VEGETATIVE, FLORAL AND FRUIT CHARACTERS IN MANGOSTEEN

(*Garcinia mangostana* L.)

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Science in Horticulture

Faculty of Agriculture

KERALA AGRICULTURAL UNIVERSITY

Department of Pomology and Floriculture

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR

KERALA, INDIA

1996

DECLARATION

I hereby declare that the thesis entitled '**Vegetative, floral and fruit characters in mangosteen (*Garcinia mangostana* L.)**' is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship, associateship or other similar title of any other university or society.

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CERTIFICATE

Certified that the thesis entitled '**Vegetative, floral and fruit characters in mangosteen (*Garcinia mangostana* L.)**' is a record of research work done independently by **Mr.Ajay Alex.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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CERTIFICATE

We, the undersigned members of the Advisory Committee of **Mr.Ajay Alex**, a candidate for the degree of **Master of Science in Horticulture**, with major in **Pomology and Floriculture**, agree that the thesis entitled **'Vegetative, floral and fruit characters in mangosteen (*Garcinia mangostana* L.)'** may be submitted by **Mr.Ajay Alex**, in partial fulfilment of the requirement, for the degree.

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ACKNOWLEDGEMENT

At this moment of fulfilment, my heart is overwhelmed with gratitude and I wish these words convey the feeling at present. My gratefulness and personal obligation go without any reservation to **Dr.Sarah T. George**, Assistant Professor, Department of Pomology and Floriculture. I, with immense pleasure, express my deep sense of gratitude and indebtedness to her for the inspiring guidance, timely and valuable suggestions, unreserved help and immense patience rendered throughout the course of my work. It is her empathetic approach that made me complete the Master's Degree Programme successfully.

I wish to extend my cordial thanks and sincere gratitude to **Dr.P.K.Rajeevan**, Professor and Head i/c., Department of Pomology and Floriculture, for the valuable help and criticisms given by him during the course of my investigation and preparation of thesis.

I sincerely acknowledge the relevant suggestions which I have received from **Dr.Lyla Mathew, K.**, Associate Professor, Department of Pomology and Floriculture. Her critical apraisal and expert guidance enabled me to prepare this piece of research work in time.

The expert and timely help received from **Dr.K.K.Ibrahim**, Assistant Professor, Department of Plant Breeding and Genetics, is thankfully acknowledged.

It gives me great privilege to express my deep sense of gratitude and appreciation towards Dr.Luckins C. Babu, Associate Professor, College of Forestry

for his whole hearted cooperation and enchanting encouragement throughout the period of investigation.

With immense delight that I acknowledge my appreciation to Dr.Mukthesh Kumar, Scientist, KFRI and Dr.Sajan Kurien, Assistant Professor, Department of Pomology and Floriculture for their valuable suggestions during the period of investigation.

I am also thankful to all the staffs and members of the Department of Pomology and Floriculture for their whole hearted cooperation during the investigation.

I extent my profound thanks to my friends, Messrs.Arumugha Prasad, Sunilkumar, K.K., Jidesh, Ajaykumar, Dhanesh, Sunilkumar, Sudheesh, Jimmy, Ajith and Ms.Sherly, Ms.Samita and Ms.Suja Thomas who were cooperative and supportive during the course of my study.

I further express my thanks to Mr.Joy for his commendable care and labour put in, to do this mundane typing work elegantly.

To my parents, family members, classmates and friends, I owe my profound gratitude as they helped me in more ways than one, in the successful completion of the endeavour.

Above all I submit this small venture at the foot of the Almighty.

AJAY ALEX

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Introduction

INTRODUCTION

Mangosteen has been considered as the most delicious fruit of the tropics and, as such, has been called 'the queen of fruits' (Fairchild, 1915) or the 'finest fruit of the world' (Dahlgren, 1947). Mangosteen (*Garcinia mangostana* L.) is one of the tropical fruit tree species that has not been researched much and has been listed as a tropical plant with promising economic value (Almeyda and Martin, 1976).

Mangosteen is indigenous to Malay Archipelago (Burkill, 1935), but the present distribution stretches from Southern India through the Malaysian region to as far as the Philippines. In India, its cultivation has been attempted in many regions, but so far, it has successfully been established only in South India on the lower slopes of Nilgiris, between 1200 and 3500 ft above mean sea level and near Courtallum in Tamil Nadu. However, mangosteen being a tropical tree adapted to regions of heavy and well distributed rainfall come up well in Kerala. Though it grows well in Kerala, its potential remains unexploited as the tree is not generally cultivated at an orchard level and is often seen neglected as a miscellaneous crop in the backyards of homesteads.

It is a tall growing evergreen tree with large shining leaves. Fruits are the size of cricket ball, green when unripe and purple when ripe. The fruit has a hard rind as the outer covering of the soft internal segments. The sweet muscillagenous pulp white in colour covering the seed is the edible part. The pulp is very delicious with an attractive flavour and has medicinal properties. Powdered dry rind is good for the treatment of diarrhoea, dysentry and cystitis. The active principle is

mangostin which accounts for the putative efficacy of this fruit in botanical medicines. The rind is also used in the form of a paste in the treatment of itch, eczema and other skin infections.

The mangosteen is unusual in many ways. It produces the fruits parthenocarpically, the establishment of seedlings is very poor and the roots of the plant do not possess any root hairs. Propagation is usually done by seedling, but it takes 10-15 years for fruiting. The serious drawbacks of this delicious fruit are the huge size and the long prebearing period of the trees and the physiological disease called gamboge.

Mangosteen does not exist in the wild state (Richards, 1990). The plants are said to be uniform and is an unusual case in which there is narrow diversity in the cultivated species. There has been severe genetic erosion of mangosteen in South East Asia. Wolf (1987) is of the view that mangosteen is one of the tropical fruits on the brink of extinction and has emphasised the need for conserving the available diversity. General awareness on the importance of this fruit is meagre and scientific studies on various aspects of the crop is scanty. It presents excellent opportunities for the development of new commercially acceptable types. The development of mangosteen has been hindered by its asexuality but it may prove possible to hybridise mangosteen with a number of its partially sexual relatives. In a crop like mangosteen, the development of hybrids by controlled sexual crosses and the subsequent genetic fixation of new varieties apomictically may prove to be an advantageous breeding strategy.

Many problems remain unanswered concerning the detailed elucidation of the reproductive biology of *Garcinia mangostana*. More basic information on

growth, floral and fruit characters is to be gathered for commencing with any improvement work in the crop. The present investigations have therefore been undertaken with a view to understand the growth habit, phases of growth, flowering, floral biology, fruiting, fruit characters, storage and germination of the seed under humid tropical conditions.

Review of Literature

2. REVIEW OF LITERATURE

Garcinia L. is a large genus of evergreen trees or shrubs which belongs to Guttiferae (Clusiaceae), the family named after the many species producing resinous gum. Anderson (1875) reported that the family is tropical with 24 genera and 250 species commonly found in Asia and America and rare in Africa. Bentham and Hooker (1894) described 5 tribes - Clusiae, Moronobeae, Garciniae, Calophyllus and Qucineae in the family Guttiferae. They described 36 species, including *Garcinia mangostana* under the tribe Garciniae. Whitemore (1973) opined that the genus *Garcinia* originated in the old world tropics, especially in Asia and described it as the biggest genus in the family with about 400 species. Majeed (1992) described several species of *Garcinia* viz., *G. handburyi, G. cambogia, G. indica, G. mangostana, G. humilis, G. livingstonei* which are economically very important. *G. hanburyi* (synonymous with *G. morella*), often called the Gamboge tree, is the primary source of resin, gamboge whereas *G. cambogia* and *G. indica* are the exclusive sources of citrin.

Being regarded as a minor fruit not much studies have been conducted in this crop on different aspects, viz., growth, flowering, fruit set, fruit development etc. Literature pertaining to these aspects in other crops which are relevant to the present investigation and the available reports in *Garcinia* are reviewed here.

2.1 Growth studies

The importance of growth studies in relation to flowering and fruiting of deciduous fruit trees was evident from earlier works of Gustafon (1926), Reed

(1929), Barnard (1932) and Mc Munn (1939). Later the relationship between vegetative growth and fruiting were studied in different tropical and sub-tropical tree crops like mango, jack, guava, sapota, annona, citrus, nutmeg etc.

Singh and Khan (1939), Naik and Rao (1942), Roy (1953), Singh (1959), Krishnamurthy *et al.* (1961) and Reddy (1983) have reported different periods of primary and extension growth in mango depending upon the variety and environmental conditions under which they are grown. The growth behaviour of mango is described as cyclic with five cycles of growth during the course of one year. Among the five flushes, March flush was more important both in intensity and duration (Naik and Rao, 1942 and Krishnamurthi *et al.*, 1961). Paulas (1964) studied the growth and flowering of different classes of shoot in a number of mango varieties and observed that flowering occurs in past season's shoot and early cessation of growth was found to be necessary for a successful flower crop in the following season.

Halma and Compton (1936), Krishnamurthy *et al.* (1960), Randhawa and Sinha (1963) and Singh and Ghose (1965) had given a detailed account of the cyclic growth behaviour of citrus shoot and root.

It is reported in sapota that the growth commences with the onset of monsoon rains in June and ceases in early summer (Sundararajan, 1961).

Growth studies undertaken in many guava varieties showed two definite seasons of growth flushes and flowering. Three classes of shoots were recognised in guava, viz., shoots which produced flowers and ceased growth, shoots which continued producing flowers and shoots purely vegetative (Aravindakshan, 1960).

The investigations carried out in bael (*Aegle marmelos*) showed only one flush of growth each year, vegetative and reproductive shoots emerged simultaneously in the second half of May after leaf fall (Singh, 1986).

Bourdeaut and Moreuil (1970) reported production of three vegetative flushes in mangosteen from Malagasy republic. A detailed study on kodampuli (*Garcinia cambogia* Desr.), related species of mangosteen, showed that shoot growth is seasonal with one main flushing period commencing from January and extending upto May. However, scattered flushes occurred throughout the year with mean growth varying significantly from month to month and having a peak during the summer months (Sherly, 1994).

2.2 Sex forms

The existence of male and hermaphrodite flowers in mangosteen were reported by CSIR (1948) and Veeraragavathatham and Balashanmugham (1989). Krishnamurthy *et al.* (1964) had reported female trees with staminodes. Mangosteen was reported to be unisexual and dioecious, but only female trees with infertile staminodes had been found in Malaya and Jawa (Purseglove, 1969). Richards (1990) observed mangosteen to be invariable and almost all being female. He suggested mangosteen as an allopolyploid derivative of *Garcinia hombroniana* and *G. malaccensis* which arose as a female from a single hybridisation event in cultivation, and which has since reproduced asexually.

Gunjate *et al.* (1982) identified nine flower types in *Garcinia indica* based on structural differentiation and classified the trees according to their bearing

tendency, flower types and morphological differentiation into three types, viz., male or staminate, hermaphrodite or bisexual and pistillate or female.

George *et al.* (1992) and Sherly (1994) described *Garcinia cambogia* as androdioecious with male and bisexual flowers occurring in separate trees.

2.3 Flower production and blossom studies

Very little work has been done on flower characters and floral biology of mangosteen. However detailed investigations in these aspects were carried out in fruit trees like mango (Singh, 1960), jack (Joseph, 1983), sapota (Sandhu *et al.*, 1987), nutmeg (Nazeem *et al.*, 1981), tamarind (Thimmaraju *et al.*, 1977) and cashew (Shivanandam *et al.*, 1986). The literature pertaining to the investigations under taken in mangosteen and its related species are given below.

2.3.1 Flowering pattern and floral biology

Chandrarathna (1948) reported that *G. morella* flowers in May. Two main seasons of flowering, viz., March and November were reported in *G. livingstonei* (Devivedi and Bajpai, 1974).

Krishnamurthi *et al.* (1964) had described two main seasons of flowering in mangosteen, the seasons being April to May and October to November. Flowers of mangosteen were borne terminally on branchlets, 5-6 cm in diameter, sepals 4 in 2 pairs, inner pair reddish, petals 4, yellowish, edge red, falling early, ovary 4-8 celled, stigma sessile with as many lobes as cells of ovary (Purseglove, 1969). Veeraragavathathan and Balashanmugam (1989) had described male flowers in mangosteen borne in 3 to 9 flowered terminal fascicles.

In kokam (*Garcinia indica)*, the flowers were reported to be terminal or fascicled having 2 to 8 buds. Flowers were described as tetramerous and hypogynous. The calyx was sepaloid consisting of four sepals arranged in decussate pairs, the inner pair being broader than the outer one. The corolla consisted of four petals slightly larger than sepals and yellow to pink coloured dorsally and dark pink coloured ventrally. Anthers of male flower were oblong, sessile on short thick filaments, adnate, four celled and very rarely in two tufts around the pistil. Stigma was sessile radiate, each ray with two lines of tubercles. Ovary was 2 to 8 celled and the placentation being axile. The bisexual flower had long pedicel, four tufts of stamens surrounding the pistil. The stigma of bisexual flower was sessile or subsessile. The bisexual flower was morphologically similar to female flower (Gunjate *et al.*, 1982).

In kodampuli (*G. cambogia*), the flowering season of both male and bisexual trees had been found to be from January to April. In male trees, flowers occurred as cymose inflorescence and bisexual flowers of hermaphrodite trees were borne singly or in groups. Both male and bisexual trees of kodampuli had flowers with four sepals and four petals each arranged imbricately. In male flowers numerous two celled anthers were seen on short filaments. In the case of bisexual flower 6-20 stamens, often sterile, were found surrounding the ovary which was two celled with 6-10 stigmatic lobes (George *et al.*, 1992; Sherly, 1994).

2.3.1.1 Anthesis and anther dehiscence

The anthesis time of both male and female flowers of *G. indica* was reported to be between 0600 hr and 0800 hr. Anther dehiscence occurred 15-20 minutes before anthesis (Karnik and Gunjate, 1984).

Sherly (1994) reported that in kodampuli anthesis time of both male and female flowers was between 1630 hr and 1830 hr. Anther dehiscence occurred 10 hours prior to anthesis.

2.3.1.2 Stigma receptivity

Heslop and Shivanna (1977) observed two types of stigma in angiosperms. These included those stigma which were dry at maturity having no free flowing secretion and those which remained wet bearing such a fluid in the receptive stage. Sporophytic self incompatibility was associated with dry papillate stigma. Trinucleate pollen not readily germinating *in vitro* tend to be associated with dry stigma while wet stigma forms having binucleate pollen easily germinated in liquid or semisolid media.

Stigma receptivity was maximum on the day of anthesis in *G. indica* (Karnik and Gunjate, 1984). In *G. cambogia* stigmatic receptivity was found to be maximum 12 hours before anthesis (Sherly, 1994).

2.3.2 Pollen studies

The science of pollen and spores has attracted the attention of research workers due to its great significance in palynological studies to taxonomists and paleontologists. It also helps in the elucidation of radiation effect (Brewbacker, 1959), facilitates classification of angiosperms (Wodehouse, 1935), helps to identify the disputed varieties or species (Nair, 1960), and provide evidence for distinguishing the amphidiploid and amphihaploid interspecific hybrids (Hossain *et al.*, 1990).

The storage and germination of pollen grains play an important role in assisted pollination and hybridisation programme.

2.3.2.1 Pollen production

Pollen production studies had been reported in fruit crops like sapota, papaya, pomegranate (Rao and Khader, 1962), Guava (Nair *et al.*, 1964) and in Varikka and Koozha types of jack by Joseph (1983)

In kokam pollen grain production per anther was estimated to be 3640 in male and 3603 in hermaphrodite flowers (Karnik and Gunjate, 1984). Sherly (1994) estimated pollen grain production per anther in 'kodampuli' to be 1394 in male and 162 in bisexual flowers.

2.3.2.2 Pollen viability

The extent of pollen viability is of vital importance in hybridisation work. Stanley and Linskens (1974) suggested various methods for testing the viability of pollen grains, including both germination and nongermination assays.

(a) Stain test

Stains which give colour to viable pollen is often used as indices of viability. Lim (1984) reported that in mangosteen pollen grains failed to stain in one per cent to 2, 3, 5 triphenyl tetrazolium chloride. High pollen stainability was found in male flowers of *Garcinia forbesii* (92.5%), *G. forbesii* (85%) and *G. corymbosa* (99.4%). But staminodes of structurally hermaphrodite flowers of *G. parvifolia* failed to take stain (Ha *et al.*, 1988). Sherly (1994) observed that 66.90 per cent pollen of male flowers took stain in acetocarmine where as only 23.47 per cent pollens of bisexual flowers took stain in the case of *Garcinia cambogia*.

(b) Germination tests

Germination tests are reported to be more accurate than stain test in assessing the pollen viability. Singh (1961) reported 25 per cent sucrose and 0.5 per cent agar concentration for pollen germination in the case of mango. Five per cent sucrose solution was found to be optimum for nutmeg (Bavappa and Banda, 1981). In kodampuli, Sherly (1994) observed maximum percentage of germination of pollen grains in four per cent sucrose at 0.5 per cent agar level.

Boric acid at a concentration ranging from 1 to 10 ppm was found to be a stimulant to pollen germination and tube growth (Schumucker, 1932). Resnik (1956) in citrus reported a 10 to 15 per cent increase in pollen germination by the addition of boric acid at concentrations ranging from 10 to 100 ppm. In kodampuli it was seen that boric acid enhanced both pollen germination and tube growth irrespective of sucrose concentrations. The maximum percentage of germination was obtained for treatment combination of four per cent sucrose and 75 ppm boric acid (Sherly, 1994).

The influence of calcium nitrate on pollen germination and tube growth was reported by various workers. Kwack and Brewbacker (1963), Kwack (1965), Ravindran (1977), Nazeem (1979) etc. have revealed the essential role of calcium in pollen germination and tube growth. However, Sherly (1994) reported that in kodampuli calcium nitrate had reduced the pollen germination drastically at all concentrations of sucrose.

2.4 Pollination and fruit set

Riabove (1930) has given a most comprehensive survey of literature on the pollination of trees containing about 800 references. He stressed the possible influence of environment on modes of pollination and physiological conditions of plant on fruit set.

High flower production could not be taken as an index for estimating the final crop yield in most of the horticultural crops. The fruit set and not the flower production was found to have a great bearing upon the yield in most crops. Inadequate pollination or condition existing after pollination were reported as one of the main reasons responsible for poor fruit set in mango (Mukherjee, 1953). Mukherjee (1949) and Singh (1954) have reported that ultimate set in mango as one per cent. In jack, Saha (1970) found that the age of branch affected fruit set. A male, female ratio of 1:10 was reported to be required for successful pollination in nutmeg being dioecious in nature (Cruickshank, 1973). Sherly (1994) described *Garcinia cambogia* as an often cross pollinated crop. She observed that hand pollination with pollen from male flowers increased the percentage set to 74.00 from 42.50 under open pollinated condition and 31.00 under self pollinated condition.

Parthenocarpic fruit development had been reported in *Zizyphus jejuba* (Lyrene, 1983) and pear (Ludnikova, 1986 and Samorodov *et al.*, 1987).

Parthenocarpy and apomixis in mangosteen had been suggested by Lim (1984). Singh (1985) also reported parthenocarpic fruit set and fruit development in mangosteen. Parthenocarpy and parthenogenesis had also been reported by Ha *et al.* (1988) in *Garcinia parviflora*. Rajput and Syamal (1993) reported vegetative or

autonomic parthenocarpy (Parthenocarpy arises without any stimulation) in crops like banana, pineapple, Washington Navel orange etc. and stimulative or aitionomic parthenocarpy (Parthenocarpy arise from external stimulus such as pollination and fruits develop owing to liberation of auxin by enzymes in pollen and pollen tube) in Black Corinth grape.

2.5 Fruit development and harvest index

Reports from Indonesia showed that in mangosteen the maximum physical growth of fruit reached at 103 days from full bloom, when pulp acidity attained its highest value and there were red patches on the skin. Soluble solid content in the pulp increased with increasing days from full bloom until the skin became purple and fruit ripened on the tree (114 days) (Sosrodiharjo, 1980).

Maturity standard for Kinnow, Srinagar and Emperor mandarins having TSS : acid ratios of 13 : 0, 12 : 7 and 13 : 0, respectively were suggested when the external rind colour became orange in Kinnow and Srinagar and red in Emperor (Bhullar, 1982). In mangosteen sugar content, acidity, sugar:acid ratio and Vitamin C content were 14.3 per cent, 0.46 per cent, 31.3 and 42.3 mg/100 g, respectively at harvest (Daryono and Sosrodiharjo, 1986). Pal (1987) suggested that harvest maturity in mango was attained 120 days after fruit set. In *Garcinia cambogia* fruits attained maturity 130 to 140 days after fruit set. The fruits showed a sigmoid growth pattern during development (Sherly, 1994).

2.6 Chemical composition of fruits

The edible part (31%) of mangosteen fruit is rich in sugars and mildly acidic. Analysis of the edible portion of a sample of fruit gave the following values:

moisture, 84.9; protein, 0.5; fat, 0.1; mineral matter, 0.2; carbohydrates, 14.3; calcium (Ca), 0.01; phosphorus (P), 0.02 on percentage basis and iron (Fe), 0.2 mg/100 g. The pulp from another sample contained organic acids (as anhydrous citric acid), 0.42 per cent, reducing sugars (as invert sugars), 3.86 per cent, and total sugars (as invert sugar), 16.42 per cent. The sugars present are sucrose, glucose and fructose (CSIR, 1948). According to Kay-ming (1990) mangosteen fruit (per 100 g of edible portion) contains water 79.2 per cent, protein 0.5 g, carbohydrates 19.8 g, citric acid 0.63 g, fibres 0.3 g, calcium 11 mg, phosphorus 17 mg, iron 0.9 mg and vitamin A (carotene) 14 IU, B (thiamin) 0.09 mg, B_2 (riboflavin) 0.06 mg, B_5 (niacin) 0.1 mg, ascorbic acid 66 mg. Pankasemsuk *et al.* (1996) reported that mangosteen has soluble solids concentration (19%), titratable acidity, as citric acid (0.38%) and the ratio of soluble solids concentration:titratable acidity (50.0).

2.7 Fruit drop

The abscission of fruits subsequent to bloom or those have developed partially occur in definite waves. Chandler (1925) recognised three waves of abscission in deciduous trees (1) at blooming time or shortly after following pistil abortion (2) two weeks after flowering following failure of fertilization (3) June drop following competition for nutrients and failure of embryo development. Chadha and Singh (1964) recorded three waves of drop in mango i.e., pin head drop, post setting or April drop and unripe fruit drop or May drop. Randhawa (1971) recorded three waves of drop in citrus.

The fruit drop in kodampuli after fruit set was found to be 35.50 per cent. The drop was maximum during the first month after fruit set. The percentage

of fruits harvested to the total number of flowers produced was 27.78 (Sherly, 1994).

2.8 Yield

The bearing in mangosteen is irregular. The yield in the first year of bearing was reported to be 200-300 fruits, gradually rising to 1,200-1,500 fruits a year. Yields vary from year to year and from orchard to orchard depending upon the weather the condition of the soil and the amount of cultivation given. The crop size was found to be adversely affected by relatively large amounts of rainfall and an increased number of rainy days during the pre-blossoming period. Prolonged dry weather preceding fruit set had been reported to favour yield in mangosteen (CSIR, 1948).

Singh (1985) reported an average yield of 200 to 400 fruits per tree in India as compared to 500 to 1,500 fruits per tree in other countries. Kay-ming (1990) observed in Hainan, China, that the average yield from 18-20 years old bearing tree was 23-25 kg indicating that the yield of mangosteen tree is rather low and not stable.

It was found that in mangosteen the total yield/tree was higher in trees grown in the river belts. The trees grown in the rocky terrain were stunted and yield/tree was significantly poor (250 to 500 fruits/tree). On the other hand, an adult healthy tree grown in the riverbelts yielded upto 15,000 fruits/tree (George *et al.*, 1996).

2.9 Storage of fruits

It is reported that mangosteen fruits which require storage and transport should be picked at an almost ripe stage and those free from injury or disease should be selected. Experimental consignments of mangosteen from Burma to England had been kept at a temperature of 50-55°F for extending the storage period to 3-4 weeks. It is also reported that mangosteen fruits can be stored for about 3 weeks at 40-50°F Fruits during storage and transport are liable to fruit rot caused by *Diplodia* sp. (CSIR, 1948). Daryono and Sosrodiharjo (1986) reported that weight loss and percentage of diseased fruit in mangosteen after seven days of storage were 3.3 per cent and 23.9 per cent at ambient temperature and 0 and 11.0 per cent at 5°C. Weight losses and percentage of diseased fruit in fruits kept open, perforated or closed polythene bags were 7.2 per cent and 22.3 per cent, 2.3 per cent and 16.1 per cent and 0.3 per cent and 13.0 per cent respectively. They also observed that cold storage neither caused any chilling injury nor had any adverse effect on fruit quality of mangosteen. According to Kay-ming (1990) fresh fruits of mangosteen can be stored for several weeks under refrigeration and at room temperature (25-30°C) the fruits can be kept for 5-7 days.

Storage studies of pear showed that fruits can be stored for several months at 5°C. Fruits when stored at 18 to 20°C, quality deterioration was rapid with marked softening occurring in 2-6 days. Ascorbic acid content of the fruit during storage decreased by 30-50 per cent from its original level (Millin *et al*, 1982). Pota *et al.* (1987) observed that storage life of pomegranates in sealed poly-ethylene bags at 10°C was extended upto 12 weeks with slight changes in quality such as weight loss, total soluble solids (TSS), titratable acidity (TA) and TSS : TA

ratio but showed symptoms of chilling injury after keeping at 5°C for 10 weeks. When stored in plastic baskets and sealed polyethylene bags under room temperature for one week, those fruits in plastic baskets were severaly shrivelled and those in sealed polyethylene bags were rotten.

2.10 Seed storage and viability

CSIR (1948) reported that seedlings of mangosteen were not truly zygotic since they developed from the embryos which were not produced as a result of fertilisation, but adventitiously on the inner walls of the ovary and mangosteen seeds exhibited slight polyembryony. Duarte (1982) observed that seeds of mangosteen were not zygotic, being formed from nucellar tissues of carpel walls in the fruit and seeds were low in viability, but could germinate in 4-6 days under good nursery management.

In peach seed viability, indicated by seed germination *in vivo* was positively correlated with embryo maturity. Seeds harvested upto 89 days after full bloom failed to germinate *in vivo* but those harvested at 110 days gave 71.9 per cent germination (Chopra *et al.*, 1986).

Muller *et al.* (1991) reported that in mangosteen emergence of seeds held inside the fruits were 99.5 and 65.3 per cent at days 0 and 35 respectively, where as for extracted seeds held in plastic bags these figures were 93.5 and 80.0 per cent respectively.

Materials and Methods

3. MATERIALS AND METHODS

The investigations were carried out on the trees maintained in the orchard, Department of Pomology and Floriculture, College of Horticulture, Vellanikkara, Agricultural Research Station, Mannuthy as well as by the farmers of the nearby locality during the period from April 1995 to July 1996.

Six trees selected were evaluated for growth parameters, flowering habit, floral characters, fruit development and yield attributes. On each tree, the canopy was arbitrarily divided for convenience into four quadrants, considering each aspect, viz., East, West, North and South as a quadrant for recording observations.

3.1 Plant characters

3.1.1 Height of the tree

Height of the tree was measured using the instrument clinometer. The instrument gave direct reading of the height.

3.1.2 Crown area

To determine the crown area the average radius was estimated by measuring the crown diameter using the method adopted by Larson and Zaman (1986). The crowns of each tree were viewed from below and longest axis identified. The two radii of the long axis were measured followed by the two radii in the axis perpendicular to the first axis. The four radii were then averaged. This average radius was then used to estimate the crown area using the formula πr^2.

3.1.3 Girth of the tree

The girth at breast height over bark (1.37 m from the base) was measured using DBH-tape. The measurement was quantified in the standard S.I. system

$$\text{Average diameter at breast height (DBH)} = \frac{\text{Girth at breast height}}{\pi} \text{ cm}$$

3.2 Shoot growth and leaf development

3.2.1 Growth of shoots

One hundred lateral shoots of fourth order on each quadrant were selected at random on individual trees which were tagged and numbered serially during April 1995. The extension growth was measured in centimeter scale at monthly intervals for a period of one year.

3.2.2 Leaf emergence, growth and development

Periodic observations were made on the shoots tagged for the extension growth of shoots to determine the season of flushing. Fifty vegetative buds were tagged at random on the shoots of individual trees to observe the growth pattern of leaves of mangosteen from emergence to maturity. Linear measurements were recorded at 3 days interval during this period.

3.3 Flowering and floral characters

3.3.1 Pattern of flowering

Pattern of flowering was studied by tagging 100 shoots selected at random on each tree. Observations on the number of shoots flowered, nature of flowering shoot and the number of flowers per flowered shoot were made.

3.3.2 Flower bud development

One hundred lateral shoots on each quadrant which were tagged for extension growth studies were periodically examined during flowering season to determine the exact time of visual emergence of flower buds. Progressive stages of flower bud development was studied by labelling and closely watching 100 buds selected on each tree. Buds were tagged immediately after the emergence of bud as a light green protruberance having a pinkish tinge lining. Photographs of developing buds were taken at different stages. Buds were also observed to determine whether any drop of buds occurred upto anthesis.

3.3.3 Floral biology

Studies on various aspects of floral biology, viz., anthesis, anther dehiscence, stigma receptivity and pollen characters were carried out on individual tree. The flowers were described and drawings made.

3.3.3.1 Anthesis

Preliminary observations showed that flower opening takes place in the evening hours. In order to know the exact time of anthesis, 50 mature buds were tagged in the morning and observations were made at half hourly intervals from

15.00 hours onwards. The maturity of the buds was determined from the size of the buds. The experiment was repeated over a period of one week.

3.3.3.2 Anther dehiscence

The period of anther dehiscence was studied by observing 25 buds each at different stages of development. Anthers were examined for dehiscence using a hand lens as well as by observing it under powerful microscope in the laboratory.

3.3.3.3 Stigma receptivity

To determine the receptivity of stigma, stigma was observed periodically for any exudation. Further controlled pollination was done and this was observed for fruit set. Mature buds were emasculated and covered for this purpose. The stigma of these buds were later rubbed with anthers collected from mature buds. This was done at six hourly intervals starting from one day prior to anthesis and continued till one day after anthesis. Twenty five buds were utilized for this purpose.

3.3.4 Pollen studies

Pollen studies with respect to pollen morphology, fertility and germination were carried out. Anthers for the studies were collected from mature buds ready for anthesis. Anthers collected were forced open to get enough count of pollen grains.

3.3.4.1 Estimation of pollen production

The number of pollen per flower was estimated using haemocytometer as suggested by Rao and Khader (1962). Mature buds just prior to anther dehiscence

were collected. Perianth parts were carefully removed and anthers were separated ffom the base of the stigmatic lobes. The anthers were observed under a handlens for non-dehiscence. Hundred such anthers were gathered in small vials and stored in a desiccator over calcium chloride for 4 to 6 hours to facilitate dehiscence. Anthers which failed to dehisce were forced open. To the contents 2.5 ml of water containing 0.05 per cent teepol was added and stirred thoroughly in order to obtain an even dispersion of the pollengrains in the suspension. A drop of the suspension drawn in a fine pipette was transferred to each of the two counting chambers of a Spencer Bright Line Haemocytometer. Each chamber has an area of nine square millimeter ruled into smaller divisions. Each of the four corner square millimeter areas are ruled into smaller divisions. The counting chambers are 0.1 mm in depth so that the volume over one mm^2 is 0.1 mm^3. On this basis, the number of pollen grains per flower can be derived as follows.

The contents of 100 anthers are suspended in a 2.5 ml of solution. Thus the contents of each anther are suspended in 0.025 ml of the solution or 25 mm^3.ls1

If N = average number of pollen grains counted per square and

X = number of pollen grains per anther

N:X = 0.1 : 25

0.1 X = 25 N

X = 250 N

The pollen grains in each of the four corner squares of each counting chamber were counted using low power (10 X) objective of the microscope.

Accordingly ten counts were made examining ten flowers in each case.

3.3.4.2 Pollen fertility

Twenty five well shaped mature buds were selected. To determine pollen fertility pollens from forced open anthers of each bud were collected in acetocarmine (1%) glycerin mixture kept on a slide and covered with a clean cover slip. The slides were kept undisturbed for 30 minutes to allow the pollen grains to take the stain properly, and later examined under the microscope.

3.3.4.3 *In vitro* pollen germination

To determine pollen germination different media were tried. Different concentrations of sucrose ranging from 2 to 25 per cent at different levels of agar such as 0.5, 1.0 and 1.5 per cent were tried .

Effect of boric acid on pollen germination was tested at different levels of sucrose with 0.5 per cent agar. The different levels tried were 0, 2, 4, 6, 8 and 10 per cent in case of sucrose and 25, 50, 75 and 100 ppm in case of boric acid.

Calcium nitrate was also tested to determine pollen germination at different levels of sucrose with 0.5 per cent agar. The different level of sucrose tried ranged from 0 to 10 per cent and in the case of calcium nitrate from 0 to 100 ppm.

3.3.5 Pollination studies

3.3.5.1 Pollinating agents

To study whether any agents are helping in pollination of mangosteen, individual trees were closely observed during flowering season. To trap the insects visiting the flowers during flower opening, flowers in one squaremeter area were

sprayed with insecticide sumicidin 0.1 per cent at 14.00 hours. A muslin cloth was tied below the flowering branches of the tree and suspended to collect the insect which might fall down. Observations were made just after spraying and next day morning. This treatment was repeated on different aspects of the canopy of the trees during flowering season.

3.3.5.2 Mode of pollination and fruit set

To know the mode of pollination, fruit set by four modes of pollination was studied. All the studies were taken up utilising 100 flowers for each experiment. Observations on fruit set was noted 10 days after pollination (DAP).

a) Natural/Open pollination

In order to know the extent of pollination under natural conditions individual flower buds were selected and tagged before anthesis. These were later examined for fruit set and extent of natural pollination was worked out.

b) Self pollination

For knowing the extent of self pollination, individual flowers were selected and covered one day prior to anthesis for preventing any pollen contamination from outside. Covers were removed one day after flower opening and fruit set was recorded.

c) Natural cross pollination

To determine whether any natural cross pollination occurred in mangosteen, flowers were emasculated one day prior to anthesis and left for natural cross

pollination from other flowers of the same tree. The extent of subsequent fruit set was determined by noting down the number of flowers setting fruit.

d) Hand pollination

Flowers were emasculated and covered one day before opening. These flowers were hand pollinated on the next day by rubbing the anthers collected from mature buds against the stigmatic surface of the emascuated flower. Flowers were tagged and observed for fruit set.

e) Parthenocarpic fruit set

To ascertain the parthenocarpic fruit development in mangosteen on individual trees 50 flowers from each aspect of the tree were emasculated one day before flower opening. These emasculated flowers were covered and left unpollinated. Observations were recorded till the harvest of the fruits.

3.4 Fruit development and fruit drop

3.4.1 Fruit development

3.4.1.1 Physical changes during fruit development

Young fruits soon after set were tagged for studying the development stages of the fruit. Hundred fruits were tagged on each tree and observations on length and girth were made using a scale and non-elastic twine. The observations were taken at weekly interval and continued upto harvest stage.

In order to study the changes with respect to physical parameters such as total weight, volume, rind thickness, number and weight of seeds, etc., fruit samples were picked at fortnightly interval commencing from fruit set till harvest and observations were made.

3.4.1.2 Chemical changes of fruit associated with development

Fruit samples were drawn at fortnightly interval from fruit set to harvest and the pulp was subjected to analysis in order to know the chemical composition of the pulp during different stages of fruit development. The fruits were analysed to determine TSS, acidity, ascorbic acid, reducing sugar, non reducing sugars and total sugars. Also sugar acid ratio was determined.

3.4.2 Fruit drop

To know the extent of fruit drop, fruits immediately after set were tagged and observed at monthly interval and fruit drop was recorded in 100 fruits selected at random for these observations.

3.4.3 Harvest index and method of harvest

Harvest index was determined taking into consideration the physical and chemical changes associated with the fruit development and suitable method of harvest is suggested.

3.5. Yield

Number of fruits obtained from each tree during each harvest was recorded to arrive at the total yield from individual tree.

3.6 Sensory evaluation

A sample of 100 fruits from individual trees were subjected to sensory evaluation to determine the taste and juiciness of the fruits.

Fruits were also observed to determine the fruit characters like pulp colour, number of segments, number of viable seeds, colour of rind and percentage occurrence of gamboge.

3.7 Biochemical studies

Fresh fruits after ripening were collected from different trees to assess the quality of the fruits. The methodology followed for the analysis of chemical characteristic is given below.

3.7.1 Total soluble solids (TSS)

Total soluble solids was determined in freshly extracted juice of ripe fruit using Erma hand refractometer range of 0 to 30° brix and expressed in degree brix (A.O.A.C., 1975).

3.7.2 Titratable acidity

Acidity in pulp at ripe stage was estimated as described by Ranganna (1977).

3.7.3 Total sugars, reducing sugars and non reducing sugars

Total sugars, reducing sugars and non reducing sugars were estimated by the Lane and Eynon method as outlined by Ranganna (1977).

3.7.4 Ascorbic acid and ß carotene

Ascorbic acid and ß carotene was determined as described by Ranganna (1977).

3.7.5 Sugar:acid ratio

Sugar:acid ratio was worked out from total sugars and acidity estimated.

3.7.6 Moisture

Moisture content was determined by drying the sample in hot air oven at 60-70°C till two subsequent weights recorded showed no or little difference.

3.7.7 Nitrogen

Nitrogen content was determined by the microkjeldahl digestion and distillation method as described by Jackson (1958).

3.7.8 Phosphorus

The phosphorus content from the diacid extract was determined colorimetrically by the vanadomolybdophosphoric yellow colour method in nitric acid system.

3.7.9 Potassium

The potassium content was estimated by diluting the extract and reading in flame photometer (Jackson, 1958).

3.7.10 Calcium and magnesium

Calcium and magnesium was determined by EDTA titration as described by Hesse (1971).

3.8 Storage studies

In order to understand the optimum storage conditions required for the fruits, fresh ripened fruits were harvested and subjected to different treatments. The various treatments included in the study were

i) T_1 - Shelf life under refrigerated condition (10°C)

ii) T_2 - Shelf life under refrigerated condition (20°C)

iii) T_3 - Shelf life in polythene cover

iv) T_4 - Shelf life in polythene cover + $KMNo_4$

v) T_5 - Shelf life in wooden boxes

vi) T_6 - Shelf life in bamboo baskets

vii) T_7 - Shelf life in cardboard boxes

viii) T_8 - Shelf life in the open

The percentage loss of fruits for each treatment was recorded at four days interval. The percentage loss in weight of fruits for each treatment was determined by recording the weight of fruits at four days interval. The fruits were also subjected to biochemical analysis to determine the chemical changes occurred during storage. The analysis was done for TSS, acidity, total sugars and reducing and non reducing sugars. Sugar : acid ratio at different interval was also determined.

3.9 Seed viability

To determine the seed viability, percentage germination of seeds sown at weekly intervals were recorded. Five seeds were sown in each polythene bag maintaining three replications with total of five polythene cover in each replication.

3.10 Statistical analysis

Data were subjected to statistical analysis wherever it was found necessary as per Panse and Sukhatme (1985).

Results

4. RESULTS

Mangosteen, known as the queen of fruits, is considered to be the most delicious among tropical fruits. Although homesteads of Kerala are endowed with a rich germplasm of mangosteen, being an under exploited fruit crop, no serious attempt has been made so far on the improvement of the crop. The present investigation taken up with the objective of studying systematically the growth habit, flowering pattern, fruit set and fruit development throws light on the basic information on floral and fruit characters which is essential for commencing with any improvement work in the crop. The results of the detailed studies on these aspects are presented in this chapter.

4.1 Plant characters

Data on the plant characters like tree height, diameter at breast height (DBH), crown area and number of primary branches are presented in Table 1.

Tree number T_4 with more number of primary branches (56) recorded a maximum height of 11.80 cm. But DBH and crown area were maximum in tree number T_1 having a height of 9.57 m. Tree number T_3 with a height of 9.90 m had DBH and crown area almost equal to that of tree number T_1. All the plant characters, viz., height, DBH, crown area and number of primary branches were the lowest in tree number T_2.

4.2 Shoot growth and leaf development

4.2.1 Shoot growth

The data on the shoot growth measured as mean monthly extension and

Table 1. Plant characters of different trees

Sl. No.	Tree No.	Height (m)	Diameter at breast height (DBH (cm)	Crown area (m^2)	No. of primary branches
1	T_1	9.57	26.11	58.74	47
2	T_2	7.00	14.33	17.34	40
3	T_3	9.90	25.88	58.39	48
4	T_4	11.80	25.48	51.50	56
5	T_5	10.45	25.86	56.45	50
6	T_6	8.80	24.33	49.85	44

percentage of shoots that showed growth at a time for a period of one year are given in Table 2. The growth in mangosteen is not continuous because shoot growth was not observed throughout the year. The increment in growth was recorded twice in a year, viz., June-August and January-February. The extension in growth during other months of the year was nil. The maximum extension in growth was during the month of July (2.45 cm) accounting for about 35.45 per cent of total growth. Another peak in shoot growth was during the month of February (2.12 cm). This mean growth accounted for 30.68 per cent of the total growth.

The growth in mangosteen coincided with the emergence of new leaves. Thus it is evident from Table 2, that in mangosteen, two seasons of flushing are present corresponding to periods during which extension in growth had been noticed. Out of the six trees observed for growth only five produced two flushes in a year. The tree which putforth new flushes only once showed no growth during the months of January and February.

The percentage of shoots which showed growth in different months did not follow the same pattern as that of mean extension growth (Fig.1). Maximum percentage of shoots showed growth in the month of July (73.40) followed by June (71.5). Though a second peak in extension growth was noticed during the month of February, only 10.50 per cent shoots showed growth during that period suggesting that main season of flushing in mangosteen is during the months of June and July. Ninety per cent of the total shoots that showed growth during the months of January and February were new shoots which did not show any growth during the main season of flushing (June-August). Remaining 10 per cent shoots putforth new growth in both the seasons of flushing.

Table 2. Mean extension growth and percentage of growing shoots at monthly interval

Month		Mean extension growth (cm)	Percentage contribution towards growth	Percentage shoots showing growth
1995	April	0	0	0
	May	0	0	0
	June	1.14	16.49	71.50
	July	2.45	35.45	73.40
	August	0.14	2.02	16.25
	September	0	0	0
	October	0	0	0
	November	0	0	0
	December	0	0	0
1996	January	1.06	15.34	10.40
	February	2.12	30.68	10.50
	March	0	0	0

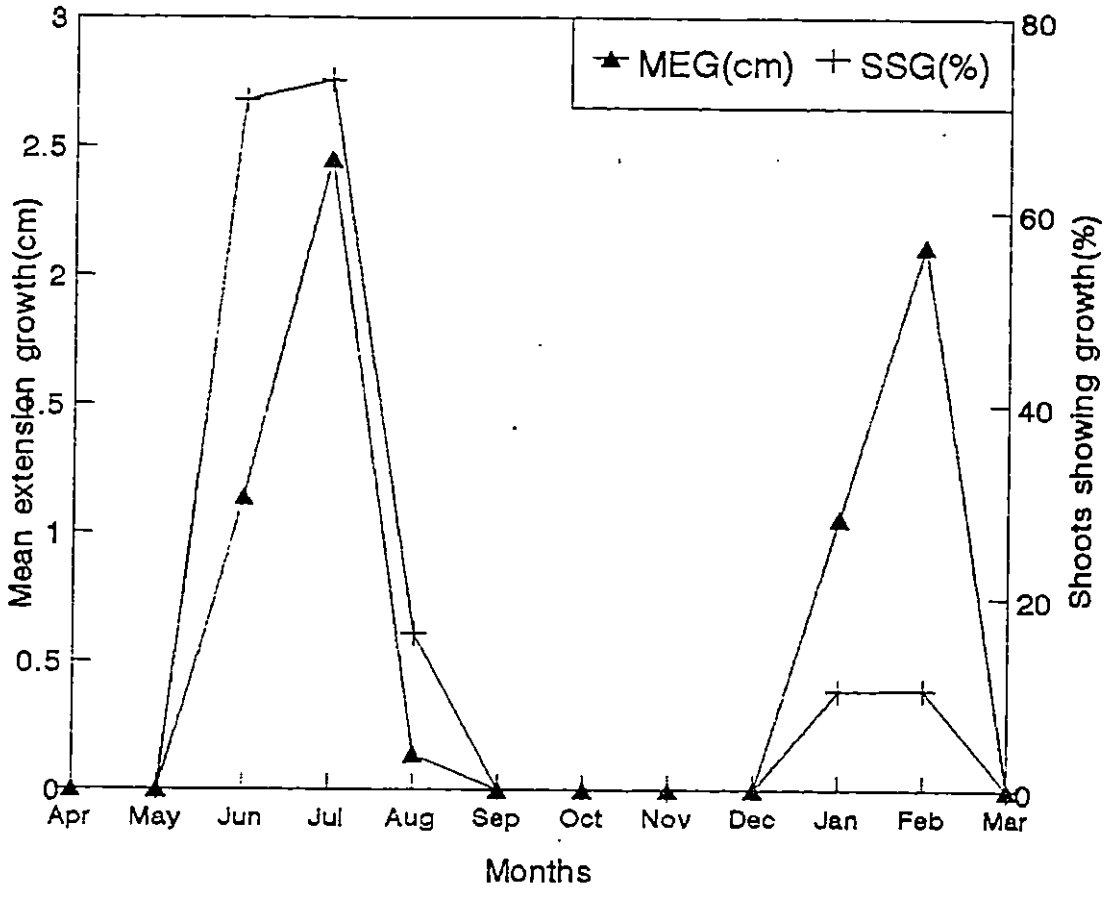


Fig.1. Mean extension growth and percentage of growing shoots over a period of one year

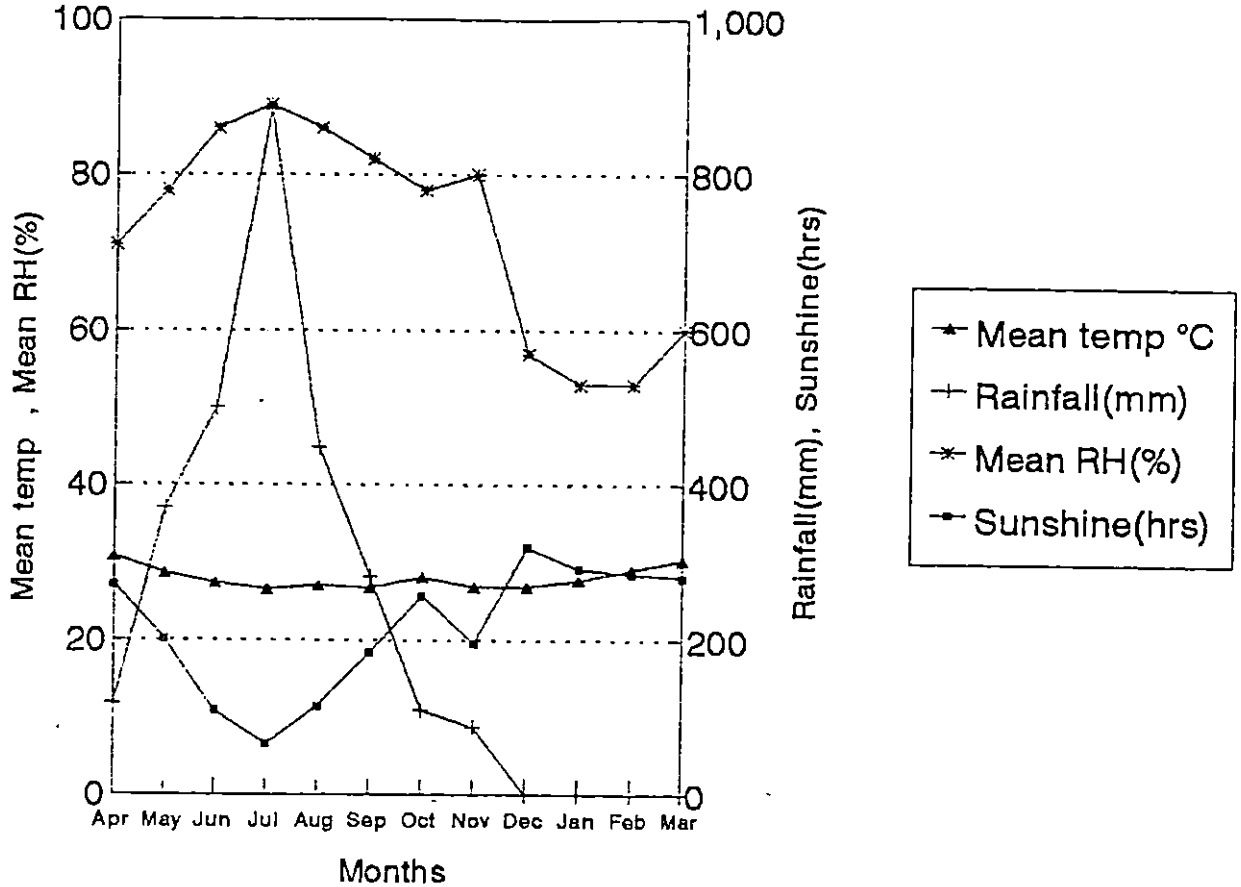


Fig.2.Weather parameters over a period of one year

Data on the mean shoot extension of individual trees and percentage shoots that showed growth over a period of one year are presented in Table 3. The mean shoot growth was maximum in tree T_1 followed by T_5, T_3, T_2 and T_6. The minimum shoot growth was found in the case of tree T_4. The percentage shoots showing growth during the period also varied among individual trees. The percentage shoots which showed growth during the period was maximum for tree T_1 (83.50) and the lowest for tree T_2 (68.00).

The weather data pertaining to the period 1995-96 are presented in Fig.2 and Appendix-I. Data indicated that the maximum and minimum monthly mean temperature ranged from 29.9°C to 36.6°C and 21.3°C to 25.2°C with mean temperature varying from 26.6°C to 30.8°C. A total rainfall of 2804.3 mm was recorded during the period of 12 months with main season of rainfall being the period from June to September.

During the period of main flushing (June-August) the mean monthly temperature ranged between 26.6°C and 27.4°C. The maximum amount of rainfall was during this period accounting to about 65 per cent of the total rainfall received during the year. The monthly relative humidity ranged between 86 and 89 per cent where as effective sunshine hours ranged from 65.6 to 109.6 hours during the period June-August. During the period of second flushing mean temperature ranged between 27.8°C and 29.1°C but the rainfall received during this period was nil. The relative humidity was recorded to be low (53%), but effective sunshine hours was high (286.1-292.7 hours) compared to that of main flushing.

Table 3. Annual growth of shoots in different trees

Sl. No.	Tree No.	Mean annual shoot growth (cm)	Percentage shoots showing growth
1	T_1	8.81	83.50
2	T_2	6.40	68.00
3	T_3	6.85	81.50
3	T_4	3.58	74.00
4	T_5	7.09	80.50
5	T_6	5.40	78.00

4.2.2 Leaf emergence, growth and development

In mangosteen new leaves emerged twice a year, viz., during the months of June-July and January-February. The main season of flushing was during June because more number of shoots produced new leaves, whereas during the period of second flushing (January), only few shoots produced new leaves. Internodal length in mangosteen corresponded to the annual extension growth of shoots. Mostly a pair of new leaves was produced at the end of shoots. But production of two pairs of leaves were not uncommon which indicated the branching of shoots. Rarely three pairs of leaves were produced from the same node which ended up in three branches with leaves at the tip of the shoot.

Data on leaf development are presented in Table 4. It took 27-29 days for the development of leaves from emergence to apparently mature dark green stage (Plate I). The emerging leaves were purplish red in colour. This purplish red colour turned to light green in 9 days and remained as such for the next 12 days, finally changing to dark green colour.

The leaves were simple, opposite and glabrous with broad acute base, acuminate tip, entire margin and prominent veins.

4.3 Flowering and floral characters

4.3.1 Pattern of flowering

Results from the studies on extent of flowering in individual trees are given in Table 5. The percentage of shoots flowered in individual trees ranged from 44-53 with no significant difference among different trees.

Table 4. Changes in linear measurement and colour during development of leaves

Sl. No.	Days after emergence	Length (cm)	Breadth (cm)	Colour
1	at emergence	0	0	Purplish red
2	3	2.6	0.9	Purplish red
3	6	5.5	1.8	Light red
4	9	9.3	3.3	Light red
5	12	12.1	4.1	Light green
6	15	14.4	4.5	Light green
7	18	18.3	6.2	Light green
8	21	20.8	7.4	Light green
9	24	22.2	8.6	Turning to dark green
10	27	23.1	9.5	Dark green
11	30	23.1	9.5	Dark green

Plate I. Colour changes during development of leaves

Plate II. Stages of flower development


Colour changes during
Development of Leaf


Stages Of Development
Of Flowers

Table 5. Extent of flowering in individual trees

Tree No.	Number of shoots observed	Number of shoots flowered	Percentage of total
T_1	400	208	52
T_2	400	176	44
T_3	400	196	49
T_4	400	212	53
T_5	400	204	51
T_6	400	184	46

$X^2 = 2.51$

Period of emergence of flower buds showed variation among different trees. In trees T_1, T_2, T_5 and T_6 flower buds emerged towards the last week of December and period of maximum flower opening was noticed during last week of January. But in trees T_3 and T_4 flower bud emergence was seen during second week of January and period of maximum flower opening during second week of February (Table 6).

Data on the percentage of shoots flowered on different aspects of the individual trees showed no significant difference (Table 7).

4.3.2 Flower bud development

After visual emergence, flower bud passed through a series of morphological changes to reach the anthesis stage. The whole period of flower bud development was divided into six arbitrary stages. The chronological order of these developmental stages and the mean size of the bud in these stages were studied and the data are summarised in Table 8. The size variation during the development of the bud is depicted in Plate II.

Stage-1

The bud seen as a light greenish protruberance had a bilobed tip with a purplish tinge. The buds did not emerge completely. Only bracts were seen protuding outside. No measurements could be taken in this stage and buds continued in this stage for 8 days.

Table 6. Treewise variation in pattern of flowering

Tree No.	Period of visual emergence of flower bud	Period of maximum flower opening
T_1	Last of week of December	Last of week of January
T_2	Last of week of December	Last week of January
T_3	Second week of January	Second week of February
T_4	Second week of January	Second week of February
T_5	Last week of December	Last week of January
T_6	Last week of December	Last week of January

Table 7. Extent of flowering in different aspects of the tree

Tree No.	Percentage of shoots flowered			
	Tree aspect			
	East	West	North	South
T_1	54	48	54	52
T_2	45	44	44	43
T_3	51	46	50	49
T_4	54	51	53	52
T_5	52	49	52	51
T_6	49	44	46	45
Average	50.83	47	49.8	48

$X^2 = 0.40$

Stage-2

The buds emerged out completely having a short pedicel but still seen within the bracts. The buds were 0.65 cm in length and 0.83 cm in breadth with pedicel length of 0.60 cm. The stage was completed in 3 days.

Stage-3

The bracts shed off in this stage completely exposing the outer whorl of calyx. The bud length and breadth increased slightly. The mean bud length was 1.00 cm, breadth 1.15 cm and pedicel length 0.85 cm. This stage lasted for 3 days.

Stage-4

The buds further increased in size and increase was maximum with pedicel length reaching 1.51 cm, bud length 1.80 cm and breadth 1.93 cm. The buds remained in this stage for 12 days.

Stage-5

Outer whorl of calyx separated at the centre and inner pair of sepals were noticed as light greenish yellow in colour. The buds were dome shaped. The bud size increased to 1.95 cm in length, 2.15 cm in breadth and 1.52 cm in pedicel length. Duration of this stage was one day.

Stage-6

Maximum bud size and anthesis were observed in this stage. Pedicel length showed no increase and remained as 1.52 cm where as bud length and breadth increased slightly. Bud length increased to 2.00 cm and breadth to 2.20 cm. In this

Table 8. Duration of different stages and size of the flower bud during development

Stages	Duration of each stage (days)	Mean size of the bud			Nature of bud at each stage
		Pedicel length (cm)	Bud length (cm)	Bud breadth (cm)	
1	8	0	0	0	Bracts seen protruding
2	3	0.60	0.65	0.83	Buds develop inside bracts
3	3	0.85	1.00	1.15	Bracts shed off
4	12	1.51	1.80	1.93	Buds mature in size
5	1	1.52	1.95	2.15	Outer whorl of calyx separates
6	1	1.52	2.00	2.20	Inner whorl of calyx separates

stage inner whorl of calyx separated at the centre, slightly exposing the yellow coloured petals with a tinge of red colour on the margin. It took one day for the completion of this stage and flower opened at the end of this stage. On complete opening of flower scarlet red coloured inner side of the sepal was clearly visible.

Treewise characteristics of flowers showed only slight variation. The average number of days between visual emergence of buds and anthesis was 28 days. Flowers showed a mean spread of 5.33 cm with mean petal length of 2.43 cm and breadth of 2.80 cm. The mean sepal length and breadth of flowers of six trees were 1.66 and 1.93 cm respectively. Sepals were persistant and remained attached to the fruit till harvest where as petals fell off within 24 to 36 hours after anthesis. Trees showed an average flower drop of 8.33 per cent. A higher percentage of flower drop (30) was noticed in tree number T_5. In rest of the trees, though flower drop was noticed it was not much pronounced.

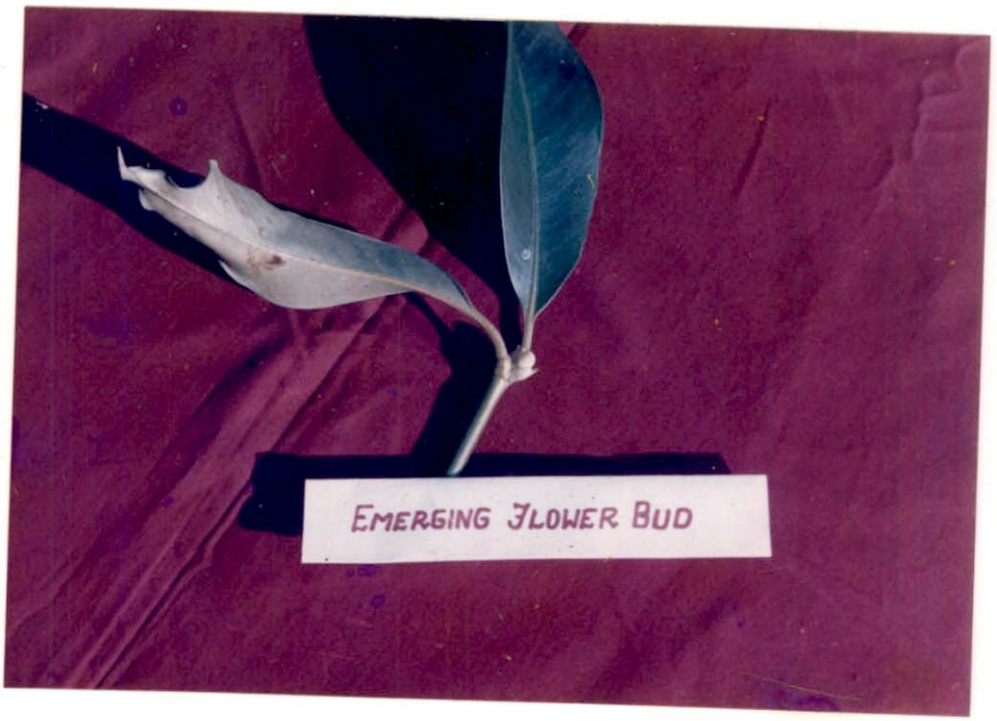
4.3.3 Floral biology

Flowers were produced both on past as well as current season shoots and flowers were borne terminally on branchlets as solitary (Plate III), but rarely in pairs or in groups of three to four (Plate IV). Flowers were massive with succulent floral parts and have got bracts and bracteoles which were cadicuous. The pedicels were erect and short having a mean length of 1.52 cm. Detailed floral biology of flowers are depicted in Plate V.

Calyx consisted of four sepals which were fleshy spatulate with descendingly imbricate aestivation. The sepals when opened were scarlet red coloured internally. Corolla consisted of four fleshy yellow coloured petals with a

Plate III. Emerging flower bud

Plate IV. Group of buds developing from a single node

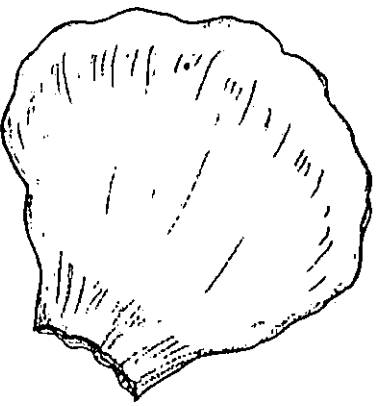

EMERGING FLOWER BUD


Node with more
number of buds

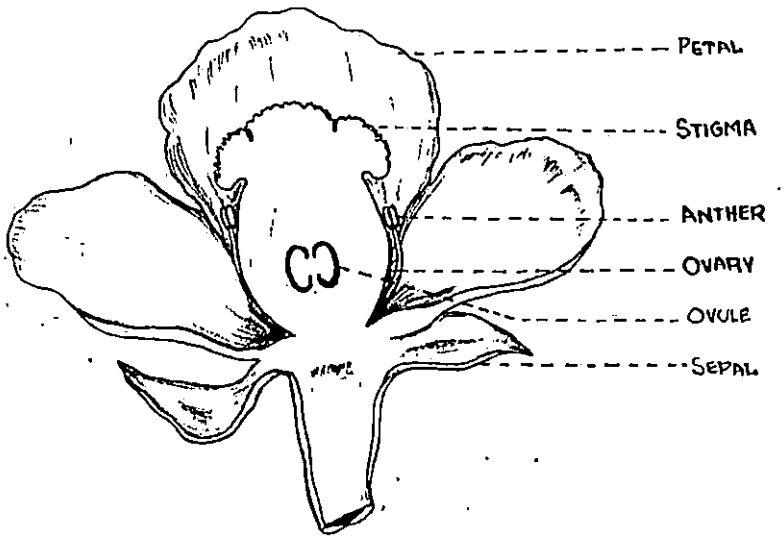
Plate VI. Shoot with opened flower


A FLOWERING SHOOT

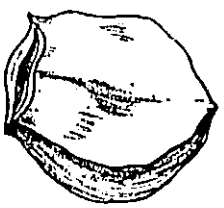
Plate V : Structure of Flower



PETAL

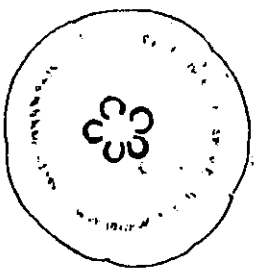


L.S. OF FLOWER

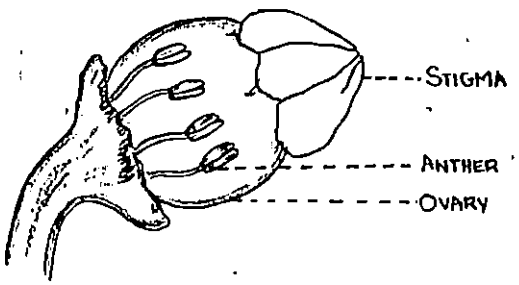


SEPAL

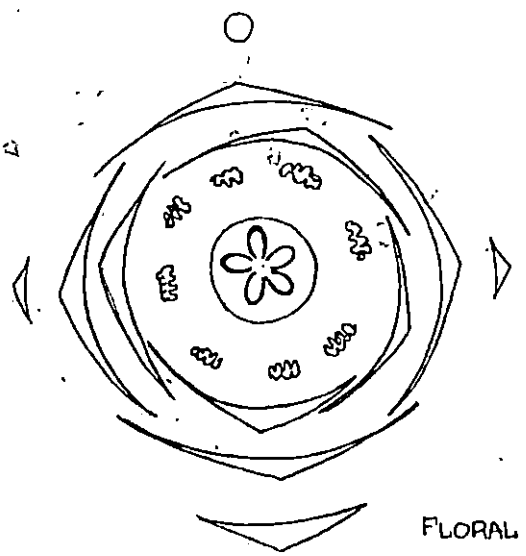
ANTHER



T.S. OF OVARY



PISTIL



FLORAL DIAGRAM

♀ ⊕ K_{2+2} C_4 A 18-20 G(5)

tinge of red and were ascendingly imbricate (Plate VI). Petals fell off 24 to 36 hours after antheses. Androecium consisted of 18 to 20 yellow coloured staminodes produced from thalamus. The connective had been prolonged above the anther lobes to form a hood. Anthers were two celled and introdes. Gynoecium was basically pentacarpillary, syncarpous, with single ovule in each chamber on axile placentation. Number of locules might have increased by the formation of false septa. Style was short and had a five to seven fid capitate stigma at its end.

4.3.3.1 Anthesis

Data on the time of anthesis of flowers of mangosteen taken at half hourly intervals are furnished in Table 9. Anthesis started from 16.30 hours and continued upto 18.30 hours. The peak period of anthesis was between 17.30 hours to 18.00 hours when on an average 52 per cent flowers opened.

4.3.3.2 Anther dehiscence

None of the anthers dehisced until flower opening. Among the opened flowers five per cent of the anthers showed signs of dehiscence with presence of longitudinal sutures along the anthers, whereas remaining anthers showed no signs of dehiscence.

4.3.3.3 Stigma receptivity

Stigma remained creamy white in colour during anthesis without any exudation from the stigmatic surface. Controlled pollination of emasculated buds at different stages of bud development showed no variation in fruit set. Stigmatic lobes were persistant and remained attached to the distal end of fruits throughout its

Table 9. Time of anthesis

Time hours	Number of buds observed	Number of buds opened	Percentage of total
1600	50	0	0
1630		3	6
1700		9	18
1730		26	52
1800		10	20
1830		2	4
1900		0	0

development. Stigmatic head turned brown in colour during the development of fruits.

4.3.4 Pollen studies

The results of the studies on different aspects of pollen grains are given below.

4.3.4.1 Pollen production

Number of anthers per flower ranged between 17 and 20. The mean number of pollen grains per anther was 13,125.

4.3.4.2 Pollen fertility

Ten to fifteen per cent of the total pollens took stain during acetocarmine test. But none of the pollens germinated under *in vitro* pollen germination studies using different concentrations of sucrose, boric acid and calcium nitrate along with agar.

4.3.5 Pollination studies

4.3.5.1 Pollinating agents

The activity of insects was low in mangosteen flowers. Very few insects to visited the flowers.

4.3.5.2 Mode of pollination and fruit set

Data on percentage of fruit set observed under different modes of pollination are presented in Table 10. The data showed that a high fruit set occurred at

Table 10. Fruit set under different conditions

Sl. No.	Treatments	Number of flowers observed	Fruit set	Percentage
1	Open pollination	50	48	96
2	Self pollination	50	46	92
3	Natural cross pollination	50	45	90
4	Hand pollination of emasculated flowers	50	45	90
5	Emasculated flower bagged without pollinating	50	45	90

$X^2 = 1.76$

all the methods of pollination with no significant difference among different modes of pollination.

4.4 Fruit development and fruit drop

4.4.1 Fruit development

Data on physical characters of fruit at different stages of development are presented in Table 11 and depicted in Fig.3 and 4. It took about 98-105 days from fruit set to complete development and maximum weight, volume, length, girth, breadth and cavity diameter were attained within this period. The different stages of fruit development at 14 days interval are illustrated in Plates VII, VIII, IX and X.

Results on the increase in weight, volume and girth recorded at 14 days interval showed that the maximum increase in weight (47.25%), volume (43.75%) and girth (38.33%) were between 42 and 56 days after fruit set. There after the percentage increment showed a decreasing trend. However, the mean weight, volume and girth increased upto the harvest stage (Fig.3).

The length and cavity diameter of fruit increased upto harvest stage (Fig. 4) with maximum percentage increment of length (30.30) and cavity diameter (45.45) seen between 42 and 56 days after fruit set. However, data on rind thickness did not follow the same trend, which increased initially and reached a maximum of 0.80 cm 42 days after fruit set. Thereafter it showed a decreasing trend and remained at 0.50 cm during harvest.

Data on the percentage contribution of pulp, rind and seed towards total fruit weight at the different stages of development of fruit are given in Table 12. Mean fruit weight steadily increased upto harvest. Mean pulp weight which was

Table 11. Physical changes of fruit during growth and development

Days after fruit set	Mean weight (g)	Percentage increase in weight	Mean volume (cc)	Percentage increase in volume	Mean length (cm)	Percentage increase in length	Mean girth (cm)	Percentage increase in girth	Cavity diameter (cm)	Percentage increase in cavity diameter	Rind thickness (cm)
Immediately after set	7.50	0	10	0	1.50	0	7.50	0	0.7	0	0.50
14	14.13	7.55	15	6.25	2.10	20.00	9.00	12.50	1.10	12.12	0.55
28	25.22	12.63	25	12.50	2.50	12.12	11.50	20.83	1.70	18.18	0.60
42	36.28	12.59	40	18.75	3.10	18.18	13.40	15.83	2.10	12.12	0.80
56	77.80	47.28	75	43.75	4.10	30.30	18.00	38.33	3.60	45.45	0.70
70	83.50	6.49	80	6.25	4.50	12.12	19.00	5.00	3.80	6.06	0.60
84	88.50	5.71	85	6.25	4.70	6.06	19.10	4.50	4.00	6.06	0.50
98-105	95.30	7.71	90	6.25	4.80	3.03	19.50	3.30	4.00	0	0.50

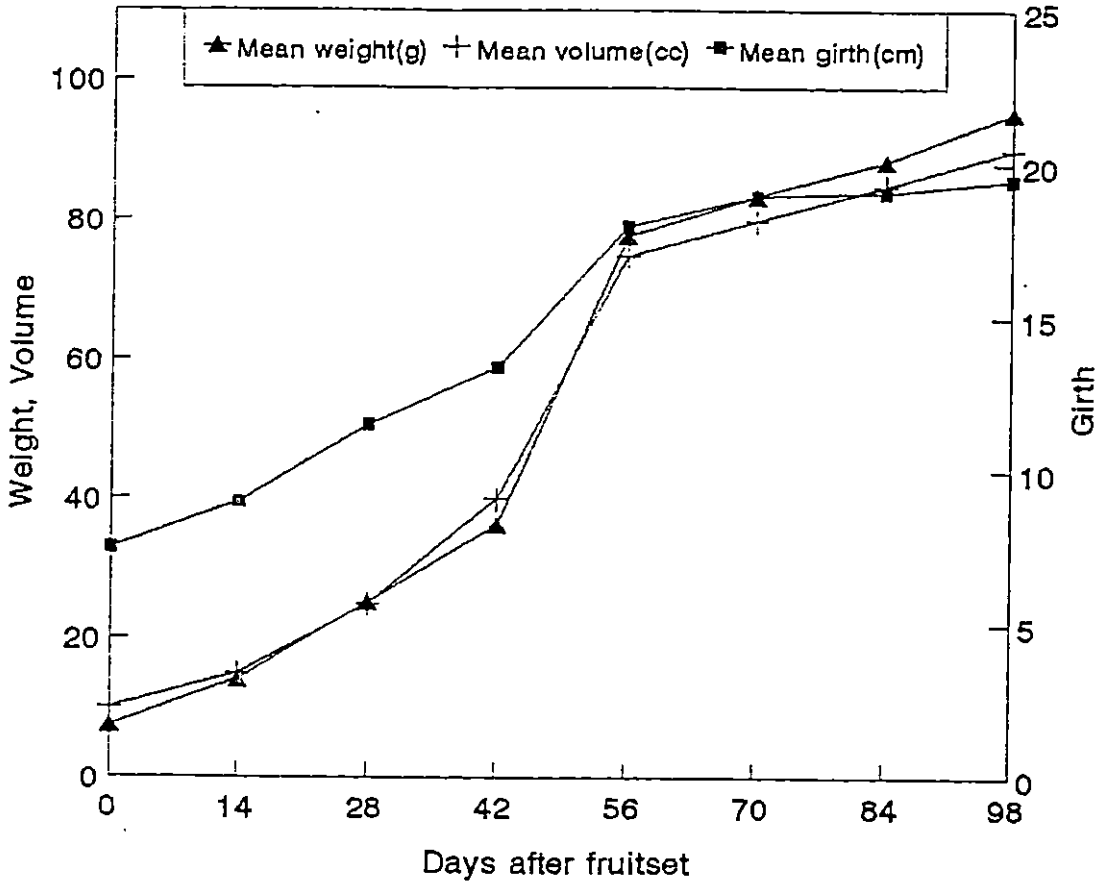


Fig.3. Changes in mean weight, volume and girth during growth and development of fruit

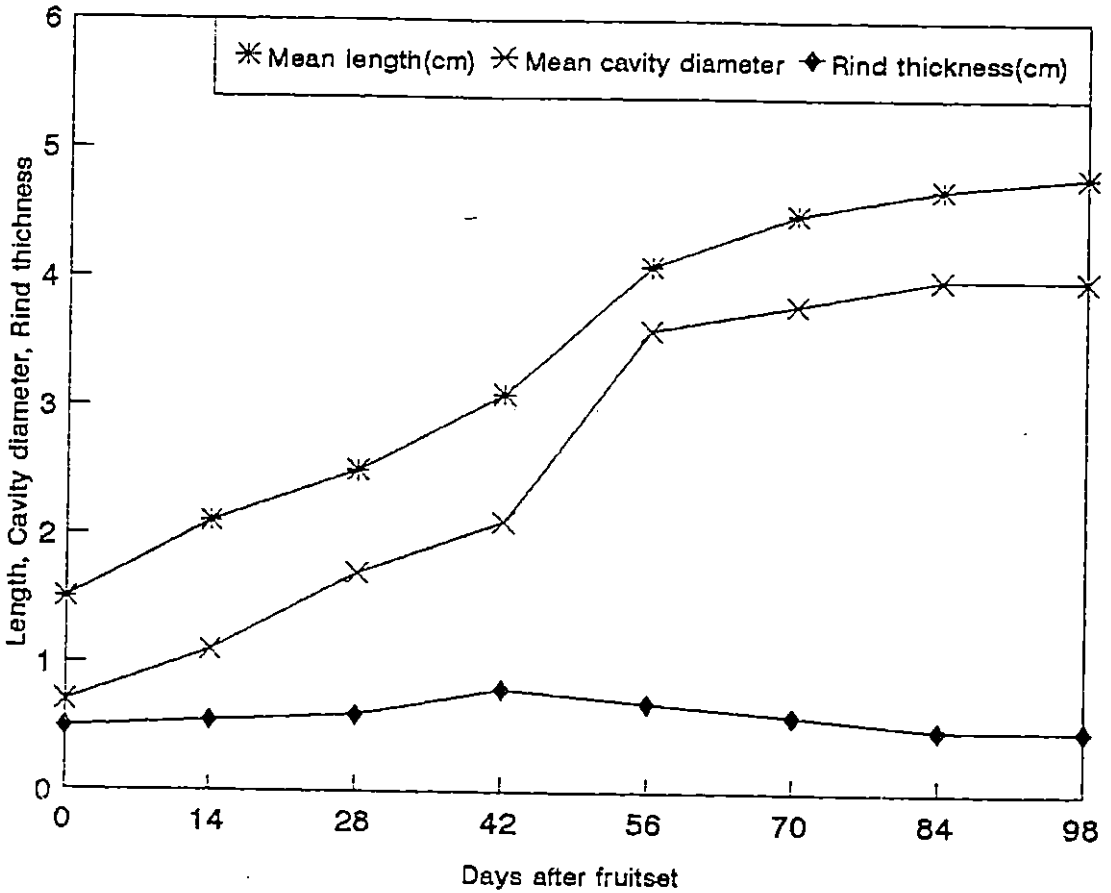


Fig.4. Changes in mean length, cavity diameter, and rind thickness during growth and development of fruits

Table 12: Percentage contribution of fruit pulp, rind and seed towards total fruit weight during growth and development

Days after fruit set	Mean fruit weight (g)	Mean pulp weight (g)	Percentage contribution towards total fruit weight	Mean rind weight (g)	Percentage contribution towards total fruit weight	Mean seed weight (g)	Percentage contribution towards total fruit weight
56	66.00	14.62	22.15	50.00	75.75	1.38	2.09
70	77.80	19.37	24.90	53.87	69.25	4.40	5.85
84	89.50	26.85	30.10	58.33	65.18	4.51	5.03
98-105	101.10	33.36	33.00	62.98	62.30	4.75	4.70

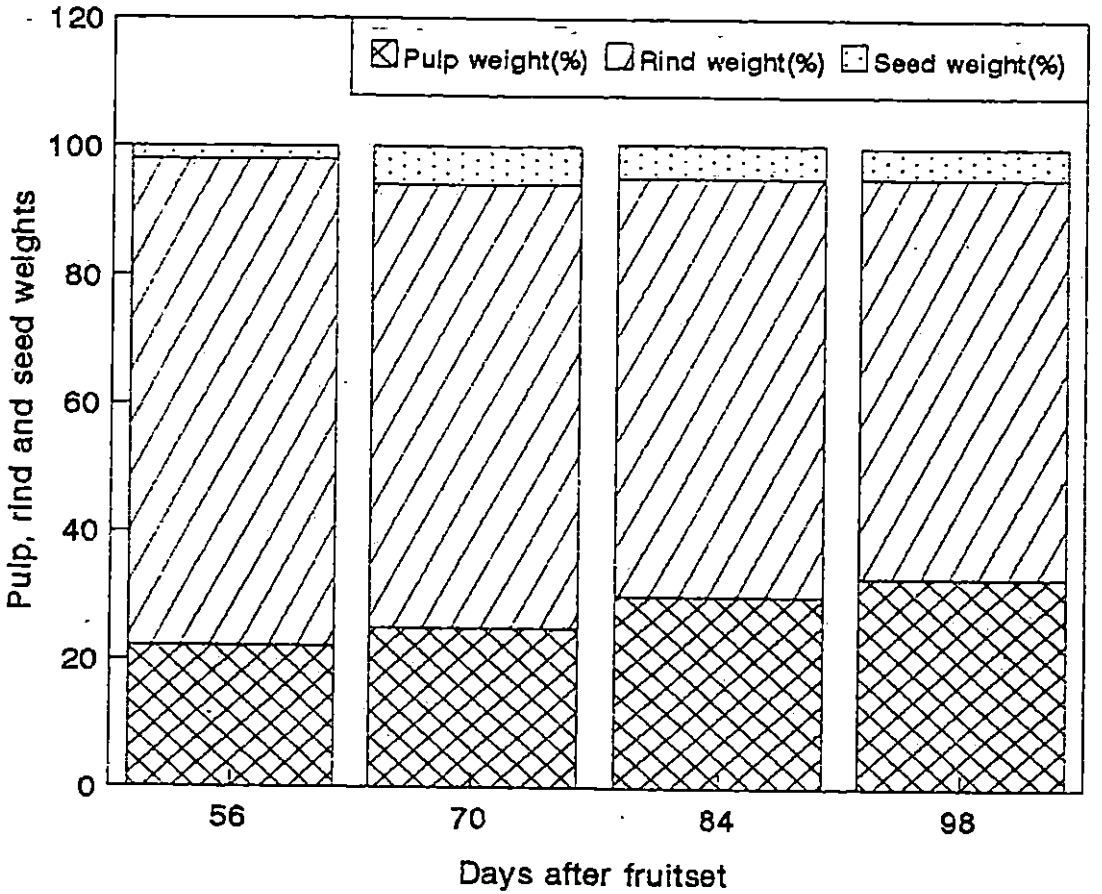


Fig.5. Percentage contribution of fruit pulp, rind and seed towards total fruit weight during growth and development of fruits

14.62 g at 56 days after fruit set increased to 33.36 g at harvest stage. Mean rind weight also increased steadily upto harvest. Seed weight showed an increase upto 70th day and later remained more or less static. The percentage contribution of pulp towards total fruit weight increased gradually with the increase in mean pulp weight. Pulp content which constituted about 22.00 per cent of the total fruit weight at 56th day increased to about 33.00 per cent at harvest. Though mean rind weight increased upto harvest, the percentage contribution of rind weight towards total fruit weight declined from 75.75 per cent to 62.30 per cent at the time of harvest. The contribution of seed weight towards fruit weight was very less compared to that of pulp and rind weight (Fig.5). Seed weight constituted about two per cent of the fruit weight initially but later on increased and remained almost constant.

Data on the chemical composition of the fruit at different developmental stages are furnished in Table 13. Chemical analysis was carried out from 56 days after fruit set because the pulp could be separated from the seed only from this stage onwards. Total soluble solids showed an increase from 18 °brix at 56 days after fruit set to 27 °brix at ripened stage. Titratable acidity showed a decreasing trend. It was as high as 1.15 per cent on the 56th day of set and slowly decreased to 0.32 per cent at harvest. Ascorbic acid content also decreased from 30 mg/100 g to a minimum of 5 mg/100 g towards ripening. Total sugars along with reducing and non reducing sugar increased during the development of fruit from 56 days onwards and reached a maximum during ripening stage (Fig.6). At ripening stage total sugars was 17.02 per cent with 3.22 per cent reducing sugars and 13.80 per cent non reducing sugars. Sugar acid ratio also showed an increasing trend reaching a value of 53.18 at ripening stage.

Table 13. Chemical composition of fruit at different stages of development

Days after fruit set	TSS (°Brix)	Titratable acidity (%)	Ascorbic acid (mg/100 g)	Total sugars (%)	Reducing sugars (%)	Non reducing sugars (%)	Sugar acid ratio
56	8.0	1.15	30	8.67	1.10	7.57	7.53
70	20.2	1.12	25	11.60	1.90	9.70	10.35
84	24.2	0.48	10	14.33	2.83	11.50	29.85
98-105	27.0	0.32	5	17.02	3.22	13.80	53.18

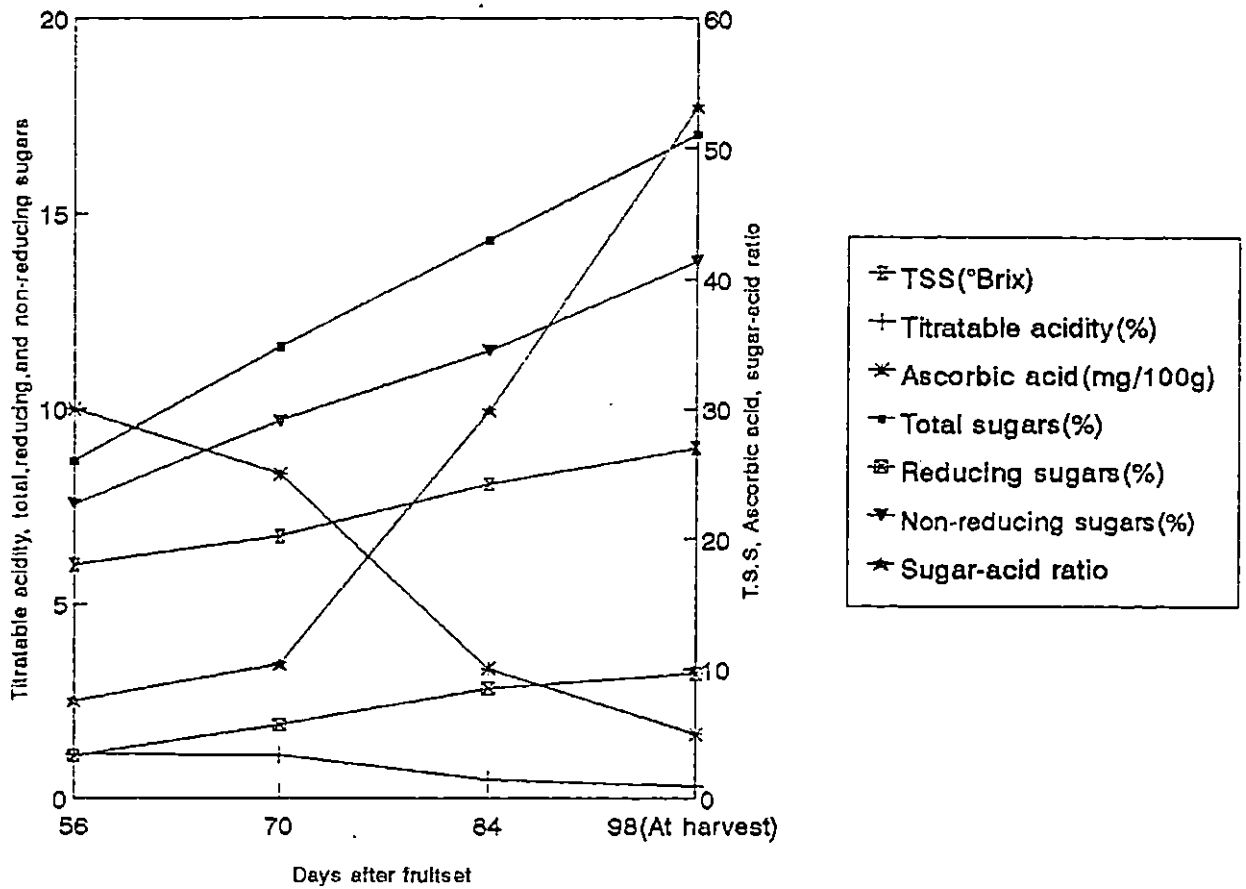


Fig.6. Chemical composition of fruit at different stages of development

Plate VII. Development of fruits from stage 1-4

Plate VIII. C.S. of the fruits from stages 1-4


1
2
3
4

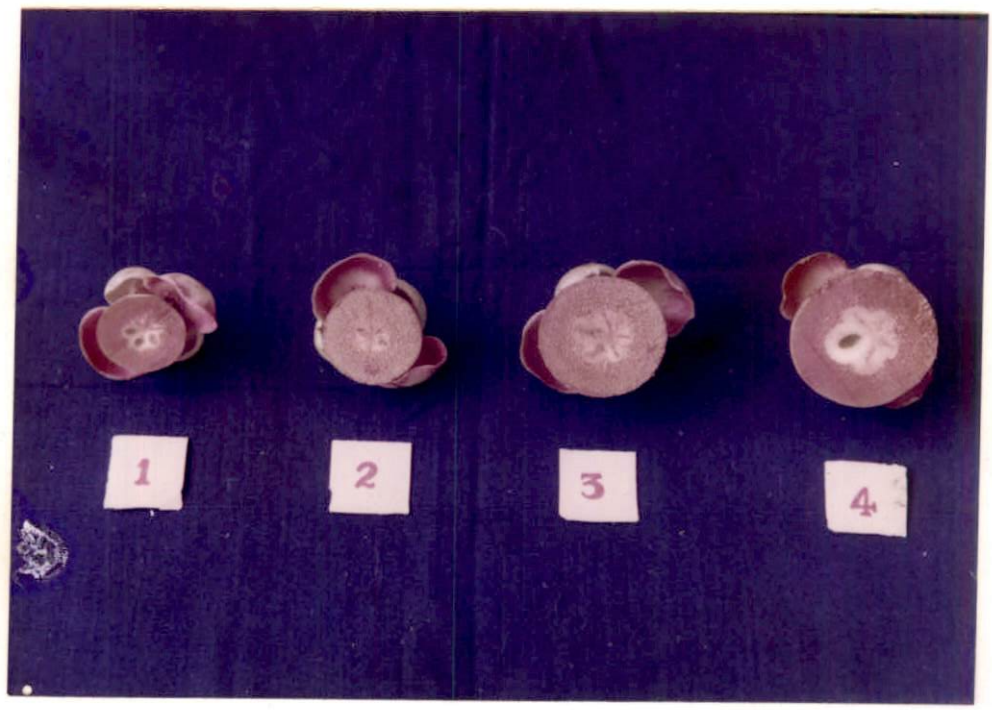

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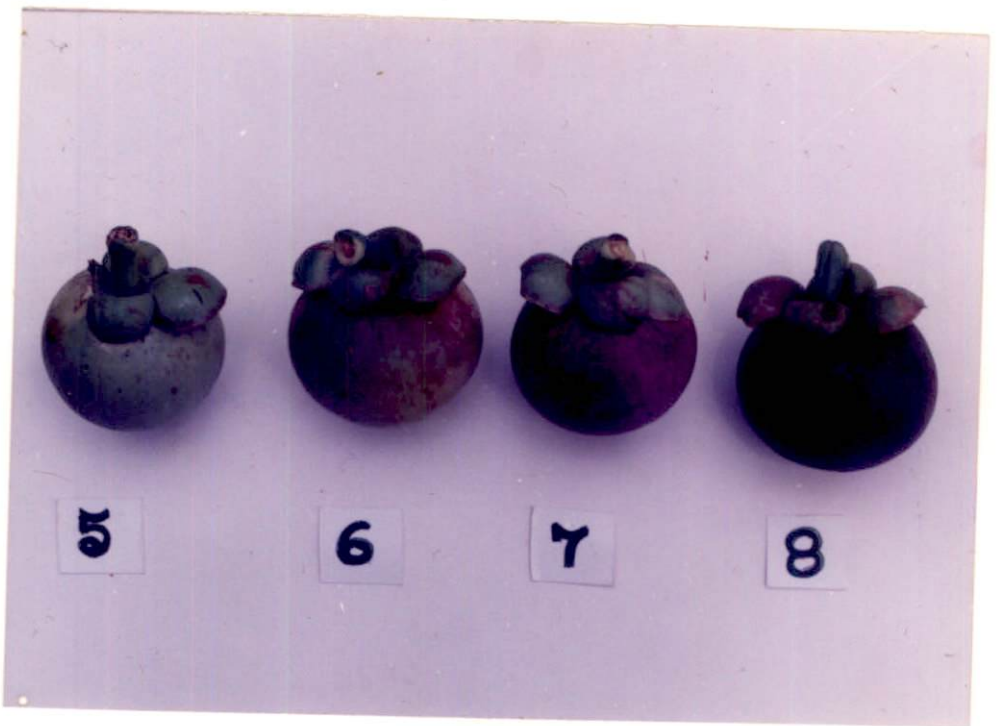
Plate IX. Development of fruits from stages 5-8

Plate X. C.S. of the fruits from stages 5-8


5
6
7
8


5
6
7
8

Individual trees showed slight variation when fruits collected from these trees were analysed for various chemical components (Table 14). The TSS varied from 26 to 27 per cent and titratable acidity between 0.32 and 0.40 per cent. Ascorbic acid content varied between 5.00 mg/100 g and 10.00 mg/100 g. Total sugars showed a difference ranging from 15.4 to 17.46 per cent and reducing and nonreducing sugars varied between 2.80 and 5.27 per cent and 11.53 and 13.80 per cent, respectively. ß carotene was present in trace amounts.

4.4.2 Fruit drop

Fruit drop recorded at 30 days interval showed that the fruit drop was maximum during the first 30 days after furit set (Table 15). This accounted for 41 per cent of the total fruit set. Another ten per cent fruit drop was observed during the second month. Thereafter fruit drop was negligible and practically no drop was observed during maturation stage. On an average the percentage of flowers that set fruit in a tree was 90-95, out of which only about 49 per cent fruits reached maturity.

4.4.3 Harvest index and method of harvest

The best time of harvest was when 25 per cent of the fruit skin had developed a purple colour which was green in the early stages. A pair of fruits seen in the middle of the plate XI shows the stage of harvest. The purple colour developed from the stalk end. It took about 90 days for the fruits to reach this stage. Physical characters like mean weight, volume, length, girth, cavity diameter and rind thickness were 95.30 g, 90 cc, 4.80 cm, 19.50 cm, 4.00 cm and 0.50 cm, respectively at this stage. TSS, titratable acidity, total sugars, reducing sugars non

Table 14. Tree wise variation in yield and chemical composition of fruit at harvest stage

Tree No.	Yield (fruits/ tree)	TSS (°Brix)	Titratable acidity (mg/100 g)	Ascorbic acid (%)	Total sugars (%)	Reducing sugars (%)	Non reducing sugars (%)	β-carotene
T_1	2500	26.0	0.40	5.00	15.40	2.80	12.60	Traces
T_2	1120	26.6	0.32	10.00	17.02	3.22	13.80	Traces
T_3	2060	27.0	0.34	7.43	17.46	5.60	11.86	Traces
T_4	3350	26.0	0.36	8.50	16.40	4.20	12.20	Traces
T_5	1860	26.4	0.33	5.00	16.80	5.27	11.53	Traces
T_6	650	26.8	0.38	5.00	17.08	5.08	12.05	Traces

Table 15. Percentage of fruit drop at monthly interval

Days after fruit set	Number of fruits retained	Number of fruits dropped	Percentage of drop
at fruit set	100	0	0
30	59	41	41.00
60	49	10	10.00
90	49	0	0
at harvest	49	0	0

reducing sugars, sugar:acid ratio and ascorbic acid at harvest stage were found to be 25.3, 0.40, 15.67, 3.05, 12.62 per cent, 39.17, 10 mg/100 g respectively. These fruits ripened normally in two days when stored at ambient temperature and no difference in quality was noticed between the tree ripened fruits and those ripened at ambient temperature. Fruits when harvested at the right stage of maturity (90 days after fruit set) showed no signs of gummy exudation at the stalk end and fruits could be detached with the same easiness as that of fully ripened fruits. However, when the fruits were harvested prior to maturity stage, a portion of the stem was also attached to the stalk end showing a gummy exudation at the point of detachment.

Mechanical injury caused due to poor harvesting and handling practices lead to the formation of Transluscent Flesh Disorder. Transluscent Flesh Disorder of mangosteen was found to be a major cause for reduced fruit quality. Symptoms, usually found in large segments of the fruit include flesh changes from white to transluscent and textural changes from soft to firm and crisp (Plate XII). Fruits which fell down during harvesting developed cracks on the rind. This hastened the formation of transluscent flesh. So care should be taken while harvesting mangosteen. It is advised to have a harvesting pole to which a small net basket with a ring around the neck is attached to receive the fruit in it so that fruits are prevented from falling down while harvesting.

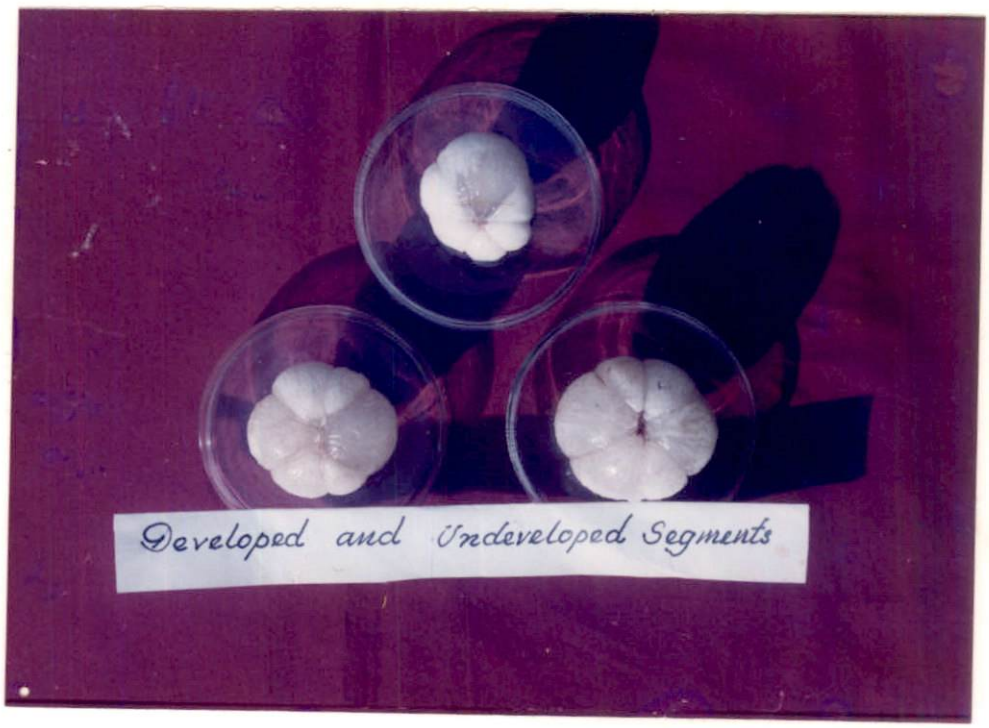
4.5 Yield

There was wide variation in yield among individual trees. It ranged from 650 to 3350 fruits/tree. The average yield was 1923.33 (Table 14).

Plate XI. Stage of harvest

Plate XII. Developed and undeveloped segments with Translucent Flesh Disorder


Stage of maturity


Developed and Undeveloped Segments

4.6 Sensory evaluation

From individual trees a sample of 100 fruits were analysed for sensory evaluation and the results are presented in Table 16. There was not much variation among trees for sweetness and juiciness. Most of the fruits tasted were moderately sweet which accounted to 56.16 per cent of the total fruits. A few fruits of 6.66 per cent were found to be least sweet. An average of 37.16 per cent fruits were extremely sweet. Most of the fruits analysed for juiciness fell in the category of extreme juicy with an average of 46.83 per cent. Almost equal number of fruits with an average of 43.00 per cent fell in the category of moderately juicy. Very few fruits were found to be least juicy (10.16%).

No marked variation among individual trees was found during sensory evaluation, hence fruits from all the trees were pooled and a random sample of 125 fruits was selected for determining fruit characters. The data are presented in Table 17. About 43.16 per cent fruits had pulp with pure white colour. Nearly 40.05 per cent fruits showed mixed colour and 16.44 per cent had dirty white pulp colour. Number of segments of fruits corresponded to the number of stigmatic lobes. Number of segments ranged from four to seven with 9.03 per cent fruits having four segments and 9.04 per cent fruits having seven segment (Plate XIII). Most of the fruits had five (35.20%) or six (46.82 per cent) segments. Number of viable seeds ranged from nil (7.37%) to three seeds (4.55%). Most of the fruits were either single seeded (50.06%) or double seeded (38.02%). About 60.86 per cent fruits had dark purple coloured rind and 8.20 per cent fruits had light purple coloured rind. Fruits with moderate purple coloured rind averaged to about 31.00 per cent. A

Table 16. Sensory evaluation of fruits

Tree No.	Number of fruits analysed	Sweetness (on percentage basis)			Juiciness (on percentage basis)		
		Least	Moderate	Extreme	Least	Moderate	Extreme
T_1	100	0	52	48	7	35	58
T_2	100	4	56	40	4	45	51
T_3	100	5	72	23	4	50	46
T_4	100	18	42	40	21	38	41
T_5	100	7	61	32	15	47	38
T_6	100	6	54	40	10	43	47
Average		6.66	56.16	37.16	10.16	43.00	46.83

Table 17. Fruit characters of mangosteen

Characters	On percentage basis		
	Extreme	Moderate	Least
Pulp colour	43.16 (pure white)	40.05 (mixed)	16.44 (dirty white)
No. of segments	9.04 (seven segments)	46.82 (six segments)	9.03 (four segments)
		35.20 (five segments)	
No. of viable seeds	4.55 (three seeds)	38.02 (two seeds)	7.37 (no seed)
		50.06 (one seed)	
Colour of rind	50.86 (dark purple)	31.00 (moderately purple)	8.20 (light purple)

Plate XIII. Variation in segments


Developed and Undeveloped Segments

random count of 100 fruits showed that the ratio of seeded to seedless segments was 1:3.5.

The occurrence of gamboge, a physiological disorder, was severe in fruits collected during the later part of the harvest season from mid June to July (Plate XIV). Fruits collected from May to mid June were practically free from this disorder. About 33.82 per cent of fruits were gamboge affected and the rest were free from this disorder. Gamboge affected fruits were characterised by exudation of an yellow gum from the rind which gradually penetrated into the fruit. Once it entered the fruit, the fruit pulp became yellow, gummy, corky in texture (Plate XV), bitter in taste and inedible.

4.7 Chemical composition of the fruit

Biochemical analysis of the edible portion at ripe stage showed that the fruit contained water 76.57, protein 0.5, citric acid 0.32, total sugars 17.02, recucing sugars 3.22, non reducing sugars 13.80, nitrogen 0.28, phosphorus 0.01, potassium 0.13, calcium 0.08, magnesium 0.24 (on percentage basis), sugar:acid ratio 53.18, TSS 27 °brix, ascorbic acid 5 mg/100 g and traces of ß carotene.

4.8 Storage studies

Fruits when stored under refrigerated conditions (10°C and 20°C) showed no loss of fruit upto 12th day of storage, where as in all other treatments except in the case of fruits stored in bamboo baskets (T_6), fruit loss was noticed from 8th day onwards (Table 18). In treatment T_6 no fruit loss was noticed on 8th day of storage but a loss 20 per cent was noticed on 12th day. In all other treatments excepting treatments T_1 (refrigerated condition 10°C) and T_2 (refrigerated condition

Plate XIV. Normal and gamboge affected fruits

Plate XV. Internal symptoms of gamboge


Gamboge.
Normal


Gamboge.

Table 18. Percentage loss of fruits kept under different storage conditions at four days interval

Sl. No.	Treatments	Percentage loss of fruit								
		Interval in days								
		4	8	12	16	20	24	28	32	36
1	(T_1) Refrigerated condition (10 °C)	0	0	0	6.66	7.8	10.00	25.00	66.66	100
2	(T_2) Refrigerated condition (20 °C)	0	0	0	7.69	9.09	18.18	32.50	72.33	100
3	(T_3) Polythene cover	0	6.6	41.35	66.66	100	-	-	-	-
4	(T_4) Polythene cover + $KMnO_4$	0	7.8	40.85	60.05	100	-	-	-	-
5	(T_5) Wooden boxes	0	9.09	33.33	50.00	100	-	-	-	-
6	(T_6) Bamboo baskets	0	0	20.00	41.33	100	-	-	-	-
7	(T_7) Cardboard boxes	0	16.00	40.15	58.45	100	-	-	-	-
8	(T_8) Kept open	0	25.00	60.45	100	-	-	-	-	-

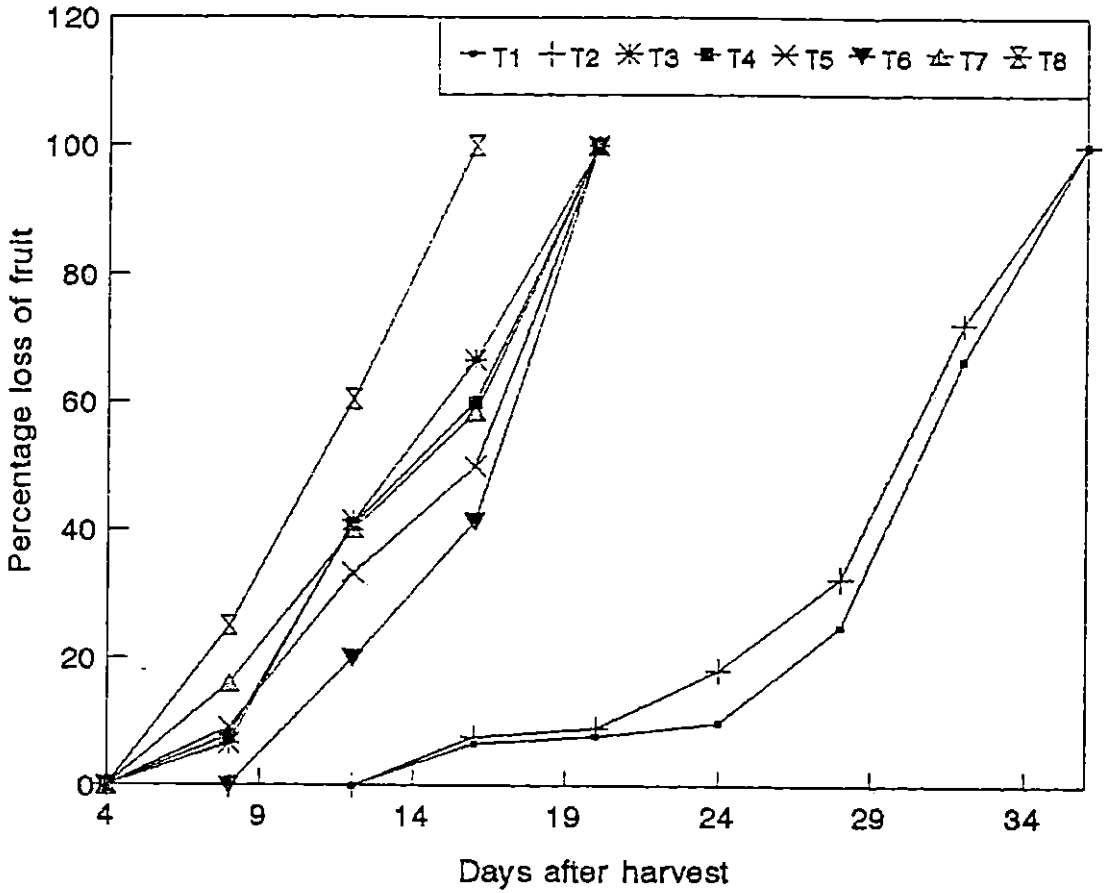


Fig.7. Percentage loss of fruits kept under different storage conditions at four days interval

Table 19. Percentage loss in weight of fruits kept under different storage conditions at four days interval

Sl. No.	Treatments	Percentage loss in weight								
		Interval in days								
		4	8	12	16	20	24	28	32	36
1	(T_1) Refrigerated condition (10 °C)	0	0.81	0.94	0.98	0.98	6.45	10.25	10.54	12.18
2	(T_2) Refrigerated condition (20 °C)	0	0.93	1.12	1.22	1.45	8.12	11.32	11.46	13.25
3	(T_3) Polythene cover	0	7.84	11.22	43.72	6.32	-	-	-	-
4	(T_4) Polythene cover + $KMnO_4$	0	6.45	10.45	41.45	7.41	-	-	-	-
5	(T_5) Wooden boxes	0	8.79	35.20	16.02	9.12	-	-	-	-
6	(T_6) Bamboo baskets	0	2.56	30.18	14.81	8.41	-	-	-	-
7	(T_7) Cardboard boxes	0	8.67	42.35	10.28	13.20	-	-	-	-
8	(T_8) Kept open	0	16.64	51.05	12.14	-	-	-	-	-

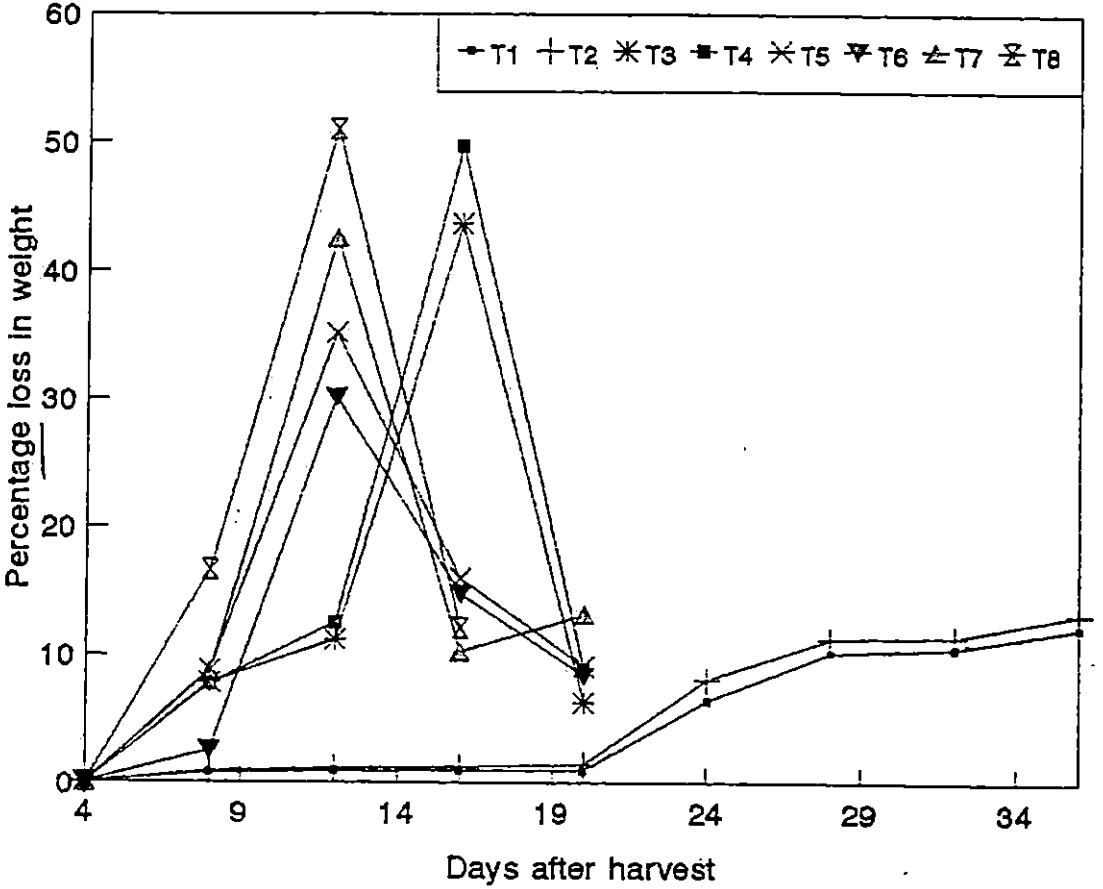


Fig.8. Percentage loss in weight of fruits kept under different storage conditions at four days interval

20°C), percentage loss of fruit was much higher which ranged from 33.33 to 60.45 on 12th day of storage. In the case of fruits stored under open condition (T_8), 100 per cent loss was noticed on 16th day itself where as in treatments T_3 (polythene cover), T_4 (polythene cover + $KMnO_4$), T_5 (wooden boxes), T_6 (Bamboo baskets) and T_7 (card board boxes), 100 per cent loss was noticed by 20 days of storage (Fig.7). For treatments T_1 and T_2 loss of fruit was noticed from 16th day onwards which remained negligible upto 24th day. There after a steady increase in percentage loss of fruit was noticed and complete fruits were lost by 36 days of storage. No chilling injury was observed for fruits stored under refrigerated conditions.

The percentage loss in weight was negligible in the case of treatments T_1 and T_2 upto 20th day of storage while complete fruits were lost in all other treatments by then (Table 19). There after a slight increase in loss in weight was noticed reaching about 12.18 and 13.25 per cent for treatments T_1 and T_2, respectively at the end of storage period (Fig.8). In the case of treatments T_5, T_6, T_7 and T_8 a higher percentage loss in weight was noticed on 12th day, where as for treatments T_3 and T_4 percentage loss in weight was maximum on 16th day of storage.

Total soluble solids, total sugar, non reducing sugars and reducing sugars showed a declining trend. However, for treatments T_1 and T_2 the decrease in TSS was gradual and negligible (Table 20 and Fig.9). Just 2.2 per cent reduction was recorded during a period of 16 days. Under open condition TSS was found to decrease from 27.0 per cent to 18.0 per cent within 16 days where as in remaining treatments other than T_1 and T_2 TSS was found to reach a minimum value on 20th day of storage. At the same time in T_1 and T_2, TSS was found to be 24 per cent at the end of 20th day and it took 36 days to reach a minimum value of 18.4 and 18.0 in T_1 and T_2 respectively.

Table 20. Changes in TSS of fruits kept under different storage conditions at four days interval

Sl. No.	Treatments	TSS (° Brix)								
		Interval in days								
		4	8	12	16	20	24	28	32	36
1	(T_1) Refrigerated condition (10° C)	27.0	27.0	26.0	24.8	24.0	23.2	22.0	20.6	18.4
2	(T_2) Refrigerated condition (20° C)	27.0	27.0	26.0	24.6	24.0	23.4	22.0	20.0	18.0
3	(T_3) Polythene cover	26.0	26.0	24.0	21.6	18.0	-	-	-	-
4	(T_4) Polythene cover + $KMnO_4$	27.0	26.6	25.2	23.0	18.6	-	-	-	-
5	(T_5) Wooden boxes	27.0	27.0	25.0	22.4	18.4	-	-	-	-
6	(T_6) Bamboo baskets	26.6	26.4	24.2	22.0	19.0	-	-	-	-
7	(T_7) Cardboard boxes	26.4	26.4	24.0	22.0	18.0	-	-	-	-
8	(T_8) Kept open	27.0	23.0	20.0	18.0	-	-	-	-	-

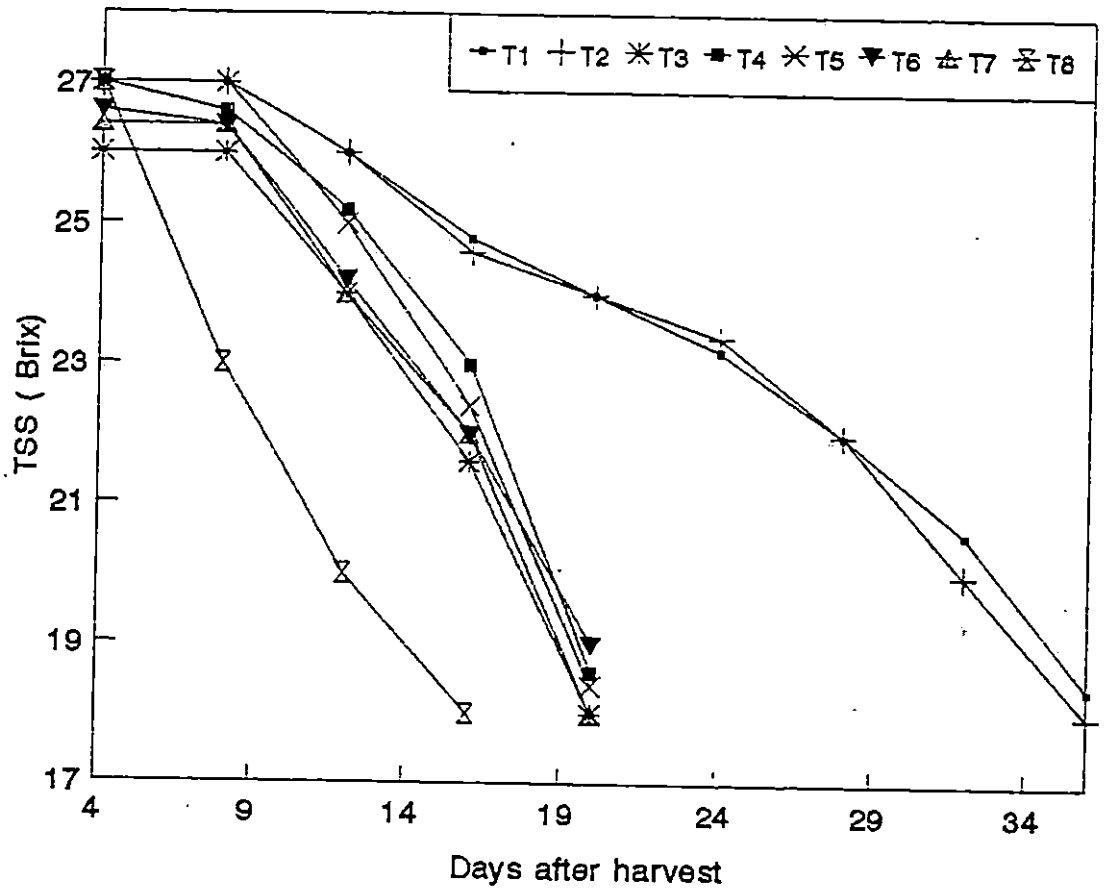


Fig.9. Changes in T.S.S. of fruits kept under different storage conditions at four days interval

Table 21. Changes in total sugars of fruits kept under different storage conditions at four days interval

Sl. No.	Treatment	Total sugars (%)								
		Interval in days								
		4	8	12	16	20	24	28	32	36
1	(T_1) Refrigerated condition (10 °C)	17.46	17.23	17.08	16.23	15.03	14.95	14.41	13.69	11.50
2	(T_2) Refrigerated condition (20 °C)	17.46	17.19	16.90	16.13	14.94	14.80	14.23	13.48	11.20
3	(T_3) Polythene cover	17.20	16.47	15.66	13.76	12.03	-	-	-	-
4	(T_4) Polythene cover + $KMnO_4$	17.42	16.62	15.80	13.90	12.25	-	-	-	-
5	(T_5) Wooden boxes	17.46	16.65	15.96	14.04	12.41	-	-	-	-
6	(T_6) Bamboo baskets	17.30	16.56	15.85	13.90	12.31	-	-	-	-
7	(T_7) Cardboard boxes	17.20	16.52	15.83	13.82	12.18	-	-	-	-
8	(T_8) Kept open	17.19	16.04	14.69	12.01	-	-	-	-	-

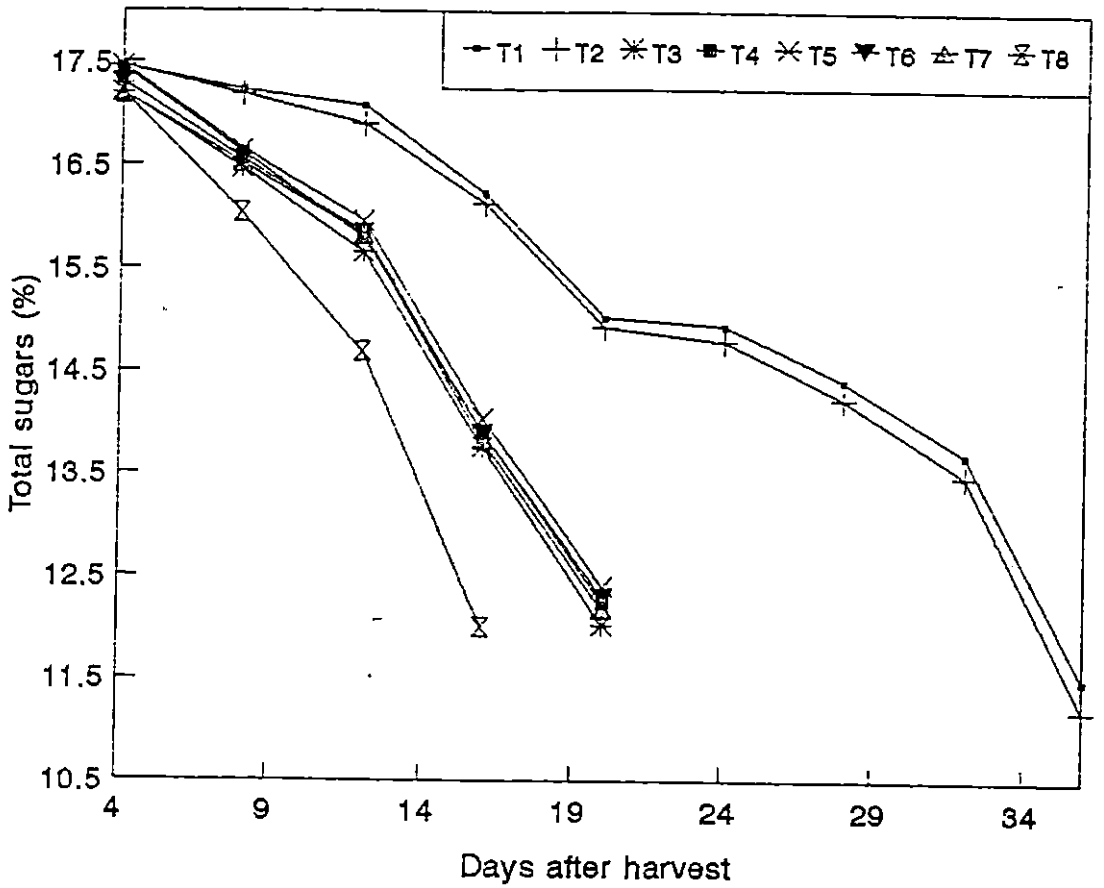


Fig.10. Changes in total sugars of fruits kept under different storage conditions at four days interval

Table 22. Changes in non reducing sugars of fruits kept under different storage conditions at four days interval

Sl. No.	Treatments	Non reducing sugars (%)								
		Interval in days								
		4	8	12	16	20	24	28	32	36
1	(T_1) Refrigerated condition (10 °C)	11.86	11.80	11.68	10.88	9.72	9.69	9.27	8.59	7.24
2	(T_2) Refrigerated condition (20 °C)	11.78	11.75	11.52	10.78	9.64	9.50	9.13	8.46	7.10
3	(T_3) Polythene cover	11.64	11.11	10.64	8.92	7.80	-	-	-	-
4	(T_4) Polythene cover + $KMnO_4$	11.84	11.28	10.70	9.02	7.94	-	-	-	-
5	(T_5) Wooden boxes	11.76	11.24	10.76	9.10	8.01	-	-	-	-
6	(T_6) Bamboo baskets	11.70	11.21	10.71	9.04	8.01	-	-	-	-
7	(T_7) Cardboard boxes	11.80	11.32	10.82	9.16	8.10	-	-	-	-
8	(T_8) Kept open	11.71	11.02	10.29	7.95	-	-	-	-	-

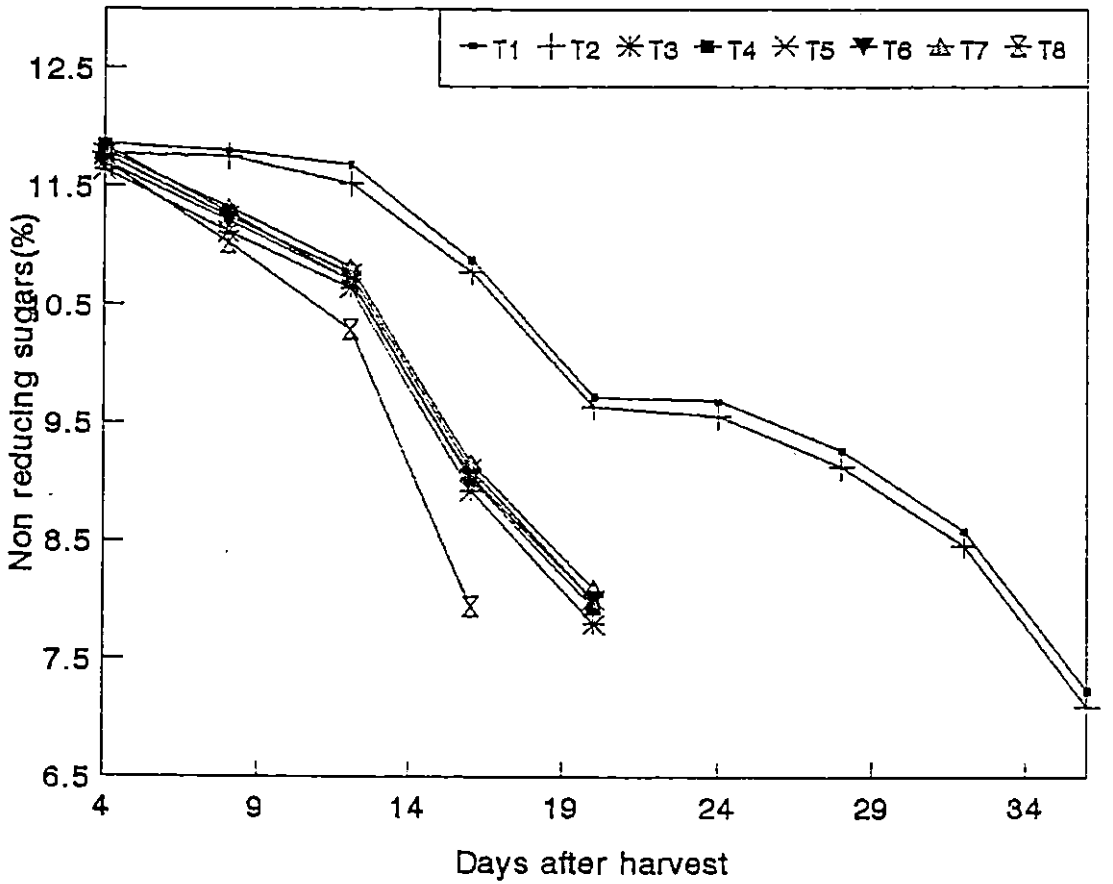


Fig.11. Changes in non-reducing sugars of fruits kept under different storage conditions at four days interval

Table 23. Changes in reducing sugars of fruits kept under different storage conditions at four days interval

Sl. No.	Treatments	Reducing sugars (%)								
		Interval in days								
		4	8	12	16	20	24	28	32	36
1	(T_1) Refrigerated condition (10 °C)	5.60	5.43	5.40	5.35	5.31	5.26	5.14	5.10	4.26
2	(T_2) Refrigerated condition (20 °C)	5.68	5.44	5.38	5.35	5.30	5.24	5.10	5.02	4.10
3	(T_3) Polythene cover	5.56	5.36	5.02	5.84	4.23	-	-	-	-
4	(T_4) Polythene cover + $KMnO_4$	5.58	5.34	5.10	4.88	4.32	-	-	-	-
5	(T_5) Wooden boxes	5.70	5.41	5.20	4.84	4.40	-	-	-	-
6	(T_6) Bamboo baskets	5.60	5.35	5.14	4.86	4.30	-	-	-	-
7	(T_7) Cardboard boxes	5.40	5.20	5.01	4.66	4.08	-	-	-	-
8	(T_8) Kept open	5.48	5.02	4.40	4.06	-	-	-	-	-

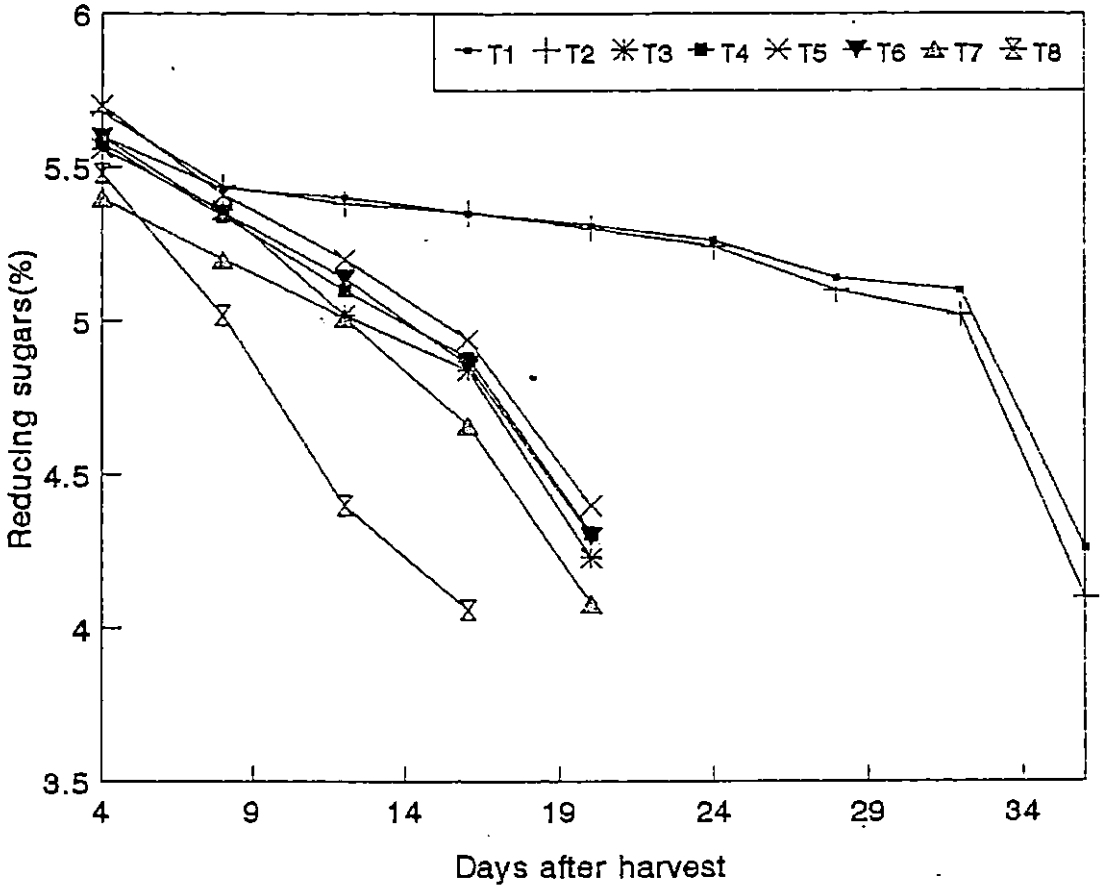


Fig.12. Changes in reducing sugars of fruits kept under different storage conditions at four days interval

Total sugars also showed a similar trend with treatments T_1 and T_2 showing a gradual and negligible decline upto 20th day at which total sugars was found to be 15.03 per cent and 14.94 per cent for T_1 and T_2, respectively (Fig.10). By the end of 20th day all other treatments except T_8 reached its minimum value which ranged between 12.03 and 12.41 per cent. In the case of T_8 a minimum value of 12.01 per cent was reached at the end of 16th day itself. For T_1 and T_2 total sugars reached a minimum value of 11.50 per cent and 11.20 per cent, respectively at 36th day of storage (Table 21). The decrease in non reducing sugars was less pronounced for treatments T_1 and T_2 upto 20th day at which treatments from T_3 to T_7 reached its minimum value which ranged from 7.80 to 8.10 per cent (Fig.11). Treatment T_8 recorded a minimum value of 7.95 towards the end of 16th day. For T_1 and T_2 the minimum value recorded was found to be 7.24 and 7.10 per cent, respectively at 36th day (Table 22). Reducing sugars decreased from 5.48 per cent to 4.06 per cent with in 16 days in the case of T_8 (Fig.12). All other treatments excepting T_1 and T_2 reached a minimum value ranging from 4.08 to 4.40 with in 20 days. A minimum value of 4.26 per cent for T_1 and 4.10 per cent for T_2 was recorded at the end of 36th day of storage (Table 23).

Titratable acidity showed a reverse trend when compared to that of sugars (Fig. 13). Titratable acidity was found to increase with the increase storage life. For treatment T_8 maximum value of 1.10 per cent was found to reach on 12th day itself. Other treatments from T_3 to T_7 reached the maximum value ranging from 0.80-1.10 per cent at 20th day of storage. Treatments T_1 and T_2 showed a gradual increase and reached the maximum value of 1.10 per cent for T_1 and 1.15 per cent for T_2 at the end of 36th day (Table 24).

Table 24. Changes in titratable acidity of fruits kept under different storage conditions at four days interval

Sl. No.	Treatments	Titratable acidity (%)								
		Interval days								
		4	8	12	16	20	24	28	32	36
1	(T_1) Refrigerated condition (10° C)	0.32	0.42	0.48	0.51	0.62	0.68	0.71	0.80	1.10
2	(T_2) Refrigerated condition (20° C)	0.32	0.42	0.51	0.51	0.68	0.71	0.72	0.85	1.15
3	(T_3) Polythene cover	0.34	0.48	0.48	0.61	0.80	-	-	-	-
4	(T_4) Polythene cover + $KMnO_4$	0.33	0.51	0.62	0.70	0.82	-	-	-	-
5	(T_5) Wooden boxes	0.33	0.50	0.56	0.80	0.87	-	-	-	-
6	(T_6) Bamboo baskets	0.32	0.48	0.51	0.71	0.84	-	-	-	-
7	(T_7) Cardboard boxes	0.34	0.51	0.60	0.81	1.10	-	-	-	-
8	(T_8) Kept open	0.34	0.80	1.10	1.10	-	-	-	-	-

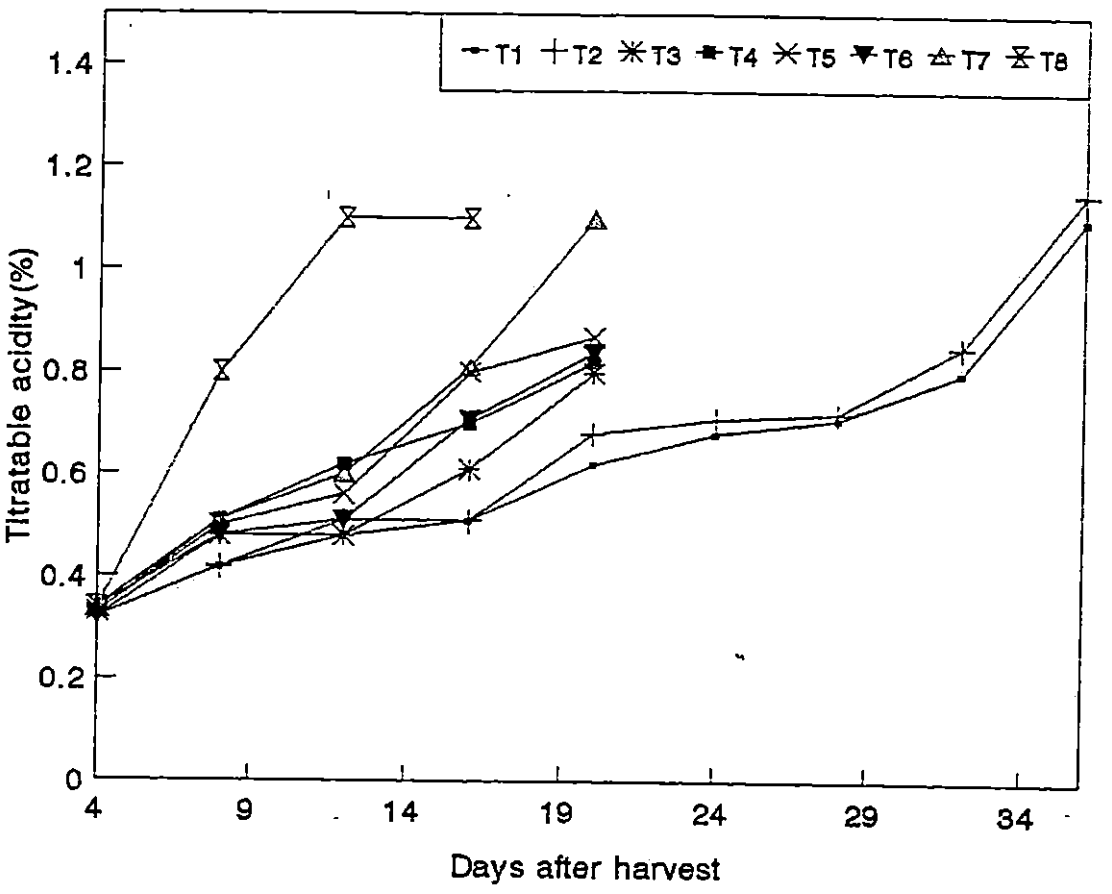


Fig.13. Changes in titratable acidity of fruits kept under different storage condtiions at four days interval

Table 25. Changes in sugar : acid ratio of fruits kept under different storage conditions at four days interval

Sl. No.	Treatments	Sugar acid ratio								
		Interval in days								
		4	8	12	16	20	24	28	32	36
1	(T_1) Refrigerated condition (10 °C)	54.56	41.02	35.58	31.82	24.24	21.98	20.29	17.11	10.45
2	(T_2) Refrigerated condition (20 °C)	54.56	40.93	33.13	31.62	21.97	20.84	19.76	15.85	9.73
3	(T_3) Polythene cover	50.58	34.31	32.62	22.55	15.03	-	-	-	-
4	(T_4) Polythene cover + $KMnO_4$	52.78	32.58	25.48	19.85	14.93	-	-	-	-
5	(T_5) Wooden boxes	52.90	33.30	28.50	17.55	14.26	-	-	-	-
6	(T_6) Bamboo baskets	54.06	34.50	31.07	19.57	14.65	-	-	-	-
7	(T_7) Cardboard boxes	50.58	32.39	26.38	17.06	11.07	-	-	-	-
8	(T_8) Kept open	50.55	20.05	13.35	10.91	-	-	-	-	-

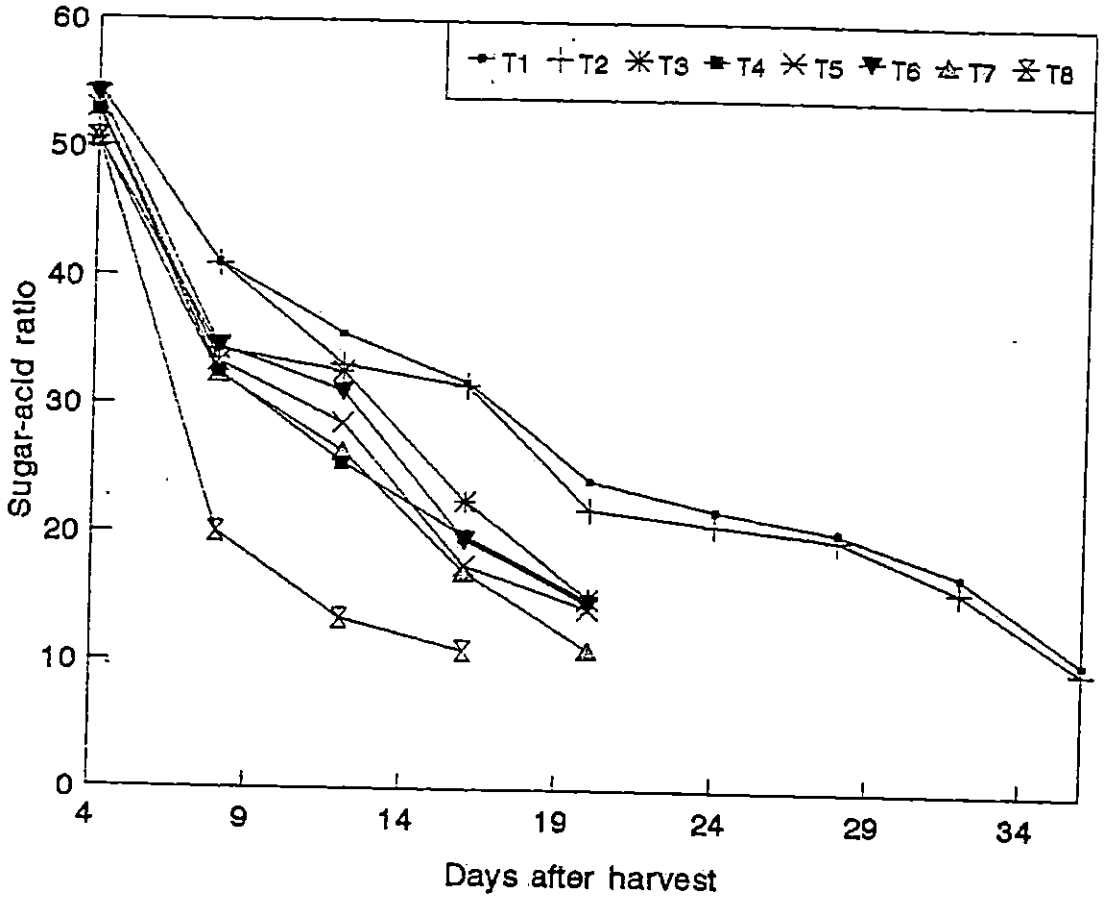


Fig.14. Changes in sugar:acid ratio of fruits kept under different storage conditions at four days interval

Sugar:acid ratio declined in the case of all treatments during the course of storage but the decline was much pronounced in all the treatments other than T_1 and T_2 (Fig.14). In the case of T_1 sugar acid ratio decreased from 54.56 to 10.45 at the end of 36th day and for T_2 the decrease was from 54.56 to 9.73 during the same period. For T_8 the decrease from 50.55 to 10.91 was noticed with in a period of 16 days and for all other treatments minimum value ranged from 11.07 to 15.03 at the end of 20th day (Table 25).

Under refrigerated conditions storage life was 32 days after harvest. But in other treatments, except those fruits kept open, fruits could be stored upto 16 days. Fruits can be kept open upto 8 days. Fruits were lost during storage due to the incidence of a disease. Infection started from the stalk end of the fruit as black sooty growth which on observation was found to be due to *Botrydiplodia* sp. These black sooty growth further spread over the entire surface of the fruit in the advance stage. Infection was also seen spreading into internal tissues. The pulp initially showed brown discolouration followed by the decaying of the pulp developing a foul odour. In the advance stage, the pulp shrank and turned into a charcoal black coloured papery mass. The fungus did not penetrate into the seeds of the fruits. The rind of the infected fruit became very hard and was very difficult to open. The healthy fruits could be easily opened by a gentle press of hand. Once infected, fruits became very hard and it required a knife to cut open the fruits.

4.9 Seed germination and viability

The fleshy segments of mangosteen may enclose a seed or it may be

Table 26. Seed germination at weekly interval

Days after harvest	No. of seeds sown	No. of seeds germinated	Days taken for germination	Percentage germination
Immediately after harvest	75	72	19	96
7	75	66	21	88
14	75	54	21	72
21	75	39	21	52
28	75	15	22	20
35	75	0	0	0

Plate XVI. Seeds of Mangosteen

Plate XVII. Germinated seedlings of mangosteen


Seeds.

seedless. The seeds were of various sizes (Plate XVI), ranging from 0.5 to 2.0 cm in width. They were brown, flattened and hypogeal in germination.

Data on seed germination and viability are presented in Table 26. Seeds when sown immediately after harvest showed maximum percentage of germination (96). Thereafter there have been a steady decline in germination which reached a minimum of 20 per cent when seeds were stored for 28 days after harvest. None of the seeds germinated when sown 35 days after harvest. Mean number of days required for germination was found to be 20.80. On germination the erect shoot system grew to a about 4.0 cm before unfolding its first pair of leaves. Germinated seedlings at different stages are shown in Plate XVII. Normally only one seedlings germinated from each seed, but in approximately ten percentage of the seeds germinated polyembryony occurred and commonly, two or three or as many as even four seedlings per seed had been observed.

Discussion

5. DISCUSSION

The results of the present investigation on various aspects of growth, flowering, fruit set, fruit development and storage studies in mangosteen (*Garcinia mangostana*) are discussed in this chapter.

5.1 Growth characteristics of mangosteen

Mangosteen is a typical tropical fruit tree, requiring tropical climate with high humidity, moderate temperature and abundant rainfall as well as a shady environment especially during the early stage of growth. In mangosteen shoot growth coincided with the emergence of new flushes. Shoot growth as quantified in terms of increase in elongational growth during the period of study showed two periods of growth activity, viz., June-August and January-February, corresponding to two seasons of flushing. Shoot growth during other months of the year was nil. Though two peaks in shoot growth were noticed during the months of July and February, most of the shoots (73.40%) showed growth during July. Only 10.50 per cent shoots showed growth during the month of February. Thus the main season of flushing in mangosteen is during the period June-August.

Growth behaviour of mangosteen in relation to environmental factors showed that the period of main flushing coincided with the periods of high rainfall, high relative humidity and low temperature. Second flushing, which was not noticed in all the trees coincided with periods of no rainfall, low relative humidity and high temperature.

The increased growth during June-August is quite reasonable considering the high soil moisture level and optimum temperature during the periods. This is in conformity with the observations made by Nazeem (1979) in nutmeg. The low moisture level in summer, coupled with comparatively low relative humidity may be the reason for the absence of growth during summer months. The climatic factors such as temperature and relative humidity may not be the only limiting factors for the growth of mangosteen under the humid tropical conditions of Kerala. The moisture level of soil and the internal physiological conditions of the tree may be the controlling factors, as the data indicated that the growth was possible more than once in a year.

The main flushing which is seen immediately after the end of reproductive phase would be a mechanism of the crop to cope up with the food necessity during the following flowering season. Second flushing, a meagre one compared to that of main flushing, was seen synchronous with the flowering season. The tree that lacked second flushing happened to be a neglected tree that did not receive proper and adequate irrigation. Thus, in mangosteen, soil moisture, in addition to many other factors, plays an important role in determining the flushing season. However, in *Garcinia cambogia*, shoot growth was greatly influenced by temperature (Sherly, 1994). Maximum shoot growth was observed during summer months when temperature was high and minimum shoot growth was observed during rainy season when temperature was low.

In this experiment the mean extension growth over a period of one year was found to be only 6.91 cm which was very low as compared to that of many

other tropical fruit trees. This might be the reason for refering mangosteen as a slow growing tree in literatures.

Serious drought with high temperature during summer was found to cause sun burn and drying of tips and margins of leaves. Mangosteen always prefers to have a shaded condition for its proper growth and development. High yield was recorded in trees grown under partial shaded condition. Similar observation was made by Kay-ming (1990).

5.1.1 Tree architecture

The seedling of mangosteen which is slow growing consists of a parent shoot on which the leaf pairs are arranaged spirally. Newly emerging leaves are distinct from the mature leaves by the conspicuous purplish red colour. The first pair of branches produced by the trunk axis, marks the end of the seedling stage. Branching in mangosteen is sylleptic with lateral meristems in the axils of the upper most leaf pair seen developing contemporaneously with the parent shoot. The same pattern is continued by the mature tree.

The tree has a monopodial orthotropic trunk meristem which shows continuous growth. Branches are produced in pairs spirally on the trunk in the same manner as leaves are produced on the seedlings. Lateral branches are plagiotropic, and are sympodial with each branchlet having a terminal inflorescence. About 90 per cent of the branchlets produced from primary branches are plagiotropic while the remaining branches exhibit orthotropy. Growth of mangosteen is a rhythmic one with periods of active growth alternating with periods of dormancy. Growth was observed only during five months of the year and plant remained inactive during rest

of the year. Leaf arrangement is spiral in the seedling stage but is distichous on all the branches of mature tree.

Halle *et al.* (1978) proposed several models which describe almost all possible architecture of the tropical trees. However, the architecture of mangosteen could not be included under any of these models. Observations showed that it has close proximity to Roux's model. But continuous growth, which defines the model is not seen in mangosteen. In mangosteen growth is rhythmic. Rhythmic growth is described under Massart's model but branching pattern described in this model does not conform to mangosteen. So architecture of mangosteen can be considered as an intermediary between Roux's and Massart's models.

5.2 Flowering and floral characters

5.2.1 Flowering pattern and flower bud development

During the course of present study, only trees with female flowers were seen in cultivation. There are no reports of existence of male trees in Kerala. According to Corner (1952), "the male trees have never been found in Malaya though they are said to occur rarely in Indo-China".

Mangosteen produces female flowers with staminodes. Flowering was found to occur on past season as well as current season shoots simultaneously with the second flushing. But not all the trees showed a second flushing at the time of flowering. One of the trees studied lacked the second flushing during flowering. The existince of synchronous vegetative and reproductive phase had been reported in kodampuli (*Garcinia cambogia*) with flowering found to occur on past season shoots. But in 'kodampuli' flushing during reproductive phase was reported to be

the main flushing period, although scattered flushing was seen throughout the year (Sherly, 1994). The occurrence of flower buds along with vegetative flush was reported in crops like nutmeg (Nazeem, 1979), *Annona sp.* (Thakur and Singh, 1965) etc. also. However, in these crops the flower buds were borne on the current season shoot as against mangosteen where flowers occurred both on past season as well as current season shoots.

Though there existed a synchronous vegetative and reproductive phases in mangosteen, the main flushing period was immediately after the reproductive phase. The exact picture on the relationship between these two phases is yet to be known. Further investigations on these lines are necessary for arriving at a definite conclusion.

Visual flower bud emergence commenced from the month of December in most of the trees with maximum flower opening during January and in a few trees emergence was during January with maximum flower opening during February. The flowering to fruit maturity in mangosteen coincided with the dry period of the year. During this period the rainfall received was nil with low percentage of relative humidity. However effective sunshine hours were maximum, with temperature showing a slight increase towards fruit maturity (Fig. 2). The fruit ripening was completed by May-June. This was in accordance with the observations made on most of the tropical fruit trees which complete their reproductive phase before the onset of monsoonic rain (Singh, 1961). Soil properties like soil fertility and soil moisture might possibly have a conditioning effect on the plant for putting forth blooms. The variation in flowering may be due to the variation in these soil properties. Observations in Hawaii, China indicated that serious drought during

November to April delayed blossoming in mangosteen till the rainy season (Kay-ming, 1990). In Peninsular Malaya, mangosteen is reported to produce fruits twice a year, between June and August and October and December. However, during the present study only one flowering season was noticed. The extent of flowering in individual trees and percentage of shoots flowered on different aspects of the individual tree showed no significant difference.

In mangosteen the flower bud development from bud emergence to anthesis was found to follow six arbitrary stages. Flower buds pass through a period of 28 days for complete development. The buds were seen emerging as a light greenish yellow protruberance. Initially only bracts were seen protruding outside and remained in this stage for a week. Later bracts were shed off. A day before anthesis outer whorl of calyx separated and next day inner whorl of calyx also separated. Similar observations was made by Sherly (1994) on kodampuli where she observed 7 arbitrary stages for bud development with buds taking 28 days upto anthesis in the case of bisexual flowers. However, in male trees, flowers took 32 days for anthesis.

Though flower drop was not much pronounced in most of the trees, a higher percentage of flower drop (30 per cent) was noticed in one of the trees. The tree which recorded a higher percentage of flower drop happened to be the one which did not show second flushing. The tree was found to be a neglected one which did not receive proper and adequate irrigation, where as all other trees were in a position to receive adequate irrigation and proper management.

5.2.2 Floral biology

Mangosteen produced female flowers terminally on branchlets as solitary

but rarely in pairs or in groups of three or four. Flowers were massive with succulent floral parts, non fragrant and bracteate which were cadicuous. However, had four sepals arranged in descendingly imbricate aestivation and four petals in ascendingly imbricate aestivation. Androecium consisted of 18-20 staminodes produced from thalamus. Gynoecium was syncarpous with five to seven carpels having a single ovule in each carpel. Style was short with five to seven fid capitate stigma at its end.

Lim (1984) reported from Malaysia that mangosteen flowers had superior ovary, capped by the sessile 5-8 lobed stigma and base of the ovary is surrounded by 14-16 staminodes.

The anthesis of flowers started at 16.30 hours and continued upto 18.30 hours. The peak period of anthesis was between 17.30 hours to 18.00 hours. This is in conformity with findings of Lim (1984), who observed anthesis period to be between 4 and 6 pm. Similar observation was made in *G. cambogia*, in which time of anthesis in bisexual flowers was found to be between 16.30 hours and 18.30 hours with peak period of anthesis between 17.00 hours and 17.30 hours (Sherly, 1994).

Observation on anther dehiscence showed that none of the anthers dehisced until flower opening. In opened flowers five per cent of anthers showed signs of dehiscence. Stigma remained dry without any exudation from the stigmatic surface. Variation in fruit set was not noticed when pollination was done at different stages of bud development. This suggest that the receptivity of the stigma is not a governing factor in determining the fruit set in mangosteen.

5.3. Pollen studies

Almost 85-90 per cent of the total pollen failed to take stain during acetocarmine test and none of the pollen germinated under *in vitro* pollen germination studies with different concentrations of sucrose, boric acid and calcium nitrate along with agar. This points to the fact that, though stamens are present in mangosteen flowers, the pollen grains produced are sterile and the anthers present in the flower are staminodes. This reaffirms the earlier study of Corner (1952) and Lim (1984). Lim (1984) had reported that in young anthers, the microspore mother cells were well formed and prominent. However, as they entered into the meiotic division, their nuclei disintegrated first and then their cytoplasm, causing most of them to degenerate.

5.3.1 Pollinating agent

The activity of insects was low in mangosteen flowers. Though flowers were massive and attractive, very few insects were found to visit flowers. This may be due to the nonfragrant nature of flowers and moreover no exudation was noticed from stigmatic surface.

5.3.2 Mode of pollination and fruit set

A higher percentage of fruit set occurred, with all the methods of pollination. Fruit set in the flowers bagged with anthers removed and anthers intact (open pollination) was 90 per cent and 96 per cent, respectively. This suggests that pollination and fertilisation are not necessary for fruit formation. The removal of anthers

from the buds before anthesis also excludes the possibility of self pollination. Other methods of pollination also gave fruit set suggesting that rubbing of anthers on stigmatic surface had no inhibitory effect on fruit set. The percentage of fruit set in flowers with intact stamens is higher than that with the anthers removed, possibly because of the unavoidable injury while emasculating. The above findings show that for fruit and seed development in mangosteen, pollination and fertilization are not necessary and therefore parthenocarpy is the rule for fruit set. Parthenocarpy and apomixis in the species had been suggested by Corner (1952) and Lim (1984). Thus mangosteen can be considered as an obligate agamosperm (seed apomixis). Seedlings are formed from proembryos produced from integuments (Sprecher, 1919; Horn, 1940; Lim, 1984; Richards, 1990).

Mangosteen being an obligate agamosperm and probably lacking male trees has the capacity to produce genetically uniform populations of seedlings through asexual seeds. In this case there will be conservation of variability achieved through any multiple hybridisation involved in its origin, and through periodic mitotic mutations which would not be swamped out by sexual recombination in large populations of offsprings. However, it is possible that there will be a gradual attrition of genetic variation if natural selection is operative. The result will be decreasing ability to adapt to environmental changes and eventual extinction (Ha *et al.*, 1988).

But Richards (1990) suggested that mangosteen is an allopolyploid dervative of *G. hombroniana* and *G. malaccensis* and arose as a female from a single hybridsation event in cultivation and it has since then reproduced asexually. He also suggested that to overcome difficulties in propagation and establishment that

mangosteen presents, attemptes should be made to graft and hybridise mangosteen with its presumptive parents.

5.4 Fruit development and fruit drop

5.4.1 Fruit development

The fruits took 98-105 days after anthesis to complete development. The increase in length, girth, weight, volume and cavity diameter expressed as percentage was maximum during the period from 42 to 56 days after fruit set. However, rind thickness was found to increase upto first 42 days but thereafter it declined and remained constant after 84 days.

The growth of mangosteen fruits showed a sigmoid growth pattern. Sigmoid growth pattern has been reported in many fruits like citrus (Motilal, 1964), carambola (Nand, 1971), mango (Saini *et al.*, 1972) and kodampuli (Sherly, 1994). The growth in mangosteen fruit was slow initially upto 42 days after fruit set and became rapid for the next 14 days, further the growth was slow upto harvest. Similar observation was made by Sherly (1994) in kodampuli. The fruit growth in kodampuli was slow upto 40 days after fruit set and became rapid for the next 20 days. In mangosteen the peak period of growth of fruit was found directly associated with the peak growth period of seed. The seed and aril development was not significant upto 42 days after fruit set but became rapid since them upto 70 days after harvest. This is supported by the observation of Chacko *et al.* (1970) that in mango the period of rapid fruit growth is directly associated with the period of maximum activity of auxin and gibberellin like substance in the seed. Singh (1990) reported that size of the seed also contributes to the size of the fruit in mango. This rapid

development of fruit may be due to rapid development of seed and a decrease in the inhibitor content in the pericarp.

Further decrease in growth rate may be due to the reduced growth rate of rind, which had a major share of fruit weight, as compared to that of pulp and seed. The increase in weight during the maturity in guava was attributed to an increase in flesh content which enabled maximum possible accumulation of food substance (Dhillon *et al.*, 1987)..

The percentage contribution of fruit pulp, rind and seed weight to the total fruit weight was also studied in mangosteen. The percentage contribution of pulp towards total fruit weight increased from 56 days after fruit set upto harvest, where as rind weight showed a declining trend. However, contribution of seed increased initially which later remained almost constant. This shows that though rind had a major share (62.30%) of fruit weight at harvest stage, the rate of increase in pulp weight was much higher than that of rind weight during the development of fruit from 56 days onwards which is evident from the increasing trend showed by the percentage contribution of pulp towards fruit weight and the declining trend showed by the rind.

Chemical analysis of fruit showed that TSS content of the pulp increased till harvest stage while the ascorbic acid content and acidity showed decreasing trend towards harvest. Total sugars, reducing sugars non reducing sugars and sugar : acid ratio were also found to increase till harvest.

Slight variation among the trees in the chemical composition of fruits like TSS, acidity, ascorbic acid content, total sugars, reducing and non reducing

sugars may be due to the variation in soil properties like soil fertility and soil moisture.

5.4.2 Fruit drop

Fruit drop recorded was maximum (41%) during the first 30 days of fruit development and thereafter it was found negligible.

In mangosteen a very high percentage of fruit set was noticed (90-95). Hence in the early stages numerous fruits were seen and consequently the competition between growing fruits for nutrition and water requirements became greater which would be the probable reason for higher percentage of drop in the earlier stages. However, when the fruit number is reduced the competition is greatly reduced and hence the fruit drop was found to be negligible in the later stages. Chadha (1963) had attributed the competition between young developing fruits as the main cause of fruit drop, especially in the early stages in mango. The fruit drop may also be the result of an abscission mechanism as reported by Addicot and Lynch (1955), Chadha and Singh (1963) and Randhawa (1971) in different crops. However, Bardwaj (1975) suggested the imbalance between various plant growth regulators as the possible reason for fruit drop. Further detailed studies may have to be taken up to determine the exact cause of high initial fruit drop in mangosteen.

5.4.3 Harvest index and method of harvest

The best time of harvest was when 25 per cent of the fruit skin had developed a purple colour which was green in the early stages. It took about 90 days for the fruits to reach this stage. Though the physical characters like weight, length, volume, girth and cavity diameter were found to attain its maximum values, at this

stage, chemical analysis of fruit at this stage showed a slightly lower value for TSS, total sugars, reducing and non reducing sugars and sugar:acid ratio than the tree ripened fruit. But titratable acidity and ascorbic acid content was higher than that of tree ripened fruit. However, these fruits ripened normally in two days when stored at ambient temperature. There was no difference in fruit quality between the tree ripened fruit and those fruits ripened at ambient temperature. Fruits ripened on the tree by about 98 to 105 days after fruit set. But fruits were ready for harvest by 90 days after fruit set which when stored for two days at ambient temperature ripened normally. Therefore it is advisable to harvest mangosteen when 25 per cent of the fruit skin had developed a purple colour by which we can save a period of one week or so, required for ripening of the fruit when left on the tree itself.

If the fruits are harvested prior to maturity stage, a portion of the stem will also be attached to the stalk with a gummy exudation at the point of detachment. Fruits when harvested at the right stage of maturity showed no signs of gummy exudation at the stalk end and fruits could be detached with same easiness as that of fully ripened fruits. Since no variation was noticed in the quality of tree ripened fruits and those harvested at full maturity stage, an early harvest at this maturity stage can be recommended for transport to distant markets.

Harvesting of fruit is done mostly by hand or by means of knife attached to a long pole. It is likely to cause injury to the pericarp of the fruit if the fruits are allowed to drop to the ground or fall upon one another. Hence it is advised to have a harvesting pole to which a small net basket with a ring around the neck is attached to receive the fruit in it, there by preventing the fruits from falling down.

Proper harvesting and handling practices are important in mangosteen. Mechanical injury caused due to poor harvesting and handling practices might lead to the formation of Translucent Flesh Disorder which reduced the fruit quality. Symptoms usually found in large segments of the fruit included flesh changes from white to translucent and textural changes from soft to firm and crisp. The fruit also became very hard and difficult to cut open. The major reason for the malady is the cracking of the rind through which moisture absorption takes place as reported by Pankasemsuk *et al.* (1996). Other reasons suggested are nutrient imbalance (Phlompaat, 1989) and pathogens (Wannasiri, 1990). The loss due to Translucent Flesh Disorder can be reduced to a greater extent by careful harvesting and proper handling of the fruits.

5.5 Yield

There was large variation in yield among individual trees. The yield ranged from a minimum of 650 to 3350 fruits/tree. The variation in yield may be due to the difference in the age, condition of the soil and amount of cultivation given. In a survey conducted in Kerala by George *et al.* (1996), it was found that the total yield/tree was higher in trees grown in the river belts. The trees grown in the rocky terrain were stunted and yield/tree was significantly poor (250 to 500). On the other hand, an adult healthy tree of about 80 years grown in the riverbelts yielded upto 15,000 fruits/tree.

It had been reported that the yield in the first year of bearing was 200-300 fruits which gradually rose to 1,200-1,500 fruits a year. Mangosteeen did not begin to bear until they were 7-10 years old; usually fruiting started after 15

year. It was also reported that crop size was adversely affected by relatively large amounts of rainfall and an increased number of rainy days during the pre-blossoming period. Prolonged dry weather preceeding fruit was reported to favour yield (CSIR, 1948).

5.6 Sensory evaluation and fruit characters

Fruits when subjected to sensory evaluation showed that there was not much variation among trees for sweetness and juiciness. Most of the fruits came under the class moderately sweet but a very good number of fruits were found to be extremely sweet and juicy.

Variability was noticed in pulp colour, number of segments, number of viable seeds and colour of rind. The ratio of seeded to seedless segments was found to be 1:3.5. Number of segments ranged from 4 to 7, where as number of viable seeds ranged from 0 to 3. It was seen that fruit size increased with the increase in number of seeds. Fruits with three seeds had extraordinary size.

The occurrence of gamboge, a physiological disorder was severe in fruits collected during the later part of the harvest season from mid June to July. Fruits collected from May to mid June were practically free from this disorder. This showed that the disease was greatly influenced by seasonal fluctuations. A higher incidence of the disorder was noticed when harvesting coincided with monsoon period. About 33.82 per cent of fruits were gamboge affected. The cause for the occurrence of gamboge could be attributed to the sudden expansion and cracking of the fruits followed by exudation of an yellow gum from the rind which gradually penetrated into the fruit. Once it entered the fruit, the fruit pulp became yellow,

gummy, corky, bitter in taste and inedible. Occurrence of rains from June onwards might be the major factor responsible for cracking of mature fruits. If flowering could be induced at an early date so that harvesting of the fruits were completed before the onset of monsoon, the loss of fruits due to gamboge could be reduced considerably. Therefore investigations are to be taken up to work out suitable measures to save the fruits from gamboge.

5.7 Chemical composition of the fruit

Biochemical analysis of the edible portion at ripe stage showed that the fruit contained water 76.57, protein 0.5, citric acid 0.32, total sugars 17.02, reducing sugars 3.22, non reducing sugars 13.80, nitrogen 0.28, phosphorus 0.01, potassium 0.13, calcium 0.08, magnesium 0.24 (on percentage basis), sugar : acid ratio 53.18, TSS 27 °brix, ascorbic acid 5 mg/100 g and traces of ß carotene. This is in conformity with the report of Kay-ming (1990).

5.8 Storage studies

As compared to many tropical fruits, the shelf life of mangosteen was found to be better even under open conditions of storage. The quality of the fruits remained unchanged for a period of 8 days with out giving any kind of treatments. This is an added advantage of the fruit and the increased storage life might be due to the presence of hard and thick rind which protects the internal edible portion.

Complete loss of fruit was noticed only by 20 days of storage in all the treatments except fruits stored under refrigerated conditions for which the loss was negligible upto 24th day. Under refrigerated condition storage life was found to extent upto 36 days after harvest. In treatments T_3 (polythene cover), T_4 (polythene

cover + $KMnO_4$), T_5 (wooden boxes), T_7 (cardboard boxes) and T_8 (open condition) fruit loss was noticed from 8th day onwards where as in treatment T_6 (bamboo baskets) and fruits kept under refrigerated condition fruit loss was observed only from 12th day and 16th day onwards, respectively.

The percentage loss in weight was negligible in the case of refrigerated storage upto 20th day while complete fruits were lost in all other treatments by then. Even after 20 days the loss in weight was minimum in the case of T_1 and T_2 when compared to that of other treatments. For treatments, T_5, T_6, T_7 and T_8 maximum percentage of loss in weight was noticed on 12th day where as for treatments T_3 and T_4 it was seen on 16th day of storage.

Total soluble solids, total sugars, non reducing sugars and reducing sugars showed a declining trend in all the treatments. However, for treatments T_1 and T_2 the decrease was gradual and negligible initially. TSS was found to decrease from 27 per cent to about 18 per cent but at varying intervals for different treatments. For T_1 and T_2 the minimum value reached at the end of 36 days. For T_8 it took about 16 days to reach the minimum, whereas for other treatments 20 days elapsed before reaching the minimum value.

The maximum value of total sugars which ranged from 17.0 to 17.5 per cent decreased to a minimum value ranging between 11.0 and 12.41 at the end of storage period. However, the storage period varied among treatments with maximum storage life for treatments T_1 and T_2 and least for T_9, others being in between corresponding to the reduction in total sugars, reducing and non reducing sugars were also found to decrease during the storage period.

Titratable acidity showed a reverse trend when compared to that of sugars. Titratable acidity was found to increase with storage life. For treatment T_3 to T_7 the maximum value reached at the end of storage period which ranged between 0.80 and 1.10 per cent. For treatments T_8, T_1 and T_2, it was found to be 1.10, 1.10 and 1.15 per cent respectively at the end of their respective storage period.

Sugar:acid ratio was found to decline in the case of all treatments during the course of storage but the decline was much pronounced in all the treatments other than T_1 and T_2 which showed a gradual and negligible decrease initially and reached a minimum towards the end of storage period.

The fruits were lost during storage due to dehydration as well as incidence of a disease caused by *Botrydiplodia sp.* Infection started from the stalk end of fruit. Black sooty growth was seen spreading on the rind surface. Meanwhile the internal tissue turned brown. In the advance stage, the pulp shrank and turned into a charcoal coloured papery mass. The fungus did not penetrate into the seed. The fruits became very hard and were difficult to open due to the infection.

Botrydiplodia had been reported to cause charcoal pod rot in cocoa during dry season. The loss of moisture during storage may probably provide a congenial environment for the infection of this disease and this may be the reason for hardening of the rind during storage (Wood and Lass, 1985).

Storage losses of fresh produce in Kerala are high due to high temperature and humidity. Storage at low temperature immediately after harvest reduces the rate of respiration resulting in reduction of building up of the respiration heat,

thermal decomposition, microbial spoilage and also helps in retention of quality and freshness for a long period. This might be the reason for increased storage life under refrigerated condition. In the present study, neither reduction in quality nor occurrence of chilling injury of fruits were noticed upto 24th day of storage when stored under refrigeration. Thereafter no chilling injury was noticed, however gradual decline in quality was noticed. Daryono and Sosrodiharyo (1986) reported that in mangosteen after seven days of storage weight loss and percentage of diseased fruits were 3.3 per cent and 23.9 per cent at ambient temperature and 0 and 11.0 per cent respectively at 5°C. Mukherjee and Srivastava (1980) reported that Red Delicious apples could be stored for 6 months at 0-1.5°C and 85 per cent RH in wooden boxes lined with paper. Safeda guava fruits could be stored for 4 weeks in cold storage at 8.5 to 14°C (Singh and Mathur, 1954).

The loss of fruit was very fast when kept open. This is because of the greater exposure of the fruit to the external environment compared to that of other treatments. There was not much difference among other treatments. All these treatments recorded 100 per cent loss after 20 days of storage. However fruits kept in bamboo baskets showed loss of fruit only after 12 days, where as in other treatments loss was noticed from 8th day onwards. In the absence of refrigeration facilities, it is better to store the fruits in bamboo baskets rather than keeping it in polythene covers or open condition.

5.9 Seed germination and viability

The seeds did not have definite shape. They were flattened and brown in colour. The size varied between 0.5 and 2.0 cm. The viability of mangosteen seeds was very high (96%) when sown immediately after harvest. Storage of the seeds

reduced the viability and it was completely lost by 35 days of storage. On an average the seeds took 20 days for germination. About 10 per cent polyembryony was also noticed with two to four seedlings per seed. To obtain a high percentage of germination sowing of seeds immediately after harvest is suggested. Low viability of the seeds during storage was also reported by Muller *et al.* (1991).

Mangosteen is a fruit crop which performs well under humid tropics of Kerala. It fetches high returns with minimum inputs. On an average, one kilogram of fruit contains 14-18 fruits and it costs thirty five to forty rupees per kilogram. Most of the produce from our homesteads is sold in the markets of Madras, Bombay and Culcutta. Mangosteen, when kept under storage conditions lasts for one months and in bamboo baskets for a fortnight. This is an added advantage of mangosteen over other fruits and hence can be transported to distant markets without any deterioration in quality. However, it is a rare commodity in our markets. General awareness of the importance of this fruit is meagre among our people. It is a pity that such a fruit of immense value still lies in the category of minor fruits and remains underexploited. It is high time since we realised its importance and improved its status by popularising the cultivation and uplifting the marketing facilities. This would certainly benefit our farmers in terms of monitory returns and our people in terms of health at large.

Summary

6. SUMMARY

The present investigations on growth habit, phases of growth, flowering, floral biology, fruit set, fruit characters, seed viability and storage life of mangosteen (*Garcinia mangostana* L.) were undertaken in the Department of Pomology and Floriculture, College of Horticulture during the period of two years commencing from September 1994.

Shoot growth in mangosteen coincided with the emergence of new flushes. Two seasons of flushing were noticed with one main flushing during the period June to August and a second flushing from January to February. Shoot growth was not observed during rest of the year and was highest during the month of July.

Mean extension growth did not show much variation among different trees. On an average, mean extension growth in an year was found to be 6.91 cm which was very low when compared to that of other tropical fruit trees. Hence mangosteen is a slow growing tree.

Average height of a mature tree was around 9 m with 48 primary branches. The tree had a monopodial orthotropic trunk meristem which showed continuous growth. Branching was sylleptic. Branches produced were plagiotropic and showed sympodial growth. Growth was rhythmic. Leaf arrangement was spiral in the seedling stage but distichous on the branches of mature tree. The emerging leaves which were purplish red in colour later changed to dark green.

Flowering was seen during the period December to January which extended over a period of one month. The flower bud development was divided into six arbitrary stages. On an average the bud development was completed in 28 days. It produced female flowers terminally on branchlets. Flowers were found usually singly and rarely in pairs or in groups of three to four. Flower drop, in general, was meagre.

Anthesis started from 16.30 hours and continued upto 18.30 hours with peak period of anthesis seen between 17.30 and 18.00 hours. Petals shed off 24-36 hours after anthesis but sepals and stigmatic lobes remained persistant on the fruit.

Flowers had four sepals and four petals having imbricate aestivation. Androecium consisted of 18-20 staminodes produced from thalamus. Gynoecium was syncarpous with five to seven carpels having a single ovule in each locule on axile placentation. Style was short and had a five to seven fid capitate stigma at its end. None of the anthers dehisced until flower opening. Only a few anthers showed signs of dehiscence when opened flowers were examined. Stigma showed no signs of receptivity. Anthers produced numerous pollen grains but none of them were fertile and they failed to germinate *in vitro*.

A higher percentage of fruit set was seen in mangosteen. Different methods of pollination did not have any effect on fruit set. Fruit development in mangosteen was confirmed as parthenocarpic and seed development as parthenogenetic. Seeds produced were viable. Therefore, mangosteen can be considered as an obligate agamosperm.

The fruits ripened on the tree by 98-105 days after fruit set. The fruits showed a sigmoid growth pattern during development. Physical characters increased upto harvest, but rate of increase was maximum between 42 and 56 days after fruit set. The rate of increase in pulp weight was higher than that of rind during fruit development. The percentage contribution of pulp towards total fruit weight at ripening stage was 33.00 per cent, while it was 62.30 and 4.70 per cent in the case of rind and seed respectively.

Chemical composition of pulp showed that TSS content increased upto harvest, while ascorbic acid and acidity decreased till ripening. Total sugars, reducing sugars, non reducing sugars and sugar : acid ratio were also found to increase till harvest.

The mean fruit drop was 51 per cent and was maximum during the first month after fruit set.

The best time of harvest in mangosteen was when 25 per cent of the fruit skin had developed a purple colour. It took about 90 days for the fruits to reach this stage. These fruits ripened normally in two days when stored at ambient temperature and showed no difference in quality as compared to that of tree ripened fruit. Appearance of purple spots on the base of the fruit and smooth scar formation at the stalk end, without any gum exudation could be used as harvest index in mangosteen.

Proper harvesting and handling practices are essential in mangosteen to avoid mechanical injury and to save fruits from Transluscent Flesh Disorder. Wide variation in yield, among individual trees, was noticed. The yield ranged between 650 and 3350 fruits/tree.

Fruits were highly sweet and juicy. Number of segments ranged from 4-7 and viable seeds from 0-3. Number of segments corresponded to the number of stigmatic lobes.

Biochemical analysis showed that ripened fruit contained water 76.57, protein 0.5, citric acid 0.32, total sugars 17.02, reducing sugars 3.22, non reducing sugars 13.80, nitrogen 0.28, phosphorus 0.01, potassium 0.13, calcium 0.08, magnesium 0.24 (on percentage basis), TSS, sugar : acid ratio and ascorbic acid, 27 °brix, 53.18, 5 mg/100 g, respectively.

About 33.82 per cent of fruits showed incidence of gamboge. The fruits with gamboge were characterised by an exudation of yellow gum from the rind which gradually penetrated into the fruit. Once it entered the fruit, the fruit pulp became yellow, gummy, corky, bitter in taste and inedible. Fruits caught in the rain were severly affected with gamboge.

Fruits could be stored for 3-4 weeks under refrigerated condition without any quality deterioration and fruit loss. Keeping fruits in bamboo baskets also yielded good results. Keeping quality of the fruits even without any treatments was found to be more than a week.

Viability of mangosteen seeds was high (96%) when sown immediately after harvest. Storage of seeds reduced the viability and it was completely lost by 35 days of storage. Seeds usually took about 20 days for germination. Seeds varied in size and shape ranging from 0.5 to 2.0 cm in width and were brown in colour with hypogeal germination. Normally single seedling aroused from a seed but 10 per cent polyembryony with 2-4 seedlings/seed was also noticed.

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* Originals not seen

APPENDIX-I

Weather data for the period from 1995 April to 1996 March

Month		Total rainfall (mm)	Temperature Maximum	Temperature Minimum (°C)	Mean	Relative humidity (%)	Sunshine hours
1995	April	118.7	36.6	24.9	30.8	71	271.7
	May	370.5	38.5	23.9	28.7	78	201.9
	June	500.4	31.6	23.1	27.4	86	109.6
	July	884.7	29.9	23.2	26.6	89	65.6
	August	448.7	30.6	23.7	27.1	86	115.3
	September	282.5	30.1	23.5	26.8	82	184.4
	October	110.4	33.2	23.2	28.2	78	257.7
	November	88.4	31.3	22.5	26.9	80	196.7
	December	0	32.5	21.3	26.9	57	319.5
1996	January	0	33.1	22.4	27.8	53	292.7
	February	0	34.7	23.4	29.1	53	286.1
	March	0	36.4	24.3	30.4	60	281.3

VEGETATIVE, FLORAL AND FRUIT CHARACTERS IN MANGOSTEEN

(Garcinia mangostana L.*)*

By

AJAY ALEX

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Science in Horticulture

Faculty of Agriculture

KERALA AGRICULTURAL UNIVERSITY

Department of Pomology and Floriculture

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR

KERALA, INDIA

1996

ABSTRACT

The present investigations on the growth habit, phases of growth, flowering and floral biology, fruit set, fruit development, seed viability and storage life of mangosteen were carried out in the Department of Pomology and Floriculture, College of Horticulture, during the period 1994-96.

The studies indicated that shoot growth in mangosteen coincided with the main flushing season from June to August and with a second one from January to February. Maximum shoot growth was observed during July. The growth of the tree was slow, with an extension growth of 6.91 cm in an year. The tree had a monopodial orthotropic trunk meristem which showed continuous growth. Laterals exhibited plagiotropy, sympodial growth and sylleptic branching habit. Leaf arrangement was spiral in the seedling stage but distichous on the branches of mature tree. Emerging leaves which were purplish red, later changed to dark green.

The flowering season was from December to January. Bud development was completed in 28 days. Flowers were female and borne terminally on branchlets either singly or in groups of two to four. Flower drop was meagre. Peak anthesis period was between 17.30 and 18.00 hours. Flowers had four scarlet red sepals and four yellow petals each having imbricate aestivation. Androecium consisted of 18-20 staminodes. Gynoecium was syncarpous with five to seven carpels having single ovule in each locule on axile placentation. Style was short and had a five to seven fid capitate stigma at its end. Anthers failed to dehisce until flower opening but a few showed signs of dehiscence after anthesis. Stigma showed no signs of

receptivity. Anthers produced numerous non viable pollen grains which failed to germinate *in vitro*.

Different methods of pollination had no effect on fruit set. Initial set was high but a fruit drop of 41 per cent occurred during first month. Though fruit development was parthenocarpic and seed development parthenogenetic, seeds produced were viable. Therefore, mangosteen can be considered as an obligate agamosperm where proembryos developing from integuments of embryosac mature into embryos. Pulp development took place from 42nd day onwards. Average weight of ripened fruit was 100 g. The percentage contribution of pulp towards total fruit weight at ripening stage was 33.00 per cent as against 62.30 and 4.70 per cent in the case of rind and seed, respectively. Chemical composition of pulp showed that TSS increased upto harvest, while ascorbic acid and acidity showed a decreasing trend. Total sugars, reducing sugars, non reducing sugars and sugar : acid ratio increased upto harvest.

Season of harvest coincided with South West monsoon. Stage of harvest was identified as 90 days after fruitset. Such fruits ripened normally in two days at ambient temperature and showed no difference in quality as compared to that of tree ripened fruit. At this stage, 25 per cent of the fruit skin developed a purple colour and scar formed at the stalk end was smooth, without any exudation of gum.

Mechanical injury should be avoided during harvesting and handling to save fruits from Transluscent Flesh Disorder. Yield varied from 650 to 3350 fruits/tree. Number of segments, which was same as that of stigmatic lobes, ranged from four to seven. However, number of viable seeds ranged from zero to three. Fruits caught in the rain were severely affected with gamboge, a disorder, which

accounted to about 33.82 per cent fruit loss. Exudation of yellow gum from the rind was the characteristic symptom. The fruit pulp also became yellow, gummy, corky, bitter in taste and inedible.

Biochemical analysis showed that ripened fruit contained water 76.57, protein 0.5, citric acid 0.32, total sugars 17.02, reducing sugars 3.22, non reducing sugars 13.80, nitrogen 0.28, phosphorus 0.01, potassium 0.13, calcium 0.01 and magnesium 0.24 on percentage basis. Sugar : acid ratio, TSS and ascorbic acid content was 53.18, 27.00 °brix and 5 mg/100 g, respectively. ß carotene was only in traces.

Fruits stored under refrigerated conditions showed no quality deterioration and fruit loss even after one month of storage. Fruits kept in bamboo baskets lasted for a fortnight. Keeping quality of fruits even without any treatment was more than a week. During storage TSS, sugars and sugar : acid ratio decreased, whereas acidity increased with the storage period.

Seeds varied in size and shape. Viability was very high when sown immediately after harvest. Storage reduced the viability and was completely lost by 35 days of storage. Seeds took 20 days for germination. Germination was hypogeal with single seedlings arising normally, but 10 per cent polyembryony with 2-4 seedlings/seed was also noticed.