345	-0.2430

Residual effects = 0.8044

@ The diagonal values (underlined) are the direct effects and the horizontal values are the indirect effects.

* Significant at 5 per cent level

Mysore and Vazhukka) and here, the effects were positive.

The indirect effects of relative humidity and soil moisture on panicle production (although negative) were more through rainfall in the cultivars Malabar and Vazhukka. The indirect effect of mean temperature was more through soil moisture in these cultivars, although negative.

In Mysore cultivar, the indirect effect of relative humidity on panicle production was more through soil moisture and those of temperature and soil moisture were more through relative humidity.

The correlation values of the climatic factors (rainfall relative humidity and soil moisture) were negative for the three cultivars. The mean temperature exhibited positive correlation with panicle initiation for the three cultivars.

The correlation between the climatic factors and panicle initiation was not significant. The only correlation that showed significance was that between temperature and panicle initiation in the Mysore cultivar ($r = 0.5810$).

4.3.3 Direct and indirect effects of climatic factors on the number of flowers opened par clump

Table 32 details the effects of climatic factors on flower production in a clump.

The four factors together contributed to 92.43 per cent variation in Malabar, 83.76 per cent variation in Mysore and 92.84 per cent variation in Vazhukka.

In the three cultivars, the maximum direct effect on flower opening par clump was exhibited by soil moisture. These effects were positive and of the sequence 1.0644 (Malabar), 0.9859 (Mysore) and 0.9141 (Vazhukka). The direct effects of temperature on flowering in the three cultivars were also positive and ranked second in Mysore and Vazhukka. The Malabar cultivar had the second highest direct effect by rainfall, although negative.

The highest indirect effects of the three climatic factors (rainfall, relative humidity and temperature) on flower opening were through soil moisture in the cultivars Mysore and Vazhukka. In the case of Malabar cultivar also the highest indirect effects of rainfall and relative humidity were through soil moisture; but the indirect effect of temperature on flowering was through relative humidity.

Table 32 @ Direct and indirect effects of climatic factors on the number of flowers opened in a clump

32.1 cv. Malabar

	Rainfall	Relative humidity	Mean temperature	Soil moisture	Correlation
Rainfall	-0.7138	0.5462	0.0021	0.8547	0.6850*
Relative humidity	-0.5974	0.6526	-0.2764	0.8813	0.6600*
Mean temperature	0.0024	-0.2819	0.6399	-0.2703	0.0090
Soil moisture	-0.5732	0.5403	-0.1625	1.0644	0.8690**

Residual effects = 0.2751

32.2 cv. Mysore

Rainfall	0.1404	-0.1930	-0.0009	0.7917	0.7390**
Relative humidity	0.1175	-0.2295	-0.1304	0.8164	0.5740
Mean temperature	-0.0005	0.0991	0.3018	-0.2504	0.1500
Soil moisture	0.1127	-0.1900	-0.0766	0.9859	0.8320**

Residual effects = 0.4030

32.3 cv. Vazhukka

Rainfall	-0.2268	0.2924	-0.0014	0.7340	0.7980**
Relative humidity	-0.1899	0.3492	-0.1872	0.7569	0.7290**
Mean temperature	0.0007	-0.1508	0.4332	-0.2322	0.0510
Soil moisture	-0.1821	0.2891	-0.1101	0.9141	0.9110**

Residual effects = 0.2676

@ The diagonal values (underlined) are the direct effects and the horizontal values are the indirect effects.

* Significant at 5 per cent level

** Significant at 1 per cent level

Correlation between rainfall and flower opening was significant at one per cent level in the case of Mysore and Vazhukka cultivars and at five per cent level in the case of Malabar cultivar. The correlation between relative humidity and the number of flowers opened per clump was also significant at one per cent level in Vazhukka and was significant at five per cent level in Malabar. Soil moisture exhibited a highly significant correlation with flower opening for the three cultivars ($P < 0.01$).

4.3.4 Direct and indirect effects of climatic factors on the percentage of fruit set per clump

Table 33 indicates the influence of climatic factors on the percentage of fruit set per clump. The climatic factors contributed 94.00 per cent variation in Malabar, 90.40 par cent variation in Mysore and 91.08 per cent variation in Vazhukka.

The maximum direct effect was recorded by soil moisture in Malabar (0.7235) and Mysore (0.6331), whereas in Vazhukka relative humidity had the highest direct effect (0.6086). The second highest direct effects were for temperature in Malabar and Mysore (0.4694 and 0.4994 respectively) and for soil moisture in Vazhukka (0.5081).

Table 33 Direct and indirect effects of the climatic factors on the percentage of fruit set per clump

33.1 cv. Malabar

	Rainfall	Relative humidity	Mean temperature	Soil moisture	Correlation
Rainfall	0.1015	0.1730	-0.0015	0.5810	0.8540**
Relative humidity	0.0850	0.2067	-0.2028	0.5990	0.6880*
Mean temperature	-0.0003	-0.0893	0.4694	-0.1838	0.1960
Soil moisture	0.0815	0.1712	-0.1183	0.7235	0.8570**

Residual effects = 0.2429

33.2 cv. Mysore

Rainfall	0.0800	0.2582	-0.0016	0.5083	0.8450**
Relative humidity	0.0670	0.3085	-0.2157	0.5242	0.6840*
Mean temperature	-0.0003	-0.1333	0.4924	-0.1608	0.2050
Soil moisture	0.0643	0.2555	-0.1268	0.6331	0.8260**

Residual effects = 0.3098

33.3 cv. Vazimukka

Rainfall	-0.0478	0.5094	-0.0016	0.4080	0.8680**
Relative humidity	-0.0400	0.6086	-0.2103	0.4207	0.7790**
Mean temperature	0.0002	-0.2629	0.4868	-0.1291	0.0950
Soil moisture	-0.0384	0.5039	-0.1237	0.5081	0.8500**

Residual effects = 0.2987

● The diagonal values (underlined) are the direct effects and the horizontal values are the indirect effects.

* Significant at 5 per cent level

** Significant at 1 per cent level

In the cultivars Malabar and Mysore, the indirect effects of rainfall, relative humidity and temperature on fruit set were more through soil moisture. The fruit set per clump in Vazhukka cultivar was influenced by rainfall and temperature indirectly through relative humidity. The indirect influence of relative humidity on fruit set was more through soil moisture.

The correlations between rainfall and soil moisture and fruit set per clump were highly significant in the three cultivars ($P<0.01$). However the correlation between relative humidity and fruit set was highly significant only in the case of Vazhukka, in the case of Malabar and Mysore cultivars the correlation being significant only at five per cent level.

4.3.5 Direct and indirect effects of climatic factors on the percentage of capsules matured in e clump

Table 34 presents the effects of climatic factors on the maturity of capsules in cardamom.

The weather parameters contributed to 94.25 per cent variation on capsule maturity per clump in Malabar, 86.08 per cent variation in Mysore and 92.48 per cent variation in Vazhukka.

Table 34 Direct and indirect effects of the climatic factors on percentage of capsules carried to maturity

34.1 cv. Malabar

	Rainfall	Relative humidity	Mean temperature	Soil moisture	Correlation
Rainfall	-0.0683	0.1243	-0.0015	0.7485	0.8030**
Relative humidity	-0.0572	0.1485	-0.2012	0.7718	0.6620*
Mean temperature	0.0002	-0.0642	0.4657	-0.2368	0.1650
Soil moisture	-0.0548	0.1230	-0.1183	0.9321	0.8820**

Residual effects = 0.2398

34.2 cv. Mysore

Rainfall	0.2823	0.0465	-0.0012	0.5104	0.8380**
Relative humidity	0.2363	0.0555	-0.1622	0.5263	0.6560*
Mean temperature	-0.0009	-0.0289	0.3754	-0.1615	0.1890
Soil moisture	0.2267	0.0460	-0.0953	0.6356	0.8130**

Residual effects = 0.3731

34.3 cv. Vazhukka

Rainfall	-0.2876	0.4688	-0.0016	0.6344	0.8140**
Relative humidity	-0.2407	0.5601	-0.2054	0.6545	0.7680**
Mean temperature	0.0009	-0.2419	0.4757	-0.2007	0.0340
Soil moisture	0.2309	0.4637	-0.1208	0.7900	0.9020**

Residual effects = 0.2742

@ The diagonal values (underlined) are the direct effects and the horizontal values are the indirect effects

* Significant at 5 per cent level

** Significant at 1 per cent level

Soil moisture showed the highest direct effects on capsule maturity in the three cultivars (0.9321, 0.6356 and 0.7900 respectively in Malabar, Mysore and Vashukka). The second highest direct effects were for mean temperature in the cultivars Malabar and Mysore (0.4657 and 0.3754 respectively) and for relative humidity in Vashukka (0.5601).

The indirect effects of rainfall and relative humidity on capsule maturity were high, through soil moisture for the three cultivars and the effects were positive. The indirect effect of temperature on capsule maturity was more through soil moisture in the case of Malabar and Mysore cultivars (-0.2368 and -0.1615 respectively) and through relative humidity in the case of Vashukka cultivar (-0.2419). These indirect effects were negative.

The correlations of soil moisture and rainfall with capsule maturity were significant at one per cent level in the three cultivars. Relative humidity had highly significant correlation with capsule maturity in Vashukka ($P<0.01$) and significant correlation in the cultivars Malabar and Mysore ($P<0.05$).

4.4 Effect of exogenous application of growth substances on enhancing flowering, fruit set and yield

4.4.1 Standardisation of the dose

The data given in Table 35 show the effect of growth substances tried in the preliminary trial on the morphological characters and yield of cardamom. The aim of this investigation was to select the best dose for each of the growth substance.

The parameters studied for fixing the concentration of various growth substances were number of panicles produced per clump, total number of flowers borne, percentage of fruit set, percentage of capsule drop and yield of capsules. Based on the influence of the growth substances on the above mentioned morphological characters, the most effective doses were determined to be alpha NAA(40 ppm), 2,4-D(4 ppm), 2,4,5-T (6 ppm), Ethrel (100 ppm) and GA_3 (100 ppm). Statistical analysis of the data revealed that the growth substances significantly influenced four of the five characters studied. The per cent fruit set per clump was the only exception which was not significantly altered by the application of growth substances. The treatments alpha NAA (40 ppm) and 2,4-D(4 ppm) were on par

Table 35 Effect of exogenous application of growth substances on flowering, fruit set and yield (Standardisation experiment)

Growth substance and its concentration (ppm)	Number of panicles produced per clump	Total number of flowers borne in a clump	Per cent fruit set per clump	Per cent dropping of immature capsules	Yield of capsules by fresh weight (g)
2,4-D 2	55.50	1388.50	58.00	22.00	606.00
" 4	67.00	1761.00	74.50	13.50	914.00
" 6	54.00	1478.00	58.00	23.50	588.00
" 8	61.50	1553.50	59.50	22.00	675.00
2,4,5-T 2	50.50	1459.50	58.00	25.50	648.50
" 4	63.50	1447.00	59.50	26.00	602.50
" 6	67.50	1636.50	64.50	17.00	835.00
" 8	53.50	1449.00	60.50	22.50	527.50
Alpha NAA 20	56.00	1527.00	57.50	26.50	612.50
" 40	72.00	1949.00	67.00	13.00	1082.00
" 60	51.00	1585.50	59.50	27.50	537.50
" 80	64.50	1458.50	59.50	25.50	505.00
BA 10	60.00	1338.50	57.50	25.50	467.50
" 20	54.50	1438.00	60.00	27.50	560.00
" 30	63.00	1427.00	59.00	24.00	587.50
" 40	61.00	1372.50	55.50	27.50	487.50
GA_3 25	57.00	1511.50	58.50	25.00	520.00
" 50	63.00	1490.50	56.50	28.00	527.50
" 75	64.50	1489.00	57.50	27.50	522.50
" 100	69.00	1806.50	63.00	18.50	706.50
Ethrel 25	70.00	1882.00	62.00	22.00	765.50
" 50	51.00	1384.00	53.50	31.00	460.00
" 75	49.50	1328.50	54.50	32.00	393.00
" 100	47.00	1431.50	55.50	37.50	472.50
Control	55.50	1477.50	60.00	25.50	652.20
F test	**	**	NS	**	**
C.D.(0.05)	5.79	239.88	-	4.15	111.37

NS Not significant

* Significant at 5 per cent level

** Significant at 1 per cent level

with respect to the characters studied (except yield of capsules) and both the treatments were significantly superior to the control.

4.4.2 Field experiment

The growth substances were further tested at their best concentrations to establish their effectiveness on enhancing crop productivity in cardamom.

The data presented in Table 36 show that the growth substances applied did not significantly alter the number of productive and new tillers, the height of tillers, the total leaf area and the number of panicles produced by a clump. However, the number of young tillers sprouted was more with application of 25 ppm Ethrel (86), followed by 40 ppm NAA (80) as against control (74). NAA at 40 ppm gave the maximum height for tillers (294 cm) besides increasing the number of panicles produced by a clump (84.4); the corresponding values in control were for the tiller height (278 cm) and for the number of panicles (68.4).

With respect to the other characters, application of 40 ppm NAA significantly increased the length of panicles (76.8 cm), the number of flowers borne per panicle (104), the total flower production per clump (3097) and the yield

Table 36 Effect of exogenous application of growth substances on growth, flowering, fruit set and yield of cardamom (Field experiment)

Growth substance and its concentration (ppm)	Number of productive tillers	Number of young tillers sprouted	Height of the pseudostem of productive tillers (cm)	Total leaf area of the productive tillers (cm^2)	Number of panicles produced in a clump	Length of panicles	Number of racemes produced per panicle	Number of flowers borne per panicle	Total number of flowers borne in a clump	Percentage capsule setting per clump	Percentage dropping of immature capsule to the total flowers	Percentage dropping of immature capsule to the [illegible]	Yield of capsules per plant by fresh weight (g)	Percentage infestation of capsules by thrips	Percentage essential oil by fresh weight of capsules
2,4-D (4)	44	71	272	5190	68.0	70.00	23.00	98.60	2842	68.60	18.60	12.40	1762	6.46	11.64
2,4,5-T (6)	46	65	284	4946	71.2	69.80	19.20	77.40	2431	60.20	22.80	16.60	1215	11.28	10.70
alpha NAA (40)	43	80	294	5074	84.4	76.80	22.20	104.00	3097	67.60	17.40	11.80	1780	12.22	10.42
GA_3 (100)	45	77	273	4880	67.4	62.40	19.40	81.20	2586	58.60	29.20	17.2	960	16.72	9.90
Ethrel (25)	51	86	256	4756	70.2	57.80	15.80	74.40	2156	51.60	31.40	20.6	820	20.58	10.52
Control	47	74	278	5029	68.4	67.20	18.80	79.20	2386	61.80	30.40	22.8	1035	15.46	10.50
F test	NS	NS	NS	NS	NS	**	*	**	**	**	**	**	**	**	NS
C.D. (0.05)	-	-	-	-	-	9.40	3.98	14.07	392	5.85	2.98	2.17	453	3.47	-

NS Not significant

* Significant at 5 per cent level

** Significant at 1 per cent level

of capsules (1780 g). The corresponding figures in the control plot were for the panicle length (67.2 cm), the number of flowers borne per panicle (79.2), the total flower production per clump (2386) and the yield of capsules (1035 g). NAA at 40 ppm significantly reduced the immature capsule drop (11.80 per cent of the set capsules and 17.40 per cent of the total flowers produced by a clump) as against in control (22.8 per cent of the set capsules and 30.4 per cent of the total flowers). Application of 2,4-D(4 ppm) was second to NAA (40 ppm) with respect to the yield contributing characters studied. The beneficial effects of 2,4-D (4 ppm) was more pronounced than those of NAA (40 ppm) by way of its significant influence on the morphological characters namely, the number of racemes produced per panicle (23.0), the percentage of capsule setting in a clump (68.6) and the recovery of essential oils from fresh capsules (11.64 per cent). The control plot gave values of the order 13.80 racemes per panicle, 61.00 per cent capsule setting and 10.50 per cent recovery of essential oil.

When the morphological characters observed and the yield of the capsules were compared statistically, NAA (40 ppm) and 2,4-D (4 ppm) were found to be superior

treatments as they enhanced flowering, fruit set and yield of cardamom.

4.5 Endogenous levels of growth substances in developing ovaries and fruits (capsules) of cardamom

Data on the endogenous levels of growth substances namely, auxins, inhibitors and cytokinins are presented in Table 37.

4.5.1 Auxins

Auxin-like substances extracted from purified cardamom fruits were found to be consistent at Rf positions 0.3 to 0.5 in paper chromatograms. Hence, this portion was selected for the estimation of auxin activity by employing the "wheat coleoptile bioassay".

It could be seen from the data given in Table 37 that the concentration of auxin-like substances expressed as equivalents of indole acetic acid maintained a steady

Table 37 Changes in the levels of endogenous growth substances in the developing ovaries and fruits of cardamom (cv Mysore)

Time after pollination	Auxins[1]	Inhibitors[2]	Cytokinins[3]
	(ng/g on fresh weight basis)		
6 hours	140	105	3270
12 hours	125	80	2830
24 hours	110	95	3410
36 hours	315	130	3060
48 hours	270	185	2680
1 week	185	220	2090
2 weeks	95	180	2300
3 weeks	60	175	1870
4 weeks	80	170	3140

1 Expressed as equivalents of indole acetic acid

2 " abscisic acid

3 " kinetin

pattern in the ovaries of the Mysore cultivar collected at the 6th, 12th and 24th hour after pollination. The auxin concentration reached a peak (315 ng/g fresh sample) at the 36th hour. Tha auxin activity remained fairly high at the 48th hour (270 ng/g). Thereafter, the auxin concentration declined in the capsules collected during the first week after pollination.

The data presented earlier in Table 32 indicated fruit (capsule) wilting coupled with the shedding of immature capsules was severe in the Mysore cultivar within 30 days of fruit set. It was observed from this study that the auxin activity was comparatively low (95,60 and 80 ng/g fresh capsules respectively) in the capsules at the 2nd, 3rd and 4th week after fruit set.

4.5.2 Inhibitors

In paper chromatograms of cardamom fruit extracts, inhibitory substances were found to be consistent at Rf regions 0.6 to 0.8.

A perusal of the data (Table 37) indicate that the levels of inhibitory substances excepssed as equivalents of abscisic acid were low (80 to 130 ng/g fresh capsules) from the 6th to 36th hour after pollination. The inhibitor

level rose to 185 ng/g fresh capsules) at the 48th hour after pollination. Thereafter, a steady concentration (220, 180, 175 and 170 ng/g respectively) was maintained during the 1st, 2nd, 3rd and 4th week after pollination. The inhibitor level attained a peak at the end of the first week after pollination.

4.5.3 Cytokinins

The cytokinin concentration in the cardamom capsules were estimated by the "cucumber cotyledon bioassay". The concentration of cytokinin-like substances assayed in the cardamom ovaries and capsules are presented in Table 37.

The data revealed that at the end of six hours after pollination, the developing ovaries of the Mysore cultivar recorded a fairly high level of cytokinin-like substances (3270 ng/g). In the next six hours, there was a decline in the cytokinin level to 2830 ng/g fresh ovaries. At the end of 24 hours after pollination the cytokinin activity reached the peak level of 3410 ng/g. Thereafter the cytokinin level steadily declined to 1870 ng/g fresh capsules at the end of three weeks after pollination. Again the level rose to 3140 ng/g at the end of the fourth week.

4.6 Nutrient status of the cardamom plants at various stages of crop growth

The aim of this investigation was to find out the variation in plant nutrient content at five important growth stages of cardamom namely, visual appearance of panicle initials, flower bud development stage, peak flowering period, capsule maturity stage and post-harvest stage.

The results of the chemical analysis of major and minor nutrients in the different plant parts of cardamom are presented in Tables 38 to 42. The concentration of the major and secondary nutrients (N, P, K, Ca, Mg and S) are expressed as percentage by dry weight of the organ, whereas that of the micronutrients (Fe, Zn, Mn and Cu) are expressed as parts per million (ppm) by dry weight.

4.6.1 Nitrogen

It can be observed from the data that in the leaves and pseudostems, the percentage nitrogen showed a gradual decline from the visual appearance stage of the panicles to the post-harvest stage. The leaf nitrogen content was maximum at the visual appearance stage of the panicles in the three cultivars, the values recorded being 2.36 per cent in Malabar, 2.75 per cent in Mysore and

Table 38 Nutrient status of cardamom plants at different stages of crop growth

(i) Leaves

Stages of growth	Nutrient elements														
	N (%)			P (%)			K (%)			Ca (%)			Mg (%)		
	Malabar	Mysore	Vashu-kka	Malabar	Mysore	Vashu-kka	Malabar	Mysore	Vashu-kka	Malabar	Mysore	Vashu-kka	Malabar	Mysore	Vashu-kka
1	2.36	2.75	2.29	0.251	0.264	0.289	3.77	3.23	3.20	1.09	0.87	1.11	0.237	0.294	0.301
2	2.07	2.48	2.04	0.258	0.277	0.278	3.87	3.54	3.76	1.23	1.09	1.19	0.336	0.359	0.421
3	1.98	2.38	1.93	0.247	0.228	0.244	3.58	3.52	3.98	1.56	1.56	1.58	0.380	0.473	0.592
4	1.66	2.11	2.09	0.247	0.237	0.218	3.20	3.17	3.60	2.12	1.82	1.57	0.473	0.490	0.584
5	1.54	1.60	1.72	0.197	0.188	0.168	2.83	2.95	3.35	2.16	1.87	1.72	0.467	0.451	0.563
F test and C.D(0.05)															
cultivars	**	0.10		NS	--		*	0.23		**	0.08		**	0.027	
Growth stages	**	0.14		**	0.039		**	0.30		**	0.11		**	0.035	
Interaction	**	0.23		NS	--		NS	--		**	0.19		*	0.060	

(contd..)

Table 38 (contd.)

Stages of growth	Nutrient elements														
	S (%)			Fe (ppm)			Zn (ppm)			Mn (ppm)			Cu (ppm)		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka
1	0.150	0.194	0.180	212.33	188.00	190.67	26.87	31.17	28.47	367.53	490.37	319.97	13.40	7.50	9.27
2	0.198	0.180	0.180	230.67	208.33	199.00	30.77	32.40	34.93	545.10	694.07	503.47	16.10	13.23	12.23
3	0.155	0.165	0.161	237.33	187.67	200.33	32.97	42.70	43.97	747.17	800.60	861.70	20.47	12.53	27.43
4	0.123	0.135	0.148	228.67	199.67	226.33	39.80	54.40	46.33	685.10	867.20	909.23	41.97	17.10	32.27
5	0.095	0.113	0.126	225.00	210.00	227.33	43.83	47.07	48.33	679.53	800.63	841.40	56.53	33.00	36.16

test and .D (0.05)								
ultivars	*	0.010	**	11.42	**	3.25	**	15.73	**	2.55
rowth stages	**	0.013	*	14.74	**	4.21	**	20.30	**	3.29
nteraction	*	0.023	NS	-	NS	-	**	35.17	**	5.70

1 Panicle initiation stage 2 Flower bud development stage 3 Peak flowering stage

4 Capsule maturity stage 5 Post-harvest stage

NS Not significant * Significant at 5 per cent level ** Significant at 1 per cent level

Table 39 Nutrient status of cardamom plants at different stages of crop growth
(ii) Pseudostems

Stages of growth	Nutrient elements														
	N (%)			P (%)			K (%)			Ca (%)			MG (%)		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka
1	1.38	1.32	1.20	0.250	0.267	0.272	5.32	5.32	5.36	1.00	0.66	1.07	0.297	0.271	0.275
2	0.94	0.92	1.18	0.296	0.287	0.287	5.40	5.43	4.92	1.05	1.12	1.32	0.368	0.416	0.379
3	0.82	0.82	1.03	0.230	0.267	0.268	5.48	5.08	4.35	1.17	1.27	1.51	0.479	0.497	0.437
4	0.64	0.76	0.94	0.210	0.220	0.242	5.15	4.88	4.29	1.33	1.58	2.03	0.478	0.562	0.595
5	0.69	0.44	0.69	0.184	0.194	0.201	4.18	4.38	3.60	1.22	1.44	1.87	0.494	0.642	0.624

F test and C.D (0.05)										
cultivars	*	0.11	NS	-	**	0.28	**	0.01	**	0.034
Growth stages	**	0.13	NS	-	**	0.36	**	0.13	**	0.043
Interaction	NS	-	NS	-	NS	-	**	0.22	*	0.074

(contd..)

Table 39 (contd..)

Stages of growth	Nutrient elements														
	S (%)			Fe (ppm)			Zn (ppm)			Mn (ppm)			Cu (ppm)		
	Malabar	Mysore	Vashukka	Malabar	Mysore	Vashukka	Malabar	Mysore	Vashukka	Malabar	Mysore	Vashukka	Malabar	Mysore	Vashukka
1	0.055	0.077	0.077	178.67	146.67	160.33	45.63	28.17	40.83	505.80	453.97	562.07	5.63	4.53	6.07
2	0.048	0.073	0.062	182.33	140.67	162.33	49.50	28.83	52.50	568.80	479.53	709.13	6.63	5.47	7.27
3	0.038	0.053	0.058	188.67	161.67	169.33	50.70	59.93	57.60	894.73	751.33	933.37	8.10	8.53	12.17
4	0.029	0.041	0.042	188.67	161.67	167.00	68.70	67.47	65.87	703.53	871.40	791.50	8.83	13.92	16.70
5	0.029	0.040	0.035	180.33	174.67	179.33	68.93	56.93	52.40	590.13	578.53	757.83	9.70	19.73	18.77

test and .D. (0.05)								
ıltivars	**	0.007	**	11.47	**	3.62	**	24.13	**	1.43
rowth stages	**	0.008	NS	-	**	4.41	**	31.15	**	1.85
ıteraction	NS	-	NS	-	**	7.64	**	53.95	**	3.20

1 Panicle initiation stage 2 Flower bud development stage 3 Peak flowering stage

4 Capsule maturity stage 5 Post-harvest stage

NS Not significant

* Significant at 5 per cent level ** Significant at 1 per cent level

Table 40 Nutrient status of cardamom plants at different stages of crop growth
(iii) Rhizomes

Stages of growth	Nutrient elements														
	N (%)			P (%)			K (%)			Ca (%)			Mg (%)		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka
1	1.31	1.40	1.59	0.222	0.165	0.237	6.29	6.91	5.07	1.08	0.83	0.87	0.419	0.526	0.507
2	1.30	1.68	1.21	0.261	0.213	0.293	5.56	6.27	5.56	1.25	0.92	0.91	0.576	0.646	0.677
3	1.17	1.32	1.18	0.408	0.278	0.387	5.47	6.93	5.64	1.28	0.96	0.93	0.729	0.837	0.838
4	1.02	1.13	0.89	0.279	0.226	0.294	7.23	7.14	6.35	1.42	1.07	1.12	1.055	0.962	1.158
5	0.85	1.08	0.89	0.232	0.189	0.270	4.94	5.69	4.36	1.26	1.04	1.05	1.003	1.092	0.955
F test and C.D.(0.05)															
cultivars	**	0.09		**	0.027		**	0.31		**	0.08		*	0.052	
Growth stages	**	0.12		**	0.035		**	0.39		**	0.10		**	0.068	
Interaction	**	0.21		NS	-		*	0.69		NS	-		*	0.118	

(contd..)

Table 40 (contd)

Stages of growth	Nutrient elements														
	S (%)			Fe (ppm)			Zn (ppm)			Mn (ppm)			Cu (ppm)		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka
1	0.148	0.123	0.118	225.00	244.33	271.67	64.17	40.47	43.97	316.60	378.87	354.17	7.50	6.70	9.30
2	0.139	0.116	0.114	235.33	273.00	273.33	64.07	54.20	54.37	688.07	491.63	363.47	12.83	8.57	11.00
3	0.154	0.097	0.104	265.67	267.33	292.67	67.80	51.93	66.97	572.00	519.67	702.70	18.23	11.27	14.53
4	0.137	0.097	0.088	279.00	284.00	304.33	108.30	56.13	80.37	538.33	795.00	943.30	35.60	35.77	41.97
5	0.113	0.075	0.071	286.33	294.33	315.33	128.90	81.67	74.07	439.50	602.70	640.77	37.47	51.40	54.53

F test and C.D.(0.05) cultivars	**	0.017	**	15.60	**	5.33	**	25.37	*	3.24		
Growth stages	**	0.022	**	20.13	**	6.88	**	32.76	**	4.18		
Interaction	NS	-	NS	-	**	11.91	**	56.74	**	7.25		

1 Panicle initiation stage 2 Flower bud development stage 3 Peak flowering stage

4 Capsule maturity stage 5 Post-harvest stage

NS Not significant

* Significant at 5 per cent level ** Significant at 1 per cent level

Table 41. Nutrient elements of cardamom plants at different stages of crop growth

(iv) Roots

Stages of growth	Nutient elements														
	N (%)			P (%)			K (%)			Ca (%)			Mg (%)		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka
1	0.98	0.97	0.96	0.102	0.112	0.098	3.71	4.08	3.50	0.86	0.89	0.87	0.464	0.382	0.489
2	1.40	0.92	0.86	0.090	0.137	0.129	4.03	4.19	3.79	0.91	1.04	0.91	0.543	0.738	0.521
3	1.22	0.87	0.92	0.101	0.150	0.153	4.14	4.42	4.10	1.11	1.13	1.02	0.635	0.945	0.710
4	1.16	1.01	0.97	0.147	0.161	0.201	4.87	4.86	4.17	1.40	1.25	1.24	0.810	0.837	0.881
5	0.98	0.81	0.69	0.175	0.170	0.232	3.03	4.18	3.51	1.57	1.59	1.49	0.757	0.709	0.792
F test and C.D. (0.05)															
cultivars	**	0.12		**	0.024		**	0.20		NS	-		**	0.029	
Growth stages	*	0.15		**	0.031		**	0.26		**	0.16		**	0.037	
Interaction	NS	-		NS	-		*	0.45		NS	-		**	0.065	

(contd..)

Table 41 (contd.)

Stages of growth	Nutrient elements														
	S (%)			Fe (ppm)			Zn (ppm)			Mn (ppm)			Cu (ppm)		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vashukka
1	0.035	0.034	0.043	336.67	352.00	331.33	47.80	81.67	88.70	199.47	217.90	231.43	29.20	14.37	14.43
2	0.042	0.038	0.054	331.00	352.67	339.00	44.13	81.20	76.10	296.27	345.13	213.80	35.43	20.30	18.57
3	0.047	0.059	0.078	335.67	356.00	354.67	63.07	54.17	75.33	316.10	515.60	434.47	42.23	19.93	21.37
4	0.080	0.080	0.070	337.00	360.33	341.67	81.87	57.47	76.90	625.17	662.77	650.00	35.17	24.67	29.53
5	0.055	0.065	0.055	349.00	361.00	338.00	52.93	51.27	69.83	336.13	614.43	662.87	31.80	20.20	22.33
F test and C.D.(0.05) cultivars	*	0.005		*	13.38		**	4.51		**	25.95		**	2.17	
Growth stages	**	0.007		NS	-		**	5.82		**	33.50		**	2.80	
Interaction	**	0.012		NS	-		**	10.07		**	58.03		**	4.85	

1 Panicle initiation stage 2 Flower bud development stage 3 Peak flowering stage

4 Capsule maturity stage 5 Post-harvest stage NS Not significant

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 42 Nutrient status of cardamom plants at different stages of crop growth

(v) Panicles and capsules

Stages of growth	Nutrient elements														
	N (%)			P (%)			K (%)			Ca (%)			Mg (%)		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka
1	1.51	1.09	1.53	0.193	0.163	0.178	3.58	3.89	4.49	1.09	0.86	0.66	0.376	0.374	0.574
2	1.49	1.38	1.37	0.255	0.198	0.263	4.93	4.47	4.84	1.26	1.04	0.84	0.521	0.877	0.937
3	1.60	1.73	1.54	0.298	0.246	0.313	5.19	4.96	4.88	1.42	1.17	1.16	0.563	0.997	1.035
4	1.89	1.68	1.52	0.316	0.283	0.311	5.29	4.96	5.46	1.38	1.68	1.53	0.952	1.163	1.097
5	1.13	1.44	1.15	0.303	0.268	0.275	4.93	4.82	4.27	2.03	1.76	1.35	1.114	1.260	0.178

F test and C.D. (0.05)									
cultivars	NS	-	**	0.024	NS	-	**	0.10	** 0.059
Growth stages	**	0.22	**	0.031	**	0.46	**	0.13	** 0.077
Interaction	NS	-	NS	-	NS	-	**	0.22	** 0.133

(contd..)

Table 42 (contd.)

Stages of growth	Nutrient elements														
	S (%)			Fe (ppm)			Zn (ppm)			Mn (ppm)			Cu (ppm)		
	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka	Malabar	Mysore	Vazhukka
1	0.078	0.063	0.078	147.00	155.00	154.00	27.66	59.80	33.77	418.47	580.00	685.90	10.00	15.43	17.47
2	0.101	0.076	0.093	151.67	165.00	164.00	44.10	61.13	49.67	553.70	624.03	710.53	13.37	18.03	16.80
3	0.130	0.085	0.140	154.33	194.67	173.67	64.13	55.67	52.57	597.87	757.30	754.20	16.57	22.27	22.70
4	0.145	0.107	0.161	171.00	194.00	184.33	75.67	79.93	70.43	800.23	903.97	905.63	14.63	14.80	35.83
5	0.178	0.166	0.152	175.67	215.00	196.67	80.03	89.87	83.70	672.23	779.30	736.90	15.67	17.90	29.67

F test and C.D. (0.05)					
cultivars	** 0.016	** 8.65	** 4.98	** 13.87	** 1.88
Growth stages	** 0.020	** 11.17	** 6.43	** 17.90	** 2.43
Interaction	NS -	NS -	** 11.13	** 31.01	** 4.20

1 Panicle initiation stage 2 Flower bud development stage 3 Peak flowering stage

4 Capsule maturity stage 5 Post-harvest stage NS Not significant

** Significant at 1 per cent level

2.29 per cent in Vazhukka. The nitrogen content of leaves was minimum at the post-harvest stage (1.54, 1.60 and 1.72 per cent respectively in Malabar, Mysore and Vazhukka).

The maximum values for nitrogen recorded in the pseudostems were at the panicle initiation stage (1.38, 1.32 and 1.20 per cent respectively in Malabar, Mysore and Vazhukka). The decline in nitrogen content of the pseudostems from the panicle initiation phase to the later phases of crop maturity followed a progressive sequence as that was observed in the case of leaves.

The rhizomes also exhibited a similar trend with respect to nitrogen percentage except in Mysore, where the flower bud development stage showed a peak for nitrogen concentration (1.68 per cent), followed by the panicle initiation phase (1.40 per cent).

The root nitrogen level was high at the flower bud development stage in the cultivar Malabar (1.40 per cent) and at the capsule maturation stage in Mysore and Vazhukka cultivars (1.01 and 0.97 per cent respectively). In the three cultivars the root nitrogen was low at the post-harvest stage.

The pattern of nitrogen accumulation in the panicles indicated wide variation among the growth stages in the three cultivars. In Malabar, nitrogen level was high

at the capsule maturity stage (1.89 per cent) whereas it was high at the peak flowering stage in Mysore and Vazhukka cultivars (1.73 and 1.54 per cent respectively).

Statistical analysis revealed that the differences in the mean nitrogen percentage was significant among the cultivars as well as among the growth periods. The only exception found was the nitrogen content of the panicles which did not give any significant difference among the cultivars.

4.6.2 Carbohydrates and C/N ratio

The data on total soluble carbohydrate content of leves and the ratio of carbohydrates to nitrogen at tne five growth stages studied are presented in Table 43.

The total soluble carbohydrates in the leaves varied from 4.03 to 5.51 per cent in Malabar, 3.40 to 5.53 per cent in Mysore and 3.10 to 4.69 per cent in Vazhukka. The maximum level of carbohydrates were at the flower bud development stage in Malabar and Vazhukka and at the panicle initiation stage in Mysore. The post-harvest stage was characterised by a low level of carbohydrates in the three cultivars.

Total 43 Total soluble carbohydrates, nitrogen and C/N ratio in the leaves of cardamom at five major crop maturity stages

Stages of growth	Malabar			Mysore			Vazhukka		
	Carbohydrates (per cent)	Nitrogen (per cent)	C/N ratio	Carbo-hydrates (per cent)	Nitrogen (per cent)	C/N ratio	Carbo-hydrates (per cent)	Nitrogen (per cent)	C/N ratio
Panicle initiation stage	4.35	2.36	1.84	5.53	2.75	2.01	4.37	2.29	1.91
Flower bud development stage	5.51	2.07	2.66	4.67	2.48	1.88	4.69	2.04	2.29
Peak flowering stage	4.80	1.98	2.42	5.30	2.38	2.22	3.98	1.93	2.06
Capsule maturity stage	4.29	1.66	2.58	4.61	2.11	2.18	3.51	2.09	1.68
Post-harvest stage	4.03	1.54	2.61	3.40	1.60	2.11	3.10	1.72	1.80

The C/N ratio at the five growth stages ranged between 1.84 and 2.66 in Malabar, 1.88 and 2.22 in Mysore and 1.68 and 2.29 in Vazhukka. The C/N ratio did not exhibit any definite relation to the flowering and fruit bearing habit of the crop. However, the C/N ratio was high at the flower bud development stages of Malabar and Vazhukke cultivars (2.66 and 2.29 respectively) and at the peak flowering stage of the Mysore cultivar (2.22).

4.6.3 *Phosphorus*

Phosphorus content of the leaves registered a high status at the flower bud development stage in the cultivars, Malabar and Mysore (0.258 and 0.277 per cent respectively) and at the panicle initiation stage in Vazhukka (0.289 per cent). At the post-harvest stage, P was low in the leaves of the three cultivars (0.197, 0.188 and 0.168 per cent respectively).

The flower bud development stage indicated a high level for P in the pseudostems of the three cultivars (0.296, 0.287 and 0.287 per cent respectively) while the post-harvest stage indicated a low level (0.184, 0.194 and 0·201 per cent respectively)

Phosphorus concentration of the rhizomes was comparatively low at the panicle initiation phase of the three cultivars (0.222, 0.168 and 0.237 per cent respectively)

which rose at the flower bud development period and reached a peak at the flowering period (0.408, 0.278 and 0.387 per cent respectively). Subsequently the P concentration of rhizomes fell at the capsule maturity and the post-harvest stages.

The root P concentration showed maxima in the three cultivars at the post-harvest phase (0.175, 0.170 and 0.232 per cent respectively in Malabar, Mysore and Vazhukka). The least level of root P was observed at the flower bud development stage in Malabar (0.090 per cent) and at the panicle initiation stage in Mysore and Vazhukka (0.112 and 0.098 per cent respectively).

The P concentration of panicles was minimum at the panicle initiation stage (0.193, 0.163 and 0.178 per cent respectively) and maximum at the capsule maturity stage in Malabar and Mysore cultivars (0.316 and 0.283 per cent respectively) and at the peak flowering stage in the Vazhukka cultivar (0.313 per cent).

Statistical analysis of the data showed that the P concentration in the leaves was not significantly different among the cultivars whereas it was significantly different among the five growth periods. The concent of P in the pseudostem did not reveal statistically significant difference either among the cultivars or among the growth

periods. The P concentration of the rhizomes, roots and panicles were significant among the cultivars as well as growth periods.

4.6.4 Potassium

The concentration of potassium in the leaves were high at the flower bud development stage in Malabar and Mysore (3.87 and 3.54 per cent respectively) whereas it was high at the peak flowering period in Vashukka (3.98 per cent). The leaf K concentration subsequently fell towards the later stages of crop maturity.

The potassium concentration of the pseudostems did not show a definite peak among the growth stages of the three cultivars. The post-harvest stage exhibited the minimum K level in the three cultivars (4.18, 4.38 and 3.60 per cent respectively). The range in pseudostem K was from 4.18 to 5.48 per cent in Malabar, 4.38 to 5.43 per cent in Mysore and 3.60 to 5.36 per cent in Vashukka.

The rhizomes accumulated more K at the capsule maturity stage in the three cultivars (7.23, 7.14 and 6.35 per cent respectively). The K content fell to a low level at the post-harvest stage (4.94, 5.69 and 4.36 per cent respectively). The pattern of K accumulation in the rhizomes was rather erratic at the other growth stages.

The root K concentration was high at the capsule maturity stage (4.87, 4.86 and 4.17 per cent respectively) in the three cultivars. The K concentration was low at the panicle initiation stage in Mysore and Vazhukka cultivars (4.08 and 3.50 per cent respectively) and at the post-harvest stage in Malabar cultivar (3.03 per cent).

The panicle K concentration increased with the increase in the crop age. It attained a peak at the capsule maturity stage (5.29, 4.96 and 5.46 per cent respectively) in the three cultivars.

In the statistical analysis of the data the K concentration of leaves, pseudostems, rhizomes and roots exhibited significant differences among the cultivars and at the different growth stages. The K concentration of panicles however, differed significantly among the growth stages only. The cultivars did not reveal significant difference.

4.6.5 Calcium

The calcium concentration showed a gradual increase from the panicle initiation stage to the capsule maturity stage in all the plant parts of the three cultivars. The peaks of Ca accumulation were at the post-harvest stage (leaves, roots and panicles) and at the capsule maturity

stage (pseudostems and rhizomes). When the cultivars and the growth stages were considered together, the range of variation in Ca content was from 0.87 to 2.16 per cent in the leaves, 0.66 to 2.03 per cent in the pseudostems, 0.83 to 1.42 per cent in the rhizomes, 0.86 to 1.59 per cent in the roots and 0.66 to 2.03 per cent in the panicles.

The Ca content of the leaves, pseudostems, rhizomes and panicles exhibited statistically significant difference among the cultivars as well as growth stages. The root Ca content did not show significant difference among the cultivars, whereas it was significant among the growth stages.

4.6.6 Magnesium

The magnesium accumulation followed a pattern similar to that of calcium. The concentration rose from the panicle initiation stage to the capsule maturity stage in the three cultivars. The Mg accumulation in the leaves attained a maximum at the capsule maturity period in Malabar and Mysore and at the flowering period in Vazhukka. The post-harvest stage exhibited a peak for Mg accumulation in the pseudostems and panicles. Mg concentration in the rhizomes and roots of Malabar and Vazhukka attained the peak at the capsule maturity stage.

In the Mysore cultivar, Mg concentration was maximum at the post-harvest stage in the rhizomes and at the flowering stage in the roots. The Mg concent (percentage) varied from 0.237 to 0.592 in the leaves 0.271 to 0.642 in the pseudostems, 0.419 to 1.158 in the rhizomes, 0.382 to 0.945 in the roots and 0.374 to 1.260 in the panicles.

The cultivars as well as growth periods revealed statistically significant difference for the Mg content of the various plant parts.

4.6.7 Sulphur

The pattern of distribution of sulphur in the plant parts did not reveal any definite trend among the growth periods. The post-harvest stage was characterised by a low S concentration in the leaves, pseudostems and rhizomes whereas the panicle initiation stage showed low S concentration in the roots and panicles in the three cultivars. The S concentration attained a peak at the panicle initiation stage in the leaves, pseudostems and rhizomes whereas the capsule maturity and post-harvest stages exhibited the maximum for S concentration of roots and panicles, respectively. The variation in S concentration was from 0.095 to 1.980 per cent in the leaves,

0.029 to 0.077 per cent in the pseudostems, 0.071 to 0.154 per cent in the rhizomes, 0.034 to 0.080 per cent in the roots and 0.063 to 0.178 per cent in the panicles.

Statistical analysis of the data indicated that the differences in the S concentration of three cultivars were significant at the five growth periods studied.

4.6.8 Iron

The concentration of iron in the various plant parts of Cardamom (at the different growth periods) showed a gradual increase from the panicle initiation phase to the later phases of crop maturity. The data indicated three exceptions. The peak flowering period recorded the highest level for leaf Fe content in the Malabar cultivar and that of the root Fe content in the Vazhukka cultivar. The maximum Fe content of the pseudostems was observed at the capsule maturity stage of the Malabar cultivar.

The Fe concentration of different organs varied from 187.67 to 237.33 ppm in the leaves, 140.67 to 188.67 ppm in the pseudostems, 225.00 to 315.33 ppm in the rhizomes, 331.00 to 361.00 ppm in the roots and 147.00 to 215.00 ppm in the panicles. The differences in the Fe concentration

among the cultivars as well as among the growth stages were statistically significant. The exceptions observed were that of the Fe content of the pseudostems and roots during the different growth periods.

4.6.9 Zinc

The concentration of zinc showed a gradual increase from the panicle initiation phase to the later phases of crop maturity. The only exception was the roots of the cultivars Mysore and Vashukka which at the panicle initiation phase showed the peak Fe content. In the other plant organs of the three cultivars, the lowest level of Zn was at the panicle initiation stage and the highest level, either at the capsule maturity stage or at the post-harvest stage. The range of variation in Zn concentration was from 26.87 to 54.40 ppm in the leaves, 28.17 to 68.93 ppm in the pseudostems, 40.47 to 128.90 ppm in the rhizomes, 44.13 to 88.70 ppm in the roots and 27.66 to 89.87 ppm in the panicles and capsules.

Stetistical analysis of the date revealed significant differences in the mean Zn levels among the cultivars as well as among the growth phases.

4.6.10 Manganese

The manganese content of the different plant organs indicated a gradual increase from the panicle

initiation stage to the later crop maturity stages. The lowest concentration of Mn was at the panicle initiation stage in the three cultivars. The only exception was the root Mn content of the Vazhukka cultivar which showed the lowest level at the flower bud development stage. The range of variation in Mn content was from 319.97 to 909.23 ppm in the leaves, 453.97 to 933.37 ppm in the pseudostems, 316.60 to 943.30 ppm in the rhizomes, 199.47 to 662.87 ppm in the roots and 418.47 to 905.63 ppm in the panicles. The differences among the cultivars as well as among the growth stages were statistically significant for the Mn content.

4.6.11 Copper

The concentration of copper in the various organs of cardamom was low at the panicle initiation stage in the three cultivars. The maximum Cu content of the leaves, pseudostems and rhizomes were observed at the post-harvest phase of the three cultivars. The root Cu content was high at the flowering stage in Malabar and at the capsule maturity stage in Mysore and Vazhukka. The panicle Cu concentration attained a peak at the flowering stage in Malabar and Mysore cultivars and at the capsule maturity stage in the Vazhukka cultivar.

The Cu concentration ranged from 7.5 to 56.53 ppm in the leaves, 4.53 to 19.73 ppm in the pseudostem, 6.70 to 54.53 ppm in the rhizomes, 14.37 to 42.23 ppm in the roots and 10.00 to 35.83 ppm in the panicles. The mean differences in Cu concentration of the three cultivars as well as that at the five growth stages were statistically significant.

4.6.12 Uptake of nutrients by cardamom tillers

The data presented in Table 44 indicated that for production of one kg dry capsules the Mysore cultivar depleted more nutrients (total of 1617.88 g), whereas only less nutrients were depleted by Malabar (932.86 g) and Vazhukka (779.50 g) cultivars. The depletion of K was highest by the three cultivars Mysore, Malabar and Vazhukka (898.46 g, 540.05 g and 393.96 g respectively) while Cu was depleted to the lowest extent (0.34 g, 0.22 g and 0.25 g respectively). The order of depletion of nutrients followed a similar path in the three cultivars (K, Ca, N, Mg, P, S , Mn, Fe, Zn and Cu).

4.7 Rate of photosynthesis and translocation of photosynthates at various stages of growth

The photosynthetic efficiency of cardamom leaves was assessed at various intervals of a day and also at

Table 44 Uptake of nutrients (g) by cardamom tillers for production of one kg dry capsules

Nutrient elements	Cultivars		
	Malabar	Mysore	Vazhukka
N	117.83	221.88	115.94
P	24.90	42.23	22.84
K	540.05	898.46	393.96
Ca	159.08	293.35	155.01
Mg	68.23	118.37	69.33
S	12.10	23.29	11.93
Fe	2.32	3.52	1.95
Zn	0.76	1.20	0.60
Mn	7.17	15.24	7.69
Cu	0.22	0.34	0.25
Total	932.66	1617.88	779.50

the different canopy positions using detached as well as intact leaves. The photosynthetic efficiency was determined by relating the capacity of a leaf to fix $^{14}CO_2$ under controlled conditions as explained earlier in item 3.8. The relative contribution of photosynthates by the various leaves (the extent to which the leaves acted as source in supplying photosynthates to various organs) also formed another aspect of study. Apart from these experiments, the sink effects of the different plant organs were studied at five major crop maturity periods.

4.7.1 Rate of photosynthesis at different intervals of a day

This experiment was conducted on detached leaves of PV-1 at hourly intervals between 8.30 a.m. and 6.00 p.m. on 12th March, 1984. The time allowed was 30 minutes for each set of $^{14}CO_2$ feeding. The photosynthetic rate as related to counts per minute (cpm) of radioactivity are given in Table 45. Correlation was worked out between the light intensity that prevailed at the time of $^{14}CO_2$ feeding and the cpm/100 mg dry weight of the leaves.

It is evident from the data that the photosynthetic efficiency was more during the morning and evening hours. A significant negative correlation was observed

170991

Table 45 Rate of photosynthesis at different intervals of a day: Genotype, PV-1 (Malabar)

Time of feeding $^{14}CO_2$	cpm / 100 mg leaves on dry weight basis (immediate fixation of $^{14}CO_2$ by leaves)	Mean light intensity (lx)
8.30 to 9.00 a.m.	8824	1780
9.30 to 10.00 "	6151	3340
10.30 to 11.00 "	4391	4730
11.30 to 12.00 "	2166	9300
12.30 to 1.00 p.m.	465	10000
1.30 to 2.00 "	544	18000
2.30 to 3.00 "	3762	7670
3.30 to 4.00 "	9504	5460
4.30 to 5.00 "	8093	6150
5.30 to 6.00 "	11544	1580
F test	**	-
C.D (0.05)	633	
Correlation of light intensity vs $^{14}CO_2$ fixation	-0.8644**	

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between $^{14}CO_2$ fixed by leaves and the light intensity that prevailed at the time of feeding (r = -0.8644). The maximum fixation of $^{14}CO_2$ was from 5.30 p.m. to 6.00 p.m. (cpm = 11544) when the light intensity was rather low (1580 lx). During the morning hour (from 8.30 a.m. to 9.00 a.m.) also (when the light intensity was 1780 lx) the $^{14}CO_2$ fixation was high (cpm = 8824). It was further observed that as the light intensity increased on reaching the noon hours of the day, the rate of $^{14}CO_2$ fixation declined. The radioactivity fixed from 11.30 a.m. to 12.00 a.m. was fairly low (cpm = 2166) at 9300 lx. From 12.30 p.m. to 1.00 p.m. and from 1.30 p.m. to 2.00 p.m., when the light intensity was more than 10,000 lx, very low amounts of radioactivity were fixed (cpm = 465 and 544 respectively). There was, thus a progressive decrease in $^{14}CO_2$ fixation by the leaves from the morning to noon period. From the noon to evening, $^{14}CO_2$ fixation by the leaves gradually increased.

4.7.2 Photosynthetic efficiency at different canopy levels (in detached leaves of cardamom)

The photosynthetic efficiency of ten fully opened leaves were assessed in terms of immediate fixation of $^{14}CO_2$ by the different leaf canopies. The

Radioactive counts obtained in the leaf discs sampled from the ten leaf canopies are presented in Table 46.

The data pertaining to 20th April, 1984 revealed that the first opened leaf fixed fairly high amount of $^{14}CO_2$ (cpm = 2919). The radioactive fixation was minimum in the second leaf (cpm = 1176). From the third to the seventh leaf, the radioactivity increased gradually (from cpm = 1259 to 2598). The eighth leaf recorded a reduction (cpm = 1884) and the ninth gave the highest value (cpm = 4978). The tenth leaf showed a reduction to cpm = 1759.

The data pertaining to $^{14}CO_2$ feeding on 21st April, 1984 also gave an erratic trend as far as the fixation by the individual leaves was concerned. In this case, the $^{14}CO_2$ fixation by the tenth, ninth and first leaves (cpm = 4475, 3254 and 2902 respectively) was high. The lowest fixation was by the third leaf (cpm = 1300).

The experiment on 22nd April, 1984 gave the maximum $^{14}CO_2$ fixation by the first, tenth, third and ninth leaves (cpm = 8431, 8304, 7095 and 5322 respectively). The fixation of $^{14}CO_2$ by the second leaf was the lowest (cpm = 3106).

Table 46 Photosynthetic efficiency at different canopy levels in detached leaves of cardamom Genotype : PV-1 (Malabar)

Time of feeding: 2.30 p.m. to 3.30 p.m.

Treatments (leaf canopy levels)	Date of $^{14}CO_2$ feeding				Mean radio-active counts (cpm)
	20-4-1984 (Replica-tion 1)	21-4-1984 (Replica-tion 2)	22-4-1984 (Replica-tion 3)	23-4-1984 (Replica-tion 4)	
	Radioactive counts (cpm/100 mg leaves on dry weight basis)				
1st	2919	2902	8431	5375	4907
2nd	1176	2156	3106	9039	3869
3rd	1259	1300	7095	5311	3741
4th	1552	2309	3489	5855	3301
5th	1811	2002	4100	5136	3262
6th	1843	1704	4647	4395	3147
7th	2598	2397	4486	8953	4609
8th	1884	2570	3948	5978	3595
9th	4978	3254	5322	8251	5454
10th	1759	4475	8304	8461	5750
Mean radio-active counts (cpm)	2178	2507	5294	6675	4164
F test	-	-	-	-	Not signifi-cant
Light intensity (lx)	8367	7000	5767	3770	

A definite trend of $^{14}CO_2$ fixation was not seen in the experiment conducted on 23rd April,1984 also. Here, the $^{14}CO_2$ fixation by the second leaf (cpm=9039) was the highest, followed by fixation by the seventh, tenth and ninth leaves (cpm = 8953, 8461 and 8251 respectively).

The mean c pm values computed from the four sets of $^{14}CO_2$ feedings (Table 46) indicated that the fixation by the tenth, ninth, first and seventh leaves (cpm = 5750, 5454, 4907 and 4609 respectively) were comparatively more than that by the others. When the light intensity that prevailed during the radioactive feeding was examined *vis a vis* fixation of radioactivity, it was observed that $^{14}CO_2$ fixation was more under low light intensities (cpm = 2178, 2507, 5294 and 6675 respectively at light intensities 8367, 7000, 5767 and 3770 lx).

Statistical analysis of the data did not reveal any significant difference among the radioactive counts obtained from the ten leaf canopies.

4.7.3 Photosynthetic efficiency at different leaf canopies (using intact leaves)

This experiment was conducted on monoclonal plant population of the genotype, PV-1 on ten successive

days that commenced on the 18th May, 1984 and ended on 27th May, 1984. The time of feeding $^{14}CO_2$ was kept constant (10.00 a.m. to 10.45 a.m.) The data are presented in Table 47.

The immediate fixation of $^{14}CO_2$ was maximum by the third leaf, followed by the fourth, first and second leaves (cpm = 84469, 72356, 72187 and 71436 respectively). The fixation of $^{14}CO_2$ by the other leaves was comparatively low. High light intensities (7630 to 9000 lx) prevailed during the time of feeding $^{14}CO_2$ in these experiments. The residual radioactivity in the fed leaves after one month of feeding $^{14}CO_2$ ranged from 7.47 per cent to 13.66 per cent of the radioactivity counted originally (immediately after fixation of $^{14}CO_2$). On the tillers where the leaf position one to three were fed with $^{14}CO_2$, the translocation of the photosynthates were more to the apical region of the pseudostem (12.79, 11.63 and 14.80 per cent, respectively). The middle region of the pseudostem accumulated more radioactive photosynthates when leaf positions four to six were fed with $^{14}CO_2$ (12.07, 15.63 and 15.31 per cent, respectively). In experiments where the lower leaf canopies (seven to ten) were fed with $^{14}CO_2$, more radioactivity was translocated to the lower

Table 47 Photosynthetic efficiency at different leaf canopies (as judged by $^{14}CO_2$ fixation by intact leaves) and relative translocation of photosynthates to other leaves and organs

Treatments (position of leaves and organs)	Dates of feeding $^{14}CO_2$ (Time of feeding: 10.00 a.m to 10.45 a.m														
	18-5-1984			19-5-1984			20-5-1984			21-5-1984			22-5-1984		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1st opened leaf	72187	9151	12.68		3126	4.38		2894	3.43		984	1.36		308	0.60
2nd "		936	1.30	71436	7240	10.13		3818	4.52		1750	2.42		464	0.92
3rd "		526	0.73		304	0.42	84469	9007	10.60		2671	3.69		714	1.42
4th "		156	0.22		276	0.38		552	0.66	72356	9889	13.66		490	0.96
5th "		166	0.22		230	0.32		306	0.36		682	0.94	50018	5064	10.12
6th "		182	0.26		160	0.22		294	0.34		352	0.48		402	0.80
7th "		176	0.24		184	0.26		234	0.26		246	0.34		354	0.70
8th "		92	0.12		110	0.14		162	0.18		260	0.36		292	0.58
9th "		86	0.12		112	0.16		188	0.22		266	0.36		242	0.56
10th "		72	0.10		96	0.12		208	0.24		290	0.40		212	0.42
pseudostem apex		9238	12.79		8308	11.63		12500	14.80		7264	10.03		4312	8.62
pseudostem middle portion		4752	6.58		6540	9.16		9729	11.52		8734	12.07		7818	15.63
pseudostem base		2886	3.99		5565	7.79		9620	11.39		6578	9.09		5153	10.30
rhizome		17315	23.99		13192	18.47		18158	21.49		14835	20.50		10470	20.93
root		732	1.01		2840	3.98		2444	2.89		3068	4.24		4720	9.44
F test		**			**			**			**			**	
C.D.(0.05)		484			579			614			754			708	
Light intensity (lx)		5770			5230			4170			5430			8100	
Total translocation			64.36			67.60			82.86			79.94			82.00

1: Immediate fixation of $^{14}CO_2$ (cpm) 2: Residual radioactivity (cpm) 3: Translocation (%)

** Significant at 1 per cent level

contd..

Table 47 (contd..)

Treatments (position of leaves and organs)	Dates of feeding $^{14}CO_2$ (Time of feeding: 10:00 a.m to 10:45 a.m:														
	23-5-1984			24-5-1984			25-5-1984			26-5-1984			27-5-1984		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1st opened leaf		88	0.18		86	0.18		100	0.22		76	0.14		76	0.18
2nd "		264	0.58		124	0.28		82	0.18		66	0.12		150	0.30
3rd "		312	0.70		108	0.24		124	0.28		124	0.24		160	0.22
4th "		370	0.82		78	0.16		92	0.20		100	0.20		168	0.34
5th "		484	1.08		80	0.16		174	0.40		190	0.38		196	0.40
6th "	44292	3966	8.95		260	0.58		168	0.38		204	0.40		220	0.46
7th "		268	0.60	44525	3328	7.47		346	0.80		324	0.64		268	0.56
8th "		128	0.28		406	0.90	42278	3953	9.35		336	0.66		298	0.62
9th "		212	0.46		480	1.06		344	0.80	49591	5151	10.30		454	0.94
10th "		162	0.36		104	0.22		302	0.70		430	0.86	47468	5752	12.12
pseudostem apex		3840	8.67		1872	4.20		2856	6.76		1854	3.74		1290	2.72
pseudostem middle portion		6782	15.31		3960	8.89		3498	8.27		3996	8.06		2907	6.12
pseudostem base		4370	9.87		8421	18.91		6445	15.24		9227	18.61		9825	20.70
rhizome		8819	19.91		12084	27.14		9148	21.63		12590	25.39		12403	26.13
root		4008	9.05		5896	13.24		5364	12.69		5800	11.70		6028	12.69
F test		**			**			**			**			**	
C.D.(0.05)		819			827			711			714			789	
Light intensity (lx)		7630			8330			7860			9000			8400	
Total translocation		76.82			83.63			79.90			81.44			84.48	

1: Immediate fixation of $^{14}CO_2$ (cpm) 2: Residual radioactivity (cpm)

3: Translocation (%)

**: Significant at 1 per cent level

portion of the pseudostem (18.91, 15.24, 18.61 and 20.70 per cent respectively). The data revealed that the mean fixation of $^{14}CO_2$ by intact leaves were about ten to twenty times higher than the fixation by detached leaves (cpm range 42,278 to 84,469 Vs cpm range 2178 to 6675).

The sink effects caused by the rhizomes increased when $^{14}CO_2$ feeding was shifted from the top to the bottom canopies. When the first leaf was fed with $^{14}CO_2$ translocation of the photosynthates to the rhizome was 23.99 per cent and when the tenth leaf was fed, translocation of the photosynthates to rhizome increased to 26.13 per cent. Mobilisation of ^{14}C metabolites to the roots also showed a pattern similar to that found in the case of the rhizomes. The light intensity and $^{14}CO_2$ fixation showed a significantly negative correlation ($r = -0.9418^{**}$).

4.7.4 Photosynthetic mobilisation at different periods of crop growth

The study was conducted on monoclonal plants of the genotype, PR-107 at five crop maturity periods, namely, panicle initiation stage, flower bud development stage, peak flowering stage, capsule maturity stage and post-harvest stage. The radioactive counts were tabulated and are presented in Table 48.

Table 48 Mobilization of photosynthates at different periods of crop growth

Treatments (position of leaves and other plant organs)	Stages of crop growth and dates of feeding ^{14}CO														
	Panicle initiation stage 28-12-1983			Flower bud development stage 31-3-1984			Peak flowering stage 18-6-1984			Capsule maturity stage 24-9-1984			Post-harvest stage 20-12-1984		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1st opened leaf	68,231	7496	3.83	45,529	10,629	6.22	74,367	13,048	5.00	72,817	10,089	3.70	81,262	30,463	11.02
2nd "	52,546	8300	4.24	50,648	12,805	7.49	65,491	16,680	6.39	77,462	12,940	4,75	76,429	27,703	10.03
3rd "	48,178	7636	3.90	43,176	11,505	6.73	59,253	10,990	4,21	68,339	10,093	3,70	59,678	25,631	9.28
4th "	26,669	5673	2.89	31,448	10,230	5.98	61,729	9,825	3.76	53,628	7,111	2.61	58,939	26,674	9,65
5th "		790	0.40		698	0.40		707	0.27		713	0.26		228	0.08
6th "		873	0.44		819	0.47		596	0.22		592	0.21		170	0.06
7th "		703	0.35		591	0.34		289	0.11		613	0.22		85	0.03
8th "		830	0.42		638	0.37		159	0.06		517	0.18		102	0.03
9th "		433	0.22		446	0.26		208	0.07		566	0.20		128	0.04
10th "		-	-		385	0.22		162	0.06		452	0.16		167	0.06
11th "		-	-		355	0.20		191	0.07		339	0.12		104	0.03
12th "		-	-		-	-		115	0.04		121	0.04		50	0.01
13th "		-	-		-	-		95	0.03		107	0.03		48	0.01
14th "		-	-		-	-		-	-		75	0.02		67	0.02
15th "		-	-		-	-		-	-		-	-		55	0.01
Pseudostem tip		34,135	17.45		29,864	17.49		37,570	14.43		26,220	9.63		17,214	6.23
pseudostem middle portion		17,700	9.05		13,180	7.72		18,022	6.91		11,147	4.09		11,273	4.08
pseudostem base		10,670	5.45		4,736	2.78		12,257	4.70		8,720	3.20		2,379	0.86
rhizome		34,740	17.76		36,451	21.34		63,638	24.40		48,864	17.95		17,921	6.49
Panicle		1,760	0.89		6,715	3.93		25,064	9.60		33,795	12.41		12,122	4.39
root		12,708	6.50		21,976	12.87		25,163	9.65		12,954	4.76		9,906	3.58
F test		**			**			**			**			**	
C.D. (0.05)		2176			1849			2366			3127			2208	

1 Immediate fixation of $^{14}CO_2$ (cpm) 2 Residual radioactivity (cpm) 3 Translocation (%)

** Significant at 1 per cent level

The data indicate that the tips of the pseudostems accumulated fairly good amounts of ^{14}C metabolites (6.23 to 17.49 per cent), since $^{14}CO_2$ was fed to the four opened leaves from the apex in all the experiments. The rhizomes exhibited the maximum sink effect at all the crop maturity stages studied (6.49 to 24.40 per cent). The initiating primordia showed only little radioactivity (0.88 per cent). At the capsule maturity stage, the panicles accumulated more ^{14}C photosynthates (12.41 per cent) whereas at the post-harvest stage the accumulation was considerably reduced (4.39 per cent). The rhizomes accumulated the maximum photosynthates (24.40 per cent) at the peak flowering period. Translocation of ^{14}C metabolites to the roots declined from the flower bud development stage to the post-harvest stage (12.87 per cent to 3.58 per cent). Translocation of ^{14}C assimilates to the non-fed leaves was found to be minimal (0.01 to 0.47 per cent). The basal portion of the pseudostems accumulated lesser amounts of ^{14}C photosynthates (0.86 to 5.45 per cent) compared to the portions above it. At the post-harvest stage, the fed leaves (first to fourth from the apex) retained as much as 39.98 per cent of the radioactivity fed to them. Only 26.11 per cent radioactivity was transported to all the organs together.

The correlation between light intensity and $^{14}CO_2$ fixation was found to be negative ($r = -0.6390^*$) and

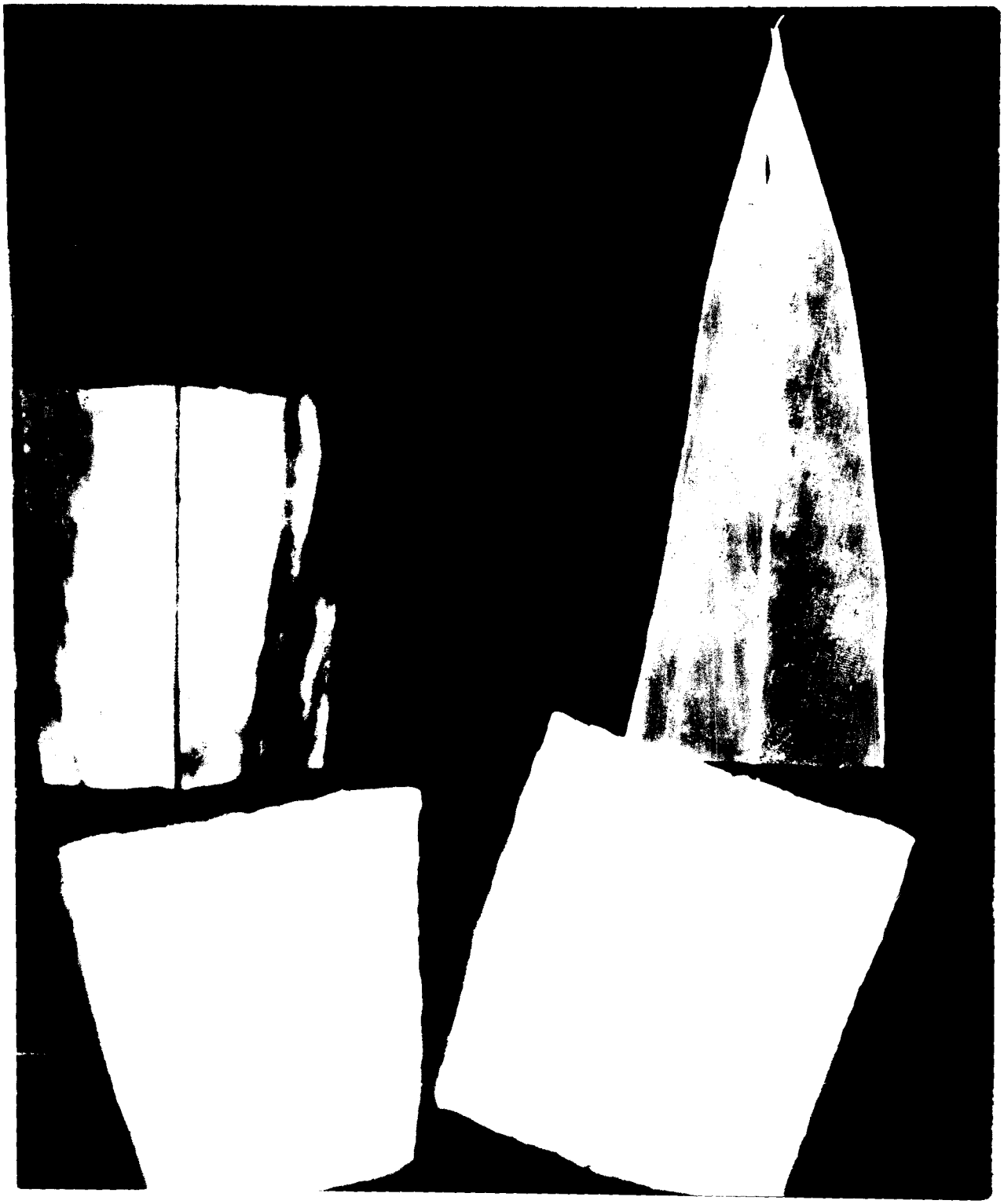


Plate 44 (Scale 1:1)

Plate 45 Posive print from the autoradiograph showing the translocation of more ^{14}C photosynthates to the tertiary rootlets when compared with the primary and secondary roots

significant.

4.7.5 Autoradiography

Pictorial information the ^{14}C accumulation by the leaves (to which $^{14}CO_2$ was fed) and the translocation of the radioactivity to the non-fed leaves and roots was obtained by the autoradiography. The apical four leaves in a potted plant of PV-1 were fed simultaneously with $^{14}CO_2$ inside a "perspex" leaf chamber.

Plate 44 (positive print obtained from the autoradiograph) shows that the radioactivity was strong in the first and second opened leaves which appeared alike (bright white). The third leaf also exhibited fairly strong radioactivity, though not to the same degree as was observed in the leaf positions one and two. The fed leaves accumulated varying amounts of ^{14}C. As the position of non-fed leaves moved away from the site of feeding, the radioactivity decreased, as evident from the relatively more darkened leaf impressions obtained from the fifth to seventh non-fed leaves.

It can also be seen from the autoradiograph that in the $^{14}CO_2$ fed leaves, the radioactivity moved out of the mid rib whereas more radioactivity accumulated in the mid rib and veins of the non-fed leaves.

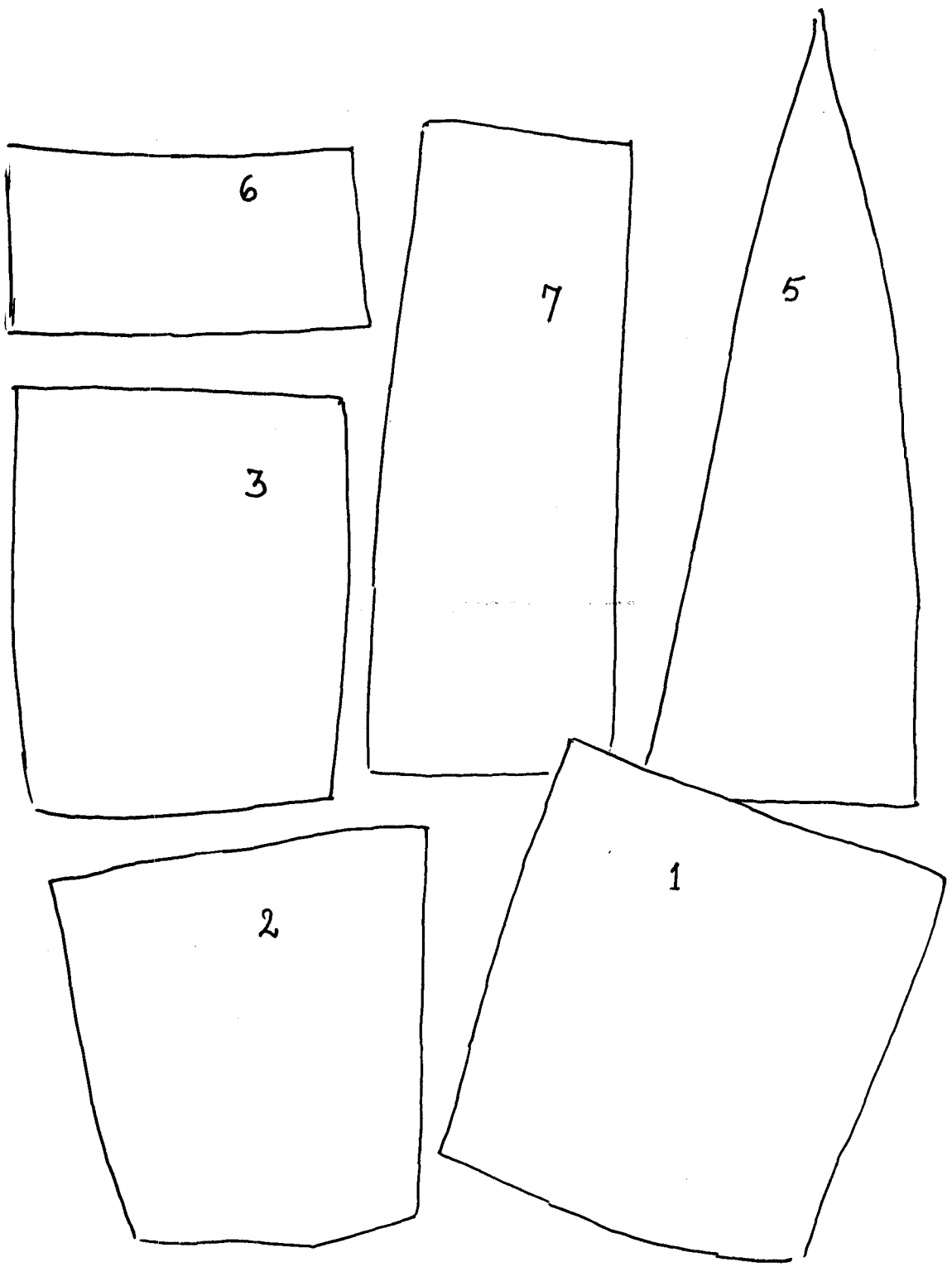


Plate 44 Positive print from the autoradiograph showing varied pattern ^{14}C accumulation by leaves (Leaves 1 to 3 were fed with $^{14}CO_2$ whereas leaves 5 to 7 were not fed)

Plate 45 (Scale 1:1)

Autoradiograph of the root system (Plate 45) indicated that the translocation of ^{14}C photosynthates to the primary and secondary roots ware low and more radioactivity accumulated in the tertiary rootlets.

4.8 Changes in the flavour components of cardamom capsules at different seed maturity stages

Cardamom oil was extracted from fruits (capsules) by steam distillation at five growth maturity stages of seeds (tender, greenish-yellow, brown, black and ripe). The representative genotypes utilized for this experiment were PV-1 (Malabar), PR-107 (Mysore) and PV-5 (Vazhukka).

Table 49 depicts the changes of twelve major aromatic components in the essential oil distilled at five seed maturity phases mentioned earlier. Identification of the componants and the quantitative estimation were done after fractionating the essential oils into their constituents in a gas chromatograph. The results of the analysis are given below.

4.8.1 Alpha pinene

The maximum concentration of alpha-pinene was observed to be at the greenish-yellow seed stage in the genotypes PV-1 and PV-5 (0.987 and 0.554 per cent respectively) and that the ripe seed stage in PR-107

Table 49 Flavour characteristics of cardamom oils at different maturity stages

Cultivars/ Oil samples	Chemical components (%)											
	alpha pinene	beta pinene	d-limonene	1,8-cineole	linalool	terpene-4-ol	alpha terpeniol	linalyl acetate	terpenyl acetate	geraniol	geranyl acetate	nerolidol
PV-1 (Malabar) tender seed	0.296	0.919	0.976	17.295	1.582	2.343	2.935	2.366	57.830	0.843	5.987	0.819
" greenish-yellow seed	0.987	3.336	2.634	30.231	1.490	2.937	2.962	1.933	41.147	0.483	3.781	0.376
" brown seed	0.532	1.909	1.597	47.441	1.223	2.835	2.366	2.349	27.489	0.476	1.948	0.302
" black seed	0.793	2.370	2.145	54.671	0.864	2.461	2.107	2.382	24.256	0.998	0.966	0.146
" ripe seed	0.591	1.753	1.683	50.677	0.864	3.193	2.477	2.017	25.041	1.813	0.536	0.160
Mean	0.640	2.057	1.807	40.063	1.205	2.754	2.569	2.209	35.152	0.922	2.644	0.360
PR-107 (Mysore) tender seed	0.158	0.700	0.638	4.054	3.988	2.646	4.448	2.326	61.202	0.708	7.087	1.927
" greenish-yellow seed	0.231	0.836	1.042	14.924	1.878	3.357	3.651	2.033	56.813	0.556	6.032	0.703
" borwn seed	0.326	1.407	1.051	19.023	5.790	3.729	4.691	2.491	46.650	0.494	4.126	0.677
" black seed	0.231	0.826	0.805	18.815	5.351	3.744	5.212	3.813	48.617	0.919	3.425	0.657
" ripe seed	0.554	1.534	1.814	32.232	2.856	3.297	3.659	1.835	38.311	1.504	2.290	0.547
Mean	0.300	1.061	1.070	17.810	3.973	3.355	4.332	2.500	50.318	0.836	4.592	0.902
PV-5 (Vazhukka) tender seed	0.244	0.943	0.792	5.925	3.540	2.807	4.254	1.926	63.006	0.575	6.547	1.512
" greenish-yellow seed	0.554	2.302	1.902	21.034	3.581	3.367	3.993	1.627	48.650	0.457	3.879	0.648
" brown seed	0.346	1.333	1.277	21.779	3.687	3.241	3.733	1.908	46.177	0.552	4.090	0.849
" black seed	0.389	1.096	1.283	29.945	3.168	3.215	3.245	2.836	44.396	0.993	2.381	0.541
" ripe seed	0.184	0.623	0.754	21.315	1.523	3.177	3.172	2.354	56.067	2.505	1.217	0.691
Mean	0.343	1.259	1.202	20.000	3.100	3.161	3.679	2.130	51.659	1.016	3.623	0.848
General Mean	0.428	1.459	1.360	25.958	2.759	3.090	3.527	2.280	45.710	0.925	3.620	0.703

(0.554 per cent). Alpha pinene content was low at the tender seed stage in the three genotypes (0.296, 0.158 and 0.244 per cent respectively in PV-1, PR-107 and PV-5) and at the ripe seed stage in PV-5 (0.184 per cent). The genotype PV-1 showed more alpha pinene content (0.640 per cent) in the essential oil followed by PV-5 (0.343) and PR-107 (0.300) when the mean of the five seed maturity phases were computed.

4.8.2 Beta pinene

The concentration of beta pinene followed a similar trend as that of alpha pinene in the three genotypes. The concentration was high at the greenish-yellow seed stage of PV-1 and PV-5 (3.336 and 2.302 per cent respectively) and at the ripe seed stage of PR-107 (1.534 per cent). The low levels of the bet-pinene were at the tender seed stages of PV-1 and PR-107 (0.919 and 0.700 per cent respectively) and at the ripe seed stage of PV-5 (0.623 per cent). The mean beta pinene content in the three genotypes were of the order 2.057 per cent (PV-1), 1.259 per cent (PV-5) and 1.061 per cent (PR-107).

4.8.3 d-limonene

The concentration of d-limonene ranged from 0.976 to 2.634 per cent in PV-1, 0.638 to 1.814 per cent

inPR-107 and 0.754 to 1.902 per cent in PV-5 at the five seed maturity stages. PV-1 ranked top for the mean d-limonene content (1.807 per cent) followed by PV-5 (1.202 per cent) and PR-107 (1.070 per cent).

4.8.4 1,8 - Cineole

The concentration 1,8-cineole in the essential oil gradually rose in the three genotypes as the maturity of seeds progressed. This increase continued till the ripe seed stage in PR-107 while the concentration fell at the black seed stage in PV-1 and PV-5. 1,8-cineole content varied from 17.295 to 54.671 per cent in PV-1, from 4.054 to 32.232 per cent in PR-107 and from 5.925 to 29.945 per cent in PV-5. The content of 1,8-cineole was 40.063 per cent in PV1, 20.000 per cent in PV-5 and 17.810 per cent in PR-107.

4.8.5 Linalool

PR-107 excelled the other genotypes for the mean linalool content (3.973 per cent) and PV-1 occupied the bottom rank (1.205 per cent). The genotype PV-5 stood intermediate (3.100 per cent). The concentration of linalool was high at the brown seed stage in the genotypes PR-107 and PV-5 (5.790 and 3.687 per cent, respectively). Thereafter, the concentration fell gradually to 2.856

and 1.523 per cent at the advanced stages of seed maturity. From the young tender seed stage to the fully ripe seed stage, the percentage of linalool in PV-1 steadily declined (1.582, 1.490, 1.223, 0.864 and 0.864 per cent respectively at the seed growth stages).

4.8.6 Terpene-4-ol

The concentration of terpene-4-ol increased from the tender to greenish-yellow seed stage in the three genotypes. Thereafter, it maintained a steady level. The range in concentration was from 2.646 to 3.744 per cent in PR-107, from 2.807 to 3.367 per cent in PV-5 and from 2.343 to 3.193 per cent in PV-5. The mean terpene-4-ol concentration in the three genotypes were 3.355, 3.161 and 2.754 per cent respectively.

4.8.7 Alpha terpeniol

The concentration of this component showed a trend similar to that of terpene-4-ol, wherein the genotype PR-107 stood first followed by PV-5 and PV-1. A decline in alpha terpeniol concentration was observed in the genotypes PV-5 and PV-1, from the tender seed stage to the ripe seed stage. The trend of accumulation of this component was rather erratic in the genotype, PR-107.

The extent of variation of alpha terpeniol in the three genotypes was from 3.651 to 5.212 per cent in PR-107, from 3.172 to 4.254 per cent in PV-5 and from 2.107 to 2.962 per cent in PV-1. The mean values for the three genotypes were 4.332, 3.679 and 2.569 per cent respectively.

4.8.8 Linalyl acetate

More or less uniform levels were exhibited by linalyl acetate at the five capsule growth stages studied. The peak of accumulation of linalyl acetate was at the black seed stage. The peak values were 3.813 per cent in PR-107, 2.836 per cent in PV-5 and 2.382 per cent in PV-1. The mean values for linalyl acetate concentration in the three genotypes were 2.500 per cent in PR-107 (range 1.835 to 3.813 per cent), 2.130 per cent in PV-5 (range 1.627 to 2.836 per cent) and 2.209 per cent in PV-1 (range 1.933 to 2.382 per cent).

4.8.9 Geraniol

The variation in geraniol concentration at the five capsule growth stages gave a common trend in the genotypes studied. The geraniol content attained a peak at the ripe seed stage in the three genotypes (2.505 per cent in PV-5, 1.813 per cent in PV-1 and 1.504 per cent in PR-107). The mean geraniol content in these genotypes were 1.016 per cent (range 0.457 to 2.505 per cent)

0.922 per cent (range 0.474 to 1.813 per cent) and 0.836 per cent (range 0.494 to 1.504 per cent) respectively.

4.8.10 Alpha terpenyl acetate

A decline in concentration of this component was observed in the three genotypes from the tender stage to ripe seed stages. The mean alpha terpenyl acetate levels were 51.659 per cent in PV-5 (range 44.394 to 63.006 per cent) 50.318 per cent in PR-107 (range 38.311 to 61.202 per cent) and 35.152 per cent in PV-1 (range 24.254 to 57.830 per cent).

4.8.11 Geranyl acetate

A fall in geranyl acetate concentration was observed from the tender seed stage to ripe seed stage in the three genotypes. The variation in the three genotypes was from 2.290 to 7.087 per cent in PR-107, from 1.217 to 6.547 per cent in PV-5 and from 0.536 to 5.987 per cent in PV-1. The mean values of geranyl acetate were 4.592, 3.623 and 2.644 per cent respectively for the genotypes.

4.8.12 Nerolidol

The concentration of nerolidol also fell from the tender seed stage to ripe seed stage in the three genotypes. The maximum levels of nerolidol were observed

at the tender seed stage and the values were 1.927, 1.512 and 0.839 per cent respectively for PR-107, PV-5 and PV-1. The minimum levels of nerolidol were at the ripe seed stage for PR-107 and PV-1 (0.547 and 0.140 per cent respectively) and at the black seed stage for PV-5 (0.541 per cent).

The mean values of the twelve flavour components estimated above at the five capsule growth stages were worked out individually for the three genotypes. The data are presented in Table 50. The data revealed that alpha terpenyl acetate, 1,8-cineole, geranyl acetate and alpha terpaniol were the major constituents of the essential oil of cardamom.

The gas chromatograms obtained from the black seed (karimkai) stages of the three genotypes are depicted in Figs. 22 to 24.

Table 50 Ranking order of the important flavour components in cardamom essential oils

Flavour components	Genotypes		
	PV-1 (Malabar)	PR-107 (Mysore)	PV-5 (Vazhukka)
alpha pinene	11	12	12
beta pinene	7	9	8
d-limonene	8	8	9
1,8 - cineole	1	2	2
linalool	9	5	6
terpene-4-ol	3	6	5
alpha terpeniol	5	4	3
linalyl acetate	6	7	7
geraniol	10	11	10
alpha terpenyl acetate	2	1	1
geranyl acetate	4	3	4
nerolidol	12	10	11

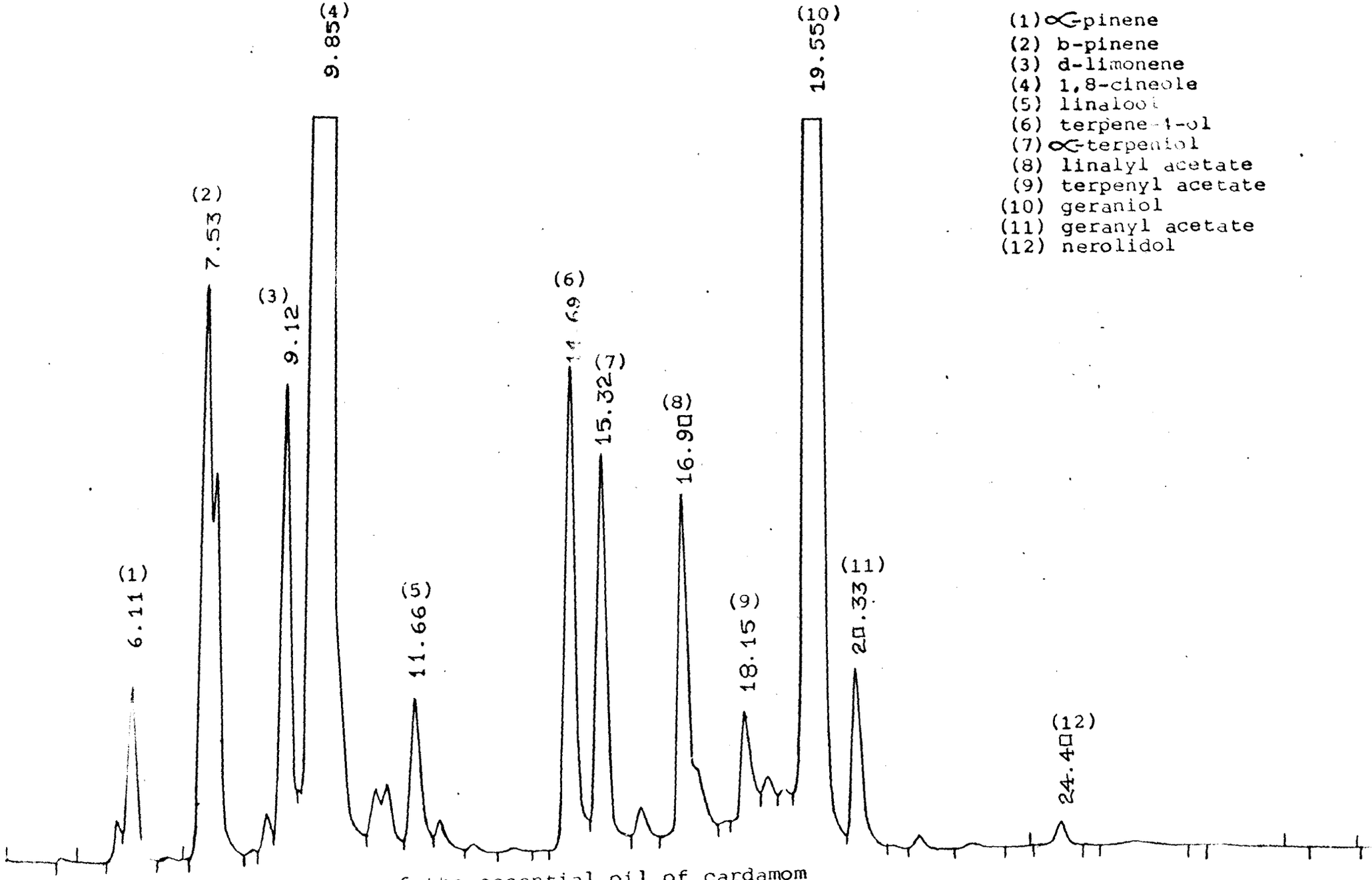


Fig.22 Gas chromatogram of the essential oil of cardamom at the black seed (karimkai) stage, Genotype: PV-1 (Malabar)

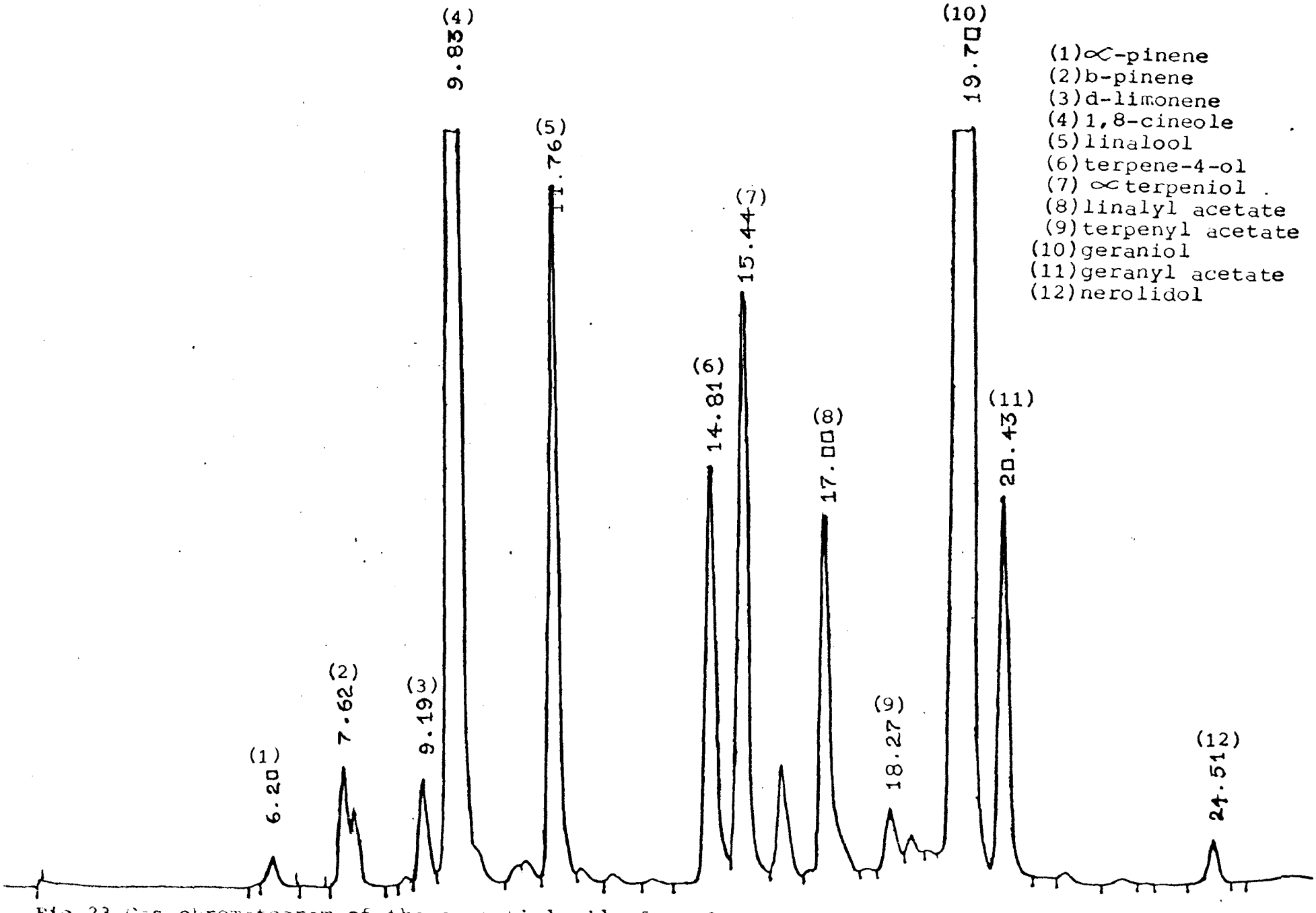


Fig.23 Gas chromatogram of the essential oil of cardamom at the black seed (karimkai)stage, Genotype: PR-107 (Mysore)

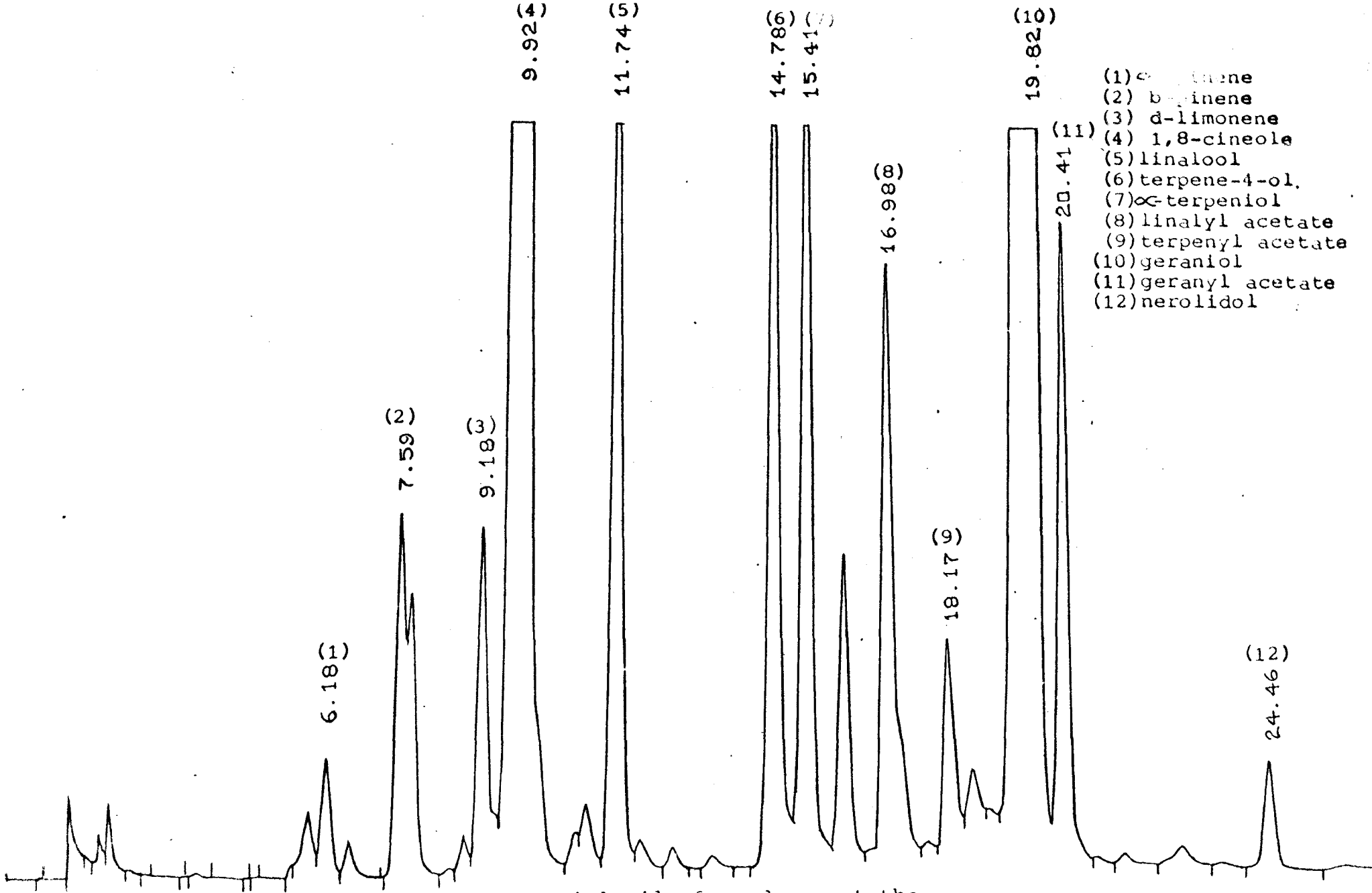


Fig.24 Gas chromatogram of the essential oil of cardamom at the black seed (karimkai) stage, Genotype: PV-5 (Vazhukka)

DISCUSSION

5 DISCUSSION

Cardamom is an important plantation crop cultivated widely in the high altitude regions of Kerala, Karnataka and Tamil Nadu. Research on different aspects of cardamom cultivation was started at various research centres in these states about four decades back.

Preliminary studies on the floral biology of cardamom were conducted at the Regional Research Station, Mudigere in Karnataka, and the studies were mostly based on the prostrate type of cardamom. The physiological bases of flowering and fruit set in the three popular cultivars, Malabar (prostrate type), Mysore (erect type) and Vazhukka (semi-erect type) have not been conducted so far in a systematic manner.

The present studies were carried out at the Cardamom Research Station, Pampadumpara and at the College of Horticulture, Vellanikkara. The basic morphological features in relation to growth and development and the dynamics of flowering and fruit set were studied, stress being on understanding the factors which caused the severe fruit shedding in cardamom.

Ecological adaptations of the crop had been investigated in detail in the present investigations. The variation in nutrient status of the plant parts at different crop maturity periods has also been critically examined. Fruit development was correlated with the internal hormonal levels. Exogenous application of hormones was tried to unravel their possible role in enhancing flowering, fruit set and yield. Radiolabelling technique was employed to examine the rate of photosynthesis at different leaf canopy levels of cardamom and to study the sink effects of the different plant organs. Essential oils of cardamom were extracted by steam distillation of capsules at five seed maturity phases of the three cultivars. Fractionation of the essential oils was done (gas chromatographically) to find out the changes in the different flavour ingredients at these five seed maturity phases. The salient findings obtained in the present investigations are discussed in this chapter.

5.1 Growth and development of the vegetative and floral parts of cardamom

Growth and development of the different plant parts examined in the three popular cultivars of cardamom (Malabar, Mysore and Vazhukka) indicated that the tallest tillers were produced by the Mysore cultivar and the shortest, by the

Malabar cultivar (Table 4). The maximum tiller height was observed at the 26th, 24th and 22nd month respectively for the cultivars, Mysore, Vazhukka and Malabar. The rate growth curve illustrated in Fig. 1 indicated two peaks in Mysore, three in Malabar and four in Vazhukka.

The rate of leaf production exhibited a trend similar to that of height of the tillers in the three cultivars (Table 4). The Mysore cultivar was the prolific leaf producert followed by Vazhukka and Malabar. However, the peaks of leaf production by the cultivars differed from the peaks of their height increments. The Malabar cultivar showed two peaks, whereas only a single peak was exhibited by the other two cultivars. It could be seen from the data that within 14 months of the emergence of the tillers, more than three fourth of the total leaves of a tiller emerged. An almost similar finding has been reported earlier by Sulikeri et al. (1978) wherein they observed that the rate of leaf production in cardamom tillers was faster during the vegetative phase or during the first year growth of the tillers.

The Vazhukka cultivar required less time for a single plastochrone whereas the Malabar cultivar required more time (Table 6). Though the total leaf production was maximum in the Mysore cultivar, the Vazhukka cultivar surpassed the Mysore cultivar in terms of the period taken for the emergence of successive leaves (plastochrone scale). The prolific nature of leaf production by the Mysore cultivar could be attributed mainly to its longer life span; whereas the faster emergence of leaves in the Vazhukka cultivar could be due to its inherited potentiality by way of natural hybridity. Vazhukka is believed to be a natural hybrid of Malabar and Mysore. A single plastochrone took a mean of 34.90 to 37.55 days among the three cultivars of cardamom. In all the cultivars the rate of leaf production was found to be faster during the summer period. Such increased leaf production with a rise in mean temperature during summer had been observed earlier in coconut (Thampan, 1981).

The leaf area was the maximum in the Mysore cultivar and minimum in the Malabar cultivar (Table 4) Tha trend in leaf area followed a similar pattern as that of the total leaf production. Since the total number of leaves produced was more in the Mysore cultivar, it is quite obvious that this cultivar showed the maximum leaf area also. A

similar finding of higher leaf area output by the Mysore cultivar was reported earlier by Korikanthimath and Subbarao (1983). The decline in the leaf area observed beyond the 22nd, 18th and 16th months in the cultivars Mysore, Vazhukka and Malabar respectively, indicated that senescence of the leaves started during this period. An instance of decline in the leaf area with the onset of leaf senescence was recorded similarly in the case of turmeric by Saifudeen (1981).

The total leaf production and the total leaf area were found to have a direct bearing on the leaf dry matter content also (Table 5). The higher dry matter accumulation by the leaves of the Mysore cultivar might be invariably due to their higher leaf production and consequently a higher expansion of leaf area. The cumulative dry matter accumulation by the pseudostems also followed a trend similar to that of the leaf dry matter. The mean incremental rate of dry matter accumulation in the pseudostems was high in Malabar, followed by in Vazhukka and Mysore. The total dry matter in the pseudostems declined at the later phases of tiller growth. The decline was observed beyond the 16th month in Malabar, and beyond the 20th month in the other two cultivars. This is indicative of the senescence of the pseudostems beyond these periods.

In the rhizomes, the dry matter accumulation maintained a slow pace during the initial periods of vegetative growth of the three cultivars (Table 5). The later growth phases of the tillers were characterised by a spurt in dry matter content of rhizomes. More over, the rhizomes did not reveal a distinct period of senescence in the three cultivars. This in turn suggested that the last organ to perish in a cardamom tiller would be the rhizome. The longer active growth period of the rhizomes in some other members of Zingiberaceae has been reported earlier by Purseglove (1975). The dry matter accumulation by the roots (Table 5) also followed a trend similar as that of the rhizomes during the initial vegetative phase of the tillers. But at the later stages of growth (beyond the age of 20 months), the roots exhibited senescence. Regeneration of roots, therefore, may not occur beyond this period.

Contrary to the vegetative organs, the panicles showed a progressive increase in growth rate that commenced right from the visual emergence stage till the capsule maturity stage (Table 5). There was a spurt in the dry weight of the panicles and capsules at the later phases of growth. Senescence of the panicle rachii occured beyond the later capsule maturity stage. They completed their life span before the rhizomes. The Malabar and Vazhukka cultivars accumulated

more biomass in their reproductive organs, whereas the Mysore cultivar accumulated less, unlike in the case of vegetative organs in which the reverse was true. The higher output of yield by the Malabar and Vazhukka cultivars may also be due to their higher accumulation of dry matter in the reproductive organs. The poor rate of dry matter accumulation by the reproductive organs of Mysore and its comparatively poor yielding habit have been observed earlier by Shankar (1980).

When the total dry matter accumulation was viewed in a broad sense (Table 5 and Fig.2) an individual tiller of cardamom exhibited two distinct growth phases namely, a vegetative phase during the first year of growth and a reproductive phase during the second year. After the production of panicles and the maturity of capsules, the tillers exhibited senescence. They were found to die approximately at the age of two years. The mean life spans of cardamom tillers were 22.98 months in Malabar, 26.37 months in Mysore and 24.88 months in Vazhukka (Table 9).

This distinct growth pattern of cardamom tillers reveal a biennial habit when each tiller is considered as an individual unit capable of perpetuating its own growth. Observations made in the present studies on the growth and

development of cardamom tillers differed fundamentally from those made by Pattanshetty and Prasad (1972). They observed a sudden diversion of energy and metabolites by the panicles and capsules during the reproductive phase of the tillers. But observations made in the present investigations suggest that the vegetative and reproductive phases are not mutually exclusive in cardamom. During the second year growth of the tillers, there was apparently a cessation in vegetative growth, but it was not observed to be a complete cessation. Growth of the vegetative and reproductive organs progressed simultaneously during this period, although the latter dominated the former. Broadly, four stages could be distinguished during the entire life span of a tiller, namely, a slow initial period of vegetative growth, a second stage of faster vegetative growth, a third stage of commencement of the reproductive growth and a gradual cessation of vegetative growth and a fourth stage of advancement of reproductive growth. The senescence of the tiller occurred at this advanced reproductive stage. Such distinct stages of growth cycles have been observed in tropical tuber crops by Coursey (1967) and Onwueme (1978). The only difference that distinguished cardamom from the tuber crops was in the duration of each growth stage within the entire growth cycle.

The production of new tillers was studied in the three cultivars during the years 1982 and 1983. High tillering ability was observed in the three cultivars during July, 1982 and August 1983 (Table 7 and Figs.3 and 4). When the frequency of sprouting of the new tillers was related to the meteorological data for the years 1982 and 1983 (Appendices I and II), it would be seen that tillering was more during the months characterised by heavy rainfall, high relative humidity and soil moisture. The cultivars also differed in their ability for tiller production. Vazhukka ranked top followed by Malabar and Mysore. That tillering of cardamom is dependent on the climatic conditions is evident from the findings of Venkitaraman (1982). He observed a high production of new tillers during June, 1982 when the rainfall and relative humidity were quite high. The three cultivars exhibited higher production of panicle bearing tillers during the year 1982 than during 1983 and 1984 (Table 8). The lower counts of productive tillers during (January) 1984 indicated that there was mortality of the tillers during 1983. The year 1983 was characterised by an unprecedented and severe drought. There was a distinct dry spell (January to April) when no rainfall was received (Appendix II). Also, the mean temperature attained a high value (range 21.1 to 26.5°C). Climatic conditions such as these are rare in the cardamom growing tracts. From the comparative

study of the three cultivars it can be concluded that the Malabar cultivar easily succumbed to the severe drought experienced during 1983. Vazhukka seems to have tolerated the drought situation to a fairly good extent. The behaviour of the Malabar cultivar, as evident from the results of the present investigations is contradictory to the belief that it can tolerate drought situations fairly better than the other cultivars. It is quite possible that even the locally adapted cultivar like Malabar can exhibit violent reaction to extreme variations in the climatic conditions of the area. Evidences in support of the better performance of Vazhukka have been obtained earlier at the Indian Cardamom Research Institute, Myladumpara (Madhusoodanan et al. 1982). Vazhukka is reported to be a hybrid derivative of Malabar and Mysore (Sahadevan, 1965). Hybrids have been found to exhibit better adaptability to adverse climatic conditions (Gardner, 1968).

The mean number of panicles borne on a tiller did not reveal much variation among the cultivars (Table 10). But when the panicle production per clump was considered the cultivars exhibited wide variation (Table 11 and Figs.5 and 6). During the year 1982, panicle production per clump was high in Vazhukka followed by in Malabar and Mysore.

This again, might have been due to the hybrid vigour of Vazhukka (Shankar, 1980). The pattern of paniole production exhibited a different trend in 1983, when the Mysore cultivar produced more number of panicles than Vazhukka and Malabar. A close scrutiny of the data indicate that the mean number of panicles produced per clump was low during the year 1983 in all the cultivars, which could be attributed to the severe drought experienced during 1983. The panicles initiated during the summer period (January to April) might have succumbed to the severe drought. The relatively higher panicle production by the Mysore cultivar during 1983 could not be in any way attributed to its inherent (genetic) potentiality for drought tolerance. The probable reason lies in the fact that since panicle production in Mysore is rather late (mid to late period of an year) this cultivar has evaded or skipped the drought period of 1983. But the case was different in Malabar and Vazhukka cultivars wherein more panicles initiated during the early period of an year which in fact coincided with the drought resulting in severe mortality of panicles.

The mean number of leaves per tiller at panicle initiation (Table 12), the time taken for visual appearance of the panicles (Table 13), the time taken from the visual emergence of the panicles to the appearance of the flower buds (Table 16) as well as the time taken from the appearance

of the flower buds to their anthesis (Table 17) exhibited trends specific to each cultivar. The data conclusively indicate earliness of the Malabar cultivar as compared to the Mysore cultivar. The Vazhukka cultivar occupied an intermediary position between the two. In a hybrid, this can be expected particularly if the genes responsible are of additive nature (Sundararaj and Thulasidas, 1966). Definite growth patterns characteristic for different cultivars of cardamom have been observed by earlier workers (Pattanshetty and Prasad, 1972; Venkitaraman, 1982).

The total extension growth of panicles was found to be high in the Vazhukka cultivar followed by the Malabar and Mysore cultivars (Table 14 and Fig.7). But the rate of panicle extension growth was high in Malabar, followed by Vazhukka and Mysore. The total number of racemes borne per panicle as well as the rate of raceme production followed a trend similar to that of the panicle extension growth (Table 15 and Fig.8). It could be elucidated from the data that the panicle extension growth continued upto 15 months in Vazhukka, 14 months in Mysore and 13 months in Malabar. But the production of racemes by panicles depicted dissimilarities among the cultivars. The raceme production in panicles ceased at the 12th month

in Malabar, 13th month in Vazhukka and 14th month in Mysore. Here again concentrated flowering (production of racemes) was seen in the Malabar cultivar whereas the Mysore and Vazhukka cultivars exhibited protracted nature. The earlier reports on the panicle growth characters (Pattanshetty and Prasad, 1972; Madhusoodanan et al., 1982 and Venkitaraman, 1982) did not indicate the differences in panicle extension growth as well as the rate of raceme opening among the three cultivars. Shankar (1980) observed that the internodal distance in panicles and raceme production are basically genetic characters that are the yield determinants in cardamom. The differences in panicle characters among the three cultivars, observed in the present study might have contributed to the differences in yield obtained from the cultivars also. The number of flowers opened per panicle was high in Vazhukka, followed by in Malabar and Mysore (Table 18 and Fig.9). The number of flowers opened per clump was high in Malabar and Vazhukka which were on par and low in Mysore (Table 19 and Fig.10). The pattern of flowering in panicles were studied on selected ones that emerged during January, 1982 whereas the flowering in clumps was studied on the basis of the total number of panicles that had emerged during the year. The difference in flower opening per panicle and per clump

exhibited by the cultivars Malabar and Vazhukka might be due to the reason that the number of flowers opened could have been rather less on panicles of the Vazhukka cultivar that emerged during the later part of the year.

The duration taken to achieve 50 per cent as well as 100 per cent flowering was comparatively less in the Malabar cultivar (Table 20) than in the others. The Mysore cultivar recorded a long duration. The Vazhukka cultivar stood intermediate between the two in this respect. The extent of variability was found to be high in Vazhukka cultivar. Venkitaraman (1982) postulated that the three popular cardamom cultivars behaved more or less similar in the panicle characters, the intensity and spread of flowering. This might be due to the reason that his study being confined only to the peak flowering period he could not observe the basic difference in flowering behaviour of the cultivars. However he too observed the shorter flowering span of the Malabar cultivar and the broad spectrum of variability of the Vazhukka cultivar.

The duration from fruit set to capsule maturity was less in Malabar. Mysore required more time and Vazhukka occupied an intermediate position (Table 21).

The three cultivars took approximately four months time to reach the black seed stage of capsules. Earlier reports based on experiments conducted at the Indian Cardamom Research Institute, Myladumpara (Madhusoodanan et al., 1982) are in conformity with the results of the present investigations.

Growth and development of cardamom fruits (capsules) in terms of the length, girth and volume of capsules exhibited double sigmoid curves (Table 22 and Figs.11,13 and 14). The capsule growth in the three cultivars revealed two spurts during their entire growth cycle. In between the peaks, periods of suspended growth were observed. Such double sigmoid patterns have been observed in nutmeg (Naseem, 1980) and also in certain temperate stone fruits like peach, apricot, plum and cherry (Leopold and Kriedemann, 1980).

The mean percentage of fruit set per clump was high in Vazhukka followed by in Malabar and Mysore (Table 23 and Fig.18). The immature fruit (capsule) shedding was severe in Malabar, followed by in Mysore and Vazhukka (Tables 24 and 25 and Figs. 19 and 20). The data revealed that the climatic conditions during January to April and September to December, 1982 induced

severe capsule shedding. The behaviour of the cultivars with respect to fruit setting per clump and capsule shedding reflected on the percentage of capsules matured in a clump. The high percentage of fruit setting coupled with a low percentage of capsule shedding actually contributed to the high percentage of capsule maturity in the Vazhukka cultivar. This is evident from the data presented in Table 26 and Fig.21 wherein Vazhukka ranked top for capsule maturity per clump followed by Malabar and Mysore. In the present investigation Malabar was found to be prolific in flower opening per clump. The reduction in capsule maturity observed in Malabar might be due to its medium nature of fruit setting and severity of capsule shedding. The fruit setting and capsule shedding characters in turn, influenced the yield of the capsules obtained per clump, as evident from the data presented in Table 27. The yield of capsules per clump (both on fresh weight basis and dry weight basis) was more in the Vazhukka cultivar than in the Malabar and Mysore cultivars. The higher yield potential of the Vazhukka cultivar has been reported by earlier workers (Shankar 1980; Madhusoodanan et al., 1982 and Venkitaraman, 1982).

The above mentioned aspects on the floral morphology and flowering behaviour of cardamom are applicable to the other prostrate, erect and semi-erect types that are cultivated in the high ranges of Kerala although some of the plants may not conform to the typical description of the three cultivars. Most of the earlier reports on cardamom are based on the experiments conducted at the Regional Research Station, Mudigere and the Cardamom Research Stations at Pampadumpara and Myladumpara. The results obtained in the present investigations differed fundamentally from the observations on aspects of flowering and fruit set, reported by earlier workers (Pattanshetty and Prasad, 1972; Parameswar, 1973 and Parameswar and Venugopal, 1974) from Mudigere. The large variability present in the experimental material used and the totally different agroclimatic conditions of the two localities (in Karnataka and Kerala) could have given rise to the basic differences observed. The dynamics of flowering, fruit set and capsule maturation in cardamom are aspects dependant on the type of cultivar grown as well as on the environmental conditions of the locality. The variation observed between the two years 1982 and 1983 could be attributed to the difference in weather conditions between the two years.

In order to obtain a clear picture the influence of climatic factors on some of the important aspects of flowering were worked out separately.

5.2 Histological studies on flowering

Although studies on some of the fundamental histological aspects have been attempted earlier (Mercy et al., 1977) a systematic study of the floral morphogenesis has not been made so far in cardamom.

The pattern of flower bud differentiation was studied in the genotype PV-1 (Malabar) from November, 1983 to April, 1984. Flower bud differentiation markedly increased from November, 1983 onwards and attained a peak in December 1983. Substantial number of flower buds exhibited differentiation during January to February, 1984 also.

Flower bud differentiation declined during March and April 1984. The paried from November to April is normally characterized by a low moisture status in the high range soils, because the rains received are rather scanty during this period. A moisture stress during this period would lower the water potential in the cardamom plants, particularly in the rhizomes. Consequent on the

lowering of the water potential in the rhizomes, there will be marked reduction in the translocation of water and metabolites to the other organs from the rhizomes. This in turn will result in an accumulation of the metabolites and the endogeneous growth substances during the stress period. Such a situation may possibly trigger the differentiation of floral primordia which normally occurs at the nodal regions of the rhizomes. Instances of flower bud differentiation in the aerial shoots of Dioscorea spp. consequent on the physiological changes occurring in the tubers have been observed by Onwueme (1978). He concluded that a moisture stress situation was necessary prior to the initiation of floral primordia.

The studies with respect to the chronology of the different stages of flower bud differentiation indicated that two weeks were required for the meristematic zone in the rhizome to initiate a distinct panicle primordium. The transition of the primordium from its vegetative phase to the reproductive phase was completed by the fifth week. Individual racemes appeared at the sixth week and continued their development during the seventh week. Bracts and flower buds were initiated within a raceme at the ninth week. The primordial phase lasted upto this stage. Development of anther and pistil

took place respectively at the 12th and 13th weeks.

Histology of the apical meristem was also examined in the PV-1 genotype of cardamom. The shoot meristems appeared as conical structures during their primordial phase of development (Plates 12 and 13). Leaf primordia originated as notches or depressions on the apical shoot meristem (Plate 15). The primordium depicted the characteristic morphological features of a shoot meristem at this stage. A characteristic phenomenon observed in cardamom was the site specificity in the initiation of different types of primordia (vegetative primordia originating on the rhizomes from the fourth node from the apex towards the lowest node and panicle primordia originating from the apical three nodes of rhizome). Such a predetermined zonation of meristematic activity for vegetative shoots and panicle bearing shoots points out that the transition from vegetative to reproductive phase is not a simple morphological event in cardamom. The shoot as well as the panicle primordia exhibited their distinct morphological characteristics right from their pre-primordial stage. Leaf primordia could be identified on the shoot meristem, originating in spiral whorls (Plates 17 and 18). The shoot meristem in cardamom that originate from the mother rhizome (of the parent tiller)

primarily functions as a leaf producing organ. In due course of development of the shoot meristem, the formation of a new rhizome takes place and the shoot attains its separate entity as a tiller. The pseudostem is in effect formed by successive wrapping up of a series of leaf sheaths. As tiller growth proceeds a central core of stem-like axis develops from the rhizome that gives support to the pseudostem. Though Mercy et al. (1977) have assigned the term "aerial stem" to the pseudostem of cardamom mainly because the central axis possess anatomical features resembling that of the rhizome, the term aerial stem which they meant as that of a true stem, can be accepted only after further confirmative experiments with regard to the origin of leaves and the central axis of the pseudostem. Moreover the central axis of the pseudostem lacks distinct nodes and also the present investigations reveal that the leaves originate on shoot primordia that emerge directly from the rhizomes of the parent tiller. The differentiation of other organs like panicles and roots may be through lateral or intercalary meristems situated in the nodal regions of the rhizomes. A similar meristematic activity of the apical meristem in performing the sole function of leaf production has been observed in the case of oil palm (Hartley, 1979). The growing point in cardamom may be either seated at the

apex of the rhizome or pushed upward to the tips of the pseudostem in the normal course of tiller growth. However, these aspects need further detailed experimentation.

The panicle (inflorescence) meristem appears on the rhizome nodes as a flattened zone in median longitudinal section (Plate 19). As the development proceeds, the panicle primordium resembles an arc like structure (Plate 20). The individual raceme initials that appeared on the panicle primordia (Plate 25) were larger than those of the leaf primordia that appeared on the shoot meristems (Plate 18). The raceme initials also seemed to emerge in spiral whorls at the panicle apex (Plate 27). They were seen encircled individually by floral bracts. Thus the panicle primordium differed structurally from the shoot primordium and also in its mode of development. The panicle primordium was found to be determinate in its growth, whereas the shoot primordium was rather indeterminate. Such determinate growth habits have been observed with respect to floral meristems of several plants (Cutter, 1978).

Formation of an abscission zone in the fruit stalks, prior to the immature shedding of the capsules, has been observed (Plate 34). Cardamom has the anatomical

features of a monocot plant. Vascular elements of the stem and leaf (Plates 35 and 37) lack the cambium. A prominent vascular zonation in the rhizome nodes, prior to the initiation of panicle primordia at this region, has been observed (Plate 35). The typical monocotyledonous structure of the rhizome, aerial stem, leaf sheath and root of cardamom has been reported earlier (Mercy et al., 1977). In the absence of cambium in the vascular system, the probability exists for the formation of an abscission zone from certain intercalary meristems. Formation of an abscission zone in coconut prior to the shedding of immature buttons has been found to be activated by certain intercalary meristems (Menon and Pandalai, 1949). The physiology of fruit abscission in cardamom needs further detailed investigations to yield comprehensive information. There can be a probable role of the cell wall digesting enzymes like pectinase and cellulase which may cause dissolution of the cell walls, leading to capsule shedding. These aspects need further studies.

The development of individual floral initials are depicted in Plates 28 and 29. The anther matured first (Plate 30) followed by the pistil (Plate 31). The pollen grains were found to be uninucleate and they were distinctly visible in a longitudinal section through the anther lobes (Plates 32 and 33). Since the pollen grains

are uninucleate, it may be possible that they were at a stage prior to the meiotic division.

Histology of the seeds revealed that starch grains started their development at the greenish-yellow seed stage (Plates 39 and 40). The lignification of the testa occurred at the brown seed stage (Plate 41). The formation of starch grains was completed at the black seed stage (Plates 42 and 43). At this stage, mucilage started developing above the testa layers. The staining schedule adopted in the present investigations was found to be insufficient for locating the essential oil cells present in cardamom seeds. The formation and development of the essential oil cells _vis a vis_ stages of seed maturity will be interesting aspects for further studies. Further experimentation with different staining schedules will help to trace the formation and development of essential oil cells. Combined use of differential stains and scanning electron microscopy may also be worthwhile.

5.3 The influence of climatic factors (rainfall, temperature, relative humidity) and soil moisture on flowering and fruit set in cardamom

Cardamom is highly sensitive to the fluctuations in climatic conditions. The crop comes up well in the high altitude regions of the humid tropics wherein the

shade provided by the luxuriant growth of forest trees creates a congenial micro- climate. In this habitat, fluctuations in climatic conditions are very mild. The large scale denudation of shade trees is posing a threat to the very existence of the cardamom industry in the country in as much as it causes drastic and sudden fluctuations in the climatic conditions. According to Cherian (1977), another situation now facing the cardamom industry in our country is the one arising out of environmental pollution in its natural habitat.

The present investigations, probed into the role played by the three major climatic factors (rainfall, temperature and relative humidity) on the flowering behaviour of the crop. The role of soil moisture was also assessed. Five important growth parameters (frequency of production of new tillers, number of panicles produced, number of flowers opened, percentage of fruit set and the percentage of capsules carried to maturity) were recorded on a whole-clump basis and correlated with the climatic and soil factors recorded during the year 1982. Path co-efficient analysis was done to assess the direct and indirect effects of the weather parameters on the flowering behaviour and tillering habit.

The frequency of production of new tillers in a clump was significantly influenced by the relative humidity and rainfall, in the three varieties. The direct effects of relative humidity and rainfall were positive. It could be seen from Table 30 that the number of tillers sprouted was maximum in the month of July, 1982 for all the three cultivars and the minimum, in February 1982. The peak months of tillering were July and November during the year 1982. The meteorological data (Appendices I to III) indicate that rainfall and relative humidity were high during the July and November months. Close examination of the path analysis data indicates that relative humidity favoured the tillering through the indirect effects of rainfall and soil moisture. It could, thus, be concluded that the distribution of rainfall is very important as far as the production of vegotative tillers is concerned, because soil moisture and relative humidity are chiefly dependant on rainfall.

The number of panicles produced in a clump was negatively correlated with the weather parameters, rainfall and relative humidity (Table 31). The mean temperature had the most pronounced effect on panicle production of the three cultivars exhibiting highly significant positive correlation. More number of panicles

were initiated during the period of January to April, 1982 (Table 11). During this period, rainfall was scanty, relative humidity was low and the mean temperature was high. These conditions indicate that a period of moisture stress coupled with a relatively high temperature regime accelerated the emergence of panicles in cardamom.

With respect to flower opening in a clump, soil moisture had the maximum direct effect, the effect being positive (Table 32). Temperature ranked second among the factors exhibiting the direct effects on the flowering behaviour of the three cultivars. Soil moisture had the maximum correlation with flowering also. Table 17 shows that flowering in cardamom was of a protracted nature, (extending from March to September, 1982). Since the mean temperature was more during March to May and rainfall was more during June to August, it could be concluded that a period of high temperature triggered the flowering mechanism in cardamom, which was in turn carried forward during the rainy period. Nalini (1983) also made a similar observation in the flower bud differentiation mechanism in pepper. She found that the receipt of the premonsoon showers after the dry spell (December to April) triggered the flower bud differentiation activity

in pepper. Subsequent investigations on the flower bud differentiation of pepper (Rajan, 1985) confirmed that the high temperature of summer season prior to the onset of the South-west monsoon was conducive for the step up of the flower bud differentiation activity.

The percentage of the fruit set and the percentage of capsules matured in a clump were significantly influenced by soil moisture and rainfall. Correlation coefficients were high for soil moisture and rainfall on tho one hand and fruit sot and percentage of capsule maturity on the othar (Tables 33 and 34). It was further observed that during the period May to August (when rainfall and soil moisture were high), maximum number of flowers opened in a clump attained fruit set and they were carried to maturity.

An overall analysis of the influence of the climatic factors on the flowering and fruit set in cardamom indicates that a period of soil moisture stress coupled with high temperature favoured the initiation of panicles. The onset of rains together with high temperature induced flowering. A high soil moisture regime combined with a high status of relative humidity (which resulted from a well distributed rainfall) was more

advantageous to the sprouting of the tillers, fruit setting and maturation of the capsules. The flowering behaviour, fruit set and capsule maturation of cardamom are aspects dependant on the moisture status of the soil. The concept of hydroperiodism put forward by Alvim (1973 and 1977) with respect to flowering in coffee, therefore, holds good for cardamom also. Differentiation of panicles and their development occurred during a dry period. However the flower buds that were produced on the panicles were quiescent (dormant) until sufficient rains were received. Such a quiescence (dormancy) of the flower buds of pepper was also observed by Nalini (1983). Subsequently Rajan (1985) observed a hormonal regulation of the flower bud differentiation activity in pepper, wherein he recorded a low level of inhibitors during the summer months and this low level was found to persist throughout the peak period of flower bud differentiation. Like the cases of coffee and pepper, two phases of dormancy can be operative in cardamom. One is the innate dormancy brought about by the internal hormonal relations of the plant. A decline in the inhibitors might be responsible for the initiation of panicle primordia on the rhizomes. The second phase is the quiescence or dormancy induced by the environmental factors of which the soil moisture regime has been found

to be the most important. However, unlike in the case of coffee, a bud burst is not pronounced in cardamom on receipt of the summer showers, because panicle primordia are produced in a protracted manner. Once the flower buds have appeared on the panicles, for the opening of flowers, setting of the fruits and development of the fruits, adequate moisture is absolutely necessary in cardamom.

5.4 Effect of exogenous application of growth substances on flowering, fruit set and yield of cardamom

The preliminary trial conducted on the Mysore cultivar during the year 1982 helped to select the ideal concentration of the different growth substances for the subsequent trial. Four different concentrations were tried in the growth substances (2,4-D, 2,4,5-T, alpha NAA, GA_3 and Ethrel). Based on their effectiveness on panicle production per clump, flowering behaviour, fruit set and yield, the best level for each growth substance was fixed. The cytokinn(BA) tested in the preliminary trial was eliminated for the detailed field experiment because it was not found beneficial to the Mysore cultivar of cardamom. The detailed field experiment indicated that alpha NAA (40 ppm) was superior to the other growth substances tested (Table 36). Alpha NAA (40 ppm) was

able to increase the plant height, increase the panicle length, induce production of more flowers, cause reduction in the capsule dropping and enhance the yield. With respect to the characters mentioned above, 2,4-D (4 ppm) stood second to alpha NAA (40 ppm). With respect to the number of racemes produced per panicle, the percentage of capsule setting in a clump, the yield of essential oil and the percentage of thrips infestation of the capsules, 2,4-D (4 ppm) excelled the other growth substances including alpha NAA(40 ppm). Another notable result of the experiment was the induction of more tillering by Ethrel (25 ppm).

The beneficial effects of alpha NAA and 2,4-D on enhancing fruit set and yield in cardamom have been observed by Gurumurthy et al.(1985). Prior to that Pattanshetty (1980) observed that Ethrel (250 ppm) encouraged the sprouting of tillers in cardamom. The observations made in the present studies agree with the findings of the earlier workers, except for the differences in the most beneficial concentrations. The earlier pieces of work reported were conducted at the Regional Research Station, Mudigere which had a different agroclimatic situation from that of the high ranges of Kerala. Further, the Malabar (prostrate) type of cardamom was employed for the experiments at Mudigere, whereas the Mysore (erect)

type was employed for the present investigations at Pampadumpara. The time and frequency of application of the growth substances were also different in these experiments. The differences observed in the effective concentration of the growth substances could be attributed to the reasons suggested above.

The auxins 2,4-D and NAA markedly reduced the immature capsule shedding of cardamom. Since a drop in the endogenous auxin levels and a spurt in the inhibitor levels caused the immature capsule shedding of cardamom, it is obvious that the auxins supplied exogenously have favourably altered the hormonal balance within the cardamom fruits thereby preventing the abscission of fruits. Evidences in support of this view have been obtained in several other crops by various workers (Nair et al., 1974; Sinha et al., 1977; Mayura and Singh, 1979; Joseph and Peter, 1981 and Hariharan and Unnikrishnan, 1985).

5.5 Endogenous levels of plant hormones in the developing ovaries and fruits of cardamom

The concentration of endogenous auxins in the ovaries remained steady from the time of pollination till 24 hours later. The auxin concentration increased to high levels at 36 and 48 hours after pollination. Subsequently,

there was a drop in auxin concentration upto one month after fruit set. Fruit (capsule) wilting was very severe in the Mysore cultivar of cardamom from the fruit set stage until one month after the fruit set. The development of the endosperm was not complete during the initial stages of seed development in cardamom (Plates 38 and 39). In the absence of a well developed endosperm, the rate of production of auxins in the seeds of immature capsules of cardamom can be expected to be low, which in turn might have caused the shedding of immature capsules at the early stage of their development.

Similar role of seeds in the development of fruits by endogenous synthesis of auxins have been established in strawberry (Nitsch, 1950), in black currant (Wright, 1956), in fig (Crane et al., 1959) and in grapes (Coombe, 1960 and Nitsch et al., 1960). There was formation of a clear cut abscission zone in cardamom (Plate 34) that led to the fruit shedding. Formation of abscission zone leading to/followed by a loss of membrane integrity and dissolution of the cellular contents at the abscission regions have been recorded in several fruit plants (Sacher, 1957). The sudden decline in the endogenous auxin level observed in the fruit can be attributed to the formation of this abscission zone, which induced fruit drop. The increase in

the auxin activity of ovaries observed from 24 to 36 hours after pollination indicated that fruit set had occurred during this period. A striking increase in the diffusible auxin concentration in the ovaries of tobacco flowers after pollination to fruit set has been observed (Muir, 1942).

The concentration of inhibitors, expressed as equivalent of abscisic acid, was high in the cardamom capsules, one month after the fruit set. The increase in the concentration of inhibitory substances and the subsequent lowering of the auxin/inhibitor ratio might have been predominant factors that induced the immature capsule shedding in cardamom. The stimulation of fruit abscission due to a substantial increase in the endogenous ABA content has been observed in a variety of fruit plants (Davis and Addicott, 1972; Lu et al., 1982 and Martin et al., 1982).

The endogenous cytokinin levels in the developing ovaries and the fruits of cardamom did not reveal any direct influence on the growth and development of cardamom capsules. However, a slight increase in the cytokinin levels was observed from the time of pollination to fruit set. This is a stage characterised by faster cell division and since cytokinins are substances that promote cell

division in the initial stages of ovary development, increased levels can be expected. The role of endogenous cytokinins in cell division and fruit set in grapes was postulated earlier by Weaver et al.(1966).

5.6 Nutrient status of the cardamom plants at various periods of crop growth

The nutrient status of the different plant parts of cardamom was estimated at five major crop growing periods, namely, panicle initiation stage, flower bud development stage, peak period of flowering, capsule maturity stage and post-harvest stage in the three popular cultivars. Standard analytical techniques were employed to assess the concentration of N, P, K, Ca, Mg, S, Fe, Zn, Mn and Cu.

The nitrogen status of the pseudostems, leaves and rhizomes declined with the advancement of the growth phases. The concentration of root N and panicle N increased with the advancement of crop age and they indicated the maxima at the capsule maturity stage.

The total soluble carbohydrate content of the leaves was high during the initial stage. A decline in the carbohydrate concentration in the leaves was observed at the capsule maturation and post-harvest stages.

However, the C/N ratio did not reveal any definite relation to the flowering behaviour of the crop. The high status of carbohydrates at the panicle initiation and flower bud development stages helped to build up or accumulate the carbohydrates, thus favouring the development of floral parts in cardamom. A similar instance of carbohydrate accumulation was observed (Nalini, 1983) prior to the flower bud differentiation in pepper. The C/N ratio exhibited at the end phases of crop growth was basically due to a very low status of N, consequent to the higher mobilisation of N from the leaves. Since the rhizome of cardamom is a storage organ, which is the immediate source of carbohydrates for the growth and development of the panicles, analysis of carbohydrates in the rhizomes could have revealed its possible role in flowering. An accumulation of carbohydrates in the underground tubers of edible species of Dioscorea (Coursey, 1967 and Onwueme, 1978) and diosgenin bearing species of Dioscorea (Vasanthakumar, 1979) was observed prior to floral induction in these yams. The rhizomes which obtained metabolites from the leaves had the capacity to store them for longer durations and to release them slowly for the development of floral sheets and vegetative tillers. Therefore, further studies on the carbohydrate content of the rhizomes need to be taken up

for unravelling the exact relationship between rhizome carbohydrates and flowering.

The P content of the leaves and the pseudostems declined at the later periods of crop growth. The rhizome P showed an increase from the panicle initiation phase to the peak flowering phase. Subsequently, it declined. The roots and the panicles accumulated more P from the panicle initiation stage to the capsule maturity stage.

The potassium content of the different organs showed a trend as that of P at the different crop maturity periods studied. In general, the different organs of cardamom contained fairly rich amount of K than the other elements. That cardamom is a heavy feeder of potash has been well documented by several workers (John, 1967; Kulkarni et al., 1971; Zachariah, 1978; Khader et al., 1982 and Dileepkumar, 1983).

Organ-wise distribution of nutrients in the three cultivars of cardamom revealed that the leaves accumulated more of N and Ca, rhizomes accumulated more of K and Mg and panicles accumulated more of P. These observations are in conformity with the earlier work conducted at CPCRI (Khader et al., 1982). The exceptions observed were that

the accumulation of Ca on a whole clump basis occupied the second position, followed by N (third) from the present analytical results whereas Khader et al. (1982) found a higher accumulation of N than Ca. Moreover the nutrient status of rhizomes was not estimated in their analysis which otherwise accumulated fairly large quantities of the macro, secondary and micro nutrients.

Analytical results of the present investigations further showed that there was a decline in the concentration of N, P and K in the leaves from the panicle initiation to the post-harvest stage. These major nutrients, are highly mobile within the plant (Tisdale and Nelson,1970). In the course of development of the organs, they might have been transported from the leaves (source) to their sites of utilization namely the rhizomes, the panicles and the roots (sinks). This is further evident from the accumulation of more P and K in the rhizomes at the peak flowering and capsule maturity periods. Kulkarni et al. (1971) have concluded that these elements exhibit direct influence on the yield and quality of cardamom. The concentration of the secondary nutrients, namely, Ca and Mg increased in all the organs from the panicle initiation phase to the capsule maturity phase. Kulkarni et al (1971) also have observed similar trend in respect of these base elements from the juvenile to the senescent periods

of cardamom. Though the precise role of Mg nutrition on the growth and yield of cardamom is not well documented, Dileepkumar (1983) obtained a positive response for Mg in enhancing crop growth and productivity. Magnesium, a constituent of chlorophyll, is involved directly in the photosynthetic activity of the leaves. This may be the reason for enhancement of yield in cardamom, consequent to the high assimilation of photosynthates brought about by a saturation of Mg in the leaves.

The sulphur concentration of the organs did not reveal any definite relation to the flowering and crop productivity in cardamom. However, high levels of S at the panicle initiation phase in the leaves and the rhizomes and their accumulation in the roots and the panicles at the capsule maturity period, are indicative of a higher utilisation of S for the capsule maturation of cardamom.

Quantitative estimation of the micronutrients (Fe, Zn, Mn and Cu) in the plant parts at the five growth stages studied, indicated a common trend in the three cultivars (Malabar, Mysore and Vazhukka). There was a general increase in the concentration of these micro nutrients from the panicle initiation stage to the capsule maturity stage in all the plants. The high range soils where cardamom is extensively grown are characteri-

sed by heavy and well distributed, rainfall. Consequent on the heavy down pour, there are chances for leaching of the base elements of the soil. Since the base saturation of the soil is lowered considerably, a high acidic range develops, a phenomenon typical of the high range (humid tropical soils). The availability of micronutrients (Zn, Fe, Mn and B) will be hanced in an acidic condition of the soil. A similar general phenomenon occurring in acidic soils has been well established by Black (1973) and specifically for cardamom soils by Dileepkumar (1983). The comparatively high availability of Zn, Fe and Mn in the cardamom soils might have led to their high rate of absorption by the various organs of cardamom. Since these micro nutrients are immobile within the plant and their utilisation is fairly low for the various physiological processes, it might have led to their high accumulation in the different organs of cardamom with the advancement of crop maturation. Supporting evidences in favour of the higher absorptivity of micronutrients by cardamom have been recorded by Dileepkumar (1983).

The uptake of the nutrients by individual tillers of cardamom indicated beyond doubt that cardamom is a heavy feeder of potash (Table 44). For production of

unit biomass of capsules, the Mysore cultivar required more nutrients, followed by Malabar. The Vazhukka cultivar depleted less nutrients than the other two cultivars. The magnitude of depletion of nutrients followed a similar trend in the three cultivars. They were, in the descending order of magnitude, K, Ca, N, Mg, P, S, Mn, Fe, Zn and Cu. Some of the earlier investigators have also observed similar trends in the uptake of nutrients by cardamom (John, 1967; Raman and Khan, 1967; Kulkarni et al., 1971; Korikanthimath, 1984).

5.7 Rate of photosynthesis and translocation of photosynthates at different stages of crop growth

Cardamom is a crop of the tropical rain forests where it is grown amidst forest trees that provide dense shade at different strata above the level of the crop. Observations made by earlier research workers have led them to conclude that adequate number of trees that provide shade at three canopy levels (upper, middle and lower) improve the growth and productivity of cardamom (Kuttappa, 1969; Cherian, 1977 and Kurup, 1984). In these situations the insolation that is incident on the leaves of cardamom is rather low. That cardamom is a shade loving plant (psiophyte) and that its better

performance is under shaded situations have been established by field experiments conducted at the Cardamom Research Stations located at Pampadumpara and Myladumpara (Anon; 1984). However, systematic attempts to obtain physiological explanation to the phenomenon have not been made so far. The present investigations aimed at assessing the comparative photosynthetic efficiency of cardamom leaves at different light intensities and at different canopy levels. Studies were also made to unravel the pattern of translocation of the photosynthates at five selected crop maturity stages.

The photosynthetic rate, as indicated by the efficiency of a leaf to fix $^{14}CO_2$, was found to be high in subdued light intensities (Table 45). A significant reduction in the rate of fixation of $^{14}CO_2$ activity by the leaves (of the PV-1 genotype) was observed as the light intensity rose from the morning (1780 lx) to noon hours (10,000 lx). During the early afternoon (from 12.30 p.m. to 2.00 p.m.) when the light intensity was more than 10,000 lx, the fixation of $^{14}CO_2$ gradually increased thereafter and reached a peak by the evening hours (from 5.30 p.m. to 6.00 p.m.).

From these observations, it could be postulated that the photosynthetic rate in cardamom bears a negative relation to the light intensity and that a low light-

compensation point favours the photochemical processes in a leaf. Psiophytic species of plants usually possess greater efficiency for CO_2 fixation and utilisation at low light intensities because of the low resistance offered by their stomates for CO_2 diffusion (Radmer and Kok, 1977). Further, the chlorophyll complexes of these plants are adapted to utilise the absorbed CO_2 under subdued light. The analysis of the photosynthetic efficiency of different canopy levels of cardamom did not reveal any definite trend, either in the experiments using detached leaves or those using intact leaves (Tables 46 and 47). The mean radioactive counts obtained from detached leaves declined from leaf positions 1 to 6 under identical conditions of $^{14}CO_2$ feeding (inside a perpex leaf chamber). The radioactive CO_2 fixation by the 7th to 10th leaves showed an increase. Since the $^{14}CO_2$ fixation during a particular time of feeding depended largely on the micro-climate that prevailed inside the perpex leaf chamber, a comparison between the leaves of the different sets of feeding would not be meaningful. A meaningful comparison is feasible only when the leaves are fed simultaneously with $^{14}CO_2$. It may be concluded from the experiments using detached leaves that the lower leaf canopies utilised $^{14}CO_2$ more efficiently than the upper leaf canopies. A similar instance of efficient

$^{14}CO_2$ fixation by the lower leaf canopies of sorghum was observed by Jacob (1984).

Studies on $^{14}CO_2$ fixation in intact leaves (Table 47) which were conducted on ten consecutive days could not give a true picture of the efficiency of a particular leaf in performing the function of photosynthesis. The changes in the environmental conditions during each set of $^{14}CO_2$ feeding might have contributed to the varying trends recorded by the leaves at different sets of radioactive feeding experiments. Contrary to what was observad from the experiment using detached leaves, the intact leaves indicated a high $^{14}CO_2$ fixation efficiency by the leaf positions 1 to 4 and a decline thereafter to the lower canopies. In all the experiments, the rhizomes transported more ^{14}C assimilates from the radioactive fed leaves. The role of subterranean stems as storage organs for metabolites has been observed by several workers (Edelman, 1963; Coursey, 1967; Thompson and Kelly, 1972; Onwueme, 1978 and Purseglove et al., 1981). It was further observed that the transport of labelled metabolites from the $^{14}CO_2$ fed leaves to the other organs was confined mainly to the organs situated in the close vicinity of the treated leaf. Since the rhizomes, pseudostems and roots were the major sinks, the transport

of photosynthates could be mainly regarded as basipetal. However, fairly high ^{14}C activity could be observed in the non-fed leaves above the $^{14}CO_2$ fed leaves when leaf positions 1 to 4 were employed for the study. This phenomenon gave an indication that the metabolites were transported acropetally also. A predominently basipetal transport of the metabolites in rhizomatous plants has been documented earlier by Zimmermann (1961).

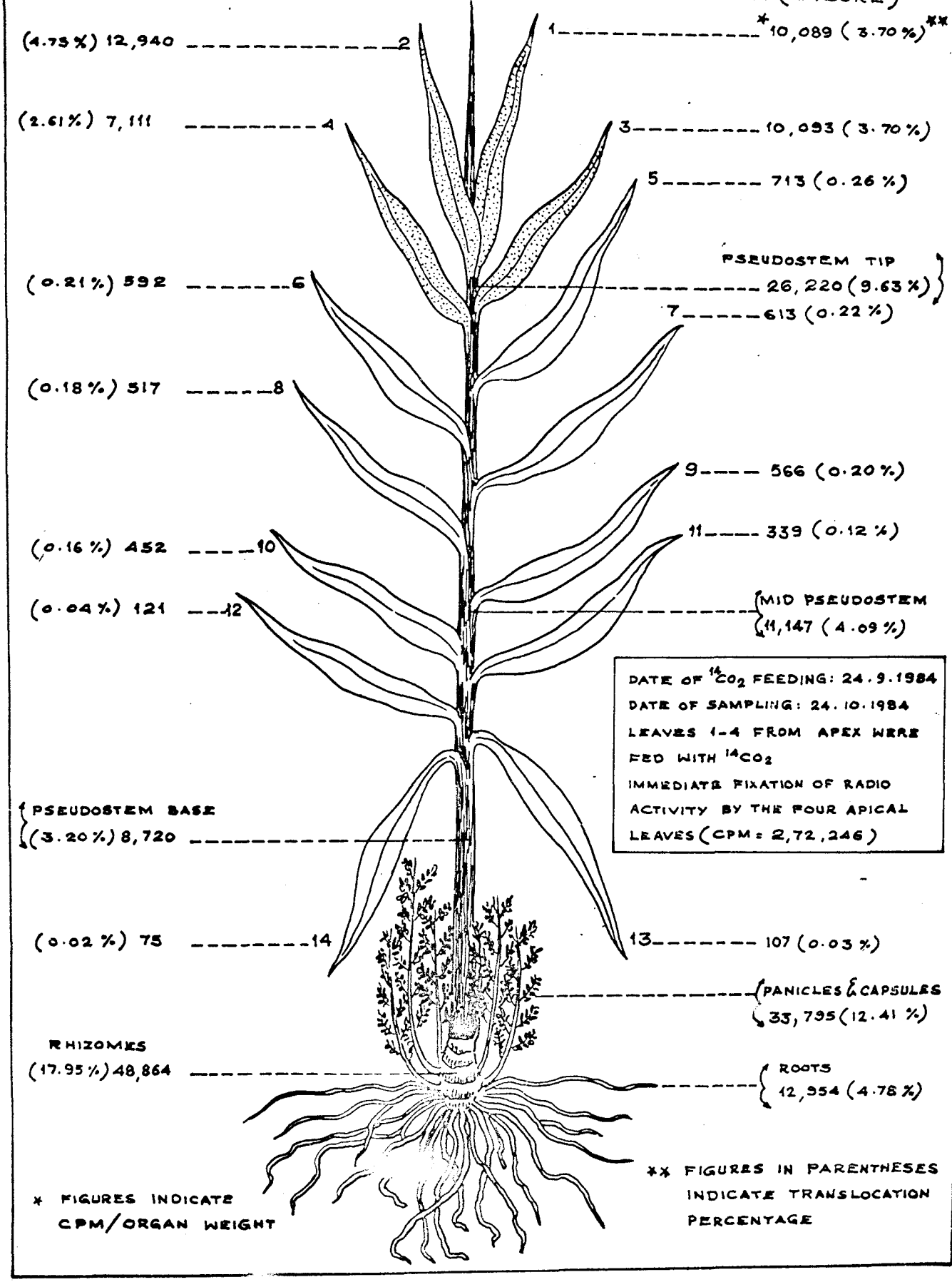
The results of the present investigations clearly indicate that the efficiency of $^{14}CO_2$ fixation by cardamom leaves was high under low light intensities (1500 to 5000 lx). The efficiency exhibited by the lower canopies (to fix more $^{14}CO_2$) might have been due to the diffused light (because of the mutual shading by the leaves) that was incident on those leaves). Increased efficiency of lower canopies of leaves to utilise diffused light has been observed in certain forage grasses by Sheehy and Cook (1977).

In the genotype PR-107 (Mysore), the rhizomes transported more metabolites during all growth stages. There was also a localisation of radioactivity in the apical portion of the pseudostem when the apical four leaves were fed with $^{14}CO_2$. Fairly high proportions of labelled assimilates were detached from the panicles and the roots.

Since the label could be traced from the organs including the non-fed leaves, it can be presumed that ^{14}C photosynthates were distributed to all the sinks of a tiller.

The developing panicles and roots accumulated less amounts of ^{14}C metabolites when compared to the rhizomes. It appeared that the rhizome (the true stem) of cardamom, situated at a subterranean region, is the most vital organ which acted as a storage tissue of assimilated food material. The organs that arose from the rhizomes, (panicles and roots) obtained their supply of photosynthates, in turn, from the rhizomes. This meant that the rhizomes functioned as a reservoir of photosynthates subsequently releasing them to the panicles (including the capsules) and the roots. Since the time interval allowed for recording the translocation rate of photosynthates during the present investigations was only for one month, the real sink effects due to the rhizomes could not be ascertained. Investigations on these lines are necessary on the other promising genotypes of cardamom to arrive at definite conclusions. The pattern of photosynthate mobilisation at the capsule maturity stage is shown diagrammatically in Fig. 25.

FIG. 25 DISTRIBUTION OF ^{14}C - PHOTOSYNTHATES IN DIFFERENT SINKS OF A CARDAMOM TILLER. GENOTYPE : PR-107 (MYSORE)



* FIGURES INDICATE CPM/ORGAN WEIGHT

** FIGURES IN PARENTHESES INDICATE TRANSLOCATION PERCENTAGE

The autoradiographs (Plates 47) indicated that the ^{14}C assimilates accumulated more strongly in the mid ribs and veins of non-fed leaves. The tertiary feeder roots accumulated more photosynthates than the primary and secondary roots (Plate 45). It may be pointed out that tertiary rootlets of cardamom are the main feeder roots and as such, the main site of utilisation of photosynthates. The presence of only feeble radioactivity in the mid-ribs of $^{14}CO_2$ fed leaves indicates that photosynthates have moved out of the mid-ribs. This, in turn, suggests the existence of phloem transport of leaf assimilates. The tracing of the transport of the metabolites using autoradiography has been a well established method in several horticultural crops (Wareing and Philips, 1973; Street and Opik, 1976; Baron, 1979 and Ramulu, 1982).

5.8 Changes in the flavour components of cardamom capsules at five seed maturity phases

A critical examination of the data on flavour components *vis a vis* capsule maturity (Tables 49 and 50 and Figs. 22 to 24) revealed that the concentrations of alpha and beta pinenes, and d-limonene were high at the greenish-yellow seed stage in the genotypes PV-1

(Malabar) and PV-5 (Vazhukka) and at the ripe seed stage in the genotype PR-107 (Mysore). The concentrations of I, 8-cineole, terpene-4-ol, alpha terpeniol, linalyl acetate and geraniol were comparatively high at the black seed and ripe seed stages in the three genotypes studied. The steady accumulation of these flavour components from the young stage to the later stages of seed maturity indicated that peak development of the charecteristic flavour of cardamom occurred at the black seed and ripe seed stages. The results of the preliminary studies on the relative accumulation of these components in the three popular cultivars of cardamom by Sankarikutty et al. (1982) are in general agreement with those of the present investigations. However, in the present investigations, high contents of alpha-terpenyl acetate, geranyl acetate and nerolidol were observed at the tender seed stage of the capsules. The concentration of these components declined with the advancement of maturity of the capsules. A recent study conducted at the Regional Research Laboratory, Trivandrum (Sumathikutty et al., 1985) also indicated similar results as those of the present studies. Alpha terpenyl acetate, being a major component of the spice, the decline in its accumulation with the advancement of seed maturity will be a topic of special interest for the

oleophysiologist. The higher concentration of these components at the tender seed stage may be due to their higher rate of synthesis during the early period of seed development. Though Sumathikutty et al. (1985) have not assigned any specific reason for such a declining trend in the accumulation of alpha terpenyl acetate, possibility exists for a back conversion of this component to some other constituent components with the advancement in seed maturity of the spice. Such interconversions of components with advancement of crop maturity has been well established in some other aromatic plants by Guenther (1950). These aspects require further detailed experimentation.

The results point out that for commercial extraction of the essential oils as well as for use as a spice, the capsules should be harvested at the black seed stage ('Karimkai'). Among the three genotypes PV-1 ranked first in terms of alpha as well as beta pinenes, d-limonene and 1,8- cineole. The concentrations of these components were the minimum in the genotype PR-107. PV-5 exhibited intermediate levels. The concentrations of linalool, terpene-4-ol, alpha terpeniol, linalyl acetate, geranyl acetate and nerolidol were high in the genotype PR-107, followed by in PV-5 and PV-1. The genotype, PV-5 ranked first for only two components, geraniol and alpha-terpenyl acetate. It is thus obvious

that the genotype PR-107 (Mysore) is superior to the others in quality aspects. The genotype, PV-1 (Malabar) possessed only low proportions of the chief constituents which imparted the characteristic flavour to the spice. PV-1 possessed a high content of 1,8 cineole which gave a more harsh campheraceous flavour to its oil. The dominance of campheraceous flavour is supposed to be an inferior factor as far as the quality aspects of cardamom are concerned. Such an accumulation of high cineole in the capsules of Malabar has been found by earlier workers also (Shankaranacharya and Natarajan, 1971). The presence of high levels of the esters, alpha terpenyl acetate linalyl acetate and geranyl acetate could have contributed to the sweet, spicy, floral and fruity flavour of the genotype PR-107. The Mysore cultivar, in general, possessed a high quantity of these components thus making it the most popular among the cultivars of cardamom. Confirmative evidences for the superior quality of Mysore cultivar have been presented by Sumathikutty et al. (1985).

The floral flavour and lemony note of PR-107 could be due to the presence of high levels of the alcohols, linalool, alpha terpeniol and geraniol. The woody pine like flavour dominant in the essential oil of

PV-1 might be due to high levels of alpha and beta pinenes. Similar observations have been made by Sankarikutty *et al.* (1984) and Sumathikutty *et al.* (1985) at the Regional Research Laboratory (CSIR), Trivandrum. Detailed studies employing cardamom flowers and fruits right from the anthesis stage until the capsule maturity stages, at weekly intervals in the other promising genotypes of cardamom may be able to provide additional information on these aspects.

SUMMARY

6 SUMMARY

Investigations were carried out at the Cardamom Research Station, Pampadumpara and at the College of Horticulture, Vellanikkara during 1982 to 1984 to gather information on the physiological bases of growth, flowering, fruit set and capsule development in cardamom. The causes of fruit (capsule) shedding were also examined with a view to evolve methods of control.

6.1.1 The studies revealed that the Vazhukka cultivar possessed more tillering ability than the other two. The Mysore cultivar was found to be comparatively weak.

6.1.2 The total leaf production, the total leaf area and the dry matter accumulation in the leaves were high in Mysore, followed by in Vazhukka and Malabar. For a single plastochrone, the Vazhukka cultivar required less time compared to the other two cultivars.

6.1.3 Among the different organs of a tiller the last to undergo senescence was the rhizome. The pseudostems and leaves senesced earlier than the other organs (rhizomes, panicles and roots).

6.1.11 Growth and development of cardamom capsules in terms of the length, girth and volume of the capsules exhibited double sigmoid curves.

6.1.12 The different aspects of flowering and fruit set studied, indicated rather high variability in the Vazhukka cultivar and low variability in the Mysore cultivar. An early crop bearing habit was exhibited by Malabar whereas Mysore possessed a late bearing habit.

6.2.1 The studies revealed that tillering in the three cultivars, was more during the months characterised by high rainfall, relative humidity and soil moisture. The mature as well as the newly sprouted tillers of Vazhukka tolerated the drought situation better than those of the other cultivars. The newly emerged tillers of Malabar easily succumbed to drought.

6.2.2 A distinct dry spell that prevailed from January to April triggered the panicle initiation process. The onset of rains coupled with high temperatures was conducive to more of flower opening. A high soil moisture regime combined with a high status of relative humidity (which resulted from a well distributed rainfall) improved the fruit (capsule) setting and increased the number of capsules carried to maturity.

6.3.1 Histological studies conducted in the genotype PV-1 (Malabar) showed that differentiation of panicle primordia was more during November to March. The shoot primordium originated as a conical meristem whereas the panicle primordium was arc-like. The site of initiation of the panicle and the shoot primordia were at distinct nodes on the rhizome. The panicle primordium was determinate in its growth habit.

6.3.2 Vascularisation at the rhizome nodes was observed prior to the initiation of panicle primordia.

6.3.3 Histology of the seeds revealed the development of starch grains at the greenish-yellow seed stage. The lignification of the testa occurred at the brown seed stage. The development of starch grains was completed at the black seed stage.

6.4.1 Endogenous auxin-like substances were found consistent at Rf positions 0.3 to 0.5 in the paper chromatograms. The auxin activity attained a peak (315 ng/g fresh ovaries) 36 hours after pollination. Subsequently the auxin levels dropped to 80 ng/g fresh ovaries with one month of fruit set which favoured the formation of an abscission zone, leading to immature capsule shedding.

6.4.2 The concentration of inhibitors were found consistent at Rf regions 0.6 to 0.8 in the paper chromatograms. The level of inhibitory substances rose from 12 hours after pollination (80 ng/g capsules) to one week after fruit set (220 ng/g).

6.4.3 Eventhough an increase in cytokinin activity was observed from the time of pollination to the fruit set stage, the cytokinin levels did not reveal any definite relation with the growth and development of capsules.

6.5.1 Exogenous application of NAA (40 ppm) and 2,4-D (4 ppm) increased the plant height, enhanced the production of panicles and flowers, reduced the capsule drop and improved the yield.

6.5.2 Ethrel (25 ppm) promoted the tillering ability of cardamom.

6.5.3 2,4-D (4 ppm), 2,4,5-T (6 ppm) and NAA (40 ppm) were effective in enhancing the total content of essential oil in the capsules.

6.6.1 The total soluble carbohydrate content in the leaves was high during the initial stage of floral development. The C/N ratio did not bear any definite relation to the flowering behaviour of cardamom.

6.6.2 The N, P and K content of the leaves and pseudostems declined towards the later stages of crop growth. The rhizomes showed an increase in the concentration of the major elements from the panicle initiation stage to the peak flowering period.

6.6.3 The concentration of Ca, Mg, Fe, Zn, Mn and Cu increased in all the organs from the panicle initiation stage to the capsule maturity stage.

6.6.4 The uptake of nutrients by individual tillers of cardamom indicated that cardamom is a heavy feeder of potash. The nutrient uptake (total of N, P, K, Ca, Mg, S, Fe, Zn, Mn and Cu) revealed that for the production of 1 kg dry cardamom capsules the Vazhukke cultivar depleted less amounts of nutrients (779.50 g) than the Mysore cultivar (1617.88 g). The mean nutrient depletion on a whole clump basis by the three cultivars could be ranked as follows:

$$K > Ca > N > Mg > P > S > Mn > Fe > Zn > Cu$$

6.7.1 The studies based on the fixation of $^{14}CO_2$ showed that the photosynthetic efficiency was more under subdued light intensities (1500 to 5000 lx). A low light compensation point was found to favour the photochemical processes in the leaves of cardamom. Assessment of the photosynthetic efficiency at different canopy levels (using either detached leaves or intact leaves) did not reveal any conclusive pattern.

6.7.2 The rhizomes were found to be the main sinks. Fairly high proportion of the labelled assimilates were detected from the panicles and roots also. The rhizomes, hence, functioned as a reservoir of photosynthates for subsequent release to the other parts of the tillers.

6.7.3 The movement of the labelled metabolities was mostly basipetal. Acropetal transport of the metabolites was observed to a small extent. The tertiary feeder rootlets were found to be the main sites of utilisation of the photosynthates.

6.8.1 Gas chromatographic estimation of cardamom oils at the five seed maturity stages revealed that the components 1,8-cineole, terpene-4-ol, alpha terpeniol, linalyl acetate and geraniol were comparatively high at the "black" and "ripe" seed stages.

6.8.2 A high content of alpha terpenyl acetate, geranyl acetate and nerolidol was observed at the young tender seed stage of the capsules.

6.8.3 The Mysore genotype, PR-107 was found to be superior in quality because of the high content of the esters, alpha terpenyl acetate, geranyl acetate and linalyl acetate. The capsules of PR-107 on steam distillation gave a high recovery of essential oil.

6.8.4 The quality of capsules of the genotype PV-1 (Malabar) was inferior to that of the other two genotypes, mainly because of a high content of 1,8-cineole which imparted a harsh and campheraceous odour to the spice. The recovery of essential oil was also low in PV-1.

6.8.5 For consumption as a spice as well as for distillation of the essential oils, the black seed stage ('Karimkai') was found to be the most ideal stage in cardamom.

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APPENDICES

APPENDIX- I

Meteorological data of the Cardamom Research Station, Pampadumpara

1982

Month	Rainfall (mm)	Relative humidity (%)	Temperature (°C)			Soil moisture (%)
			Maximum	Minimum	Mean	
January	-	75.29	23.52	14.32	18.92	13.09
February	-	68.10	27.88	14.70	21.29	11.52
March	3.50	73.28	29.61	16.60	23.11	9.24
April	126.10	70.43	29.73	18.85	24.29	12.80
May	153.80	75.72	27.69	18.95	23.32	21.60
June	265.00	90.90	23.18	17.87	20.53	33.60
July	206.30	91.30	22.80	17.60	20.20	27.40
August	214.00	90.40	22.00	17.00	19.50	30.50
September	71.90	75.80	25.00	17.00	21.00	18.40
October	146.20	79.40	26.00	17.70	21.85	15.25
November	201.30	85.90	23.30	17.10	20.20	14.14
December	23.70	74.90	22.20	14.70	18.45	13.54
Total	1411.80	951.12	302.91	202.39	252.66	221.08
Mean	117.65	79.26	25.24	16.87	21.06	18.42

APPENDIX-III

Meteorological data of the Cardamom Research Station, Pampadumpara

1984

Month	Rainfall (mm)	Relative humidity (%)	Temperature (°C)		
			Maximum	Minimum	Mean
January	28.90	79.60	24.20	16.10	20.15
February	28.40	80.20	22.80	16.50	19.65
March	132.50	68.20	27.13	18.90	23.02
April	92.20	69.20	28.20	19.70	23.95
May	91.80	70.00	29.20	19.70	24.45
June	789.90	92.70	20.97	15.82	18.40
July	547.30	92.00	22.37	15.95	19.16
August	226.80	91.00	23.94	17.05	20.50
September	426.70	83.40	24.25	17.62	20.94
October	240.20	83.80	24.44	16.56	20.50
November	138.10	85.60	24.30	15.43	19.87
December	63.70	76.69	23.93	14.28	19.11
Total	2767.00	972.39	295.73	203.61	249.70
Mean	230.58	81.03	24.64	16 97	20.88

APPENDIX - II

Meteorological data of the Cardamom Research Station, Pampadumpara

1983

Month	Rainfall (mm)	Relative humidity (%)	Temperature (°C)		
			Maximum	Minimum	Mean
January	-	66.20	26.20	16.00	21.10
February	-	59.80	30.20	18.30	24.25
March	-	57.10	32.40	19.00	25.70
April	-	56.30	33.90	19.20	26.55
May	129.80	70.60	29.00	19.60	24.30
June	211.40	85.20	23.50	18.70	21.10
July	305.00	83.30	23.40	18.30	20.85
August	423.50	88.60	22.20	19.10	20.65
September	329.00	83.70	23.60	17.80	20.70
October	183.20	82.60	23.40	20.10	21.75
November	203.20	81.70	25.00	16.50	20.75
December	79.00	80.40	23.20	15.90	19.55
Total	1864.10	895.50	316.00	218.50	267.25
Mean	155.34	74.63	26.33	18.21	22.27

APPENDIX IV

Growth of the vegetative organs (Extracts of analysis of variance)

Source of variability	df	Height of tillers		Number of leaves		Total leaf area		Dry matter of leaves		Dry matter of pseudostems	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Cultivars	2	187.16	1.48	47.20	1.33	366162	2.05	11.74	1.84	131.79	1.75
Sampling intervals	12	172.85	1.39	52.94	1.49	300851	1.68	25.40	3.98**	167.53	2.22*
Error	194	124.76		35.66		178616		6.38		75.31	

Source of variability	df	Dry matter of rhizomes		Dry matter of roots		Dry matter of panicles and capsules		Total dry matter	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Cultivars	2	5.96	1.68	1.71	1.44	14.12	1.82	229.36	1.81
Sampling intervals	12	19.09	5.38**	5.27	4.42**	22.17	2.85*	462.67	3.65**
Error	194	3.55		1.19		7.76		126.72	

* Significant at 5% level

** Significant at 1% level

APPENDIX V

Growth and development of vegetative and floral parts
(Extracts of analysis of variance)

Source of variability	df	Production of new tillers (1982)		Production of new tillers (1983)	
		MSS	F ratio	MSS	F ratio
Cultivars	2	758	126.33**	576	192.00**
Months	11	403	67.16**	137	45.67**
Interaction	22	58	9.67**	32	10.67**
Error	140	6		3	

Appendix V (contd)

Source of variability	df	Production of panicle bearing tillers					
		Malabar		Mysore		Vashukka	
		MSS	F ratio	MSS	F ratio	MSS	F ratio
Replications	4	11.60	1.09	7.96	0.97	43.55	9.93
Treatments	2	100.86	9.50**	74.43	9.07**	41.35	9.43**
Error	8	10.61		8.20		4.38	

Appendix V (contd.)

Source of variability	df	Life span of a tiller		Number of panicles per tiller	
		MSS	F ratio	MSS	F ratio
Replications	9	0.68	0.89	1.41	1.82
Treatments	2	28.87	37.60**	0.70	0.90
Error	18	0.77		0.72	

Appendix V (contd..)

Source of variability	df	Plastochrome scale		Number of panicles per clump (1982)			Number of panicles per clump (1983)		
		MSS	F ratio	df	MSS	F ratio	df	MSS	F ratio
Cultivars	2	4.12	1.34	2	34141	51.92**		23.57	19.36**
Season	3	3.98	1.29	11	88291	134.28**		43.65	35.85**
Interaction	6	2.57	0.83	22	5113	7.77**		11.89	9.76**
Error	44	3.08			657			1.22	

APPENDIX V (CONTD..)

Time taken from fruit set to different seed maturity stages
(Extracts of analysis of variance)

Source of variability	df	Tender seed		Greenish-yellow seed		Brown seed		Black seed		Ripe seed	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Replications	9	4.13	0.40	71.35	1.08	58.48	0.84	208.87	3.41	52.06	0.58
Treatments	2	38.80	3.71*	840.90	12.77**	122.03	1.76	496.13	8.11**	299.03	3.32
Error	18	10.47		65.82		69.25		61.21		90.18	

Appendix V (contd..)

Growth and development of ovaries/ capsules
(Extracts of analysis of variance)

Source of variability	df	Length		Diameter		Girth		Volume		Fresh weight		Dry weight		Drying percentage	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Replications	2	2.21	2.78	0.45	0.87	1.40	0.40	0.0009	1.70	370.20	0.80	19.52	1.05	0.03	0.03
Treatments	19	4.01	5.05**	1.37	2.62**	24.30	6.90**	0.0020	3.72**	2110.60	4.58**	144.84	7.76**	6.79	7.39**
Error	38	0.79		0.52		3.52		0.0005		460.37		18.66		0.92	

Appendix V (contd.)

Fruit set, fruit drop and capsule maturity per clump
(Extracts of analysis of variance)

Source of variability	df	Fruit set		Capsule drop to total flowers		Capsule drop to set fruits		Capsule maturity	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Cultivars	2	1133	27.33**	1345	18.03**	3988	11.17**	645	13.61**
Months	11	2817	67.96**	199.87	2.65**	1320	3.70**	4814	101.58**
Interaction	22	55	1.34*	301.42	4.04**	807	2.26*	286	6.03**
Error	140	42		74.94		357		47	

Appendix V (contd..)
Yield of capsules per clump
(Extracts of analysis of variance)

Source of variability	df	Fresh weight		Dry weight	
		MSS	F ratio	MSS	F ratio
Replications	4	13856	0.88	739	0.94
Treatments	2	225033	14.42**	12,758	15.37**
Error	8	15601		829	

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

Appendix V (contd..)

Source of variability	df	Number of leaves at panicle initiation		Time take for panicle initiation		Time taken from panicle initiation to flower bud stage		Time taken from flower bud to anthesis	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Replications	9	0.70	0.09	428	1.62	68.59	2.17	12.72	1.01
Treatments	2	18.10	23.60**	7413	27.86**	185.20	5.87*	68.80	5.45*
Error	18	0.77		266		31.57		12.61	

Appendix V (contd.)

Source of variability	df	Extension growth of panicles		Number of racemes per panicle		Number of flowers per panicle		Number of flowers per clump	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Cultivars	2	2191	35.93**	109.95	23.01**	156.93	68.46**	87.45	30.87**
Months	11	1963	32.04**	249.14	52.17**	335.47	146.36**	116.89	41.27**
Interactions	22	1498	24.56**	172.34	36.13**	35.87	15.65**	13.74	4.85**
Error	140	61		4.77		2.29		2.83	

Appendix V (contd..)

Source of variability	df	Days to 50 per cent flowering		Days to 100 per cent flowering	
		MSS	F ratio	MSS	F ratio
Replications	9	228.96	8.80	996.68	0.58
Treatments	2	2973.33	10.39**	14170.80	8.21**
Error	18	286.18		1725.17	

APPENDIX VI

Exogenous application of growth substances Standardisation experiment (Extracts of analysis of variance)

Source of variability	df	Number of panicles		Total flowers		Per cent fruit set		Per cent capsule drop		Yield of capsules	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Replications	1	1.28	0.16	9522	0.71	1.28	0.04	50.10	12.37	4841	1.66
Treatments	24	99.25	12.62**	53978	3.99**	37.35	1.13	57.94	14.34**	48321	16.60**
Error	24	7.86		13507		33.11		4.04		2911	

Exogenous application of growth substances
Field experiments (Extracts of analysis of variance)

Source of variability	df	Number of productive tillers		Number of young tillers		Height of productive tillers		Total leaf area		Number of panicles		Length of panicles		Number of racemes per panicle	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Replications	4	232.33	3.06	81.08	1.91	154.33	1.17	398887	3.16	207.05	2.18	110.00	2.17	9.13	1.01
Treatments	5	40.00	0.53	265.50	0.87	816.83	1.27	116665	0.92	206.80	2.14	218.05	4.31**	33.49	3.68**
Error	20	75.93		304.48		643.53		126284		96.15		50.72		9.09	

(contd..

Exogenous application of growth substances
Field experiment (contd.)

Extracts of analysis of variance

Source of variability	df	Number of flowers per panicle		Total flowers per clump		Per cent capsule setting		Per cent capsule drop by total flowers		Per cent capsule drop by set fruits		Yield of capsules by fresh weight		Per cent thrips infestation		Per cent essential oil	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Replications	4	99.20	0.87	115902	1.31	7.21	0.37	2.97	1.09	12.12	2.37	141954	1.20	9.77	1.41	2.98	4.01
Treatments	5	760.20	** 6.68	575533	** 6.50	195.80	** 9.95	94.94	** 35.08	191.31	** 37.54	858630	** 7.27	119.97	** 17.36	1.63	2.20
Error	20	113.82		88535		19.68		2.71		5.10		118134		6.90		0.74	

** Significant at 1 % level

APPENDIX VII

Nutrient status of cardamom plants at different stages of crop growth
(Extracts of analysis of variance)

		N		P		K		Ca		Mg	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Leaves	1	0.46	23.82**	0.000005	0.003	0.34	3.37*	0.19	14.42**	0.05	38.79**
	2	0.87	44.66**	0.0109	6.770**	0.71	7.11**	1.41	106.95**	0.09	69.92**
	3	0.07	3.79**	0.00077	0.475	0.16	1.59	0.06	4.86**	0.003	2.72*
Pseudostems	1	0.09	5.03*	0.009	0.454	1.58	10.91**	0.72	42.43**	0.07	5.59**
	2	0.61	31.34**	0.007	0.343	2.35	16.26**	0.75	44.31**	0.14	65.18**
	3	0.04	2.12	0.018	0.890	0.18	1.25	0.07	4.09	0.006	2.88
Rhizomes	1	0.12	7.87**	0.028	20.88**	5.36	31.19**	0.41	37.54**	0.02	4.25*
	2	0.42	26.82**	0.029	21.96**	4.21	24.68**	0.09	8.59**	0.54	109.89**
	3	0.04	2.40*	0.001	0.79	0.43	2.51*	0.004	0.41	0.01	2.63*
Roots	1	0.32	12.17**	0.006	5.77**	1.14	15.60**	0.02	0.93	0.02	15.76**
	2	0.08	3.89*	0.012	11.74**	1.54	20.99**	0.68	26.42**	0.23	146.31**
	3	0.04	1.37	0.001	1.12	0.21	2.82*	0.009	0.37	0.03	18.62**
Panicles and capsules	1	0.04	0.75	0.008	7.56**	0.14	0.62	0.41	22.56**	0.32	50.21**
	2	0.31	5.92**	0.023	22.79**	2.02	8.81**	1.06	59.23**	0.77	121.98**
	3	0.09	1.81	0.0006	0.60	0.33	1.44	0.08	4.65**	0.03	5.19**

APPENDIX VII (Contd.)

		S		Fe		Zn		Mn		Cu	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Leaves	1	0.0009	5.41*	3035.36	13.005**	192.76	10.15**	61125.59	138.16**	636.12	54.66**
	2	0.0082	45.44**	792.41	3.39*	585.58	30.83**	305916.27	691.46**	1511.04	129.84**
	3	0.0005	2.91*	333.91	1.43	29.98	1.58	16473.18	37.23**	132.69	11.40**
Pseudostems	1	0.00126	16.29**	2754.22	11.49**	273.28	13.05**	64075.27	61.56**	74.07	20.13**
	2	0.00204	26.32**	482.03	2.05	1271.89	60.74**	189570.96	182.13**	181.008	49.19**
	3	0.00006	0.75	148.47	0.63	189.71	9.06**	15958.22	15.33**	21.24	5.77**
Rhizomes	1	0.0073	14.72**	4159.09	9.53**	3628.21	71.47**	34375.67	26.39**	70.33	3.74*
	2	0.0026	5.28**	3932.94	9.04**	3114.59	61.36**	196144.65	170.38**	2876.68	153.13**
	3	0.0002	0.34	205.39	0.47	472.48	9.31**	59913.47	52.04**	68.07	3.62*
Roots	1	0.0003	5.30*	1480.27	4.62*	1382.41	38.09**	58116.09	48.26**	1014.59	120.77**
	2	0.0021	43.88**	172.59	0.54	316.04	8.71**	138976.56	115.39**	141.26	16.82**
	3	0.0002	5.03**	116.91	0.36	598.11	16.48**	30069.18	24.97**	31.82	3.79*
Panicles and capsules	1	0.0038	8.57**	2342.29	17.49**	617.11	13.92**	94864.19	275.88**	422.36	66.85**
	2	0.012	27.72**	2765.36	20.65**	2879.88	64.94**	121339.67	352.85**	100.34	15.88**
	3	0.0008	1.79	168.54	0.26	183.12	4.13**	5688.19	16.54**	72.73	11.51**

1 Cultivars 2 Growth stages 3 Interaction

* Significant at 5 per cent level

** Significant at 1 per cent level

APPENDIX VIII

Radiotracer experiments
(Extracts of analysis of variance)

Rate of photosynthesis at different intervals of a day

Source of variability	df	MSS	F ratio
Treatments	9	45344583	328**
Error	20	138221	

Photosynthetic efficiency at different canopy levels (detached leaves)

Source of variability	df	MSS	F ratio
Treatments	9	3603403	0.56
Error	30	6399015	

Photosynthetic efficiency at different canopy levels (intact leaves)

Leaf positions

Source of variability.	df	1		2		3		4		5		6		7		8		9	
		MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio	MSS	F ratio
Treatments	14	16813451	6579**	10122422	4442**	15871699	338**	18155402	2110**	9609118	2282**	5341015	1246**	2956802	504**	5109691	1151**	5745467	1240**
Error	30	2556		2279		4707		8605		4210		4287		5866		4441		4634	

Source of variability	df	10	
		MSS	F ratio
Treatments	14	10651748	2933**
Error	30	3632	

Mobilization of photosynthates at different periods of crop growth

Source of variability	Floral initiation			Flower bud stage			Peak flowering stage			Capsule maturity stage			Post-harvest stage		
	df	MSS	F ratio	df	MS	F ratio	df	MSS	F ratio	df	MSS	F ratio	df	MSS	R ratio
Treatments	14	28499644	558**	13	13070285	224**	13	93836121	248**	13	52717179	602**	20	143725493	769**
Error	28	51040		34	594543		38	378332		40	87519		42	186930	

** Significant at 1% level

ABSTRACT

Investigations were carried out at the Cardamom Research Station, Pampadumpara and at the College of Horticulture, Vellanikkara during 1982 - '84 to gather information on the physiological factors governing flowering, fruit set and capsule development of the three popular cardamom cultivars, Malabar, Mysore and Vazhukka. Emphasis had been given to unravel the causes of fruit (Capsule) shedding so as to evolve methods of control.

Studies on growth and development in a broad sense depicted that an individual tiller of cardamom had a biennial growth habit. The different aspects of flowering and fruit set studied, indicated that the variability was high in the Vazhukka cultivar and low in the Mysore cultivar. An early crop bearing habit was exhibited by Malabar, whereas Mysore possessed a late bearing habit and Vazhukka exhibited varying trends. The percentage of fruit set was high in Vazhukka, followed by Malabar and Mysore.

Influence of climatic components on the physiology of flowering showed that a distinct dry spell triggered the panicle initiation process. The onset of rain coupled with high temperature was congenial for flower opening. A high soil moisture status combined with a high status of relative humidity (which resulted from a well distributed rainfall) enhanced the setting of capsules.

Histological studies conducted in the genotype PV-1 (Malabar) showed that differentiation of panicle primordia was more during November to March. A prominent vascular zonation was observed in the rhizome nodes prior to the initiation of panicle promordia. Histology of the seeds revealed the development of starch grains at the greenish-yellow seed stage.

Biological assays for endogenous auxins, inhibitors and cytokinins in the developing capsules indicated a spurt in auxin and cytokinin activity preparatory to fruit set. The level of inhibitory substances rose after the fruit set stage, while that of auxins fell which favoured the formation of an abscission zone causing shedding of immature capsules.

Exogenous application of NAA(40 ppm) and 2,4-D(4 ppm) increased the plant height, enhanced the production of panicles and flowers, reduced dropping of immature capsules and increased the yield.

The uptake of nutrients revealed that cardamom is a heavy feeder of potash. The Vazhukka and Malabar cultivars depleted less nutrients than the Mysore cultivar for producing unit yield of capsules.

Radiotracer studies showed that the photosynthetic efficiency of cardamom was more under low light intensities. The rhizome was found to be the main sink in a cardamom tiller.

Gas chromatographic estimation of cardamom oils indicated that the Mysore genotype (PR-107) was superior in quality aspects (because of high content of the esters, alpha terpenyl acetate, geranyl acetate and linalyl acetate) when compared with the Vazhukka genotype (PV-5) and Malabar genotype (PV-1). For consumption as a spice as well as for distillation of the essential oils, the black seed stage ('karimkai') was the most ideal stage in cardamom.