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# **SELECTION INDEX AND ACTIVATION OF SEEDLING GROWTH 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 - 680 654

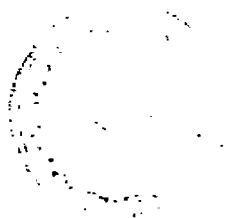
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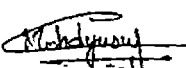
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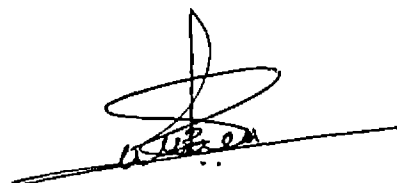
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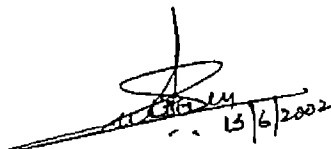
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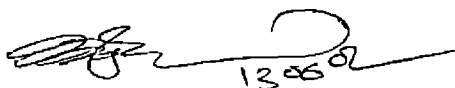
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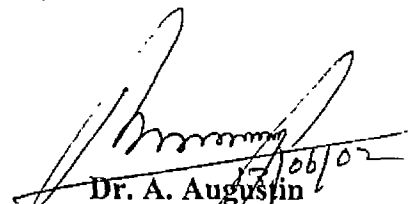
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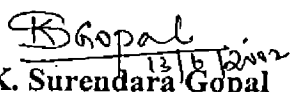
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## ACKNOWLEDGEMENT

*First of all I bow my head before god the almighty whose blessing were always with me and enabling me to undertake this endeavour successfully.*

*I wish to place on record my profound sense of gratitude and indebtedness to Dr. Sajan Kurien, Associate Professor, Department of Pomology and Floriculture, College of Horticulture, Vellanikkara, Thrissur for his versatile guidance and supervision, constant encouragement and creative suggestion throughout the course of my investigation and preparation of manuscript. The deep interest that he has bestowed on me to complete my investigation is respectfully acknowledged and remembered with extreme gratitude. At all stages of my investigation, he was my constant source of inspiration and guiding spirit. I am proud for having worked under his guidance and without his enthusiasm this work would not have been completed this much soon.*

*I am deeply indebted to Dr. P. K. Rajeevan, Associate Professor and Head, Department of Pomology and Floriculture, College of Horticulture, Vellanikkara, Thrissur for his support, guidance and encouragement throughout the entire course of research work is thankfully acknowledged.*

*I have immense pleasure to express my sincere indebtedness to Dr. A. Augustin, Associate Professor, Biochemistry for his sincere support and guidance in the biochemical analysis, valuable suggestions, constructive criticism and immense help rendered during the entire course of research work. I am extremely grateful to him for critical evaluation of my thesis and for making available the facilities of his laboratory.*

*I express my sincere gratitude to Dr. K. Surendra Gopal, Assistant Professor, Department of Plant Pathology, for the valuable help rendered during the course of my research work and for his critical evaluation of my thesis.*

*I extended my sincere thanks to Dr. Sally K. Mathew, Associate Professor, Department of Plant Pathology and College of Horticulture for the sincere help, suggestions and wholehearted co-operation rendered during the course of my thesis work.*

*I am extremely thankful to Mr. S. Krishnan, Associate Professor, Department of Agricultural Statistics for the valuable help rendered for analyzing the data collected and interpreting the results.*

*My heartfelt thanks are due to Dr. Ezha Murugu, Associate Professor, Department of Microbiology, and Tamil Nadu Agricultural*

*University for the timely valuable help to get the AM fungi and Azospirillum pure culture needed for my research work.*

*My thanks are also due to all the staff members of the Department of Pomology and Floriculture for their support and assistance at various stages of my thesis work.*

*The sincere help received from M. Murugan, Assistant Professor, Instructional farm, KAU and S. Vallal Kannan, Ph.D Scholar, Department of Agronomy are gratefully acknowledged.*

*On a personal note, I would like to pour out my heartfelt love and thanks to all my friends. More personally I would like to thank to Dr. Arunachalam, Kurupayan, Beena, Fathima, Sherin, Pattabi, Sanjeev Nair, Senthil, Shirish, Suresh, Mishra, Kingsly, Jinesh, Karthik, Lakshmi Kanthan, Mohana, Kalimuthu, Ravisanker, Ganapathi, Muthukannan, Alemayehu, Boopathi, Manikandan, Anbarasan, Rajasaker, Sundararasu, Sanker, vineel, Radha Krishnan, Kamalakannan and Jaisal for their love, concern and extending their helping hands whenever I was in need. I appreciate all my friends whom helped me in one way or the other.*

*My heartfelt thanks to Mr. Jee, Mr. Santhosh, Mr. Prince and Mr. Joy for their kind help in the entire computer related works.*

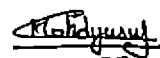
*The help and assistance rendered by smt. Devagi and Sri Vijayan throughout this investigation is gratefully remembered.*

*The award of KAU junior fellowship is thankfully acknowledged.*

*I place on record my indebtedness to my Alma Mater, Kerala Agricultural University for giving an opportunity to carry out my humble investigation.*

*My heartfelt gratitude and love for my brother, sister, Grandmothers and my uncles for their moral support and inspiring encouragement which helped me to undertake this strenuous toil successfully.*

*All the above I dedicated this thesis to my parents for their effort and pains have made me what I am today.*



L. MOHAMED YUSUF



Dedicated



to  
my beloved parents

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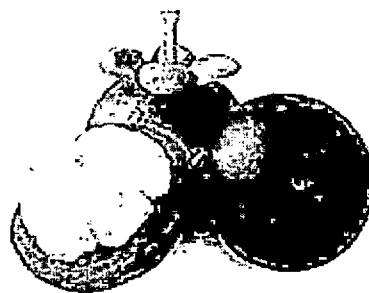
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## LIST OF ABBREVIATIONS

|                                  |                                  |
|----------------------------------|----------------------------------|
| ABA                              | - Absciscic acid                 |
| AMF                              | - Arbuscular mycorrhizal fungi   |
| Az.                              | - Azospirillum                   |
| BA                               | - Benzyl adenine                 |
| CK                               | - Cytokinins                     |
| cm                               | - Centimeter                     |
| FAA                              | - Formalin: Acetic acid: Alcohol |
| G.f.                             | - <i>Glomus fasciculatum</i>     |
| G.m.                             | - <i>Glomus mosseae</i>          |
| GA                               | - Gibberelic acid                |
| GA <sub>4</sub>                  | - Gibberelic acid - 4            |
| GA <sub>7</sub>                  | - Gibberelic acid - 7            |
| HCl                              | - Hydrochloric acid              |
| IAA                              | - Indole acetic acid             |
| K                                | - Potassium                      |
| mg                               | - Milligram                      |
| ml                               | - Millilitre                     |
| MPN                              | - Most probable number           |
| N                                | - Nitrogen                       |
| Na                               | - Sodium                         |
| Na <sub>2</sub> HCO <sub>3</sub> | - Sodium-bi-carbonate            |
| nm                               | - Nanometre                      |
| P                                | - Phosphorus                     |
| rpm                              | - Rotations per minute           |
| UV                               | - Ultraviolet                    |

# *INTRODUCTION*



## CHAPTER - I

### INTRODUCTION

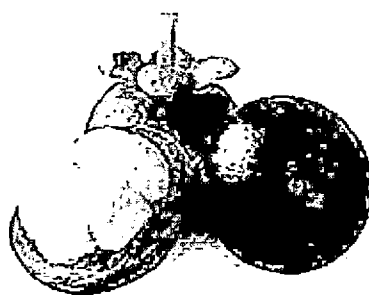
Mangosteen (*Garcinia mangostana* L.), the queen of the tropical fruits (Almeyda and Martin, 1976; IBPGR, 1986 and Kusumo and Verheij, 1994) is a very important crop of the warm humid tropics. The crop like most other polyaxial tropical and sub tropical trees such as rubber, mango, cashew and citrus, exhibit a rhythmic growth habit each under relatively constant environmental condition of the tropics (Alvim, 1964; Wareing, 1970 and Borchert, 1973). It bears profusely and fits very well as a component of the home gardens of Kerala. Though it is a fruit crop with immense potential both as a monocrop and as an intercrop in the coconut gardens with very high domestic and foreign demand, its cultivation on a commercial basis is limited by its long gestation phase. (Wiebel *et al.*, 1995)

The apomictic mangosteen (Richards, 1990 and Normah *et al.*, 1992) seedlings used for commercial planting are extremely slow growing both at the nursery stage and in the orchards (Hume, 1947; Almeyda and Martin, 1976; Wiebel *et al.*, 1992a and Wiebel *et al.*, 1995). The slow growth rate and the consequent long pre-bearing phase has been a cause for concern wherever mangosteen is grown. Though the long gestation period ranging from 10-15 years (Lim, 1984; Richards, 1990 and Wiebel *et al.*, 1995). can be reduced by resorting to vegetative propagation, the problem of slow growth becomes all the more conspicuous (Wiebel *et al.*, 1991 and Wiebel *et al.*, 1995). Referred to as a crop, which lack root hair (Richards, 1990) one of the prime reasons for slow growth could be, this reduced vital link responsible for absorption of nutrients and water. Low carbon acquisition capacity and prolonged dormancy of buds at the apex have also been listed as probable causes of the slow growth rate (Downton *et al.*, 1990). This study was undertaken with the specific objectives of primarily identifying some of the basic reasons responsible for the slow growth rate. Secondly, it is expected to address this problem by identifying the mother plant, fruit and seed characters in relation to seedling growth and formulating the selection indices at the above three basic levels and thirdly to accelerate the growth rate.

Accelerating growth rate of mangosteen trees and thereby reducing the gestation period is thus one of the pre-requisites for the extensive

commercialisation of this crop. The second and third experiments follow a two directional approach the former involving plant hormones (Plant growth regulators) and the latter using arbuscular mychorrizal fungi (AMF) and Azospirillum are both aimed at overcoming the basic causes of slow growth and thus accelerate growth rate.

# *REVIEW OF LITERATURE*



## CHAPTER - II

### REVIEW OF LITERATURE

#### 2.1. SELECTION INDEX

##### 2.1.1. Influence of parent tree characters

A critical review of the literature revealed that only very few references on the crop exist. Selection index studies are available in palms but the aims differ as the thrust of present work is on growth rate. Hence an attempt is made to consolidate the available work on perennial horticultural crops.

##### (i) Tree age

Collection of seed nuts from old coconut palms whose previous history is known well is an age-old practice. Menon and Pandalai (1960) were of the view that selected mother palms for the collection of seed nuts have to be marked out on the basis of age of the palm also. Nursery studies conducted at the Agricultural Research Station, Nilesishwar-III (Kerala, India) did not reveal any difference among the seedlings raised from young, middle aged and old trees. One of the reasons for suggesting that middle aged trees are best for selection as mother palms is that the plants will be in their prime of life and one can easily spot out really good yielders from mediocre or poor ones. Under normal condition, the palms between 25 and 60 years of age would have reached the full bearing stage and can be selected as mother palms.

Falade (1981) grouped the varieties with comparable ages on the basis of colours and shapes of their apples in cashew. The variation in the size of the trees was found to be comparatively narrower than that in the yield. In citrus, Reddy (1997) revealed that seeds obtained from healthy, virus-free, old trees, which have a pedigree performance had produced vigorous, uniform seedlings in citrus.

##### (ii) Other characteristics

##### a) On fruit

In Cashew, canopy spread (Nair, 1981; Parameswaran *et al.* 1984 and Manoj, 1992), height of trees and trunk girth (Nair, 1981 and Manoj, 1992), more

lateral shoots, more panicles per unit area (Nawale, 1983), duration of flowering (Manoj, 1992), percentage of flowering, shoot per unit area (Nawale, 1983 and Parameswaran *et al.* 1984), higher sex ratio (Damodaran *et al.* 1966), percentage of hermaphrodite flowers (Rao, 1974 and Anitha *et al.* 1991), highest number of nut set per panicle (Nawale, 1983; Anitha *et al.* 1991 and Manoj, 1992), and individual nut weight (Manoj, 1992), were positively and significantly correlated with yield.

#### **b) On seed**

In cashew, mean nut weight exhibited negative correlation with the number of nuts per panicle that reached maturity. The maximum regression coefficient on yield was observed in case of number of nuts that reached maturity (Anitha *et al.*, 1991). Weight of the kernel showed the highest positive direct effect on nut yield per tree followed by mean canopy spread and number of nuts per panicle whereas individual nut weight and weight of apple had negative direct effects (Manoj, 1992).

#### **c) On seedling growth**

In coconut Patel (1937) reported that palms with a high setting percentage also exhibited the characters of early germination. Seedlings raised from 12 months old nuts collected from high yield group were better in terms of the number of green leaves, height and girth at collar. At the young stage, such palms showed significant difference in the mean number of days for the emergence of successive leaves, number of leaves on the crown, length of leaf and number of leaflets (Nambiar and Nambiar, 1970). Nambiar and Nair (1963) found that progenies of high yielding mother palms were superior to those derived from poor yielding mother palms in respect of field survival and vegetative growth. In contrast to this Cheyne (1952) reported no significant difference in progenies of high and low yielding mother palms and from those selected at random.

A study with 37 mother palms and their progenies conducted by Ninan and Pankajakshan (1961) revealed no relationship between the yield of the parent and the progeny characters like girth, number of leaves or between parent girth and progeny yield.

#### **d) On progeny yield**

In coconut, progenies of high yielding mother palms were superior in yield and growth to progenies of poor yielding mother palms (Patel, 1937, Rockwood, 1953; Liyanage and Sakai, 1960; Menon and Pandalai, 1960; Kannan, 1976 and Kannan and Nambiar, 1979).

Harland (1957) used the term '*prepotency*' to describe palms that were able to transmit the high yielding character to their progenies. Only palms with dominant yield genes could be relied upon to transmit their superiority to their progeny in coconut.

Liyanage (1953) reported that phenotypic selection of mother plants for high yield was ineffective as a means of genetic improvement. Harland (1957) pointed out that all high yielders need not necessarily transmit their high yielding character to progenies and that the real genetic improvement was possible only through the identification of pre-potent palms. Further studies by Liyanage (1958) confirmed that no correlation existed between mother palm and progeny yields under open pollination.

#### **2.1.2. Influence of fruit characters**

##### **a) On number of seeds and seed size**

Experiments in teak clones based on the fruit size, revealed that significant variation occur in number of seeds per fruit. The percentage of four seeded fruits was found to be minimum in all the clones followed by three seeded fruits. The small and medium sized fruits invariably had only one or two locules. There appear to be no relationship between the number of fully formed seeds and the size of the fruit (Bedell and Vijayachandran, 1994).

##### **b) On seedlessness**

In teak, generally the small fruits are seedless, and large fruits contain the seeds. Large fruits can sometimes be seedless and small and medium sized fruits often contain well-formed seed (Bedell and Vijayachandran, 1994).

### **c) On seed germination**

In coconut, Smith (1933) reported that better germination from medium sized nut than from larger nuts. Under sized and relatively light nuts did not germinate properly and have to be rejected. When the volume of any fruit/nut in the bunch was too small or too big from the mean volume, this invariably never germinated or germinated very late (Patel, 1938). The ventral or dorsal position of the nut in the bunch has no great influence on germination or seedling characters (Patel, 1938 and Umali, 1940).

### **d) On seedling growth**

In coconut, the shape of the seed nuts did not influence the leaf length of seedlings but it influenced the number of leaves, number of roots and seedling weight (Macedew, 1933). Silva and George (1971) found that the overall germination and seedling growth were better in medium sized nuts six months after sowing.

## **2.1.3. Influence of seed characters**

### **a) On germination**

The seed nut size as reflected by the polar diameter, equatorial diameter and volume of the nut had been reported to have some influence on the germination of nuts in coconuts. When the volume of any seed nut in the bunch was too small or too big from the mean volume, they never germinated or the germination was very late (Patel, 1938). Silva and George (1971) from a study of seed nuts of three sizes (15.0, 17.5 and 20.0 cm short axis) found that the overall germination rate was better in medium sized nuts, six months after sowing. Thomas (1978) observed that nut size influenced the earliness and total germination.

Seed nuts collected from the bunches with 12 nuts or more germinated much quicker than from light bunches (6 nuts and below) and that light seed nuts weighing 680 g and below gave much reduced germination than heavy ones weighing more than 680 g (Patel, 1938 and Umali, 1940). According to Thomas (1978) planting large seeds (1000-1300 g) horizontally was preferable.

In mangosteen, Reddy (1997) revealed that the size of the seeds was highly variable and the difference in seed weight brought about the variation in germination. The ability to germinate and grow successfully is related to the amount of food stored in the seed. Campbell (1966) opined that is better to establish new plantings only from the larger seeds weighing one gram and above.

#### **b) On growth of seedlings**

The shape of nuts influenced the number of leaves, number of roots and seedling weight in coconut (Macedew, 1933). Silva and George (1971) found that in coconut the overall germination rate and seedling growth were better in medium sized nuts.

Menon and Pandalai (1960) reported that seed nuts should be harvested in the months of February to May as these nuts are bigger in size, have the maximum copra content, give a high percentage of germination (95%) and larger out turn of good seedlings in coconut. Vogel (1980) reported that generally the rate of growth immediately after germination was mainly determined by the food contents and the genetic properties of the seeds. In mango, the bolder stones produced seedlings with more vigour (Reddy, 1997).

Seedlings with exposed food storing or haustorial cotyledons are very vulnerable, and this attractive exposed food source when present above the ground is prone to attack by rodents. But in *Garcinia* type, the food reserve is stored in the hypocotyl, which is protected by the envelopments and situated at (or) below soil level that makes it less vulnerable (Vogel, 1980).

### **2.1.4. Influence of seedling characteristics**

#### **a) On growth**

In coconut the number of days taken for germination of seed nuts had profound influence on the growth of seedlings (Patel, 1938). Srinivasa and Ramu (1971) reported that coconut seedlings from nuts, which germinated early (within 4 months) had more leaves. Early germinated nuts produced seedlings having more collar girth, vigour and early splitting of leaves (Valsala, 1981).

### **b) On survival**

Vogel (1980) demonstrated that the first germinated ones had a much better chance to survive. Last germinated ones have a mortality seven times higher than those, which germinated first. The first germinated ones were also for a much longer period resistant against adverse external factors in rose wood (*Dalbergia latifolia*).

### **c) On flowering and yield**

In coconut, Jack and Sands (1929) concluded that early-germinated seedlings flower early. Highly significant positive correlation was observed between sprouting of seed nuts and flowering in palms. Liyanage (1955) and Charles (1959) reported that higher yields in the early years of bearing have been obtained from seedlings grown from early sprouting nuts. Namboothiri *et al.*, (1975) reported that there was a significant genetic correlation between yield and number of leaves at seedling stage. Kannan and Nambiar (1979) found that the vigorous and intermediate seedlings are significantly superior in terms of initial growth, nut production and copra yield. No significant differences were noticed between vigorous and intermediate seedlings in coconut.

## **2.2. PLANT GROWTH REGULATORS**

Plant growth regulators (PGR) or more correctly plant bioregulators (PBRs), undoubtedly control the mechanisms of growth and development. They are natural 'switches' in a biological system and exert strong controls. Exhaustive reviews of PGRs and their mode of action are mostly available in conifers (Ross *et al.*, 1983).

This part of the review attempted to consolidate the work on only auxins, gibberellins (GA), cytokinins (CK) and two growth inhibitors namely phenols and abscisic acid (ABA), which have been used in the study with special reference to activation of growth.

### **2.2.1. Plant growth promoters**

#### **a) Auxins**

Since the classic experiments of Went and Thimann (1937), there has been a quantum leap in the knowledge on effect of auxins on various physiological

processes. Within the broad realm of growth, the manifestation of auxins can be observed in different ways. Most research with auxins has been conducted on herbaceous species or upon tree parts rather than on a whole tree basis (Bandurskii and Nonhebel, 1984 and Degroote and Larson, 1984). Shoot growth is often considered as an effect of favourable environmental factors wherein auxins particularly IAA does indicate the response (Pharis, 1976 and Lassoie and Hinckley, 1991).

The epicotyl elongation, which is an early phase of growth and used as curvature test in bioassays is one of the most typical effects of auxin on growth (Lavender and Zaerr, 1967 and Mitchell and Livingston, 1968). Again, apical dominance and tree form are apparently mediated by auxins (Pharis, 1976; Thimann, 1977; Bandurskii and Nonhebel, 1984). Branch angle is a consequence of apical dominance primarily due to auxins and this determined whether growth is orthotropic or plagiotropic (Lassoie and Hinckley, 1991).

Application of auxin generally stimulates the root growth (Thimann, 1977; Denne and Wilson, 1977 and Torrey, 1976). Early concepts were that low concentration stimulated root growth and high concentrations inhibited it (Zaerr, 1991). The balance between shoot and root growth is controlled by environmental factors (Kelly and Moser, 1983) and depending upon environmental changes, the plant shifts the balance between root and shoot growth (Zaerr and Brown, 1976). This shift is controlled by internal levels of PGRs including auxins. At the cellular level, the effects of auxin were observed at cambial cell division (Little and Wareing, 1981; Savidge and Wareing, 1984 and Wilkins, 1987), cambial cell growth (Bandurskii and Nonhebel, 1984), xylem and phloem cell differentiation (Denne and Wilson, 1977 and Degroote and Larson, 1984). However, these activities depend on whether the tissue is responsive to auxins rather than its concentrations.

Growth as a consequence of cell loosening factor brought about by changes in pH results in an increased flow of metabolites. This phenomenon described as acid growth hypothesis is widely accepted (Jones and Macmillan, 1984; Takahashi *et al.*, 1986 and Wilkins, 1987). The only effect of auxins reported on mangosteen is root induction of *in vitro* produced shoots of 10-15 mm, which were established in vermiculite/sand mixture in pots (Goh *et al.*, 1994).

## b) Gibberellins (GA)

Gibberellins are linked with RNA, protein synthesis and thus activate number of hydrolytic enzymes leading to increased mobilization of carbohydrates and growth. The first known effects of GA's on growth are on germination. A large body of literature documents this point, which have been reviewed by Chen (1975) and Wilkins (1987). Overcoming, the dormancy imposed by ABA and other inhibitors is another mode of action of GA (Taylor and Wareing, 1979).

Gibberellins characteristically increase growth by cell elongation and increasing the internodal growth (Hull and Lewis, 1959 and Davies and Holmes, 1962; Ak *et al.*, 1995) in different plant species. They are known to increase plant height (Marth and Mitchell, 1961; Marth *et al.*, 1965; Shreve and Campbell, 1967 and Taylor, 1972) and stem diameter (Rahemi and Baninasab, 2000). The sole available reference on the effect of GA in *Garcinia* species is on seed germination and is in Kodampuli (*Garcinia gummi-gutta* L.) (Mathew and George, 1995 and Muthulakshmi *et al.*, 1999).

Foliar application of GA has been reported to increase the growth in many species. This is brought about by acceleration of the cell loosening effects of auxins on cell walls (Jones and Macmillan, 1984 and Takahashi *et al.*, 1986). Tree forms is under the influence of GA (Low, 1975; Shiningar, 1975; Dunberg, 1976 and Pharis, 1976). They positively affect shoot elongation or volume growth (Ross *et al.*, 1983).

Branch angle and cambial activity are apparently affected by GA by enhancing the effects of auxin (Blake *et al.*, 1980 and Philipson and Coutts, 1980). There are few scattered reports of GA having positive effects on root growth (Ross *et al.*, 1983). Generally, root growth seems to be little affected by GA (Westing, 1959 and Wareing, 1980).

In mangosteen, gibberellins were effective in overcoming bud dormancy, but only when applied directly on to the bud. GA<sub>4+7</sub> + BA gave the best result (100% bud-break with in a week). GA<sub>4+7</sub> + BA in lanolin applied on to the buds of 4 year old field grown trees significantly increased the number of new flushes as well as leaf area (Wiebel *et al.*, 1992b).

### c) Cytokinins

The morphogenic effects of cytokinins were first reported by Skoog and Miller (1957). Ever since this report, the prime area of research interest shifted to the effects of role of cytokinins in cytokinesis (Hejnowicz and Tomaszewski, 1969) and cell differentiation (Franchlet, 1981 and Hakman and Von-Arnold, 1985). Together they contribute to growth. They have also been linked to cell enlargement, delay of senescence, hormone directed transport and light requiring processes (Lassoie and Hinckley, 1991).

Tree forms are undoubtedly controlled to some extent by cytokinins and the role on cell differentiation implies some control over bud formation and growth (Lassoie and Hinckley, 1991). Though produced in the root (Torrey, 1976; Wareing, 1980 and Horgon, 1984) they control shooting process. Franchlet (1981) showed that cytokinins are responsible for multiple shoot production. Leaf growth and development are under the control of endogenous ratios of GA to cycokinins (Letham *et al.*, 1982 and Renfroe and Brown, 1983).

At the cell biology level, it is strongly associated with t-RNA and probably is incorporated into it (Letham *et al.*, 1982). This link to protein synthesis control enzyme production and affects enzyme production and thus affects the mechanisms controlling growth. Its presence in xylem sap suggests that cytokinins are parts of the mechanisms that control shoot growth. Unfortunately there are insufficient data on cytokinin levels on growth activities to do much more than speculate on this subject at present. GA<sub>4+7</sub> + BA on the growth of 4 year old mangosteen trees significantly increased the number of leaves. Leaf area was also significantly increased, although the average leaf size of the induced flush (first flush after treatment) was significantly smaller (Wiebel *et al.*, 1992b).

GA<sub>4+7</sub> and BA when applied individually were less effective in inducing bud break than when applied together. Branched seedlings responded poorly to BA but the combination of GA<sub>4+7</sub> with BA was the most effective, causing 100 per cent bud break within a week. BA was effective only on seedlings, which had not yet begun branching. GA<sub>4+7</sub> + BA in 4 year old mangosteen trees produced significantly more shoots (Wiebel *et al.*, 1992b). They are of the view that it may be possible to enhance the growth of field-grown trees during their pre-

bearing age by inducing one or two extra flushes per year with PGRs, such as  $GA_{4+7} + BA$ , provided sufficient reserves are available to enable normal growth.

### 2.2.2. Growth inhibitors

Though there are several groups of new inhibitors identified (Wilkins, 1987) the present study is confined only to phenols and abscisic acid.

#### a) Phenols

The number of phenolic compounds present and their content were found to be different in males from that of females of some dioecious species. Phenolic compounds were found in the leaf extracts of *Carica papaya* (Singh and Jindal, 1974) and in storage roots of asparagus (Billau *et al.*, 1987). Thomas (1997) reported the presence of higher total phenol content in the leaves of male nutmeg trees.

In *Garcinia cambogia* Desr. (Malabar Tamarind), the total phenol content ranged from 265.0 to 380.8 mg/100 g. The average of total phenol content was 313.1 mg/100 g. Significant difference between male and bisexual plants was noticed with respect to the total phenol content of young and mature leaves (Muthulakshmi, 1998).

#### b) Absciscic acid (ABA)

ABA has been implicated on several physiological responses on trees and other plants (Aspinall, 1980 and Addicott and Van-Steveninck, 1983). The balance between growth promoters and growth inhibitors actually control plant response (Lassoie and Hinckley, 1991).

ABA is regarded as an inhibitor of cell elongation and generally it is negatively correlated with shoot growth (Yadava and Dayton, 1972; Sakurai *et al.*, 1985; Bensen *et al.*, 1988 and Noda *et al.*, 2000). Its effects on growth starts at the level of seed (Moore, 1979 and Walton, 1980) and bud dormancy and its early name and identification have been primarily as a result of this. Though inhibition is a normal result, the current thinking is in terms of correlative inhibition (Wilkins, 1987).

Based on the method of action, Milborrow (1984), classified ABA mediated responses into fast and slow reactions. Growth inhibition due to ABAs

have been reported in dwarf apples (Yadava and Dayton, 1972), in shoot of Thotapuri mango (Murti and Upreti, 1993) and many dwarf varieties of crops but there has not been a single reference of its role in mangosteen or in any of the related species.

However, it has been well documented that auxin, gibberellin and cytokinin levels typically decline in response to stress (Aheles, 1973; Aspinall, 1980 and Addicott and Van-Steveninck, 1983). This has led to the suggestion that balance between growth stimulators and inhibitors actually controls plant growth response (Lassoie and Hinckley, 1991)

## **2.3. MICROBIAL INOCULATIONS**

### **2.3.1. Arbuscular Mycorrhizal Fungi (AM fungi)**

The literature on root inoculation fungi is reviewed under the following major subheadings.

#### **a) Occurrence**

According to Butler's review (1939) AM fungi root infections are more abundant in orchard and plantation crops. At one conference alone in 1979 (4<sup>th</sup> North American Conference on Mycorrhiza, Fort Collins, Colorado) one half of the more than 150 papers presented were on AM fungi (Hayman, 1982a). The symbiotic association of Mycorrhiza fungi with roots of vascular plants is a century old (Mohandas, 1993). Root infections by AM fungi have been reported in many perennial fruits such as grapes and citrus (Gerdemann, 1968), citrus (Nemec *et al.*, 1981), and apple (Hayman, 1972). However, the word mycorrhiza is of recent origin. Frank (1985) coined the term "Mycorrhiza" to indicate the fungus root. Hayman (1982b) was of the view that interest in AM fungi has been increasing at a phenomenal rate. Its presence and beneficial effects in cultivated crops of Kerala have been reported by various workers (Potty, 1978; Sivaprasad *et al.*, 1982; Sivaprasad *et al.*, 1984; Girija and Nair, 1985 and Nair and Girija, 1986).

#### **b) Utilization**

Marx (1975) reported that some plants couldn't grow without the presence of mycorrhizae. Utilization of mycorrhizal fungi in crop production has been demonstrated in woody fruit species like citrus (Kleinschmidt and

Gerdemann, 1972; Schenck and Tucker, 1974 and Timmer and Leyden, 1978), peach (*Prunus* sp.) (La-Rue *et al.*, 1975 and Lambert *et al.*, 1979), avocado (Menge *et al.*, 1980).

Mohandas (1993) revealed that the AM fungi inoculation in nursery grown citrus has become a standard practice in many parts of the USA. But in India, the use of AM fungi has been confined to inoculation trials on citrus, banana, papaya and litchi.

### c) AM fungi influence on growth

#### i) Growth rate

Root inoculated perennials with AM fungi effectively enhance the growth of plants (Mosse, 1973a; Graham *et al.*, 1982, 1996 and Camprubi and Calvet, 1996) and crops like strawberry (Holvas, 1966), citrus (Manjunath *et al.*, 1983; Menge, 1983 and Kurle and Pfleger, 1994), apple seedlings (An *et al.*, 1993 and Uosukainer, 1992), banana (Rizzardi, 1990), Rough lemon (Zhenyao and Kaihen, 1984) and peach (La-Rue *et al.*, 1975).

Slow-release fertilizers in combination with mycorrhiza fungi produced plants with adequate growth rate (Maronek and Hendrix, 1979a, b, 1980 and Maronek *et al.*, 1980). Three-fold increase in growth rate was observed in citrus (Eissentat *et al.*, 1993). Shoot growth rate increased in micro propagated guava plants (Estrada-Luna *et al.*, 2000).

In contrast, Peng *et al.* (1993) reported 12 per cent reduction in citrus relative growth rates by *G. intraradices* under conditions of high soil P, but growth rate increased when P is limited (Graham, 1986). *G. mosseae* increased the growth in citrus by 0-150% depending on citrus varieties (Kleinschmidt and Gerdemann, 1972) by AM fungi.

#### ii) Shoot growth

Plant height was significantly increased by AM fungi in citrus (Shanmugam *et al.*, 1981 and Chandrababu and Shanmugam, 1983), papaya (Sukhada, 1988), *Tamarindus indicus* (Reena and Bagyaraj, 1990), cashew (Ramesh *et al.*, 1998), mango (Sukhada, 1990), banana (Rizzardi, 1990 and Yano-Melo *et al.*, 1999), guava (Estrada-Luna *et al.*, 2000). Inoculation in mangosteen resulted in significant changes in length related characteristics (Masri *et al.*, 1998).

The AM fungi increased the stem thickness or girth in various plants. The effects have been reported in acid lime (Shanmugam *et al.*, 1981), Italian lemon, *Citrus* sp, mango, acid lime (Vinayak and Bagyaraj, 1990), *Tamarindus indicus* (Reena and Bagyaraj, 1990), apple (An *et al.*, 1993), cashew (Ramesh *et al.*, 1998) and Rough lemon (Zhenyao and Kaihen (1984).

The total number of leaves per plant was significantly increased when inoculated with AM fungi in acid lime (Shanmugam *et al.*, 1981), tamarind (Reena and Bagyaraj, 1990), apple (Edriss *et al.*, 1993), cashew (Ramesh *et al.*, 1998) and leaf production rate in guava (Estrada-Luna *et al.*, 2000). Inoculation of the fungi increased the rate of shoot development in litchi (*Litchi chinensis* Son.) (Rana and Srivastava, 1984), Rough lemon (Zhenyao and Kaihen, 1984), and apple seedlings (Edriss *et al.*, 1993 and Morin *et al.*, 1994).

Positive correlations were observed between AM fungi inoculation and leaf area in micro propagated banana plantlets (Yano-Melo *et al.*, 1999), in citrus species (Syvertsen and Graham, 1999), in litchi (Rana and Srivastava, 1984) and in guava (Estrada-Luna *et al.*, 2000). Fresh shoot weight increment in citrus (Benson and Covey, 1976 and Tang and Chang, 1986), and an increase in fresh root weight in *Musa accuminata* (Jaizmevega *et al.*, 1991) were confirmed due to the inoculation of AM fungi. An increment in total dry weight was reported in papaya (Sukhada, 1988 and Cruz *et al.*, 2000), in mango (Sukhada, 1990), in apple seedlings (Edriss *et al.*, 1993) and in banana (Rizzardi, 1990 and Yano-melo *et al.*, 1999). *Glomus mosseae* proved superior to *Glomus fasciculatus* in improving plant dry weight in papaya (Sukhada, 1988). Probable reason for this increased dry weight has been attributed to higher photosynthetic rate (Estrada-Luna, 2000) or due to the production of growth promoting compounds namely auxin, gibberellins and cytokinins or thirdly due to the vitamins (Millar, 1971; Crafts and Millar, 1974 and Slankis, 1975). Plant vigour was also effectively increased by AM fungi (Maronek *et al.*, 1980) in Rough lemon (Zhenyao and Kaihen, 1984), peach (La-Rue *et al.*, 1975).

### iii) Root growth

Root growth was enhanced by AM fungi inoculation in many crops (Graham and Syvertsen, 1984; Eissenstat *et al.*, 1993 and Peng *et al.*, 1993).

Taproot penetration, root dry weight was not influenced by AM inoculation. The inoculation of AM fungi increased the root length in acid lime (Shanmugam *et al.*, 1981 and Ramesh *et al.*, 1998), and an increase in root length density by 59-87 per cent, root branching density by 20-30 per cent, number of root tips by 22-25 per cent and number of laterals by 15-26 per cent was reported in mangosteen (Masri and Azizah, 1998). Number of roots in cashew (Ramesh *et al.*, 1998) and root vigour in banana (Umesh *et al.*, 1988) were also increased by the AM fungi inoculation.

#### **iv) Total growth**

The fresh weights of shoot and root increased due to inoculation of AM fungi have been reported in ber (Shirsath *et al.*, 1998) and Cleopatra Mandarin (Manjunath *et al.*, 1983). In mangosteen, Masri and Azizah (1998) observed that the root to shoot ratio was not influenced by AM inoculation.

AM fungal inoculation effectively increased the total biomass of plants in citrus and mango (Vinayak and Bagyaraj, 1990 and Harinikumar and Bagyaraj, 1988), apple (Morin *et al.*, 1994), cashew (Ramesh *et al.*, 1998) banana (Rizzardi, 1990) and ber (Mathur and Vyas, 1996).

Total dry mass of plantlets was greater due to mycorrhiza in guava (Estrada-Luna *et al.*, 2000) and papaya (Sukhada, 1988). However, decreased dry weight ratio of root and the whole plant was observed due to the elevated CO<sub>2</sub>, P content and AM fungal colonization in two citrus species (Syvertsen and Graham, 1999). Inoculation of *Glomus mosseae* increased the dry weight of mango rootstocks up to ten per cent (Sukhada, 1990).

Masri *et al.*, (1998) observed that arbuscular mycorrhiza enhanced the growth and reduced the nursery period of mangosteen (*Garcinia mangostana* L.) seedlings. Another study by Masri and Azizah (1998) revealed that the improved growth and increased nutrient uptake of AM-inoculated seedlings were due to positive alterations of root system characteristics by the symbiosis.

#### **d) AM fungi and P uptake**

Increased uptake of phosphorus by AM infected plants was carried out first in apple by Mosse in 1957. Increase in P concentrations of plant tissue as a result of endo-mycorrhizal inoculation have been reported in various fruit crops

such as strawberry (Holvas, 1966), citrus (Kleinschmidt and Gerdemann, 1972), raspberry (Hughes *et al.*, 1979), Cleopatra Mandarin (Manjunath *et al.*, 1983), citrus (Onkarayya and Sukhada, 1986 and Tang and Chang, 1986) *Tamarindus indicus* (Reena and Bagyaraj, 1990), apple (An *et al.*, 1993 and Morin *et al.*, 1994), sweet orange (Singh and Sharma, 1993), ber (Mathur and Vyas, 1996 and Shirsath *et al.*, 1998); sour orange and sweet orange (Syvertsen and Graham, 1999), and guava (Estrada-Luna *et al.*, 2000). The role of AM fungi in increasing the mobilization and uptake of P and thereby productivity of many crops are well documented (Gerdemann, 1968; Mosse, 1973b; Meenakumari, 1987; Nelsen, 1987; Bhandari *et al.*, 1990 and Geethakumari *et al.*, 1990).

The ability of mycorrhizae to absorb phosphorus from insoluble P sources was reported in pine (*Pinus* sp) and beech (*Fagus* sp) (Bartlett and Lewis, 1973) and from sparingly soluble P sources such as rock phosphates in citrus (Zhenyao and Kaihen, 1984). Such plants showed higher leaf P status but lower leaf N and K concentrations than non-mycorrhizal seedlings. Mycorrhizas stimulated growth at both P levels in sour orange, the more mycorrhiza dependent species, but only at low P level in sweet orange, the less dependent species (Syvertsen and Graham, 1999).

Isotope dilution or fertilizer labeling techniques in a number of studies led to the conclusion that plants used the available phosphate pool, whether or not they were mycorrhizal (Sanders and Tinker, 1971; Hayman and Mosse, 1972; Mosse *et al.*, 1973 and Powel, 1975). AM fungi inoculated plants drew most of their P from the soluble pool and were more effective than non-mycorrhizal plants. The mycelial network of endomycorrhizal fungi enabled the plants to remove phosphate from a larger volume of soil extending even beyond the immediate vicinity of the root surface (Bolan *et al.*, 1984). Increased P uptake was attributed to the increase in surface area of absorption (Sanders and Tinker, 1971) and further to hyphal translocation (Hattingh *et al.*, 1973).

In mangosteen (*Garcinia mangostana* L.), alteration of root system characteristics and nutrient uptake in response to arbuscular mycorrhizae (AM) fungal inoculation has been studied. AM inoculation induced significant changes to root characteristics. This positive alterations to root systems were accompanied by

tremendous increase in nutrient uptake. Uptake of P increased by 67-88 per cent in inoculated seedlings (Masri and Azizah, 1998).

#### **e) AM fungi and other nutrients uptake**

One of the prime functions of mycorrhizal fungi in the production of field and greenhouse horticultural crops is their role in the mineral nutrition of plants. The uptake of nutrient elements by AM fungi infected plants was first studied by Mosse (1957). A number of reports showed that AM fungi increased the N concentration in plant shoots (Jain and Patriquin, 1984; Barton *et al.*, 1986 and Barea *et al.*, 1988).

Mycorrhizal treated pines (Hatch, 1937), citrus species (Onkarayya and Sukhada, 1986), papaya (Sukhada, 1988), banana (Rizzardi, 1990) accumulated more nitrogen (Umesh *et al.*, 1988 and Bhandari *et al.*, 1990) and higher phosphorus (P) and potassium (K) (Hatch, 1937 and Umesh *et al.*, 1988) than did non-mycorrhizal plants. Later works reviewed by Meyer (1974) and Trappe (1977) with a variety of woody and herbaceous plant species have substantiated Hatch's findings.

Mycorrhizal associations have been found in N fixing plants and stimulate nodulation (Crush, 1974; Carling *et al.*, 1978 and Bagyaraj and Menge, 1978). It has been suggested that the vesicles may function in enhancing storage capacity (Gerdemann and Nicolson, 1963), and continuous disintegration of arbuscules lead to availability of mineral nutrients to the host (Gerdemann, 1968). The AM fungi directly enhance the uptake of micronutrients viz. Zn, Cu and Fe (Gildon and Tinker, 1983; Tinker and Gildon, 1983; Pacovsky *et al.*, 1986; Kucey and Tanzen, 1987 and Rai, 1988). Zn deficiency could be corrected by inoculating peach (*Prunus* sp) plants growing in a sterilized Zn deficient medium with an endomycorrhizal fungus (Gilmore, 1971). It was observed that AM fungi association resulted in higher uptake of micronutrients in various plants, which was brought about by selective uptake of minor nutrients. In citrus species, Zn and Mg (Onkarayya and Sukhada, 1986), in papaya, Zn (Sukhada, 1988), in apple Cu, P and Zn (An *et al.*, 1993), in sweet orange, Zn, Cu, Fe and B (Singh and Sharma, 1993), in guava, Mg, Cu, Mo (Estrada-Luna *et al.*, 2000), in Peach, Zn and Mo

(La-Rue *et al.*, 1975) and better utilization of N, Cu, Zn and S in various crops (Bhandari *et al.*, 1990).

#### **f) AM fungi and hardening of plants**

The two species namely *Glomus mosseae* and *Glomus fasciculatum* increased survival rate and helped hardening of micropropagated plants in pineapple (Vega and Azcon, 1991), banana (Yano-Melo *et al.*, 1999), citrus (Davies and Albrigo, 1994), apple (Uosukainer, 1992) and guava (Estrada-Luna, 2000).

The survival rate of the transplants was 80 per cent in AM fungi inoculated micro propagated pineapple plantlets compared with 40 per cent in the control (Vega and Azcon, 1991). Similarly, AM fungi increased the survival rate of the green house grown seedlings when transplanted to the main field in the case of apple (Uosukainer, 1992), and citrus (Davies and Albrigo, 1994).

#### **g) AM fungi and Stress**

Pacovsky *et al.*, (1986) revealed that presence of AM fungi could decrease nutrient stress in environments linked with P, Zn, Cu and elements essential in N fixation. Mason *et al.* (1999) studied the stomatal conductance of AM inoculated plants of dry regime and found it to be greater than that of non-inoculated plants in Eucalyptus.

In papaya cv. Solo, the leaf water potential decreased during the water stress treatment and this decrease was more severe in the non-AM fungi plants. An increase of ethylene in non-AM infected roots was observed but the concentration in AM roots was slightly lower than under normal conditions (Cruz *et al.*, 2000).

#### **h) AM fungi and disease resistance**

Mycorrhizal fungi increase disease resistance in plants (Chakaravorty and Mishra, 1986 and Joseph, 1997). In black pepper, it suppressed the foot rot disease incidence (Sivaprasad *et al.*, 1995). This could be due to the production of antibiotic substances, which has already demonstrated in a large number of fungi, which form mycorrhizal association. Marx (1972) has compiled a list of over 90 species of mycorrhizal fungi, which have produced one or more types of antibiotic substances in pure culture or in basidiocarps. In banana, ill effects and nematode

population of burrowing nematode (*Radopholus similis*) were also significantly reduced by the inoculation of *G. fasciculatum* (Umesh *et al.*, 1988).

#### **i) Percent infection/Root colonization**

There is a positive correlation observed between percentage infection and (or) root colonization and growth of plants. Inoculated plants were heavily colonized with arbuscules, vesicles and endospores in litchi (Rana and Srivastava, 1984), papaya (Sukhada, 1988) and guava (Estrada-Luna *et al.*, 2000).

Bjorkman (1970) observed that mycorrhizal development was greater at higher light intensities. Some *Glomus* species have been reported to be adapted to higher soil temperatures than others (Schenck and Schroder, 1974 and Schenck *et al.*, 1975). Generally high moisture level retard mycorrhizal formation especially during the winter months, when many soils become water logged (Powell and Sithamparamanathan, 1977). Singh *et al.* (1992) found the maximum root colonization in Kinnow and Rough lemon seedlings in the months of June, and minimum in November. Shamim *et al.* (1994) observed the maximum colonization in spring, which gradually decreased in the following season and reaching minimum in winter. Baylis (1975) found a significant positive correlation between magnolioid root characteristics and endomycorrhizal infection.

### **2.3.2. Azospirillum**

#### **a) Occurrence**

Nearly 10 per cent of the soils and roots from temperate region and more than 50 per cent of the tropical soils were positive for Azospirillum (Neyra and Dobereiner, 1977). There is only scanty information available on the influence of Azospirillum in perennials crops (Rao, 1982). Azospirillum have been reported in the rhizosphere and rhizoplane of cocoa (Govindan and Nair, 1984) and in pepper cuttings (Govindan and Chandy, 1985).

#### **b) Azospirillum and crop response**

Most of the studies in Azospirillum are on field crops (Rao *et al.*, 1979). Rao and Dass (1989) found that soil inoculation with pure cell suspension of *Azospirillum brasilense* or *Azotobacter chroococcum* resulted in growth enhancement of ber and pomegranate. They argued that the growth enhancement

could be due to production of growth regulators and nitrogen fixation. Enhanced root elongation, root hair development and branching in a number of crops have been reported by azospirillum inoculation (Kapulnik *et al.*, 1983).

Hazra (1994) observed that the increase in yield through Azospirillum inoculation varied from 12-17 per cent in the case of perennials. High crude protein content was also registered in the inoculated plants (Patel *et al.*, 1993).

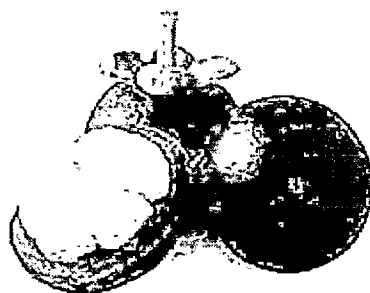
### **2.3.3. Dual inoculation of AM fungi and Azospirillum and growth response**

Combined inoculation of Azospirillum and AM fungi significantly increased shoot biomass in mulberry (Nagarajan *et al.*, 1989), plant height, shoot and root weight in pepper (Bopaiah and Khader, 1989) and shoot growth, biomass production in *Tectonia grandis* (Sugavanam *et al.*, 1998).

Sonowane and Konde (1997) revealed that co-inoculation of AM fungi and Azospirillum or Azotobacter resulted in highest leaf area in grape vine and it took less time for bud sprouting. A comparison between the two revealed that Azospirillum was found to be superior when used in conjunction with mixed culture of AM fungi (Sugavanam *et al.*, 1998).

Higher root colonization resulting in higher N and P and micro nutrients like Fe, Cu, Zn and Mn have been reported in coffee (Kumari and Balasubramanian, 1993) and teak (Sugavanam *et al.*, 1998) In grapes, marked increase in growth and corresponding higher spore count has been reported (Sonawane and Konde, 1997).

# *MATERIALS AND METHODS*



## CHAPTER – III

### MATERIALS AND METHODS

The investigation on fixing of selection index and activating the seedling growth of mangosteen (*Garcinia mangostana* L.) was carried out from March 2000 to February 2002. The study was approached from three major angles, which formed three separate experiments namely

1. Formulation of selection indices.
2. Activation of seedling growth using various growth regulators.
3. Activation of seedling growth using arbuscular mycorrhizal fungi (AMF) and Azospirillum.

The materials and methodologies used in this investigation are presented separately.

#### **3.1. Identification of mother plants belonging to various age groups**

The first experiment on fixation of selection index of the mangosteen (*Garcinia mangostana* L.) was based on the age of the mother plant, fruit, seed and seedling characters. Hence a preliminary survey was conducted in the mangosteen growing tracts of Kerala during the bearing phase ending with the onset of southwest monsoon. The main aim was to identify plant belonging to the different age groups as envisaged in the study.

Required number of plants could be located in different regions belonging to different age groups, but study was restricted to Pariyaram village of Chalakudi Taluk as age groups and numbers were available in a compact area. Hence the mother plants and fruits collection were centered from this area. This further enabled to eliminate any possible error arise from ecological point to the minimum.

#### **3.2. Location of mother trees (Pariyaram village)**

The village Pariyaram is located at 10°20'N latitude and 76°26'E longitude, at an altitude of 3.25 m above mean sea level and 5 km (East) of Chalakudi Railway Station, Thrissur District.

### **3.2.1. Climate and soil conditions of the area**

The area receives an average rainfall of 2150 mm distributed over a period a year. The mean maximum temperature range from 28-36°C with the mean of 32°C. The mean minimum temperature range from 12.8 to 20.6°C with the mean of 16.7°C. The relative humidity ranged from 90 to 98 per cent with the mean of 94 per cent.

The soil of the area, where the mother trees located was Sandy alluvium with the pH a ranging from 5.5 to 5.8 and belonging to the order of Entisol. The soil was low in available N and  $P_2O_5$  and high in available  $K_2O$ .

Once the fruit collection and observation were completed the studies on seed germination and observations on seedling characters were carried out in the central orchard attached to the Department of Pomology and Floriculture, the College of Horticulture in the main campus of Kerala Agricultural University, Vellanikkara, Thrissur district, Kerala.

The experiment site experienced a warm humid tropical monsoon climate. It is situated at 12°32'N latitude and 74°20'E longitude at an altitude of 22.5 m above mean sea level.

The soil type is a typical sandy clay loam with the pH of 5.4, EC of  $1.25 \text{ dsm}^{-1}$  and belonging to the order Ultisols.

## **3.3. MATERIALS**

### **3.3.1. Mother plants characters**

Trees belonging to various age groups were identified and categorized into the four age groups as envisaged in this investigation. The age groups were

1. Trees belonging to the age of less than 25 years.
2. Trees belonging to the age of 25-50 years.
- 3) Trees belonging to the age of 51-75 years.
- 4) Trees belonging to the age of more than 75 years.

Within each age group, ten fruits per tree were collected from five mother plants randomly, such that finally each age group had fifty fruits. Care was taken to see that the mother plants under selection fell near to the mid value of each age group and such that the five plants in a group were more or less uniform in growth (height and spread) characters. Fruits were labelled individually and

seeds were extracted from the fruits. The seeds were sown separately in black polythene bag (45 x 30 cm) filled with potting mixture comprising of farmyard manure, sand and cow dung in the ratio of 2:2:1. The following observations on various fruit, seed and seedling characters of four age groups (Plate 1) were recorded separately as presented below.

#### **3.3.1.1. Fruit characters**

Fruit weight, fruit girth, fruit volume, pulp weight, rind weight, number of segments, number of seedless fruits, number of one seeded fruits, number of two seeded fruits, number of three and more than three seeded fruits, number of seedlings produced per fruit and seed specific gravity were recorded.

#### **3.3.1.2. Seed characters**

Observations on seed weight, seed length, seed thickness at centre, seed volume, seed specific gravity, number of seeds per fruit, number of seedlings per seed, number of ungerminated seeds, number of seed producing one seedling, number of seed producing two and more than two seedlings (Plate 2), number of days taken to germination and germination percentage were recorded.

#### **3.3.1.3. Seedling characters**

Height, girth at collar, total number of leaves, and survival rate of the seedlings at three months, six months, nine months and one-year stage after germination, were recorded. Increment in height, girth, and total number of leaves at quarterly intervals up to one year were computed. Number of new flushes per year, number of leaves/flush, total leaf area were limited to at twelve-months stage.

#### **3.3.1.4. Shoot and root characters**

Shoot and root fresh weight, dry weight, root to shoot dry weight ratio, length of longest root, number of primary, secondary and tertiary roots, and total number of roots were recorded. Fruit index, seed index and seedling index and finally selection index were worked out.

### **3.3.2. Activation of seedling growth using various growth regulators**

Fruits from plants belonging to the age group of 25 to 50 years (as they formed the most abundant group) were randomly collected from the selected

Plate 1. Overall view of the seedlings raised from the mother plants of different age groups (years) in mangosteen (*Garcinia mangostana* L.)



farmer's orchard and seeds were extracted. The seeds were sown separately in black polythene bag (45 x 30 cm) filled with potting mixture comprising of farmyard manure, sand and cow dung in the ratio of 2:2:1. The seedlings were further subjected to secondary selection for uniformity of growth.

### **3.3.2.1. Treatments**

The growth regulator studies began two months after germination. Indole acetic acid (IAA) Gibberellin (GA) and Benzyl adenine (BA) at the concentrations of 50 mg l<sup>-1</sup>, 150 mg l<sup>-1</sup> and 250 mg l<sup>-1</sup> formed the growth regulator treatments. In addition there were two control treatments, a water spray (absolute control) and another no spray. The above eleven treatments formed the study and the treatments were enforced thrice. The first spray was given two months after germination, the second and third were given consecutively at four months and six months after germination. The following observations were recorded.

### **3.3.2.2. Observations**

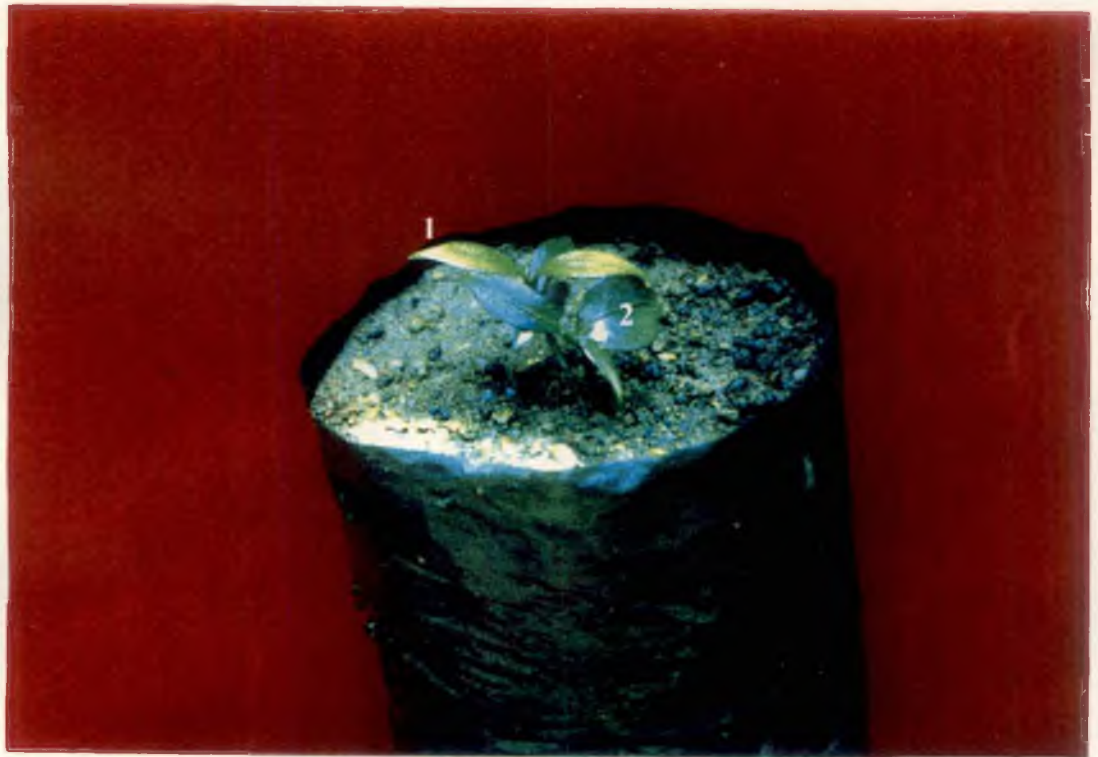
Height, girth at collar and total number of leaves of the seedlings at two months, four months, six months, eight months, nine months, ten months and at one year stage after germination were recorded. Increment in height, girth, and total number of leaves at bi-monthly intervals were computed up to one year. Observations on number of new flushes per year, number of leaves/flush, and total leaf area and survival rate at twelve-months stage were recorded.

Shoot and root fresh weight, dry weight, root to shoot dry weight ratio, length of longest root, number of primary, secondary and tertiary roots, and total number of roots were recorded.

### **3.3.3. Activation of seedling growth by using AM fungi and Azospirillum**

Fruits were collected from plants belonging to the same age group of 25-50 years from the Pariyaram area and the seeds were extracted. The seeds were sown in black polythene bags (45 x 30 cm) filled with potting mixture comprising of farmyard manure, sand and cow dung in the ratio of 2:2:1 as in the previous experiment. The weight of the potting media was 5 kg, which was uniformly maintained. Seedlings were subjected to a secondary selection for uniformity in growth. Three months after germination of the seeds, the following treatments

**Plate 2. Incidence of polyembryony in mangosteen (*Garcinia mangostana* L.)**



were effected by inoculation in the potting media. A uniform dose of 10 g of single super phosphate was added to the potting media of each polybag. The treatments were as follows.

### 3.3.3.1. Treatments

1. *Glomus mosseae* - 5 g
2. *Glomus mosseae* - 10 g
3. *Glomus mosseae* - 20 g
4. *Glomus fasciculatum* - 5 g
5. *Glomus fasciculatum* - 10 g
6. *Glomus fasciculatum* - 20 g
7. *Azospirillum* - 5 g
8. *Azospirillum* - 10 g
9. *Azospirillum* - 20 g
10. *Azospirillum* - 5 g + *Glomus mosseae* - 5 g
11. *Azospirillum* - 10 g + *Glomus mosseae* - 5 g
12. *Azospirillum* - 20 g + *Glomus mosseae* - 5 g
13. *Azospirillum* - 5 g + *Glomus mosseae* - 10 g
14. *Azospirillum* - 10 g + *Glomus mosseae* - 10 g
15. *Azospirillum* - 20 g + *Glomus mosseae* - 10 g
16. *Azospirillum* - 5 g + *Glomus mosseae* - 20 g
17. *Azospirillum* - 10 g + *Glomus mosseae* - 20 g
18. *Azospirillum* - 20 g + *Glomus mosseae* - 20 g
19. *Azospirillum* - 5 g + *Glomus fasciculatum* - 5 g
20. *Azospirillum* - 10 g + *Glomus fasciculatum* - 5 g
21. *Azospirillum* - 20 g + *Glomus fasciculatum* - 5 g
22. *Azospirillum* - 5 g + *Glomus fasciculatum* - 10 g
23. *Azospirillum* - 10 g + *Glomus fasciculatum* - 10 g
24. *Azospirillum* - 20 g + *Glomus fasciculatum* - 10 g
25. *Azospirillum* - 5 g + *Glomus fasciculatum* - 20 g
26. *Azospirillum* - 10 g + *Glomus fasciculatum* - 20 g
27. *Azospirillum* - 20 g + *Glomus fasciculatum* - 20 g
28. SSP - 10 g alone
29. Control

### 3.3.3.2. Observations

Height, girth at collar, total number of leaves, and survival rate of the seedlings at three months, six months, nine months and at one year old stage after germination. Increment in height, girth, and total number of leaves at quarterly intervals up to one year were computed. Observations on number of new flushes per year, number of leaves/flush and total leaf area were restricted at twelve-months stage.

Shoot and root fresh weight and dry weight, root to shoot dry weight ratio, Length of longest root, number of primary, secondary and tertiary roots, and total number of roots were recorded.

### 3.3.4. Biochemical analysis

The following biochemical characters were estimated in seeds and leaves of the mother plant and seedling of the four age groups. But the biochemical analyses were restricted to the treatments showing the growth of best, intermediate and least categories, in the experiments of activation of seedling growth using growth regulators and AM fungi separately.

1. Nitrogen - seeds and leaves
2. Phosphorus - seeds and leaves
3. Potassium - seeds and leaves
4. Protein - seeds and leaves
5. Sodium - seeds and leaves
6. Chlorophyll - leaves only
7. Total sugar content - seeds only
8. Total carbohydrates - seeds and leaves
9. Total phenols - seeds and leaves
10. Absciscic acid - seeds and leaves

### 3.3.5. Microbial observations

One year after the treatments were enforced observations on (1) percentage of root infection (AM fungi), (2) spore count (AM fungi), (3) Azospirillum population were recorded for each treatment.

### 3.4. METHODS

The methodologies involved in the three experiments are described below.

#### 3.4.1. Selection index

For this experiment, fully matured (Dark purple colour) fruits were harvested randomly and the following observations were taken.

##### 3.4.1.1. Fruit characters

##### 3.4.1.1.1. Fruit weight

Individual fruit was labeled immediately after harvest. Then fruit weight was recorded using an electronic balance (Contech precision balance) and the average expressed as gram.

##### 3.4.1.1.2. Fruit girth/diameter

Girth of the fruit was measured using a thread and its length measured using a metre scale and the average expressed as centimeter.

##### 3.4.1.1.3. Fruit volume

Fruit volume was measured by water displacement method and the average volume expressed as millilitre.

##### 3.4.1.1.4. Pulp weight with and without seed

The fruit hull was carefully removed and the white-segmented pulp (aril) weight of each fruit with seed was taken using an electronic balance (Contech precision balance). The seed was extracted and its weight recorded and the average expressed as gram. Pulp weight of each individual fruit alone was calculated using the formula

$$\text{Pulp weight alone (g)} = \text{Pulp weight with seed (g)} - \text{seed weight alone (g)}$$

##### 3.4.1.1.5. Rind weight

Rind weight of each individual fruit was calculated using by the formula and the average expressed as gram.

$$\text{Rind weight (g)} = \text{Total fruit weight (g)} - \text{Pulp weight with seed (g)}$$

#### **3.4.1.1.6. Number of segments**

Numbers of white juicy segments were counted immediately after the fruit were opened and the average expressed as number.

#### **3.4.1.1.7. Number of one, two, three and more than three seeded and seedless fruits**

Number of seeds per fruit were counted and categorized as one, two, three and more than three seeded and seedless fruits and the average expressed as number.

#### **3.4.1.1.8. Number of seedlings produced per fruit**

Total numbers of seedling obtained from individual fruit were counted irrespective of number of seeds per fruit and the average expressed as number.

#### **3.4.1.1.9. Fruit specific gravity**

Fruit specific gravity was calculated using the formula and the average expressed as gram / milliliter.

$$\text{Fruit specific gravity} = (\text{Fruit weight} / \text{Fruit volume})$$

#### **3.4.1.2. Seed characters**

##### **3.4.1.2.1. Seed weight**

The seeds were extracted from the pulp and the weight of the individual seeds in a fruit was taken using the electronic balance (Contech precision balance) and the average seed weight was expressed in gram.

##### **3.4.1.2.2. Seed length**

Seed length was measured using a meter scale and the average expressed as centimeter.

##### **3.4.1.2.3. Seed thickness at centre**

Seed thickness was measured using meter scale and the average expressed as centimeter.

#### **3.4.1.2.4. Seed volume**

Seed volume was measured by water displacement method and the average expressed as millilitre.

#### **3.4.1.2.5. Seed specific gravity**

Seed specific gravity was calculated using the formula and the average expressed as gram /millilitre

$$\text{Seed specific gravity} = (\text{seed weight} / \text{Seed volume})$$

#### **3.4.1.2.6. Number of seeds per fruit**

Total number of seeds present in an individual fruit was counted and the average expressed as a number.

#### **3.4.1.2.7. Number of seedlings per seed**

Total number of seedlings produced by individual seed was counted and expressed the average as a number.

#### **3.4.1.2.8. Number of ungerminated seeds**

Total number of ungerminated seeds was counted in an individual age group and the average expressed as a number.

#### **3.4.1.2.9. Number of seeds producing one and two and more than two seedlings**

The number of seedlings produced by an individual seed were counted and categorized as seeds producing one, two and more than two seedlings and the average expressed as a number.

#### **3.4.1.2.10. Number of days taken to germination**

The number of days was counted from date of sowing to date of germination of seeds and the average expressed as a number of days.

#### **3.4.1.2.11. Germination percentage**

Germination percentage was calculated for an individual age group by using the formula and the average expressed as percentage.

$$\text{Germination \%} = \left( \frac{\text{Total number of seeds germinated}}{\text{Total number of seed sown}} \right) \times 100$$

### **3.4.1.3. Seedling characters**

#### **3.4.1.3.1. Seedling height**

Seedling height was measured from the collar region to the tip of the main stem using a meter scale and expressed in centimeter.

#### **3.4.1.3.2. Seedling girth at collar**

Seedling girth was measured at the collar region using a thread, and then the thread length was measured using a scale and finally the average expressed as centimeter.

#### **3.4.1.3.3. Total number of leaves**

Total number of leaves produced by an individual seedling was counted and the average expressed as numbers.

#### **3.4.1.3.4. Increment in height, girth and total number of leaves**

The increments were calculated by computing the difference between two consecutive values of the particular interval and average expressed as centimeter.

#### **3.4.1.3.5. Number of flushes and number of leaves/flush**

The number of flushes and number of leaves/flush produced by an individual seedling were counted and the average expressed as a number.

#### **3.4.1.3.6. Leaf area**

Leaf area was calculated by multiplying the length, the breadth and the factor (0.6727) and average was expressed as cm<sup>2</sup>. The factor was pre-standardised, for this purpose, by taking hundred leaves and length and breadth of the leaves were measured. The leaf area of the corresponding leaf was measured by leaf area meter to work out the factor value. Thus the factor value (0.6727) was derived using the formula

$$\text{Factor} = (\text{Leaf area} / \text{Length} \times \text{breadth})$$

Using the factor value, the leaf area of a leaf / whole plant was calculated.

### **3.4.1.3.7. Survival rate**

Survival rate was calculated by counting the established plants and expressing it as a percentage of the total number of seedling observed after germination.

$$\text{Survival \%} = (\text{Total number of seedling observed at each interval} / \text{Total number of seedling observed immediately after germination}) \times 100$$

### **3.4.1.4. Shoot and root characters**

#### **3.4.1.4.1. Fresh weight of shoot and root**

The seedlings were uprooted one year after germination. Immediately the plants were cut and separated into shoot and root. The fresh weight of shoot and root were recorded separately using an electronic balance and the average expressed in gram.

#### **3.4.1.4.2. Dry weight of shoot and root**

The samples collected for recording the fresh weight were dried in an oven maintained at 60°C till the weight of the samples remained constant. The dry weights were recorded separately and average expressed in gram.

#### **3.4.1.4.3. Dry weight ratio of root to shoot**

Dry weight ratio of root to shoot was calculated by the formula

$$\text{Dry weight ratio} = (\text{Root dry weight} / \text{Shoot dry weight})$$

#### **3.4.1.4.4. Length of the longest root**

Length of the longest root (tap root) was measured from the collar region to growing tip of the taproot using a scale and expressed in centimeter.

#### **3.4.1.4.5. Number of primary, secondary and tertiary roots, and total number of roots**

After carefully removing the potting mixture using water spray, the number of primary, secondary, tertiary roots, and total number of roots were counted and their average expressed in number of roots.

### **3.4.2. Biochemical studies**

Leaf samples from seedlings were collected one year after germination and leaf samples from mother plants were also collected. The third leaf from the tip was collected and oven dried at 60°C, ground and used for estimating the content of N, P, K and Na.

#### **3.4.2.1. Nitrogen content**

The total nitrogen content of leaf samples was determined by microkjeldhal method (Jackson, 1973) and the average expressed in percentage.

#### **3.4.2.2. Phosphorus content**

The phosphorus content of the samples was determined using di-acid extract method (Jackson, 1973). A spectrophotometer was used for reading the colour intensity developed by Vanado-molybdo phosphoric yellow colour method and readings were taken at 420 nm wavelength. Phosphorous content was calculated using standard graph and the average expressed in percentage.

#### **3.4.2.3. Potassium**

The potassium content of sample was determined with di-acid extract, then by reading in an EEL flame photometer, at 548 nm (Jackson, 1973) and the average expressed in percentage.

#### **3.4.2.4. Crude protein content**

Nitrogen content was estimated by microkjeldhal method (Jackson, 1973). The value of nitrogen content was multiplied with the factor 6.25 to get the crude protein content and the average expressed in percentage.

#### **3.4.2.5. Sodium**

The sodium content of samples was determined with di-acid extract (Jackson, 1973), then by reading in an EEL flame photometer at 598 nm and the average expressed in percentage.

#### 3.4.2.6. Chlorophyll

Chlorophyll content (total chlorophyll, chlorophyll a and chlorophyll b) was estimated in leaf sample by Arnon's Acetone method (Sadasivam and Manikam, 1996) and the average expressed in milligram.

#### 3.4.2.7. Total sugars

Total sugars were estimated using standard procedure (AOAC, 1980) and the average expressed in milligram.

#### 3.4.2.8. Total carbohydrates

Total carbohydrates were estimated using Anthrone method (Dubois *et al.*, 1951) and the average expressed in milligram.

#### 3.4.2.9. Total phenol

Total phenol content was estimated using folin-ciocalteau method (Sadasivam and Manikam, 1996) and expressed in milligram.

#### 3.4.2.10. Procedure adopted for quantification of abscisic acid

The procedure adopted in the quantification of abscisic acid was a modification of the standard method of Little *et al.*, (1972). The modification became imperative, as bands were not obtained. The procedure was standardised and bands were obtained corresponding to the standard abscisic acid. Further quantification was done using a U-V spectrophotometer and by using standards of known concentration from which a standard graph was obtained.

#### Standard procedure

- 1) 0.5 g of leaf sample / 1g of seed sample was taken.



- 2) Extracted with 80% methanol and kept for 4 hours.



- 3) Filtered through whatman No.1 till colourless solution of methanol was obtained.



- 4) Evaporated the methanol completely in exhaustor.



↓  
5) Added 2.5 ml of 1N HCl to the residue.

↓  
6) Added 5 ml of ether and the ABA was extracted into ether. Washed the acid solution 2-3 times with 5 ml ether and separated the top ether layer using separating funnel.

↓  
7) Ether was completely evaporated.

↓  
8) 1 ml  $\text{Na}_2\text{HCO}_3$  was added to the ether residue.

↓  
9) Added 2-5 ml of 1N HCl to the  $\text{Na}_2\text{HCO}_3$ .

↓  
10) Ether extraction continued 2-3 times and separated the ether layer using a separating funnel.

↓  
11) Evaporated the ether completely.

↓  
12) 0.5 ml methanol was added to residue and kept for 30 min. in closed conditions.

↓  
13) Using capillary tube it was spotted in a silica gel ( $\text{GF}_{254}$ )

↓  
14) Kept the plate in plate in recurring solvent (Benzene: ethyl acetate: Acetic acid in ratio 14:6:1)

↓  
15) Plate taken out when running solvent had seen  $\frac{3}{4}$ <sup>th</sup> of the plate

↓  
16) Spots were marked in the same line of spots of standard under UV light

↓  
17) Scraped the spot carefully

↓  
18) Dissolved in 4.5 ml of methanol  
↓

↓

19) Centrifuged at 2000 rpm – 2 times

↓

20) The supernatant was collected and the absorption reading was taken in a UV spectrum (Lamda- 263 nm in acid, 240 nm in alkali). Absciscic acid content was finally estimated using the standard curve.

### **3.4.3. Microbial observations**

#### **3.4.3.1. Estimation of spore population in the rhizosphere**

Soil was collected from the rhizosphere of the seedlings and dried and powdered. Ten gram of the dried soil was taken and put in a beaker containing 100 ml water. Stirred it well with glass rod for 15 minutes and allowed to settle it. The supernatant was then subjected to alternate wetting and decanting as described by Gerdemann and Nicolson (1963) and was filtered through Whatman number 1 filter paper. Then the filter paper was observed under the compound microscope and the numbers of globular AMF spores were counted.

#### **3.4.3.2. Estimation of percentage of AM fungi infection**

The thin feeder roots of the plants taken from different treatments were washed and cut into bits of about 1cm. They were then transferred into test tubes and fixed in FAA for three hours. The root bits were hydrolysed in 10% KOH solution at 100<sup>0</sup> C for 15 minutes. After washing with water, it was neutralized with 1% HCl and then stained with 0.005% trypan blue in lactophenol by boiling for three minutes. The roots were observed under the microscope for AMF colonisation (Philips and Hayman, 1970). The percent infection was worked using standard formula

$$\text{Percent infection} = (\text{Number of infected root segments} / \text{Total number of root segments observed}) \times 100$$

#### **3.4.3.3. Estimation of Azospirillum colonization**

Population of Azospirillum in the rhizosphere was estimated by using serial dilution technique. Soil samples from the rhizosphere of different treatments were taken and sieved in a 2 mm mesh. One gram of the soil was suspended in 99 ml of sterilized water and serial dilutions of the suspension were prepared further upto 10<sup>-6</sup> dilutions. One ml aliquots of 10<sup>-3</sup>, 10<sup>-4</sup>, 10<sup>-5</sup> and 10<sup>-6</sup> dilutions were transferred to

sterile test tubes containing Azospirillum Okon's medium. The dilution and plating were done aseptically in a laminar flow chamber. The test tubes were incubated in a BOD incubator for three to four days at 31°C. The positive tubes were counted and their number recorded. The population was calculated using MPN technique (Cochran, 1950)

### 3.5. Statistical analysis

#### 3.5.1. Analysis of variance

The study on all morphological and biochemical characters of the four age groups and the separate experiments on activation of seedling growth using growth regulators and using a combination of arbuscular mycorrhizal fungi (AMF) + Azospirillum + Single super phosphate were analysed as completely randomized block design using the Analysis of Variance techniques. The significance was tested by F test and the treatments were compared by Duncan's multiple range test (Snedecor and Cochran, 1983).

#### 3.5.2. Generation of new variables as index

Variability in morphological characters (Thirty-eight characters) were taken. Principal component analysis (PCA) was carried out independently for 12 fruit, 11 seed and 15 seedling characters, in order to establish a list of minimum descriptors (3), enabling the identification of best age group of mother plant. The first principal component accounts for maximum possible variance, is the core collection of all characters (fruit, seed and seedling), the largest possible variance and hence selected (Manzano *et al.*, 2001).

#### 3.5.3. Estimation of correlation

Associations between the various characters were done using the Karl Pearsons product movement correlation coefficient (r). Correlations between age of mother plant, fruit characters, seed character, seedling characters, fruit index, seed index and seedling index were calculated by the method of Searle (1961).

Correlation between characters x and y

$$r_{xy} = \frac{\text{Cov}(x,y)}{\sqrt{V(x) V(y)}}$$

Where,  $r_{xy}$  = Correlation coefficient between x and y,  $\text{Cov}(x,y)$  = Covariance, between x and y,  $V_{(x)}$  = Variance of x,  $V_{(y)}$  = Variance of y and  $\Sigma$  = Covariance matrix

### 3.5.4. Principal component analysis

The observations on 12 fruit, 11 seed and 18 seedling characters of the four age groups and their corresponding index values (i.e., fruit, seed and seedling) of the 135 plants were used for the study. The volume of the data had to be reduced first for the sake of simplicity. This was based on the fact that principal component analysis is one of the variable directed techniques aimed at reduction in dimensionality of the problem and which finds new variables that make the data easier to understand (Chatfield and Collins, 1980).

The procedure involved in the calculation of principal components included the following steps.

$X^T = (x_1, \dots, x_p)$  was considered as a P - dimensional random variable with mean  $\mu$  and covariance matrix  $\Sigma$ . To find a new set of variables  $= Y_1, Y_2, \dots, Y_p$ , which were uncorrelated and whose variances decreased from first to last, each  $Y_j$  was taken to be a linear combination of the x's, so that  $Y_j = a_{1j}x_1 + a_{2j}x_2 + \dots + a_{pj}x_p = a_j T_x$

Where

$A_j^T = (a_{1j}, \dots, a_{pj})$  was a vector of constants.

The first principal component,  $Y_1$ , was found by choosing  $a_1$  so that  $Y_1$  has the largest possible variance. The second principal component was found by choosing  $Y_2$ , so that  $Y_2$  has the largest possible variance for all combinations, which were uncorrelated with  $Y_1$ . Similarly,  $Y_3, \dots, Y_p$  was derived such that it was uncorrelated with each other and to have decreasing variance. The principal component analysis and regression prediction models for fruit index, seed index and seedling index were performed using MSTAT-C package.

Also, principal component analysis (PCA) was used to determine the relationship among the fruit characters, seed character, seedling character and four age groups (Meilgard *et al.*, 1991) were performed in XLSTAT version 5.1v2 package. It was also used to provide a graphical description of the characteristics.

Factor scores were calculated for each fruit, seed and seedling characteristics, using the formula

$$\text{Factor scores} = \text{each attribute factor loading} \times \text{the original attribute mean score}$$

Although the characteristics factor scores were calculated from a single analysis, they were plotted on separate figures to facilitate interpretation. These figures then provided a visual representation of the dominant age groups and characters for each fruit, seed and seedling characters (Dever *et al.*, 1996).

### 3.5.5. Step-wise regression

To facilitate the prediction of indices reduction in number of variables is imperative and hence the step-wise regression procedure to identify major characters, which can be used to predict the fruit, seed and seedling indices, were performed separately. Further, adopting step-wise regression has been established scientifically to reduce multi-collinearity among the independent variables and to arrive at the best subset of variables (Draper and Smith, 1966).

### 3.5.6. Cluster analysis

Cluster analysis was performed to find out the similarities (or dissimilarities) between the four age groups based on absolute square euclidean distance (Johnson and Wichern, 1998). The clusters and the square euclidean distances (Chatfield and Collins, 1980) were graphically represented by the dendrograms (Manzano, 2001). The Euclidean distance was calculated using the formula

$$D_{rs} = \left\{ \sum_{j=1}^p (x_{rj} - x_{sj})^2 \right\}^{1/2}$$

Where,  $D_{rs}$  – Distance from individual  $r$  to individual  $s$ ,  $x_{rj}$  – Value of individual  $r$ ,  $x_{sj}$  – Value of individual  $s$ .

### 3.5.7. Discriminant function analysis

Discriminant function analysis was performed on the four age groups. To discriminate the four age groups, the discriminant function was fitted as

$$Z = b_1x_1 + b_2x_2 + \dots + b_nx_n$$

Where

$X_1, x_2, \dots, x_n$  were the variables measured and

$b_1, b_2, \dots, b_n$  were the weighing coefficients.

The  $b_i$  values were estimated such that based on Z values, the ratio of variance between populations to that of within the populations would be maximised. The maximization of this ratio leads to a set of simultaneous equations, which after solution provide the desired  $b_i$  values to discriminate between the age groups (Singh and Chaudhary, 1985).

The criteria and criterion for determination of age groups in mangosteen were fixed. The criteria were fixed based on the relative positional value of the age groups and the criterion for determination of the age group was based on the mid value of the criteria.

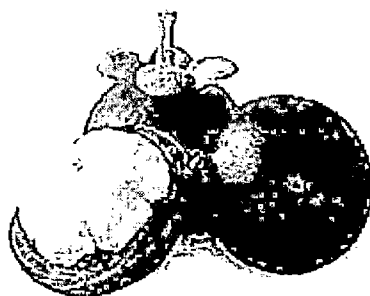
### 3.5.8. Selection Index

Selection index or total index values were worked out using the principal component analysis. Principal component analysis was performed on all the fruit, seed and seedling characters collectively and the first principal component was taken as the index value for selection as in the above described method. Regression analysis was performed for each age group separately to find out the best age group with equal weightage of all fruit, seed and seedling characters. Then the best age group or selection index (total index) was predicted using the regression equation with the fruit, seed and seedling indices as the explanatory variables. The predictor equation was found to be

$$Y = a_1 FI + a_2 SI + a_3 SDLI + C$$

Where  $a_1, a_2, a_3$  were regression coefficients or weightage of FI, SI and SDLI, which are fruit index, seed index and seedling index and C the Intercept constant (Manoj, 1992).

## *RESULTS*



## CHAPTER - IV

### RESULTS

The results of the study on “Selection index and activation of seedling growth in Mangosteen (*Garcinia mangostana* L.)” are presented aspect wise under the broad subheadings of selection index and activation of seedling growth using growth regulator treatments and activation of seedling growth using arbuscular mycorrhizal fungi (AM Fungi) separately as follows.

#### 4.1. Selection index

##### 4.1.1. Biochemical characters of mother plant

The mean values of biochemical characters of leaf of mother plants are given in the Table 1.

##### 4.1.1.1. Nitrogen content

The data revealed that age group of less than 25 years recorded the highest leaf N content. This was at par with the age group 25-50 years and significantly superior to the content recorded in the other age groups. A decrease in content of N was observed with an increase in age.

##### 4.1.1.2. Phosphorus content

Though the differences between the various age groups were not significant the data revealed that the plants with the lowest age group had the highest level and that most aged group the lowest level. The intermediate age groups registered intermediary values

##### 4.1.1.3. Potassium content

The differences between the age groups in the mean values of K were statistically significant. The lowest age group showed the highest values of K and was at par with age group 51-75 years, but significantly superior to other age groups. The age group of 25-50 years registered the least values.

Table 1. Biochemical characters of mother plant leaf samples of four age groups in mangosteen (*Garcinia mangostana* L.)

| Age groups (years) | Nitrogen (%)      | Phosphorus (%) | Potassium (%)     | Crude protein (%)  | Sodium (%) | Total phenols (mg/g) | Total carbo-hydrates (mg/g) |
|--------------------|-------------------|----------------|-------------------|--------------------|------------|----------------------|-----------------------------|
| <25                | 2.54 <sup>a</sup> | 0.09           | 0.81 <sup>a</sup> | 15.88 <sup>a</sup> | 0.36       | 5.03 <sup>a</sup>    | 8.86 <sup>a</sup>           |
| 25-50              | 2.42 <sup>a</sup> | 0.08           | 0.50 <sup>b</sup> | 15.14 <sup>b</sup> | 0.35       | 4.92 <sup>a</sup>    | 5.75 <sup>c</sup>           |
| 51-75              | 2.25 <sup>b</sup> | 0.09           | 0.68 <sup>a</sup> | 14.04 <sup>c</sup> | 0.35       | 4.49 <sup>b</sup>    | 5.36 <sup>d</sup>           |
| >75                | 2.06 <sup>c</sup> | 0.08           | 0.52 <sup>b</sup> | 12.86 <sup>d</sup> | 0.36       | 4.87 <sup>a</sup>    | 6.34 <sup>b</sup>           |
| Mean values        | 2.32              | 0.09           | 0.63              | 14.48              | 0.36       | 4.83                 | 6.58                        |
| C.D. (p< 0.05)     | 0.16              | NS             | 0.15              | 0.32               | NS         | 0.20                 | 0.34                        |

Figures with same alphabets do not differ significantly at 5 % level.

#### **4.1.1.4. Crude protein**

A distinct gradation was observed in the crude protein content with the lowest age group registering the highest value and the highest age group showing the minimum values. The difference between each group was also statistically significant.

#### **4.1.1.5. Sodium content**

No definite trend was observed in the sodium content in different age group. The plant of the minimum and maximum age groups recorded the same highest value. The second and third age groups registered equal intermediary values.

#### **4.1.1.6. Total phenols**

Total phenols were highest in the age group one followed by two, four and three which were statistically at par with each other, but significantly superior to the third age group.

#### **4.1.1.7. Total carbohydrates**

The highest content of the total carbohydrates were observed in the age group one followed by four, two and three. The differences between the age group means were also statistically significant.

#### **4.1.2. Fruit morphological characters**

The mean values of morphological character of fruits, belonging to the four age groups are presented in the Table 2.

##### **4.1.2.1. Total fruit weight**

The highest fruit weight was recorded in the age group 51-75 years. The treatment means of the age group was also significantly superior to the other age groups. The other three age groups were on par with each other.

##### **4.1.2.2. Girth of fruits**

The girth of fruits was again highest in the age group 51-75 years, which was significantly superior to other age groups. The age group of 25-50 years

Table 2. Morphological characters of fruits from mother plant of four age groups in mangosteen (*Garcinia mangostana* L.)

| Age groups (years) | Fruit weight (g)   | Girth (cm)         | Volume (ml)        | Pulp weight (g)     | Rind weight (g)     | Segments (No) | Seeds (No)         | Seedless fruits (No.) | One seeded fruits (No) | Two seeded fruits (No) | Three and multi seeded fruits (No) | Specific gravity (g/ml) |
|--------------------|--------------------|--------------------|--------------------|---------------------|---------------------|---------------|--------------------|-----------------------|------------------------|------------------------|------------------------------------|-------------------------|
| <25                | 62.25 <sup>b</sup> | 4.76 <sup>ab</sup> | 54.54 <sup>b</sup> | 17.85 <sup>ab</sup> | 43.75 <sup>b</sup>  | 5.80          | 0.95 <sup>ab</sup> | 0.13 <sup>b</sup>     | 0.78 <sup>a</sup>      | 0.03 <sup>b</sup>      | 0.06                               | 1.14 <sup>ab</sup>      |
| 25-50              | 57.79 <sup>b</sup> | 4.51 <sup>b</sup>  | 50.87 <sup>b</sup> | 15.73 <sup>b</sup>  | 41.40 <sup>b</sup>  | 5.66          | 1.29 <sup>a</sup>  | 0.03 <sup>b</sup>     | 0.73 <sup>a</sup>      | 0.18 <sup>a</sup>      | 0.06                               | 1.14 <sup>ab</sup>      |
| 51-75              | 79.32 <sup>a</sup> | 5.13 <sup>a</sup>  | 71.50 <sup>a</sup> | 21.20 <sup>a</sup>  | 57.30 <sup>a</sup>  | 5.97          | 0.80 <sup>b</sup>  | 0.45 <sup>a</sup>     | 0.48 <sup>b</sup>      | 0.05 <sup>ab</sup>     | 0.02                               | 1.11 <sup>b</sup>       |
| >75                | 65.86 <sup>b</sup> | 4.84 <sup>ab</sup> | 56.32 <sup>b</sup> | 15.21 <sup>b</sup>  | 49.94 <sup>ab</sup> | 5.81          | 0.78 <sup>b</sup>  | 0.50 <sup>a</sup>     | 0.46 <sup>b</sup>      | 0.03 <sup>b</sup>      | 0.01                               | 1.17 <sup>a</sup>       |
| Mean values        | 66.31              | 4.18               | 58.32              | 17.50               | 48.10               | 5.81          | 0.96               | 0.28                  | 0.61                   | 0.07                   | 0.04                               | 1.14                    |
| C.D. (p< 0.05)     | 12.52              | 0.37               | 10.98              | 3.69                | 10.22               | NS            | 0.37               | 0.17                  | 0.16                   | 0.13                   | NS                                 | 0.04                    |

Figures with same alphabets do not differ significantly at 5 % level.

recorded the second highest treatment mean, which was superior to the other two age groups.

#### **4.1.2.3. Volume**

The highest fruit volume was again observed in the age group 51-75 years. This was significantly superior to other age groups. The latter three age groups were at par with each other. The lowest values were observed in the age group of 25-50 years.

#### **4.1.2.4. Pulp weight**

The highest pulp weight was recorded in the age group of 51-75 years followed by less than 25 years age groups. The former was at par with the latter but superior over the other age groups. A percentage analysis of the pulp weight in terms of the whole fruit revealed that the highest fruit pulp was recorded in the lowest age group and a decrease was observed with increase in age (Fig. 1).

#### **4.1.2.5. Rind weight**

The maximum rind weight was observed in the age group of 51-75 years followed by more than 75 years age group. The mean values of age group of 51-75 years was significantly superior over the age group of less than 25 and 25-50 years, but was at par with age group of more than 75 years. Contrary to what was observed as above the rind weight when expressed as a percentage of the whole fruit weight was lowest in the least age group and was observed to increase with the age (Fig. 1).

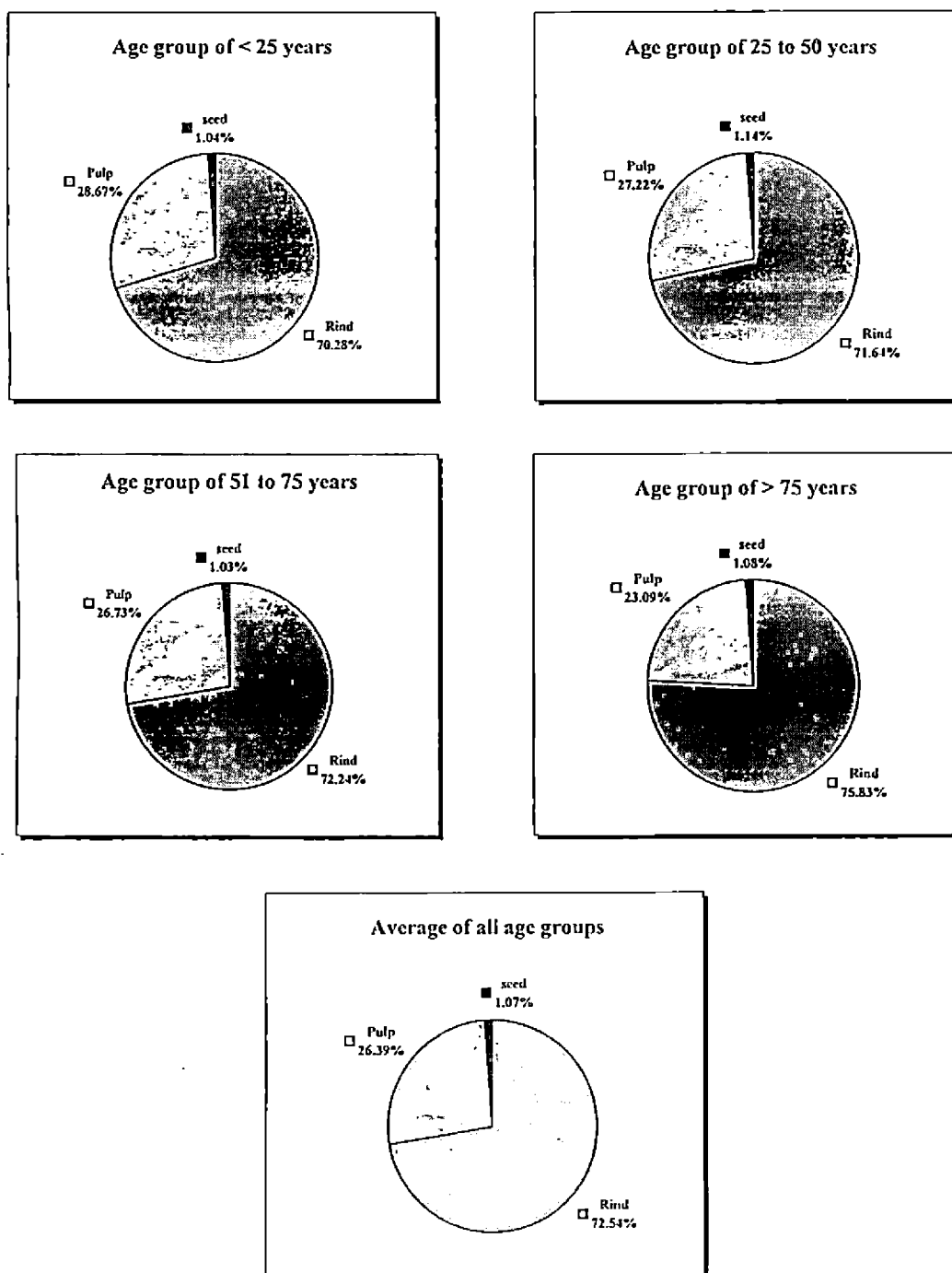
#### **4.1.2.6. Number of segments**

Highest number of segments/fruit was observed in the age group of 51-75 years. However, differences between the four age groups were not significant.

#### **4.1.2.7. Number of seeds/fruit**

The highest number of seeds per fruit was observed in the age group of 25-50 years, followed by the age group of more than 25 years. The former was significantly higher than the age group of 51-75 years and more than 75 years.

**Fig.1. Mean rind, pulp and seed percentage of the total weight of the fruits collected from the mother plants belonging to various age groups of mother plants in mangosteen (*Garcinia mangostana* L.)**



#### **4.1.2.8. Number of seedless fruits**

The maximum numbers of seedless fruits were observed in the age group of 51-75 years followed by more than 75 years. The treatment means of these two higher age groups were at par and were significantly higher than the age group of less than 25 years. A quantitative aspect was that the two higher age groups showed more than fifteen and sixteen times the incidence of seedlessness compared to the age group of 25-50 years when expressed as a percentage (Fig. 2).

#### **4.1.2.9. One-seeded fruits**

The highest number of one-seeded fruits was observed in the age group of less than 25 years followed by 25-50 years. The mean values of less than 25 years age group were significantly higher than the age groups of 51-75 years and more than 75 years, the means of which did not significantly differ. Expressed as a percentage, the less than 25 years had half times more incidence of one-seeded fruits than the higher age groups (Fig. 2).

#### **4.1.2.10. Two-seeded fruits**

The differences in the means between the age groups were significant. The highest numbers of two seeded fruits were observed in the age group of 25-50 years, followed by the age group of more than 75 years. The former was significantly higher than the age groups of less than 25 and 51-75 years, which were at par with each other. Expressed as a percentage, the mean number of two-seeded fruits was more than three times when compared to the 51-75 years age group and nearly six times more when compared to the lowest age group (Fig. 2).

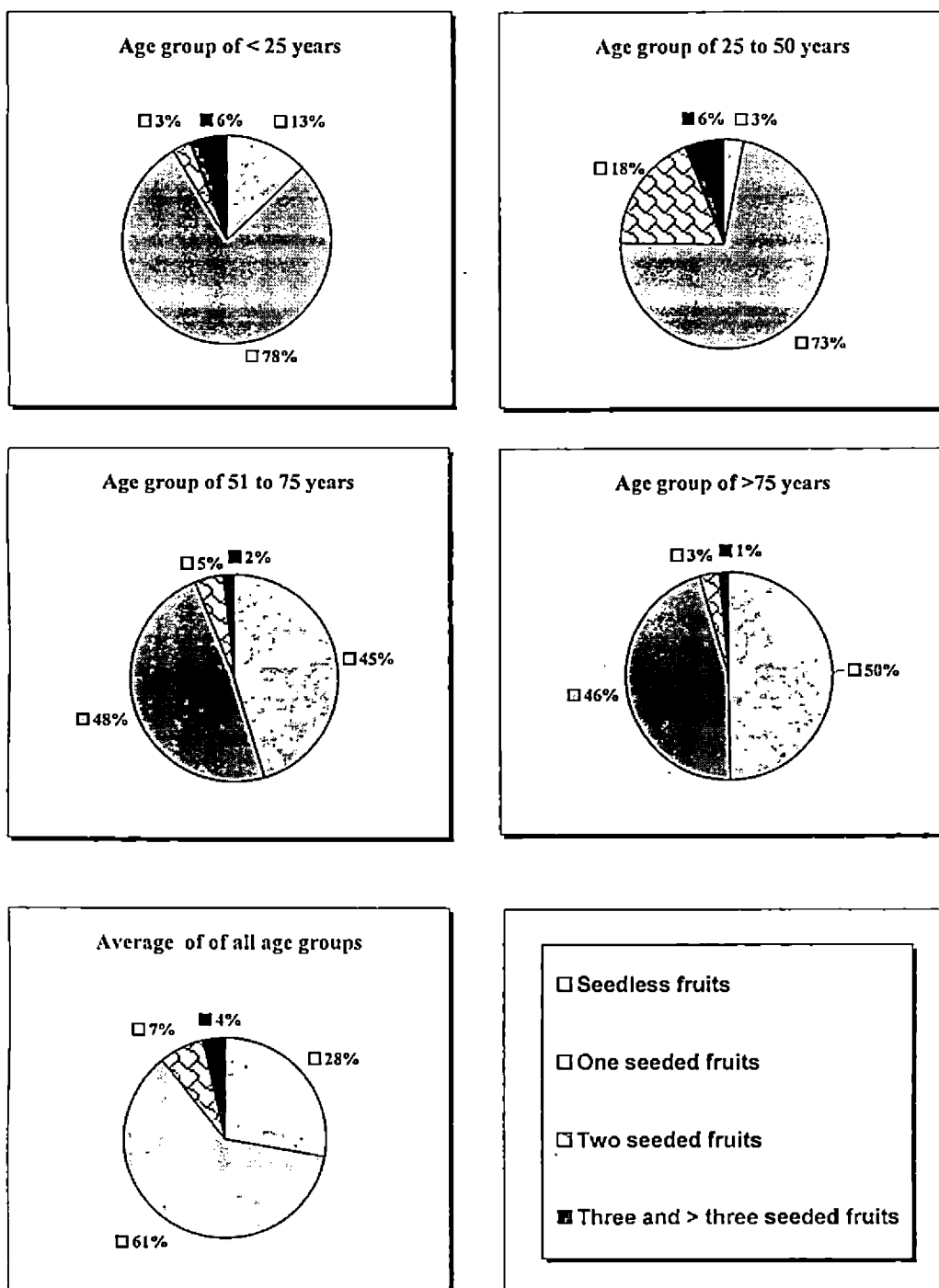
#### **4.1.2.11. Three and more than three seeded fruits**

The highest number of three and more than three seeded fruits again recorded in the lower two age groups. However, the age differences in the means of the age groups were not statistically significant.

#### **4.1.2.12. Fruit specific gravity**

The highest specific gravity of the fruit was recorded in the maximum age group of more than 75 years, followed by less than 25 and 25-50 years. The means of the age group more than 75 years was significantly higher than all other

**Fig.2. Mean number of seedless, one seeded, two seeded and three & more than three seeded fruit were collected from the mother plants belonging to various age groups in mangosteen(*Garcinia mangostana* L.)**



age groups. The differences in the means of the other three age groups were not significant.

#### **4.1.3. Seed morphological characters**

The mean values of morphological characters of seeds and germination aspects are presented in Table 3.

##### **4.1.3.1. Seed weight**

Seed weight recorded was highest in the age group of 51-75 years followed by more than 75 years. The mean values of the both the above age groups were at par with each other but the former was significantly higher than the age groups of less than 25 years and 25-50 years. A percentage analysis of the seed weight in terms of the whole fruit revealed that the highest seed weight was recorded highest in the age group of 25-50 years followed by more than 75 years (Fig. 1).

##### **4.1.3.2. Seed length**

The mean length of the seed was also highest in the age of 51-75 years followed by less than 25 years and 25-50 years, which were not significantly different. The age group more than 75 years recorded the least seed length and was significantly inferior to other age groups.

##### **4.1.3.3. Seed thickness at centre**

The maximum mean seed thickness at the centre was recorded in the age group of 51-75 years. However, no significant differences were observed between the means of all the four age groups.

##### **4.1.3.4. Volume**

Though the maximum seed volume was recorded in the age group of 51-75 years, there were no significant differences observed between the means of all the four age groups.

##### **4.1.3.5. Specific gravity**

The mean seed specific gravity was highest in the age group of 25-50 years, followed by the age group less than 25 years and were at par with the age

Table 3. Morphological and germination characters of seeds from mother plants of four age groups in mangosteen (*Garcinia mangostana* L.)

| Age groups (years) | Seed weight (g)    | Length (cm)        | Thickness at centre (cm) | Volume (ml) | Specific gravity (g/ml) | Number of seedlings / seed | Ungerminated seeds (No) | Seeds producing one seedling (No) | Seeds producing twin and multiple seedlings (No) | Days to germination (No) | Germination (%)    |
|--------------------|--------------------|--------------------|--------------------------|-------------|-------------------------|----------------------------|-------------------------|-----------------------------------|--------------------------------------------------|--------------------------|--------------------|
| <25                | 0.65 <sup>b</sup>  | 1.63 <sup>ab</sup> | 0.61                     | 0.45        | 1.44 <sup>ab</sup>      | 1.02 <sup>b</sup>          | 0.17 <sup>ab</sup>      | 0.79                              | 0.04 <sup>ab</sup>                               | 21.18                    | 78.77 <sup>a</sup> |
| 25-50              | 0.66 <sup>b</sup>  | 1.61 <sup>ab</sup> | 0.66                     | 0.44        | 1.50 <sup>a</sup>       | 1.10 <sup>ab</sup>         | 0.16 <sup>ab</sup>      | 0.76                              | 0.08 <sup>ab</sup>                               | 21.34                    | 86.98 <sup>a</sup> |
| 51-75              | 0.82 <sup>a</sup>  | 1.76 <sup>a</sup>  | 0.69                     | 0.64        | 1.28 <sup>b</sup>       | 1.15 <sup>a</sup>          | 0.06 <sup>b</sup>       | 0.82                              | 0.12 <sup>a</sup>                                | 21.00                    | 86.59 <sup>a</sup> |
| >75                | 0.71 <sup>ab</sup> | 1.57 <sup>b</sup>  | 0.62                     | 0.50        | 1.42 <sup>ab</sup>      | 1.03 <sup>b</sup>          | 0.33 <sup>a</sup>       | 0.64                              | 0.03 <sup>b</sup>                                | 21.18                    | 58.53 <sup>b</sup> |
| Mean values        | 0.71               | 1.64               | 0.65                     | 0.51        | 1.40                    | 1.08                       | 0.18                    | 0.76                              | 0.07                                             | 21.17                    | 77.72              |
| C.D. (p<0.05)      | 0.14               | 0.15               | NS                       | NS          | 0.21                    | 0.10                       | 0.21                    | NS                                | 0.08                                             | NS                       | 18.19              |

Figures with same alphabets do not differ significantly at 5 % level.

group more than 75 years. The means of the highest age groups were significantly higher than the age group 51-75 years, which recorded the lowest values.

#### **4.1.3.6. Number of seedlings/seed**

The intermediary age groups revealed their superiority. The age group 51-75 produced the highest number of seedlings/seed, followed by 25-50 years group. The means of age group 51-75 years was significantly higher than the age group more than 75 and less than 25 years but statistically at par with the age group of 25-50 years.

#### **4.1.3.7. Ungerminated seeds**

The highest value of the ungerminated seeds were in the age group of more than 75 years, which was at par with the age groups less than 25 and 25-50 years. Though the means of the above three age group were at par a critical analysis reveals that the highest age group registered more than double the values of the next highest.

#### **4.1.3.8. Seeds producing one seedling**

The mean values of number of seeds producing one seedling recorded were maximum in the age group of 51-75 years, but statistically there were no significant differences observed between all the four age groups means.

#### **4.1.3.9. Seeds producing two and more than two seedlings**

The highest number of seeds producing two and more than two seedlings recorded were in the age group of 51-75 years, followed by the age group 25-50 years, and less than 25 years respectively. The means of the above three age groups were statistically at par with each other.

#### **4.1.3.10. Number of days to germination**

The maximum earliness to germination was observed in the age group of 51-75 years. But the differences between all age group were only fraction of a day and were not statistically significant.

#### **4.1.3.11. Germination percentage**

The intermediary age groups recorded the highest germination percentage. Though the highest germination was in the age group of 25-50 years it was statistically at par with the age group of 51-75 years followed by less than 25 years. The differences in the means of the intermediately age groups were very negligible and significantly higher than the age group more than 75 years.

#### **4.1.4. Biochemical characters of seeds**

The mean values of biochemical characters of seeds obtained from mother plants belonging to the four age groups in mangosteen are presented in Table 4.

##### **4.1.4.1. Nitrogen content**

The highest nitrogen content was recorded in the age group of 25-50 years followed by 51-75 years group. The nitrogen content of age groups 25-50 was statistically at par with 51-75 groups years age group and both were significantly superior to other two age groups.

##### **4.1.4.2. Phosphorus content**

Even though the highest phosphorus content was observed in the age group of 25-50 years followed by 51-75 years, there were no significant differences observed between the means of each age group.

##### **4.1.4.3. Potassium content**

The highest potassium content were observed in the age group of 25-50 years, followed by more than 75 years, but the differences between the means of the various age groups were not statistically significant.

##### **4.1.4.4. Crude protein**

The crude protein in the seed was highest in the age group of 25-50 years followed by 51-75 years group. The differences in the means between 25-50 years and 51-75 years age group were not significant. The lowest values were recorded in the highest age group.

Table 4. Biochemical characters of seeds from mother plants belonging to the four age groups in mangosteen (*Garcinia mangostana* L.)

| Age groups (years) | Nitrogen (%)       | Phosphorus (%) | Potassium (%) | Crude protein (%)  | Sodium (%) | Total phenols (mg/g) | Total carbohydrates (mg/g) | Total sugars (mg/g) | Abscissic acid (mg/g) |
|--------------------|--------------------|----------------|---------------|--------------------|------------|----------------------|----------------------------|---------------------|-----------------------|
| <25                | 1.42 <sup>bc</sup> | 0.18           | 0.32          | 8.87 <sup>bc</sup> | 0.36       | 0.18                 | 2.86 <sup>b</sup>          | 2.09 <sup>b</sup>   | 0.11 <sup>ab</sup>    |
| 25-50              | 1.70 <sup>a</sup>  | 0.22           | 0.35          | 10.63 <sup>a</sup> | 0.25       | 0.28                 | 3.43 <sup>a</sup>          | 2.31 <sup>a</sup>   | 0.10 <sup>b</sup>     |
| 51-75              | 1.55 <sup>ab</sup> | 0.21           | 0.29          | 9.71 <sup>ab</sup> | 0.34       | 0.13                 | 2.79 <sup>b</sup>          | 1.60 <sup>c</sup>   | 0.15 <sup>ab</sup>    |
| >75                | 1.28 <sup>c</sup>  | 0.15           | 0.33          | 8.01 <sup>c</sup>  | 0.36       | 0.17                 | 2.63 <sup>c</sup>          | 1.02 <sup>d</sup>   | 0.17 <sup>a</sup>     |
| Mean values        | 1.49               | 0.19           | 0.32          | 9.31               | 0.33       | 0.19                 | 2.93                       | 1.75                | 0.13                  |
| C.D. (p< 0.05)     | 0.180              | NS             | NS            | 1.08               | NS         | NS                   | 0.14                       | 0.18                | 0.07                  |

Figures with same alphabets do not differ significantly at 5 % level.

#### **4.1.4.5. Sodium content**

The highest sodium contents were observed in the age group of less than 25 years followed by more than 75 years group. However, the differences between means of the four age groups were not statistically significant.

#### **4.1.4.6. Total phenols**

The highest phenol content was observed in the age group of 25-50 years, followed by less than 25 years group; the differences observed between the means the four age groups were not significant (Fig. 3).

#### **4.1.4.7. Total carbohydrates**

The total carbohydrates content recorded was highest in the age group of 25-50 years. This was significantly higher than the other three age groups. The lowest carbohydrate content was observed in the age group less than 75 years.

#### **4.1.4.8. Total sugars**

The highest mean value of sugar content was observed in the age group of 25-50 years followed by less than 25 years age group and the least in the highest age group. The means of all the four age groups were also significantly different from each other.

#### **4.1.4.9. Absciscic acid**

Highest abscisic acid content recorded was in the age group of more than 75 years. This was significantly higher than the next highest recorded in the age group of 51-75 years. The lowest abscisic acid content was recorded in the age group 25-50 years (Fig.3 and Plate 3).

#### **4.1.5. Morphological character of seedlings at different stages of growth**

The mean values of the growth parameters and survival rates were given at different stages of growth at three-months stage and six-months stages are presented in the Table 5, nine-months stage in Table 6 and twelve-months stage in Table 7.

Fig. 3. Total phenol and abscisic acid content in seeds obtained from the mother plants belonging to various age groups in mangosteen (*Garcinia mangostana* L.)

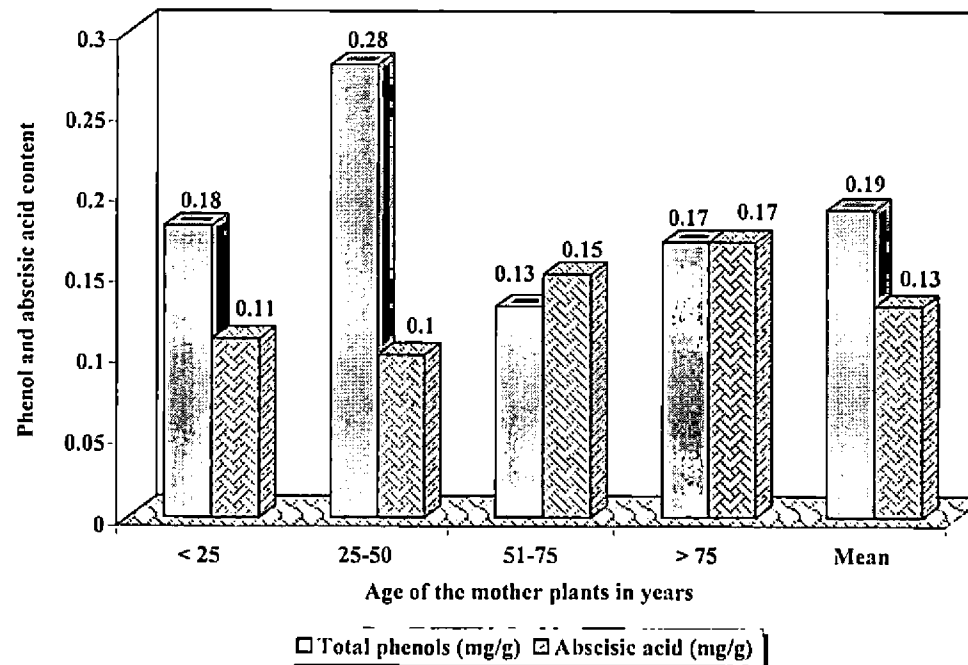


Table 5. Morphological characters of seedlings at three and six-month stages in mangosteen (*Garcinia mangostana* L.)

| Age groups (years) | Three month stage seedlings |                   |                   |                    | Six month stage seedlings |                          |            |                         |                    |                                |                     |
|--------------------|-----------------------------|-------------------|-------------------|--------------------|---------------------------|--------------------------|------------|-------------------------|--------------------|--------------------------------|---------------------|
|                    | Height (cm)                 | Girth (cm)        | Total leaves (No) | Survival rate (%)  | Height (cm)               | Increment in height (cm) | Girth (cm) | Increment in girth (cm) | Total leaves (No)  | Increment in total leaves (No) | Survival rate (%)   |
| <25                | 5.06                        | 1.25 <sup>a</sup> | 3.64              | 96.67 <sup>a</sup> | 7.08 <sup>a</sup>         | 2.02 <sup>a</sup>        | 1.36       | 0.11 <sup>b</sup>       | 6.17 <sup>ab</sup> | 2.53 <sup>b</sup>              | 87.59 <sup>ab</sup> |
| 25-50              | 5.08                        | 1.08 <sup>b</sup> | 3.53              | 95.00 <sup>a</sup> | 6.96 <sup>a</sup>         | 1.88 <sup>a</sup>        | 1.41       | 0.33 <sup>a</sup>       | 6.85 <sup>a</sup>  | 3.32 <sup>a</sup>              | 87.54 <sup>ab</sup> |
| 51-75              | 4.30                        | 1.08 <sup>b</sup> | 3.10              | 98.33 <sup>a</sup> | 4.99 <sup>b</sup>         | 0.69 <sup>b</sup>        | 1.29       | 0.21 <sup>ab</sup>      | 5.25 <sup>b</sup>  | 2.15 <sup>b</sup>              | 93.94 <sup>a</sup>  |
| >75                | 4.39                        | 1.07 <sup>b</sup> | 3.22              | 73.21 <sup>b</sup> | 6.03 <sup>ab</sup>        | 1.64 <sup>a</sup>        | 1.35       | 0.28 <sup>ab</sup>      | 5.73 <sup>b</sup>  | 2.51 <sup>b</sup>              | 76.55 <sup>b</sup>  |
| Mean values        | 4.71                        | 1.12              | 3.37              | 90.80              | 6.26                      | 1.55                     | 1.35       | 0.24                    | 6.00               | 2.62                           | 86.40               |
| C.D. (p<0.05)      | NS                          | 0.15              | NS                | 20.76              | 1.74                      | 0.92                     | NS         | 0.16                    | 0.96               | 0.52                           | 13.62               |

Figures with same alphabets do not differ significantly at 5 % level.

**Plate 3. Banding pattern observed in TLC used to quantify abscisic acid content in seeds of four age groups in mangosteen (*Garcinia mangostana* L.)**

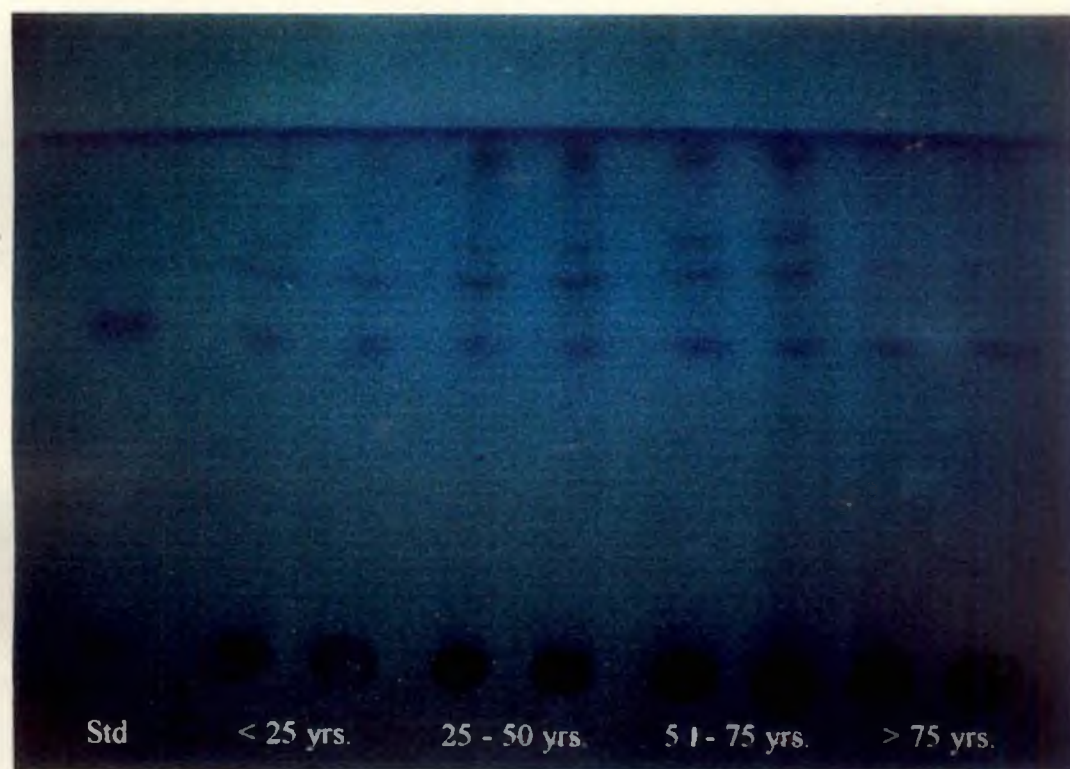
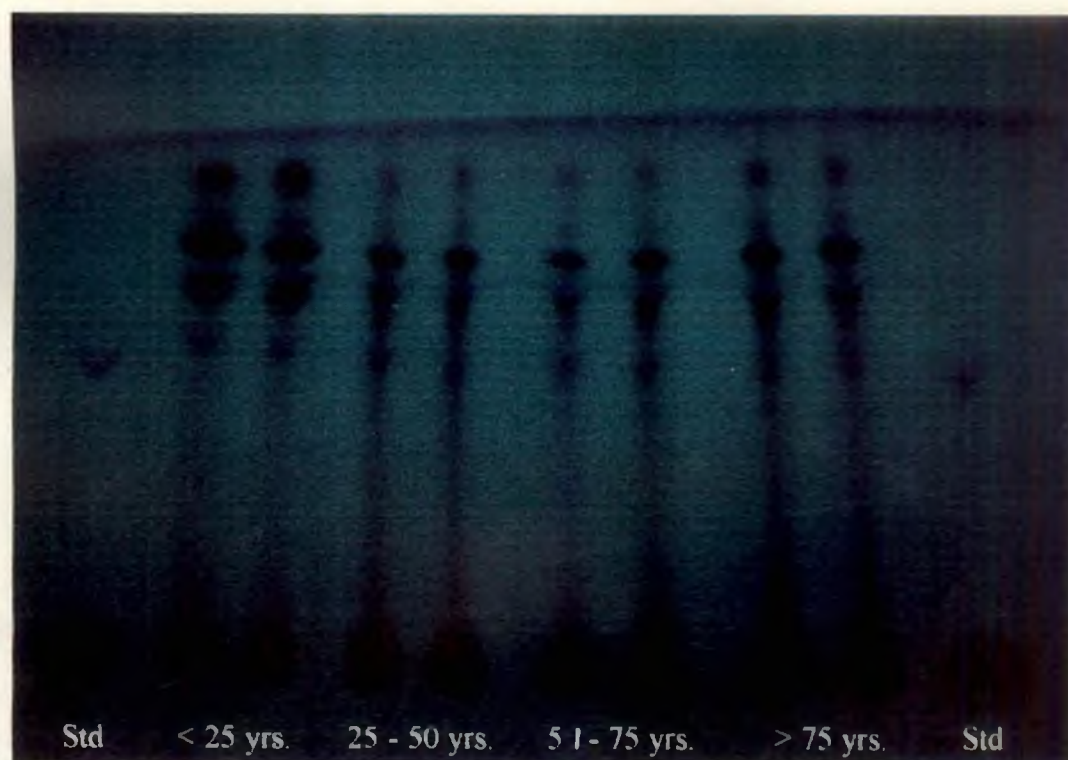


**Plate 4. Banding pattern observed in TLC used to quantify abscisic acid content in leaves of the seedlings raised from the four age groups in mangosteen (*Garcinia mangostana* L.)**



#### **4.1.5.1. Plant height**

The highest mean of plant height at three-months stage was observed in the age group of 25-50 years followed by the less than 25 years group. However, no significant differences were observed between the four age groups. At six-months stage, the lower two age groups recorded significantly higher height, which were significant. At six months and nine months stage, the maximum height was observed in the age group of less than 25 years whereas at the twelve months stage the highest was in the 25-50 year age group. However, the differences were not statistically significant.

#### **4.1.5.2. Increment in height at quarterly intervals**

The result of increment at the first quarterly interval (i.e., three months stage) was same as the height at three-months stage. At second quarterly interval (i.e., six months stage) the highest increment in height was observed in the age group of less than 25 years followed by 25-50 and more than 75 years. The means of the three groups were significantly higher than the age group 51-75 years. At the third quarterly interval (i.e., nine months stage) and the fourth quarterly interval (i.e., one year old) the highest increment in height was observed in the age groups 51-75 years and more than 75 years respectively. At the third quarterly interval, age group 51-75 recorded the maximum increment and was at par with less than 25 and 25-50 years. At the fourth quarterly interval there were no significant differences observed between the means of the four age groups. The highest age groups showed maximum increment and distinct gradation was observed in the increments with the least increment in the lowest age group.

#### **4.1.5.3. Seedling girth at collar**

At three-months stage highest girth at collar was observed in the age group of less than 25 years. This was significantly higher than all the other three age groups, which were at par with each other. At six months stage, the highest girth were observed in the age group of less than 25 and at nine months and twelve months it was highest at 25-50 years. However, the differences between the age group means were not significant at all the above three stages.

Table 6. Morphological characters of seedlings at nine-month stage in mangosteen (*Garcinia mangostana* L.)

| Age groups (years) | Height (cm) | Increment in height (cm) | Girth (cm) | Increment in girth (cm) | Total leaves (No)  | Increment in total leaves (No) | Survival rate (%) |
|--------------------|-------------|--------------------------|------------|-------------------------|--------------------|--------------------------------|-------------------|
| <25                | 8.02        | 0.94 <sup>ab</sup>       | 1.58       | 0.22                    | 7.49 <sup>a</sup>  | 1.32                           | 81.92             |
| 25-50              | 7.95        | 0.99 <sup>ab</sup>       | 1.61       | 0.20                    | 7.61 <sup>a</sup>  | 0.76                           | 86.59             |
| 51-75              | 6.52        | 1.53 <sup>a</sup>        | 1.56       | 0.27                    | 6.24 <sup>b</sup>  | 0.99                           | 77.75             |
| >75                | 6.64        | 0.61 <sup>b</sup>        | 1.58       | 0.23                    | 6.87 <sup>ab</sup> | 1.14                           | 75.12             |
| Mean values        | 7.28        | 1.02                     | 1.58       | 0.23                    | 7.05               | 1.06                           | 80.34             |
| C.D. (p< 0.05)     | NS          | 0.80                     | NS         | NS                      | 1.12               | NS                             | NS                |

Figures with same alphabets do not differ significantly at 5 % level.

#### **4.1.5.4. Increment in girth at collar**

At the first three months (i.e., at six-months stage) the age group 25-50 years recorded maximum increment, which was also statistically significant. In the second stage it was the 51-75 years age and at one-year stage again it was 25-50 years, which recorded the maximum increment. The results in the last two quarters were however not significant.

#### **4.1.5.5. Total number of leaves/seedling**

At the 3-months stage the highest number of leaves per seedling was observed in the age group of less than 25 years followed by 25-50 years. There were no significant differences between all the four age groups. At six, nine and twelve months stage the highest total number were observed in the age group 25-50 years and was at par.

#### **4.1.5.6. Increment in total number of leaves**

The maximum increment in the number of leaves was observed in the 25-50 years group at six-months stage, less than 25 years age group at nine months stage and 25-50 years age group at one-year stage. However, the results were statistically significant only at six-months stage.

#### **4.1.5.7. Number of new flushes/year**

Maximum mean number of new flushes/year/seedling was recorded in the age group of more than 75 years followed by 25-50 years, but the results were not statistically significant.

#### **4.1.5.8. Number of leaves/flush**

The same number of two leaves/flush was observed in all the four age groups.

#### **4.1.5.9. Total leaf area**

The highest total leaf area per seedling was observed in the age group of 25-50 years followed by less than 25 years. Though they were at par with each other, the difference was explicit.

#### **4.1.5.10. Survival rate**

At the early stages of three and six months, the highest survival of seedling was observed in the age group of 51-75 years. This was significantly superior to age group more than 75 years. At nine and twelve months stage, the highest survival percentage was observed in the age group of 25-50 years. However, the differences were not statistically significant.

#### **4.1.6. Shoot and root morphological character of one year old seedlings**

The data on shoot and root morphological characters of one-year-old seedlings are presented in the Table 8.

##### **4.1.6.1. Shoot fresh weight**

The highest mean values of fresh weight of shoot was recorded in the age group of less than 25 years and was significantly higher than the other three age groups. This was followed by age group 25-50 years which was significantly higher than the age group 51-75 and more than 75 years.

##### **4.1.6.2. Root fresh weight**

The fresh weight of roots also was highest in the age group of less than 25 years followed by 25-50 years, but and they were significantly higher than the age groups 51-75 and more than 75 years; which were at par with each other.

##### **4.1.6.3. Shoot dry weight and root dry weight**

Highest shoot and root dry weight were recorded in the age group of less than 25 years followed by 25-50 years. The differences between the means of the other age group were also statistically significant.

##### **4.1.6.4. Root to shoot dry weight ratio**

Though root to shoot dry weight ratio recorded was highest in the age group of more than 75 years, but the differences in the means of four age groups were not significant.

#### **4.1.6.5. Root length**

The maximum root length was observed in the age group of 25-50 years. However, there were no significant differences observed between the means of the four age groups.

#### **4.1.6.6. Number of primary roots/seedling**

The highest number of primary roots was observed in the age group of 25-50 years, followed by less than 25 years. The age group of 25-50 years was significantly higher than the age groups 51-75 and more than 75 years.

#### **4.1.6.7. Number of secondary tertiary and total roots**

The highest number of secondary, tertiary and total roots were recorded in the age groups 25-50, less than 25 and 25-50 years, respectively. However, there were no significant differences between the means of all the four age groups.

#### **4.1.7. Leaf biochemical characters of one-year-old seedlings**

The data on leaf biochemical characters of one-year-old mangosteen seedlings are presented in Table 9.

##### **4.1.7.1. Nitrogen content**

Higher nitrogen content was recorded in the age group less than 25 years. This was significantly superior only to the age group more than 75 years. A gradation in the nitrogen content of seedling leaf with increase in age was observed.

##### **4.1.7.2. Phosphorus**

The highest phosphorus content was recorded in the age group of 25-50 years. However, there were no significant differences observed between the means of the four age groups.

##### **4.1.7.3. Potassium content**

Though the highest potassium content was recorded in the age group of less than 25 years, there were no significant differences observed between the means of the four age groups.

#### **4.1.7.4. Crude protein**

The crude protein content recorded was highest in the age group of less than 25 years. This was significantly higher than the next higher age group 25-50 years. The lowest values were recorded in age group less than 75 years.

#### **4.1.7.5. Sodium content**

Maximum sodium content was recorded in the age group of less than 25. However, there were no significant differences observed in the mean values of the four age groups.

#### **4.1.7.6. Chlorophyll 'a'**

The mean chlorophyll a content was highest in the age group of 25-50 years. This was significantly higher than the age groups 51-75 and more than 75 years, but at par with less than 25 years age group.

#### **4.1.7.7. Chlorophyll 'b'**

The mean chlorophyll b content was highest in the age group of 25-50 years and was significantly higher than only the age group of more than 75 years.

#### **4.1.7.8. Total chlorophyll content**

Highest total chlorophyll content was recorded in the age group of 25-50 years followed by less than 25 years and the means of all the age groups differed significantly from each other.

#### **4.1.7.9. Total phenol content**

Even though the highest total phenol content was recorded in the age of 25-50 years, the differences in age group means were not statistically significant (Fig. 4).

#### **4.1.7.10. Total carbohydrates**

The total carbohydrate content recorded was highest in the age group of 25-50 years. The differences in the means of all age groups were also significant.

**Table 7. Morphological characters of seedlings at twelve-month stage in mangosteen (*Garcinia mangostana* L.)**

| Age groups (years) | Height (cm) | Increment in height (cm) | Girth (cm) | Increment in girth (cm) | Total leaves (No)  | Increment in total leaves (No) | New flushes / year (No) | Leaves/ flush (No) | Total leaf area (cm <sup>2</sup> ) | Survival rate (%) |
|--------------------|-------------|--------------------------|------------|-------------------------|--------------------|--------------------------------|-------------------------|--------------------|------------------------------------|-------------------|
| <25                | 9.56        | 1.54                     | 1.97       | 0.39                    | 8.45 <sup>ab</sup> | 0.96                           | 1.30                    | 2.00               | 68.15 <sup>a</sup>                 | 77.48             |
| 25-50              | 9.61        | 1.66                     | 2.00       | 0.39                    | 8.88 <sup>a</sup>  | 1.27                           | 1.33                    | 2.00               | 71.50 <sup>a</sup>                 | 84.92             |
| 51-75              | 8.38        | 1.86                     | 1.93       | 0.37                    | 7.47 <sup>b</sup>  | 1.23                           | 0.99                    | 2.00               | 39.07 <sup>b</sup>                 | 76.91             |
| >75                | 8.64        | 2.00                     | 1.93       | 0.35                    | 7.84 <sup>b</sup>  | 0.97                           | 1.42                    | 2.00               | 52.05 <sup>ab</sup>                | 72.26             |
| Mean values        | 9.05        | 1.77                     | 1.96       | 0.35                    | 8.16               | 1.11                           | 1.26                    | 2.00               | 57.69                              | 77.89             |
| C.D. (p< 0.05)     | NS          | NS                       | NS         | NS                      | 0.95               | NS                             | NS                      | NS                 | 26.36                              | NS                |

Figures with same alphabets do not differ significantly at 5 % level.

**Table 8. Shoot and root characters of one year old seedlings from seeds of mother plants of four age groups in mangosteen (*Garcinia mangostana* L.)**

| Age groups (years) | Shoot fresh weight (g) | Root fresh weight (g) | Shoot dry weight (g) | Root dry weight (g) | Root to shoot dry weight ratio | Root length (cm) | Primary roots (No)  | Secondary roots (No) | Tertiary roots (No) | Total roots (No) |
|--------------------|------------------------|-----------------------|----------------------|---------------------|--------------------------------|------------------|---------------------|----------------------|---------------------|------------------|
| <25                | 11.17 <sup>a</sup>     | 3.61 <sup>a</sup>     | 4.10 <sup>a</sup>    | 1.20 <sup>a</sup>   | 0.30                           | 25.98            | 26.00 <sup>ab</sup> | 59.00                | 18.25               | 103.25           |
| 25-50              | 7.60 <sup>b</sup>      | 3.57 <sup>a</sup>     | 3.01 <sup>a</sup>    | 1.20 <sup>a</sup>   | 0.38                           | 34.20            | 32.00 <sup>a</sup>  | 64.50                | 14.75               | 111.25           |
| 51-75              | 3.09 <sup>c</sup>      | 1.20 <sup>b</sup>     | 1.11 <sup>b</sup>    | 0.40 <sup>b</sup>   | 0.38                           | 22.73            | 21.00 <sup>b</sup>  | 32.50                | 11.75               | 65.25            |
| >75                | 2.59 <sup>c</sup>      | 1.44 <sup>b</sup>     | 0.40 <sup>b</sup>    | 0.45 <sup>b</sup>   | 1.68                           | 22.35            | 20.00 <sup>b</sup>  | 33.75                | 15.75               | 69.75            |
| Mean values        | 6.11                   | 2.46                  | 2.15                 | 0.81                | 0.69                           | 26.32            | 24.75               | 47.44                | 15.13               | 87.38            |
| C.D. (p< 0.05)     | 3.56                   | 1.97                  | 1.48                 | 0.72                | NS                             | NS               | 10.23               | NS                   | NS                  | NS               |

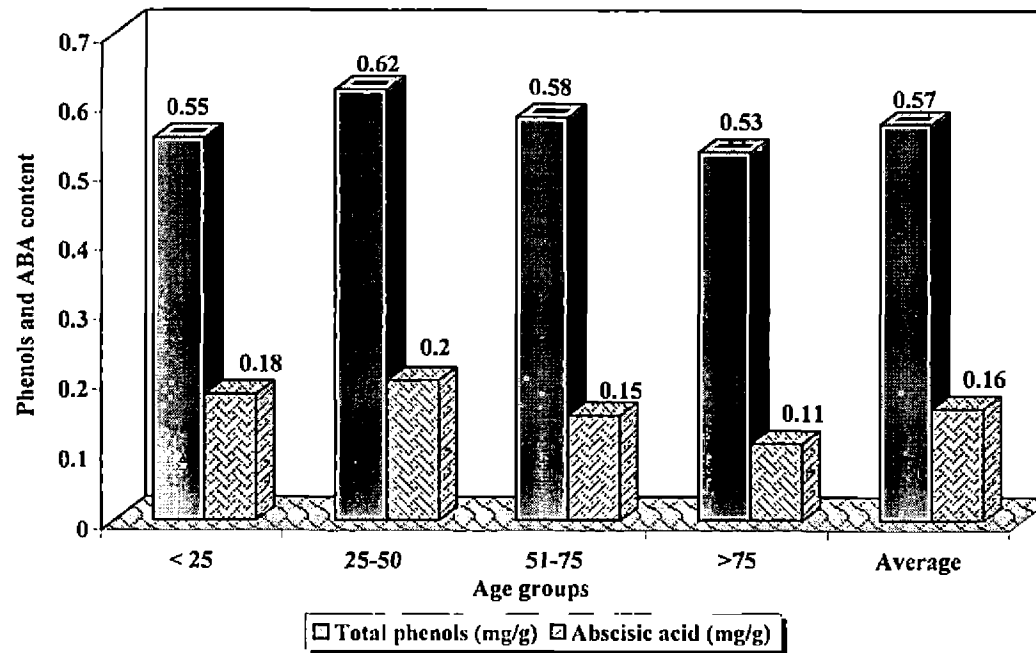
Figures with same alphabets do not differ significantly at 5 % level.

**Table 9. Leaf biochemical characters of one year old seedlings from seeds of mother plants of four age groups in mangosteen (*Garcinia mangostana* L.)**

| Age groups (years) | N (%)              | P (%) | K (%) | Crude protein (%)  | Na (%) | Chlorophyll a (mg/g) | Chlorophyll b (mg/g) | Chlorophyll a / b ratio | Total chlorophyll (mg/g) | Total phenols (mg/g) | Total carbohydrates (mg/g) | Abscissic acid (mg/g) |
|--------------------|--------------------|-------|-------|--------------------|--------|----------------------|----------------------|-------------------------|--------------------------|----------------------|----------------------------|-----------------------|
| <25                | 2.32 <sup>a</sup>  | 0.09  | 0.59  | 14.49 <sup>a</sup> | 0.35   | 0.80 <sup>ab</sup>   | 0.41 <sup>ab</sup>   | 2.05 <sup>a</sup>       | 1.21 <sup>b</sup>        | 0.55                 | 6.29 <sup>b</sup>          | 0.18 <sup>ab</sup>    |
| 25-50              | 2.10 <sup>ab</sup> | 0.10  | 0.56  | 13.10 <sup>b</sup> | 0.35   | 0.97 <sup>a</sup>    | 0.48 <sup>a</sup>    | 2.05 <sup>a</sup>       | 1.45 <sup>a</sup>        | 0.62                 | 7.09 <sup>a</sup>          | 0.20 <sup>a</sup>     |
| 51-75              | 1.82 <sup>ab</sup> | 0.09  | 0.56  | 11.35 <sup>c</sup> | 0.35   | 0.62 <sup>bc</sup>   | 0.34 <sup>ab</sup>   | 1.86 <sup>a</sup>       | 0.96 <sup>c</sup>        | 0.58                 | 5.53 <sup>c</sup>          | 0.15 <sup>bc</sup>    |
| >75                | 1.64 <sup>b</sup>  | 0.07  | 0.43  | 10.27 <sup>c</sup> | 0.34   | 0.43 <sup>c</sup>    | 0.21 <sup>b</sup>    | 2.40 <sup>a</sup>       | 0.64 <sup>d</sup>        | 0.53                 | 4.30 <sup>d</sup>          | 0.11 <sup>c</sup>     |
| Mean values        | 1.97               | 0.09  | 0.54  | 12.30              | 0.35   | 0.70                 | 0.36                 | 2.09                    | 1.07                     | 0.57                 | 5.80                       | 0.16                  |
| C.D.(p< 0.05)      | 0.58               | NS    | NS    | 1.09               | NS     | 0.19                 | 0.19                 | 0.63                    | 0.21                     | NS                   | 0.22                       | 0.05                  |

Figures with same alphabets do not differ significantly at 5 % level.

**Fig. 4. Total phenols and abscisic acid content the leaves of the seedling obtained from mother plants belonging to various age groups in mangosteen (*Garcinia mangostana* L.)**



#### **4.1.7.11. Absciscic acid content**

The absciscic acid content recorded was highest in the age group of 25-50 years and it was significantly higher than the age groups of 51-75 and more than 75 years (Fig. 4 and Plate 4).

#### **4.1.8. Fruit, seed and seedling indices**

The numbers of independent variables are high in the present study. Hence to reduce the number of descriptors the principal component analysis was performed using the deviation squares and products matrix of the twelve fruit, eleven seed, and fifteen seedling characters, independently in order to establish a list of minimum descriptors (i.e., fruit index, seed index and seedling index), thereby enabling the identification of best age group of mother plant besides reducing the complexity of the statistical analysis. The first principal components of fruit, seed and seedling characters, which accounted for the cumulative variance of 96.27, 97.63 and 70.05 percentage respectively, are given in the Table 10. As the first principal component was the largest possible and also are collections of variation of all the characters in each case (i.e., fruit, seed and seedling characters) this was selected as the index values of the same. The computed average fruit, seed and seedling index values of each age group are presented in the Table 11 and Fig.5.

##### **4.1.8.1. Fruit index**

Fruit index value was highest in the age group of 51-75 years of mother plant followed by the age group more than 75 years.

##### **4.1.8.2. Seed index**

The highest seed index value was recorded in the age group of 25-50 years followed by 51-75 years. The least seed index values were observed in the age group more than 75 years.

##### **4.1.8.3. Seedling index**

The highest seedling index was observed in the age group of 25-50 years followed by the age group of less than 25 years. One major observation was

**Fig. 5. Fruit, seed and seedling index of four age groups in mangosteen (*Garcinia mangostana* L.).**

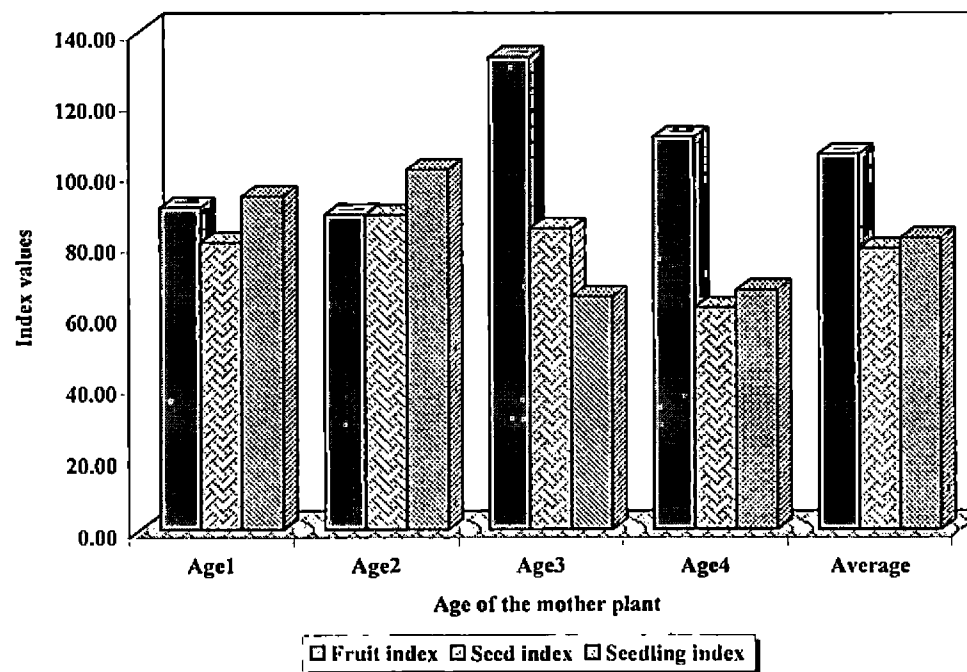


**Table 10. Latent vectors and variance of the principal component analysis performed for generating fruit, seed and seedling indices separately in mangosteen (*Garcinia mangostana* L.).**

| S.No. | Characters                              | Principle component 1 | Principle component 2 |
|-------|-----------------------------------------|-----------------------|-----------------------|
|       | <b>Fruit characters</b>                 |                       |                       |
| 1     | Fruit weight                            | 0.62                  | 0.14                  |
| 2     | Fruit volume                            | 0.62                  | 0.14                  |
| 3     | Fruit girth                             | 0.02                  | 0.00                  |
| 4     | No. of segments                         | 0.00                  | 0.00                  |
| 5     | Pulp weight                             | 0.15                  | 0.76                  |
| 6     | Rind weight                             | 0.47                  | -0.62                 |
| 7     | Fruit specific gravity                  | 0.00                  | 0.00                  |
| 8     | Number of seedless fruits               | 0.00                  | 0.00                  |
| 9     | Number of one seeded fruits             | 0.00                  | -0.01                 |
| 10    | Number of two seeded fruits             | 0.00                  | 0.01                  |
| 11    | Number of three and multi seeded fruits | 0.00                  | 0.01                  |
| 12    | Number of seedlings/Fruit               | 0.00                  | 0.04                  |
|       | <b>Cumulative variance</b>              | <b>96.27</b>          | <b>98.68</b>          |
|       | <b>Seed characters</b>                  |                       |                       |
| 1     | Seed weight                             | 0.00                  | -0.07                 |
| 2     | Seed length                             | 0.00                  | -0.04                 |
| 3     | seed thickness at center                | 0.00                  | -0.03                 |
| 4     | Volume                                  | 0.00                  | -0.08                 |
| 5     | Seed specific gravity                   | -0.01                 | 0.11                  |
| 6     | Number of seeds                         | 0.00                  | -0.04                 |
| 7     | Number of seedling/seed                 | 0.00                  | 0.00                  |
| 8     | Number of days to germination           | 0.02                  | 0.99                  |
| 9     | Seed with one seedling                  | 0.00                  | 0.00                  |
| 10    | Seed with twin and multiple seedlings   | 0.00                  | 0.00                  |
| 11    | Germination percentage                  | 1.00                  | -0.01                 |
|       | <b>Cumulative variance</b>              | <b>97.63</b>          | <b>99.50</b>          |
|       | <b>Seedling characters</b>              |                       |                       |
| 1     | Height                                  | 0.03                  | -0.01                 |
| 2     | Girth at collar                         | 0.00                  | 0.00                  |
| 3     | Total number of leaves                  | 0.03                  | 0.00                  |
| 4     | Number of flushes/year                  | 0.00                  | 0.00                  |
| 5     | Total leaf area                         | 0.98                  | -0.21                 |
| 6     | Survival rate at twelfth month (%)      | 0.04                  | 0.18                  |
| 7     | Shoot fresh weight                      | 0.01                  | 0.06                  |
| 8     | Root fresh weight                       | 0.01                  | 0.03                  |
| 9     | Total fresh weight                      | 0.02                  | 0.09                  |
| 10    | Shoot dry weight                        | 0.01                  | 0.03                  |
| 11    | Root dry weight                         | 0.00                  | 0.01                  |
| 12    | Total dry weight                        | 0.01                  | 0.04                  |
| 13    | Root to shoot dry weight ratio          | 0.00                  | 0.00                  |
| 14    | Root length (longest root)              | 0.03                  | 0.18                  |
| 15    | Total number of roots                   | 0.20                  | 0.94                  |
|       | <b>Cumulative variance</b>              | <b>70.05</b>          | <b>95.77</b>          |

**Table11. Average fruit index, seed index and seedling index values of four age groups in mangosteen (*Garcinia mangostana* L.).**

| Age groups<br>(Years) | Fruit<br>Index | Seed<br>Index | Seedling<br>Index |
|-----------------------|----------------|---------------|-------------------|
| <25                   | 90.55          | 80.54         | 93.69             |
| 25-50                 | 88.62          | 88.36         | 101.17            |
| 51-75                 | 132.90         | 84.47         | 65.20             |
| >75                   | 110.42         | 62.12         | 67.17             |
| Average               | 102.16         | 81.58         | 86.21             |

that the difference between the best group (25-50 years) and the two age groups of more than 50 years was near to one and a half times more.

Index values observed for fruit, seed and seedling characters differed but the trend was same for the seed and seedling characters. However equal importance was given for each of the three index values and the age group in finally determining the best age group of mother plant.

#### **4.1.9. Estimation of correlation among characters**

Correlation studies were undertaken using 12 fruit characters, 11 seed characters, 18 seedling characters, fruit index, seed index, seedling index and age of the mother plants. Correlation coefficients observed between fruit and seed characters are presented in Table 12, between fruit and seedling characters in Table 13 and between seed and seedling characters in Table 14.

##### **4.1.9.1. Correlations among the fruit morphological characters and between age of mother plants**

Age of the mother plant was highly and positively correlated with fruit characters viz., fruit weight ( $r = 0.32$ ), fruit volume ( $r = 0.30$ ), fruit girth ( $r = 0.29$ ), rind weight ( $r = 0.37$ ), number of seedless fruits ( $r = 0.58$ ) and fruit index ( $r = 0.32$ ). Highly significant positive correlations were observed between fruit weight with fruit volume ( $r = 0.97$ ), fruit girth ( $r = 0.96$ ), pulp weight ( $r = 0.80$ ), rind weight ( $r = 0.97$ ) and fruit index ( $r = 0.99$ ). On the contrary, negative correlations were observed with fruit specific gravity ( $r = -0.26$ ). Fruit volume was positively correlated with fruit girth ( $r = 0.93$ ), pulp weight ( $r = 0.76$ ), rind weight ( $r = 0.95$ ), number of seedlings per fruit ( $r = 0.25$ ) and fruit index ( $r = 0.99$ ) but negatively correlated with fruit specific gravity ( $r = -0.46$ ).

Pulp weight of the fruit was highly positively correlated with rind weight ( $r = 0.64$ ), number of seedlings per fruit ( $r = 0.32$ ) and also fruit index ( $r = 0.77$ ). Rind weight was significantly and positively correlated with fruit index ( $r = 0.98$ ) and significant negative correlations were recorded with fruit specific gravity ( $r = -0.28$ ). No significant positive correlation was observed between fruit specific gravity and fruit characters but a significant negative correlation was estimated with fruit index ( $r = -0.34$ ).

Number of seedless fruits showed positive correlation with the incidence of two seeded fruits ( $r = 0.24$ ) and number of seedling per fruit ( $r = 0.27$ ). On the contrary, significant negative correlations were observed with number of one-seeded fruits ( $r = -0.31$ ). The number of one-seeded fruits further showed high negative correlation with the incidence of two seeded fruit count ( $r = -0.84$ ), three and more than three seeded fruit count ( $r = -0.37$ ) and number of seedling per fruit ( $r = -0.72$ ). A high positive correlation was observed between number of two seeded fruits and number of seedlings per fruit ( $r = 0.50$ ). The number of three and more than three seeded fruits were significantly and positively correlated with number of seedlings per fruit ( $r = 0.57$ ).

#### **4.1.9.2. Correlations among the seed morphological characters and age of the mother plant**

Age of the mother plant showed a significant positive correlation with seed weight ( $r = 0.30$ ). In contrast, it showed significant negative correlations with germination percentage ( $r = -0.33$ ) and seed index ( $r = -0.33$ ).

Seed weight was significantly and positive correlated with seed length ( $r = 0.71$ ), seed thickness ( $r = 0.47$ ) and seed volume ( $r = 0.90$ ), significant negative correlation was recorded with seed specific gravity ( $r = -0.58$ ), number of days taken to germination ( $r = -0.48$ ). Significant positive correlation was recorded between seed length and seed thickness ( $r = 0.32$ ) and seed volume ( $r = 0.74$ ), whereas significant negative correlations were recorded with seed specific gravity ( $r = -0.59$ ), number of days to germination ( $r = -0.33$ ). Seed thickness revealed a significant positive correlation with seed volume ( $r = 0.71$ ) but correlations with seed specific gravity ( $r = -0.88$ ), number of days taken to germination ( $r = -0.35$ ) were significantly negative. Similarly significant negative correlations were observed in the case of seed volume with seed specific gravity ( $r = -0.73$ ) and number of days taken to germination ( $r = -0.46$ ). Seed specific gravity showed a significant positive correlation with number of days taken to germination ( $r = 0.37$ ).

Number of seedlings per seed had a significant positive relationship with seeds producing two and more than two seedlings ( $r = 0.84$ ) but the number of seeds producing one seedling bore a significant negative correlation with number

of seeds producing two and more than two seedling ( $r = -1.00$ ). Germination percentage showed a high positive correlation with seed index ( $r = 1.00$ ).

#### **4.1.9.3. Correlations among the seedling morphological characters and with age of the mother plant**

Age of the mother plant revealed a significant positive correlation with dry weight ratio of root to shoot ( $r = 0.48$ ), number of primary ( $r = 0.56$ ), secondary ( $r = 0.59$ ), tertiary ( $r = 0.50$ ) and total roots ( $r = 0.61$ ) and significant negative correlation with shoot fresh weight ( $r = -0.87$ ), root fresh weight ( $r = -0.66$ ), total fresh weight ( $r = -0.84$ ), shoot dry weight ( $r = -0.83$ ), root dry weight ( $r = -0.52$ ), total dry weight ( $r = -0.78$ ) number of primary roots ( $r = -0.34$ ), secondary roots ( $r = -0.44$ ), tertiary roots ( $r = -0.24$ ), total number of roots ( $r = -0.41$ ) and dry weight ratio of root to shoot ( $r = -0.27$ ).

Root fresh weight showed significant positive correlations with total fresh weight ( $r = 0.90$ ), shoot dry weight ( $r = 0.78$ ), root dry weight ( $r = 0.81$ ), total dry weight ( $r = 0.83$ ), root length ( $r = 0.73$ ), number of primary roots ( $r = 0.81$ ), secondary roots ( $r = 0.80$ ), tertiary roots ( $r = 0.59$ ), total number of roots ( $r = 0.81$ ) and seedling index ( $r = 0.30$ ). Total fresh weight showed a significantly positive correlation with shoot dry weight ( $r = 0.87$ ), root dry weight ( $r = 0.71$ ), total dry weight ( $r = 0.87$ ), root length ( $r = 0.57$ ), number of primary ( $r = 0.65$ ), secondary ( $r = 0.68$ ), tertiary ( $r = 0.55$ ), total roots ( $r = 0.69$ ) and the seedling index ( $r = 0.25$ ). Significant positive correlations were observed in shoot dry weight with root dry weight ( $r = 0.76$ ), total dry weight ( $r = 0.98$ ), root length ( $r = 0.43$ ), number of primary roots ( $r = 0.57$ ), secondary roots ( $r = 0.60$ ), tertiary roots ( $r = 0.37$ ) and total number of roots ( $r = 0.59$ ). Significant negative correlations were also observed with root to shoot dry weight ratio ( $r = -0.38$ ).

Root dry weight had a significant positive correlation with total dry weight ( $r = 0.87$ ), root length ( $r = 0.69$ ), number of primary ( $r = 0.80$ ), secondary ( $r = 0.79$ ), tertiary ( $r = 0.63$ ) and total roots ( $r = 0.80$ ) and also seedling index ( $r = 0.26$ ). Total dry weight was positively correlated with root length ( $r = 0.53$ ), number of primary roots ( $r = 0.67$ ), secondary roots ( $r = 0.68$ ), tertiary roots ( $r = 0.46$ ), total number of roots ( $r = 0.68$ ) and also with seedling index ( $r = 0.24$ ).

Table 13. Correlation coefficients among mother plant age and various characters of fruit and seedling in mangosteen (*Garcinia mangostana* L.)

| Variables       | X <sub>1</sub> | X <sub>2</sub> | X <sub>3</sub> | X <sub>4</sub> | X <sub>5</sub> | X <sub>6</sub> | X <sub>7</sub> | X <sub>8</sub> | X <sub>9</sub> | X <sub>10</sub> | X <sub>11</sub> | X <sub>12</sub> | X <sub>13</sub> | X <sub>14</sub> | X <sub>15</sub> | X <sub>16</sub> | X <sub>17</sub> | X <sub>18</sub> | X <sub>19</sub> | X <sub>20</sub> | X <sub>21</sub> | X <sub>22</sub> | X <sub>23</sub> | X <sub>24</sub> | X <sub>25</sub> | X <sub>26</sub> | X <sub>27</sub> | X <sub>28</sub> | X <sub>29</sub> | X <sub>30</sub> | X <sub>31</sub> | X <sub>32</sub> | X <sub>33</sub> |  |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|--|
| X <sub>1</sub>  | 1.00           |                |                |                |                |                |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>2</sub>  | **0.32         | 1.00           |                |                |                |                |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>3</sub>  | *0.30          | **0.97         | 1.00           |                |                |                |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>4</sub>  | *0.29          | **0.96         | **0.93         | 1.00           |                |                |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>5</sub>  | 0.04           | 0.22           | 0.21           | *0.24          | 1.00           |                |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>6</sub>  | 0.12           | **0.80         | **0.76         | **0.76         | 0.17           | 1.00           |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>7</sub>  | **0.37         | **0.97         | **0.95         | **0.94         | 0.22           | **0.64         | 1.00           |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>8</sub>  | 0.07           | -0.26          | **0.46         | -0.23          | 0.05           | -0.14          | *0.28          | 1.00           |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>9</sub>  | **0.58         | 0.16           | 0.19           | 0.09           | -0.07          | 0.08           | 0.17           | -0.14          | 1.00           |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>10</sub> | -0.20          | -0.15          | -0.18          | -0.15          | -0.04          | -0.22          | -0.11          | 0.12           | **0.31         | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>11</sub> | 0.16           | 0.07           | 0.09           | 0.06           | 0.03           | 0.15           | 0.04           | -0.06          | *0.24          | **0.84          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>12</sub> | 0.01           | 0.11           | 0.14           | 0.11           | -0.01          | 0.23           | 0.05           | -0.14          | 0.13           | **0.37          | -0.13           | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>13</sub> | 0.17           | 0.21           | *0.25          | 0.18           | 0.03           | **0.32         | 0.14           | -0.21          | *0.27          | **0.72          | **0.50          | **0.57          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>14</sub> | **0.32         | **0.99         | **0.99         | **0.95         | 0.22           | **0.77         | **0.98         | **0.34         | 0.17           | -0.16           | 0.08            | 0.12            | 0.22            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>15</sub> | -0.13          | -0.12          | -0.11          | -0.15          | -0.20          | 0.02           | -0.16          | -0.03          | 0.08           | -0.07           | 0.10            | -0.07           | -0.12           | -0.12           | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>16</sub> | 0.03           | -0.07          | -0.08          | -0.10          | *0.26          | 0.03           | -0.10          | 0.01           | 0.09           | -0.04           | 0.06            | 0.00            | 0.00            | -0.08           | **0.46          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>17</sub> | -0.15          | -0.04          | -0.04          | -0.04          | 0.01           | -0.03          | -0.04          | -0.04          | -0.07          | -0.10           | 0.12            | -0.07           | -0.09           | -0.04           | **0.56          | 0.17            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>18</sub> | 0.09           | -0.04          | -0.03          | -0.05          | -0.09          | 0.04           | -0.07          | -0.04          | 0.11           | -0.18           | 0.17            | 0.11            | 0.22            | 0.04            | 0.04            | 0.04            | 0.01            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>19</sub> | -0.15          | 0.01           | 0.00           | 0.00           | -0.05          | 0.07           | -0.01          | 0.00           | -0.02          | -0.04           | 0.02            | -0.01           | -0.01           | 0.00            | **0.61          | *0.27           | **0.71          | 0.01            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>20</sub> | -0.17          | **0.35         | *0.30          | **0.34         | -0.10          | *0.29          | **0.34         | -0.05          | 0.23           | -0.21           | 0.18            | 0.13            | 0.16            | **0.33          | 0.12            | 0.01            | 0.04            | 0.08            | 0.10            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>21</sub> | **0.87         | **0.33         | **0.32         | *0.29          | -0.06          | -0.18          | **0.35         | -0.01          | **0.56         | 0.14            | -0.11           | 0.01            | -0.14           | **0.33          | 0.08            | -0.06           | 0.16            | 0.06            | 0.14            | *0.36           | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>22</sub> | **0.66         | **0.41         | **0.38         | **0.39         | -0.12          | *0.30          | **0.40         | -0.03          | *0.29          | 0.04            | -0.03           | 0.05            | -0.06           | **0.40          | 0.07            | -0.04           | 0.19            | 0.01            | 0.20            | *0.51           | **0.81          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>23</sub> | **0.84         | **0.36         | **0.35         | **0.33         | -0.08          | -0.22          | **0.38         | -0.02          | **0.50         | 0.12            | -0.09           | 0.02            | -0.12           | **0.36          | 0.08            | -0.05           | 0.17            | 0.04            | 0.16            | *0.42           | **0.98          | **0.90          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>24</sub> | **0.83         | *0.30          | *0.28          | *0.27          | -0.04          | -0.14          | **0.33         | -0.05          | **0.68         | 0.14            | -0.12           | 0.02            | -0.10           | *0.30           | 0.02            | -0.05           | 0.15            | 0.01            | 0.15            | 0.20            | **0.86          | **0.78          | **0.87          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>25</sub> | **0.52         | **0.41         | **0.38         | **0.38         | -0.12          | **0.31         | **0.40         | 0.01           | **0.43         | 0.05            | -0.03           | 0.03            | -0.03           | **0.40          | 0.00            | -0.07           | 0.15            | 0.03            | 0.16            | *0.38           | **0.63          | **0.81          | **0.71          | *0.76           | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>26</sub> | **0.78         | **0.34         | **0.33         | **0.31         | -0.06          | -0.19          | **0.37         | -0.04          | **0.64         | 0.12            | -0.10           | 0.03            | -0.09           | **0.35          | 0.02            | -0.06           | 0.16            | 0.00            | 0.16            | *0.26           | **0.84          | **0.83          | **0.87          | **0.98          | **0.87          | 1.00            |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>27</sub> | **0.48         | -0.10          | -0.13          | -0.05          | 0.09           | *0.25          | -0.03          | *0.30          | 0.12           | 0.03            | -0.01           | -0.05           | -0.08           | -0.10           | -0.17           | -0.16           | 0.01            | 0.07            | -0.09           | 0.01            | *0.27           | -0.12           | -0.23           | **0.38          | 0.03            | *0.28           | 1.00            |                 |                 |                 |                 |                 |                 |  |
| X <sub>28</sub> | -0.22          | **0.38         | **0.35         | **0.37         | -0.07          | **0.32         | **0.37         | 0.02           | -0.13          | -0.04           | 0.08            | 0.03            | 0.03            | **0.37          | 0.05            | -0.05           | 0.13            | 0.05            | 0.12            | *0.67           | **0.47          | **0.73          | **0.57          | **0.43          | **0.69          | **0.53          | 0.21            | 1.00            |                 |                 |                 |                 |                 |  |
| X <sub>29</sub> | **0.34         | **0.35         | **0.32         | **0.35         | -0.08          | *0.29          | **0.34         | -0.01          | -0.20          | -0.01           | 0.03            | 0.04            | 0.02            | **0.34          | 0.03            | -0.05           | 0.17            | 0.02            | 0.15            | *0.51           | **0.56          | **0.81          | **0.65          | *0.57           | **0.80          | **0.67          | 0.13            | **0.94          | 1.00            |                 |                 |                 |                 |  |
| X <sub>30</sub> | **0.44         | **0.36         | **0.32         | **0.39         | -0.15          | *0.27          | **0.36         | -0.11          | -0.09          | -0.06           | 0.07            | 0.07            | 0.05            | **0.35          | 0.12            | 0.03            | 0.21            | 0.07            | 0.22            | *0.39           | **0.59          | **0.80          | **0.68          | *0.60           | **0.79          | **0.68          | -0.04           | **0.72          | **0.85          | 1.00            |                 |                 |                 |  |
| X <sub>31</sub> | *0.24          | -0.23          | -0.21          | -0.20          | -0.11          | -0.19          | -0.22          | -0.01          | -0.02          | -0.03           | 0.04            | 0.04            | 0.01            | -0.23           | 0.04            | -0.03           | 0.15            | 0.08            | 0.16            | *0.31           | *0.50           | *0.59           | **0.55          | *0.37           | **0.63          | **0.46          | *0.24           | *0.49           | *0.58           | **0.78          | 1.00            |                 |                 |  |
| X <sub>32</sub> | **0.41         | **0.36         | **0.32         | **0.37         | -0.14          | *0.28          | **0.35         | -0.08          | -0.10          | -0.05           | 0.06            | 0.06            | 0.04            | **0.35          | 0.10            | 0.00            | 0.21            | 0.06            | 0.21            | *0.42           | *0.61           | *0.81           | **0.69          | *0.59           | **0.81          | **0.68          | 0.04            | *0.77           | **0.88          | **0.99          | *0.82           | 1.00            |                 |  |
| X <sub>33</sub> | -0.20          | -0.04          | -0.05          | -0.05          | -0.07          | 0.02           | -0.06          | -0.01          | -0.03          | -0.04           | 0.03            | 0.00            | 0.00            | -0.04           | **0.60          | *0.26           | **0.71          | 0.00            | **0.99          | 0.16            | 0.22            | *0.30           | *0.25           | 0.22            | *0.26           | *0.24           | -0.08           | 0.22            | *0.26           | **0.35          | *0.26           | **0.33          | 1.00            |  |

\* Significantly correlated at 5 % level

\*\* Significantly correlated at 1 % level

## FRUIT CHARACTERS

X<sub>1</sub> AgeX<sub>2</sub> Fruit weightX<sub>3</sub> Fruit volumeX<sub>4</sub> Fruit girthX<sub>5</sub> Number of segmentsX<sub>6</sub> Palp weightX<sub>7</sub> Rind weightX<sub>8</sub> Fruit specific gravityX<sub>9</sub> Number of seedless fruitsX<sub>10</sub> Number of one seeded fruitsX<sub>11</sub> Number of two seeded fruitsX<sub>12</sub> Number of three and multi e seeded fruitsX<sub>13</sub> Number of seedlings/FruitX<sub>14</sub> Fruit index

## SEEDLING CHARACTERS

X<sub>15</sub> HeightX<sub>16</sub> Girth at collarX<sub>17</sub> Total number of leavesX<sub>18</sub> Number of flushes/yearX<sub>19</sub> Total leaf areaX<sub>20</sub> Survival rate at 12 th month (%)X<sub>21</sub> Shoot fresh weightX<sub>22</sub> Root fresh weightX<sub>23</sub> Total fresh weightX<sub>24</sub> Shoot dry weightX<sub>25</sub> Root dry weightX<sub>26</sub> Total dry weightX<sub>27</sub> Root to shoot dry weight ratioX<sub>28</sub> Root length (longest root)X<sub>29</sub> Number of primary rootsX<sub>30</sub> Number of secondary rootsX<sub>31</sub> Number of tertiary rootsX<sub>32</sub> Total number of rootsX<sub>33</sub> Seedling index

Height of the seedling was positively correlated with girth at collar ( $r = 0.46$ ), total number of leaves ( $r = 0.56$ ), total leaf area ( $r = 0.61$ ) and seedling index ( $r = 0.60$ ). Girth at collar of the seedling showed maximum significant positive correlations with total leaf area ( $r = 0.27$ ) and seedling index ( $r = 0.26$ ). Highly positive correlations were recorded in case of total number of leaves with total leaf area ( $r = 0.71$ ) and seedling index ( $r = 0.71$ ). Significant positive correlations were estimated in total leaf area with seedling index ( $r = 0.99$ ).

Survival rate of the seedling at twelve months stage had significant positive correlation with shoot fresh weight ( $r = 0.36$ ), root fresh weight ( $r = 0.51$ ), total fresh weight ( $r = 0.42$ ), root dry weight ( $r = 0.38$ ), total dry weight ( $r = 0.26$ ), root length ( $r = 0.67$ ), number of primary ( $r = 0.51$ ), secondary ( $r = 0.39$ ), tertiary ( $r = 0.31$ ) and total number of roots ( $r = 0.42$ ). Significant positive correlations were also observed in case of shoot fresh weight with root fresh weight ( $r = 0.81$ ), total fresh weight ( $r = 0.98$ ), shoot dry weight ( $r = 0.86$ ), root dry weight ( $r = 0.63$ ), total dry weight ( $r = 0.84$ ), root length ( $r = 0.47$ ). Ratio of dry weight of root to shoot had a significant positive correlation with number of tertiary roots ( $r = 0.24$ ).

Root length was significantly and positively correlated with number of primary ( $r = 0.94$ ), secondary ( $r = 0.72$ ), tertiary ( $r = 0.49$ ) and total number of roots ( $r = 0.77$ ). Significant positive correlations were observed among the number of primary, secondary and tertiary roots and also with the seedling index.

#### **4.1.9.4. Correlations between fruit and seed characters**

Fruit weight was positively correlated with seed weight ( $r = 0.32$ ) and seed length ( $r = 0.32$ ). Fruit volume was significantly correlated with seed weight ( $r = 0.28$ ) and seed length ( $r = 0.31$ ). Positive correlations were observed between fruit girth and seed weight ( $r = 0.30$ ) and seed length ( $r = 0.30$ ). In case of pulp weight it was observed to be positively correlated with seed weight ( $r = 0.32$ ), seed length ( $r = 0.48$ ), seed volume ( $r = 0.27$ ), number of seeds per fruit ( $r = 0.28$ ) and negatively correlated with seed specific gravity ( $r = -0.25$ ) and number of days to germination ( $r = -0.26$ ). Rind weight was positively correlated with seed weight ( $r = 0.28$ ). Significant positive correlation was recorded with the incidence in number of seedless ness in fruits with the incidence of more number of seeds per fruit ( $r = 0.32$ ).

Table 14. Correlation coefficients among various characters of seed and seedling in mangosteen (*Garcinia mangostana* L.)

| Variables       | X <sub>1</sub> | X <sub>2</sub> | X <sub>3</sub> | X <sub>4</sub> | X <sub>5</sub> | X <sub>6</sub> | X <sub>7</sub> | X <sub>8</sub> | X <sub>9</sub> | X <sub>10</sub> | X <sub>11</sub> | X <sub>12</sub> | X <sub>13</sub> | X <sub>14</sub> | X <sub>15</sub> | X <sub>16</sub> | X <sub>17</sub> | X <sub>18</sub> | X <sub>19</sub> | X <sub>20</sub> | X <sub>21</sub> | X <sub>22</sub> | X <sub>23</sub> | X <sub>24</sub> | X <sub>25</sub> | X <sub>26</sub> | X <sub>27</sub> | X <sub>28</sub> | X <sub>29</sub> | X <sub>30</sub> | X <sub>31</sub> |  |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|--|
| X <sub>1</sub>  | 1.00           |                |                |                |                |                |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>2</sub>  | **0.71         | 1.00           |                |                |                |                |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>3</sub>  | **0.47         | **0.32         | 1.00           |                |                |                |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>4</sub>  | **0.90         | **0.74         | **0.71         | 1.00           |                |                |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>5</sub>  | **0.58         | **0.59         | **0.88         | **0.73         | 1.00           |                |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>6</sub>  | 0.06           | 0.14           | 0.00           | 0.04           | -0.06          | 1.00           |                |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>7</sub>  | 0.18           | 0.10           | 0.10           | 0.16           | -0.12          | 0.00           | 1.00           |                |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>8</sub>  | **0.48         | **0.33         | **0.35         | **0.46         | **0.37         | -0.13          | 0.02           | 1.00           |                |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>9</sub>  | -0.07          | -0.03          | -0.10          | -0.07          | 0.11           | -0.07          | **0.84         | -0.04          | 1.00           |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>10</sub> | 0.07           | 0.03           | 0.10           | 0.07           | -0.11          | 0.07           | **0.84         | 0.04           | -1.00          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>11</sub> | -0.01          | 0.11           | 0.10           | 0.02           | -0.16          | 0.02           | 0.09           | 0.11           | -0.11          | 0.11            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>12</sub> | -0.01          | 0.11           | 0.10           | 0.02           | -0.16          | 0.02           | 0.09           | 0.11           | -0.11          | 0.11            | **1.00          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>13</sub> | **0.38         | **0.44         | **0.37         | **0.41         | **0.45         | 0.04           | *0.24          | **0.30         | *0.27          | *0.27           | 0.18            | 0.18            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>14</sub> | **0.34         | **0.30         | **0.34         | **0.37         | **0.36         | 0.07           | -0.05          | -0.22          | 0.05           | -0.05           | 0.17            | 0.16            | **0.46          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>15</sub> | 0.11           | 0.15           | *0.27          | 0.16           | *0.26          | 0.09           | -0.20          | -0.13          | 0.14           | -0.14           | 0.04            | 0.04            | **0.56          | 0.17            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>16</sub> | 0.08           | 0.07           | 0.03           | 0.03           | 0.02           | *0.24          | 0.14           | 0.06           | 0.11           | 0.11            | 0.16            | 0.16            | 0.04            | 0.04            | 0.01            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>17</sub> | 0.23           | **0.26         | **0.34         | *0.30          | **0.34         | 0.04           | -0.06          | *0.27          | 0.05           | -0.05           | 0.13            | 0.13            | **0.61          | *0.27           | **0.71          | 0.01            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>18</sub> | **0.33         | -0.15          | -0.10          | *0.28          | 0.11           | 0.23           | -0.03          | 0.11           | -0.07          | 0.07            | 0.06            | 0.06            | 0.12            | 0.01            | 0.04            | 0.08            | 0.10            | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>19</sub> | **0.42         | -0.20          | -0.03          | **0.33         | 0.01           | -0.12          | -0.13          | 0.11           | 0.06           | -0.06           | 0.17            | 0.17            | 0.08            | -0.06           | 0.16            | 0.06            | 0.14            | **0.36          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>20</sub> | **0.43         | *0.24          | 0.04           | **0.33         | -0.03          | 0.01           | -0.09          | 0.15           | -0.03          | 0.03            | **0.33          | **0.33          | 0.07            | -0.04           | 0.19            | 0.01            | 0.20            | **0.51          | **0.81          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>21</sub> | **0.44         | -0.22          | -0.01          | **0.35         | 0.00           | -0.09          | -0.12          | 0.13           | 0.03           | -0.03           | 0.23            | 0.23            | 0.08            | -0.05           | 0.17            | 0.04            | 0.16            | **0.42          | **0.98          | **0.90          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>22</sub> | **0.36         | -0.19          | 0.08           | *0.25          | -0.08          | -0.12          | -0.08          | 0.03           | 0.01           | -0.01           | 0.21            | 0.21            | 0.02            | -0.05           | 0.15            | 0.01            | 0.15            | 0.20            | **0.86          | **0.78          | **0.87          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>23</sub> | **0.39         | *0.25          | 0.05           | **0.31         | -0.01          | -0.01          | -0.06          | 0.06           | -0.03          | 0.03            | 0.12            | 0.12            | 0.00            | -0.07           | 0.15            | 0.03            | 0.16            | **0.38          | **0.63          | **0.81          | **0.71          | **0.76          | 1.00            |                 |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>24</sub> | **0.39         | -0.22          | 0.08           | *0.28          | -0.06          | -0.09          | -0.08          | 0.04           | 0.00           | 0.00            | 0.20            | 0.20            | 0.02            | -0.06           | 0.16            | 0.00            | 0.16            | *0.26           | **0.84          | **0.83          | **0.87          | **0.98          | **0.87          | 1.00            |                 |                 |                 |                 |                 |                 |                 |  |
| X <sub>25</sub> | -0.07          | -0.17          | -0.15          | -0.11          | 0.23           | -0.04          | -0.09          | 0.09           | 0.09           | -0.09           | **0.63          | **0.63          | -0.17           | -0.16           | 0.01            | 0.07            | -0.09           | 0.01            | *0.27           | -0.12           | -0.23           | **0.38          | 0.03            | *0.28           | 1.00            |                 |                 |                 |                 |                 |                 |  |
| X <sub>26</sub> | **0.43         | *0.26          | -0.06          | **0.36         | 0.08           | 0.10           | -0.04          | *0.24          | -0.07          | 0.07            | 0.18            | 0.18            | 0.05            | -0.05           | 0.13            | 0.05            | 0.12            | **0.67          | **0.47          | **0.73          | **0.57          | **0.43          | **0.69          | **0.53          | 0.21            | 1.00            |                 |                 |                 |                 |                 |  |
| X <sub>27</sub> | **0.41         | *0.25          | -0.01          | **0.34         | 0.03           | 0.07           | -0.01          | 0.23           | -0.09          | 0.09            | *0.25           | *0.25           | 0.03            | -0.05           | 0.17            | 0.02            | 0.15            | **0.51          | **0.56          | **0.81          | **0.65          | **0.57          | **0.80          | **0.67          | 0.13            | **0.94          | 1.00            |                 |                 |                 |                 |  |
| X <sub>28</sub> | **0.36         | -0.19          | 0.05           | *0.27          | -0.04          | 0.11           | 0.00           | 0.17           | -0.11          | 0.11            | *0.30           | *0.30           | 0.12            | 0.03            | 0.21            | 0.07            | 0.22            | **0.39          | **0.59          | **0.80          | **0.68          | **0.60          | **0.79          | **0.68          | -0.04           | **0.72          | **0.85          | 1.00            |                 |                 |                 |  |
| X <sub>29</sub> | *0.29          | -0.17          | -0.06          | *0.25          | 0.04           | 0.07           | -0.05          | 0.19           | -0.06          | 0.06            | -0.05           | -0.05           | 0.04            | -0.03           | 0.15            | 0.08            | 0.16            | **0.31          | **0.50          | **0.59          | **0.55          | **0.37          | **0.63          | **0.46          | *0.24           | **0.49          | **0.58          | **0.78          | 1.00            |                 |                 |  |
| X <sub>30</sub> | **0.38         | -0.21          | 0.02           | *0.30          | -0.01          | 0.11           | -0.01          | 0.20           | -0.10          | 0.10            | *0.25           | *0.25           | 0.10            | 0.00            | 0.21            | 0.06            | 0.21            | **0.42          | **0.61          | **0.81          | **0.69          | **0.59          | **0.81          | **0.68          | 0.04            | **0.77          | **0.88          | **0.99          | **0.82          | 1.00            |                 |  |
| X <sub>31</sub> | 0.17           | 0.23           | **0.33         | *0.24          | **0.33         | 0.05           | -0.06          | -0.23          | 0.04           | -0.04           | 0.15            | 0.15            | **0.60          | *0.26           | **0.71          | 0.00            | **0.99          | 0.16            | 0.22            | **0.30          | *0.25           | 0.22            | *0.26           | *0.24           | -0.08           | 0.22            | *0.26           | **0.35          | *0.26           | **0.33          | 1.00            |  |

\* Significantly correlated at 5 % level

\*\* Significantly correlated at 1 % level

| SEED CHARACTERS                         |                                                      | SEEDLING CHARACTERS                      |                                                  |                                                |                                          |
|-----------------------------------------|------------------------------------------------------|------------------------------------------|--------------------------------------------------|------------------------------------------------|------------------------------------------|
| X <sub>1</sub> Seed weight              | X <sub>6</sub> Number of seeds                       | X <sub>12</sub> Seed index               | X <sub>17</sub> Total leaf area                  | X <sub>23</sub> Root dry weight                | X <sub>29</sub> Number of tertiary roots |
| X <sub>2</sub> Seed length              | X <sub>7</sub> Number of seedlings/seed              | X <sub>13</sub> Height                   | X <sub>18</sub> Survival rate at 12 th month (%) | X <sub>24</sub> Total dry weight               | X <sub>30</sub> Total number of roots    |
| X <sub>3</sub> Seed thickness at centre | X <sub>8</sub> Number of days to germination         | X <sub>14</sub> Girth at color           | X <sub>19</sub> Shoot fresh weight               | X <sub>25</sub> Root to shoot dry weight ratio | X <sub>31</sub> Seedling index           |
| X <sub>4</sub> Volume                   | X <sub>9</sub> Seed with one seedling                | X <sub>15</sub> Total number of leaves   | X <sub>20</sub> Root fresh weight                | X <sub>26</sub> Root length (longest root)     |                                          |
| X <sub>5</sub> Seed specific gravity    | X <sub>10</sub> Seed with two and multiple seedlings | X <sub>16</sub> Number of flushes / year | X <sub>21</sub> Total fresh weight               | X <sub>27</sub> Number of primary roots        |                                          |
|                                         | X <sub>11</sub> Germination percentage               |                                          | X <sub>22</sub> Shoot dry weight                 | X <sub>28</sub> Number of secondary roots      |                                          |

Negative correlation was observed in number of one-seeded fruits with number of seeds per fruit. Highly significant positive correlation was estimated in number of two seeded fruits with number of seeds per fruit ( $r = 0.67$ ). Number of three and more than three seeded fruits were also positively correlated with number of seeds per fruit ( $r = 0.60$ ). Number of seedlings per fruit showed significant positive correlation with number of seeds per fruit ( $r = 0.77$ ), number of seedlings per seed ( $r = 0.53$ ) and number of seeds producing two and more than two seedlings ( $r = 0.52$ ) and negatively correlated with number of seed producing one seedling ( $r = -0.52$ ). Fruit index was significantly and positively correlated with seed weight ( $r = 0.30$ ) and seed length ( $r = 0.30$ ).

#### 4.1.9.5. Correlation between fruit and seedling characters

Fruit weight was significantly and negatively correlated with survival rate at twelfth months ( $r = -0.35$ ), shoot fresh weight ( $r = -0.33$ ), root fresh weight ( $r = -0.41$ ), total fresh weight ( $r = -0.36$ ), shoot dry weight ( $r = -0.30$ ), root dry weight ( $r = -0.41$ ), total dry weight ( $r = -0.34$ ), root length ( $r = -0.38$ ), number of primary ( $r = -0.35$ ), secondary ( $r = -0.36$ ) and total roots ( $r = -0.36$ ). Fruit volume was also negatively correlated with survival rate at twelve-months stage ( $r = -0.30$ ), shoot fresh weight ( $r = -0.32$ ), root fresh weight ( $r = -0.38$ ), total fresh weight ( $r = -0.35$ ), shoot dry weight ( $r = -0.28$ ), root dry weight ( $r = -0.38$ ), total dry weight ( $r = -0.33$ ), root length ( $r = -0.35$ ), number of primary ( $r = -0.32$ ), secondary ( $r = -0.32$ ) and total roots ( $r = -0.32$ ). Significant negative correlations were also recorded in the case of fruit girth and with survival rate at twelfth months ( $r = -0.34$ ), shoot fresh weight ( $r = -0.29$ ), root fresh weight ( $r = -0.39$ ), total fresh weight ( $r = -0.33$ ), shoot dry weight ( $r = -0.27$ ), root dry weight ( $r = -0.38$ ), total dry weight ( $r = -0.31$ ), root length ( $r = -0.37$ ), number of primary ( $r = -0.35$ ), secondary ( $r = -0.39$ ) and total roots ( $r = -0.37$ ).

Pulp weight had significant negative correlations with survival rate at twelve-months stage ( $r = -0.29$ ), root fresh weight ( $r = -0.30$ ), root dry weight ( $r = -0.31$ ), root to shoot dry weight ratio ( $r = -0.25$ ), root length ( $r = -0.32$ ), number of primary roots ( $r = -0.29$ ), secondary roots ( $r = -0.27$ ) and total number of roots ( $r = -0.28$ ).

Rind weight was negatively correlated with survival rate of twelve-months stage ( $r = -0.34$ ), shoot fresh weight ( $r = -0.35$ ), root fresh weight ( $r = -0.40$ ), total fresh weight ( $r = -0.38$ ), shoot dry weight ( $r = -0.33$ ), root dry weight ( $r = -0.40$ ), total dry weight ( $r = -0.37$ ), root length ( $r = -0.37$ ), number of primary ( $r = -0.34$ ), secondary ( $r = -0.36$ ) and total roots ( $r = -0.35$ ). Fruit specific gravity was positively correlated with root to shoot dry weight ratio ( $r = 0.30$ ). Number of seedless fruits showed significant negative correlations with shoot fresh weight ( $r = -0.56$ ), root fresh weight ( $r = -0.29$ ), total fresh weight ( $r = -0.50$ ), shoot dry weight ( $r = -0.68$ ), root dry weight ( $r = -0.43$ ) and total dry weight ( $r = -0.64$ ).

Fruit index showed significant negative correlations with survival rate at twelve-months stage ( $r = -0.33$ ), shoot fresh weight ( $r = -0.33$ ), root fresh weight ( $r = -0.40$ ), total fresh weight ( $r = -0.36$ ), shoot dry weight ( $r = -0.30$ ), root dry weight ( $r = -0.40$ ), total dry weight ( $r = -0.35$ ), root length ( $r = -0.37$ ), number of primary ( $r = -0.34$ ), secondary ( $r = -0.35$ ) and total roots ( $r = -0.35$ ).

#### 4.1.9.6. Correlations between seed and seedling characters

Seed weight showed significant positive correlations with height ( $r = 0.38$ ) and girth of the seedlings ( $r = 0.34$ ). Negative correlations with survival rate at twelve-months ( $r = -0.33$ ), shoot fresh weight ( $r = -0.42$ ), root fresh weight ( $r = -0.44$ ), shoot dry weight ( $r = -0.36$ ), root dry weight ( $r = -0.39$ ), total dry weight ( $r = -0.39$ ), root length ( $r = -0.43$ ), number of primary roots ( $r = -0.41$ ), secondary roots ( $r = -0.36$ ), tertiary roots ( $r = -0.29$ ) and total number of roots ( $r = -0.38$ ). Seed length was positively correlated with height ( $r = 0.44$ ), girth ( $r = 0.30$ ), total leaf area ( $r = 0.26$ ) and negatively correlated with root fresh weight ( $r = -0.24$ ), root dry weight ( $r = -0.25$ ), root length ( $r = -0.26$ ) and number of primary roots ( $r = -0.25$ ). Seed thickness showed positive correlation with height ( $r = 0.37$ ), girth ( $r = 0.34$ ), total number of leaves ( $r = 0.27$ ), total leaf area ( $r = 0.34$ ) and seedling index ( $r = 0.33$ ). Seed volume was positively correlated with height ( $r = 0.41$ ), girth ( $r = 0.37$ ), total leaf area ( $r = 0.30$ ), seedling index ( $r = 0.24$ ) and negatively correlated with survival rate at twelve-months ( $r = -0.28$ ), shoot fresh weight ( $r = -0.33$ ), root fresh weight ( $r = -0.33$ ), total fresh weight ( $r = -0.35$ ), shoot dry weight ( $r = -0.25$ ), root dry weight ( $r = -0.31$ ), total dry weight ( $r = -0.28$ ), root length ( $r = -0.36$ ), number of primary ( $r = -0.34$ ), secondary ( $r = -0.27$ ), tertiary ( $r = -0.25$ ) and total

roots ( $r = -0.30$ ). Seed specific gravity was negatively correlated with height ( $r = -0.45$ ), girth ( $r = -0.36$ ), total number of leaves ( $r = -0.26$ ), total leaf area ( $r = -0.34$ ) and seedling index ( $r = -0.33$ ).

Number of seeds per fruit was significantly and positively correlated with number of flushes per year ( $r = 0.24$ ). Number of seedling per seed showed negative correlation with height ( $r = -0.24$ ). Number of days to germination showed significantly positive correlation with root length ( $r = 0.24$ ) and negative correlations with height ( $r = -0.30$ ) and total leaf area ( $r = -0.27$ ). Significant positive correlation was observed between number of seeds producing one seedling and height of the seedling. Number of seeds produced two and more than two seedlings were negatively correlated with height ( $r = -0.27$ ). Germination percentage showed significant positive correlations with root fresh weight ( $r = 0.33$ ), number of primary ( $r = 0.25$ ), secondary ( $r = 0.30$ ) and total roots ( $r = 0.25$ ) and negatively correlated with root to shoot dry weight ratio ( $r = -0.63$ ). Seed index recorded significant positive correlation with root fresh weight ( $r = 0.33$ ), number of primary ( $r = 0.25$ ), secondary ( $r = 0.30$ ) and total roots ( $r = 0.25$ ) and the same was negatively correlated with root to shoot dry weight ratio ( $r = -0.63$ ).

#### 4.1.10. Principal component analysis

The principal component analysis was performed using the deviation squares and product matrix of the fourteen fruit characters, thirteen seed characters, twenty seedling characters, the age of the mother plants and all the three fruit, seed and seedling indices separately. The first two principal components, which accounted for the cumulative variance of fruit, seed and seedling character, are 88.78, 92.94 and 92.49 percentage respectively. The cumulative variance, factor scores and contribution of variation of each character are presented in the Table 15 and the same for each age group in Table 16. The fruit index among the fruit characters, seed index among the seed character and seedling index among the seedling characters were predicted using the regression equation with the first two principle components as the explanatory variables. The predictor equations were found to be

$$Y = 0.0695 P_1 - 0.1283 P_2 - 0.0197 \text{ with an } R^2 \text{ of } 0.999$$

**Table 15. Eigen vectors, factors loadings and contribution of variations by each characters in fruit, seed and seedling characters in mangosteen (*Garcinia mangostana* L.).**

| Characters                         | Eigenvectors |       | Factor loadings |       | Contributions of variation (%) |       |
|------------------------------------|--------------|-------|-----------------|-------|--------------------------------|-------|
|                                    | F1           | F2    | F1              | F2    | F1                             | F2    |
| <b>Fruit characters</b>            |              |       |                 |       |                                |       |
| Fruit weight                       | 0.30         | -0.17 | 0.96            | -0.28 | 9.27                           | 3.01  |
| Girth                              | 0.21         | -0.07 | 0.66            | -0.11 | 4.44                           | 0.44  |
| Volume                             | 0.29         | -0.24 | 0.92            | -0.39 | 8.50                           | 5.84  |
| Pulp weight                        | 0.21         | -0.46 | 0.66            | -0.73 | 4.39                           | 20.90 |
| Rind weight                        | 0.31         | -0.05 | 0.99            | -0.08 | 9.86                           | 0.25  |
| Segments                           | 0.30         | -0.14 | 0.95            | -0.22 | 9.14                           | 1.94  |
| Seeds                              | -0.28        | -0.20 | -0.87           | -0.32 | 7.70                           | 3.97  |
| Seedless fruits                    | 0.29         | 0.27  | 0.90            | 0.43  | 8.20                           | 7.08  |
| One seeded fruits                  | -0.27        | -0.24 | -0.84           | -0.39 | 7.22                           | 5.98  |
| Two seeded fruits                  | -0.21        | -0.18 | -0.65           | -0.29 | 4.29                           | 3.37  |
| Three and >three seeded fruits     | -0.27        | -0.31 | -0.84           | -0.49 | 7.16                           | 9.32  |
| Specific gravity                   | -0.11        | 0.58  | -0.34           | 0.94  | 1.16                           | 34.01 |
| Fruit index                        | 0.31         | -0.06 | 0.97            | -0.10 | 9.54                           | 0.41  |
| Selection index                    | -0.30        | -0.19 | -0.95           | -0.30 | 9.13                           | 3.49  |
| Cumulative variance                | 70.37        | 88.79 |                 |       |                                |       |
| <b>Seed characters</b>             |              |       |                 |       |                                |       |
| Seed weight                        | 0.29         | -0.28 | 0.82            | -0.55 | 8.29                           | 7.81  |
| Seed length                        | 0.34         | -0.02 | 0.98            | -0.04 | 11.68                          | 0.03  |
| Thickness at center                | 0.31         | 0.06  | 0.89            | 0.11  | 9.68                           | 0.31  |
| Seed volume                        | 0.29         | -0.27 | 0.84            | -0.54 | 8.69                           | 7.40  |
| Specific gravity                   | -0.28        | 0.29  | -0.80           | 0.57  | 7.81                           | 8.17  |
| Number of seedlings / seed         | 0.32         | 0.07  | 0.90            | 0.14  | 9.94                           | 0.49  |
| Ungerminated seeds                 | -0.30        | -0.22 | -0.87           | -0.44 | 9.30                           | 5.04  |
| Seeds producing one seedlings      | 0.26         | 0.27  | 0.74            | 0.53  | 6.69                           | 7.23  |
| Seeds producing 2 and >2 seedlings | 0.33         | 0.10  | 0.95            | 0.19  | 11.05                          | 0.94  |
| Days to germination                | -0.24        | 0.31  | -0.68           | 0.62  | 5.72                           | 9.81  |
| Germination %                      | 0.24         | 0.37  | 0.68            | 0.73  | 5.59                           | 13.73 |
| Seed index                         | 0.20         | 0.41  | 0.57            | 0.82  | 4.01                           | 17.04 |
| Selection index                    | -0.12        | 0.47  | -0.35           | 0.93  | 1.54                           | 21.99 |
| Cumulative variance                | 62.79        | 92.94 |                 |       |                                |       |
| <b>Seedling characters</b>         |              |       |                 |       |                                |       |
| Height                             | 0.26         | 0.09  | 0.99            | 0.15  | 6.85                           | 0.88  |
| Girth                              | 0.26         | -0.09 | 0.97            | -0.13 | 6.62                           | 0.74  |
| Total leaves                       | 0.26         | 0.08  | 0.97            | 0.12  | 6.60                           | 0.59  |
| New flushes / year                 | 0.10         | 0.55  | 0.39            | 0.85  | 1.09                           | 29.76 |
| Total leaf area                    | 0.25         | 0.19  | 0.95            | 0.30  | 6.35                           | 3.63  |
| Survival rate                      | 0.21         | -0.36 | 0.78            | -0.55 | 4.27                           | 12.70 |
| Shoot fresh weight                 | 0.23         | 0.06  | 0.87            | 0.09  | 5.34                           | 0.33  |
| Root fresh weight                  | 0.26         | 0.05  | 0.99            | 0.08  | 6.87                           | 0.23  |
| Shoot dry weight                   | 0.24         | -0.04 | 0.90            | -0.06 | 5.64                           | 0.14  |
| Root dry weight                    | 0.26         | 0.03  | 0.99            | 0.04  | 6.89                           | 0.08  |
| Root to shoot dry weight ratio     | -0.14        | 0.47  | -0.54           | 0.72  | 2.08                           | 21.65 |
| Root length                        | 0.23         | -0.16 | 0.86            | -0.25 | 5.23                           | 2.68  |
| Primary roots                      | 0.25         | -0.15 | 0.94            | -0.23 | 6.18                           | 2.29  |
| Secondary roots                    | 0.26         | -0.01 | 1.00            | -0.02 | 7.01                           | 0.02  |
| Tertiary roots                     | 0.14         | 0.49  | 0.55            | 0.76  | 2.09                           | 24.22 |
| Total roots                        | 0.26         | 0.01  | 1.00            | 0.02  | 7.01                           | 0.02  |
| Seedling index                     | 0.26         | -0.01 | 0.99            | -0.02 | 6.93                           | 0.02  |
| Selection index                    | 0.26         | -0.01 | 0.99            | -0.02 | 6.93                           | 0.02  |
| cumulative variance                | 79.13        | 92.49 |                 |       |                                |       |

Where  $Y$ ,  $P_1$  and  $P_2$  are the fruit index, first and second principal components respectively.

$$Y = 0.3198 P_1 + 0.6307 P_2 - 0.0135 \text{ with an } R^2 \text{ of } 1.00$$

Where  $Y$ ,  $P_1$  and  $P_2$  are the seed index, first and second principal components respectively.

$$Y = 0.7003 P_1 - 0.0703 P_2 + 3.263 \text{ with an } R^2 \text{ of } 0.999$$

Where  $Y$ ,  $P_1$  and  $P_2$  are the seedling index, first and second principal components respectively.

Also the relationship and dominance of the fruit, seed and seedling characters including four age groups of the mother plants and three (fruit, seed and seedling) indices separately were determined using factor scores. The depiction of the various characters of the factor I showed negative scores for characters such as number of seeds per fruit, specific gravity and selection index whereas factor II revealed positive scores only for seedlessness and seed specific gravity (Table 15). Distinct variations in the dominant characters were observed between the various age groups. In the case of fruit characters, fruit index, fruit weight, fruit girth, fruit volume, pulp weight, number of segments and rind weight were dominant characters of the age group three (51-75 years). On the other hand, the number of seeds per fruit the dominant characters was observed in the lesser two age groups (i.e. <25 and 25-50 years age groups). What is most interesting thing is that in the age group four (>75 years), the most dominant character was observed to be seedlessness (Fig. 6).

The depiction of the various seed characters of factor I showed negative scores for seed specific gravity, ungerminated seeds, days to germination and selection index. In the case of factor II the negative scores were in seed weight, seed length, seed volume and ungerminated seeds. All other characters showed positive factor scores. In the case of seed characters also variations in dominant characters were observed with respect to age groups. The seed index, selection index, germination percentage, seeds producing one seedling and number of seedlings per seed were the dominant characters observed in the age group two (25-50 years). In the age group one (<25 years) the number of days taken to germination and seed specific gravity were observed to be the dominant characters. In age group three, seed weight, seed volume and seed length were the dominant

**Table 16. Factors scores and contribution of variations by each age group based on the fruit, seed and seedling characters in mangosteen (*Garcinia mangostana* L.)**

| Characters                 | Factor scores |       | Contributions of age groups (%) |       |
|----------------------------|---------------|-------|---------------------------------|-------|
|                            | F1            | F2    | F1                              | F2    |
| <b>Fruit characters</b>    |               |       |                                 |       |
| Age 1                      | -1.74         | -0.62 | 6.14                            | 2.99  |
| Age 2                      | -4.34         | -0.66 | 38.27                           | 3.39  |
| Age 3                      | 4.96          | -1.76 | 49.91                           | 24.02 |
| Age 4                      | 1.60          | 3.00  | 5.21                            | 69.59 |
| Mean                       | -0.48         | 0.05  | 0.47                            | 0.02  |
| <b>Seed characters</b>     |               |       |                                 |       |
| Age 1                      | -1.64         | 1.04  | 6.59                            | 5.53  |
| Age 2                      | -0.64         | 2.87  | 0.99                            | 41.98 |
| Age 3                      | 5.26          | -1.13 | 67.89                           | 6.55  |
| Age 4                      | -3.16         | -2.99 | 24.46                           | 45.70 |
| Mean                       | 0.17          | 0.22  | 0.07                            | 0.24  |
| <b>Seedling characters</b> |               |       |                                 |       |
| Age 1                      | 3.35          | 0.92  | 15.73                           | 7.10  |
| Age 2                      | 4.93          | -0.91 | 34.14                           | 6.95  |
| Age 3                      | -4.52         | -2.27 | 28.75                           | 42.95 |
| Age 4                      | -3.90         | 2.27  | 21.35                           | 43.00 |
| Mean                       | 0.15          | -0.01 | 0.03                            | 0.00  |

Fig. 6. Plot showing the percentage of variation contributed by each fruit character and the relationship between age of the mother plant and fruit characters in mangosteen (*Garcinia mangostana* L.)

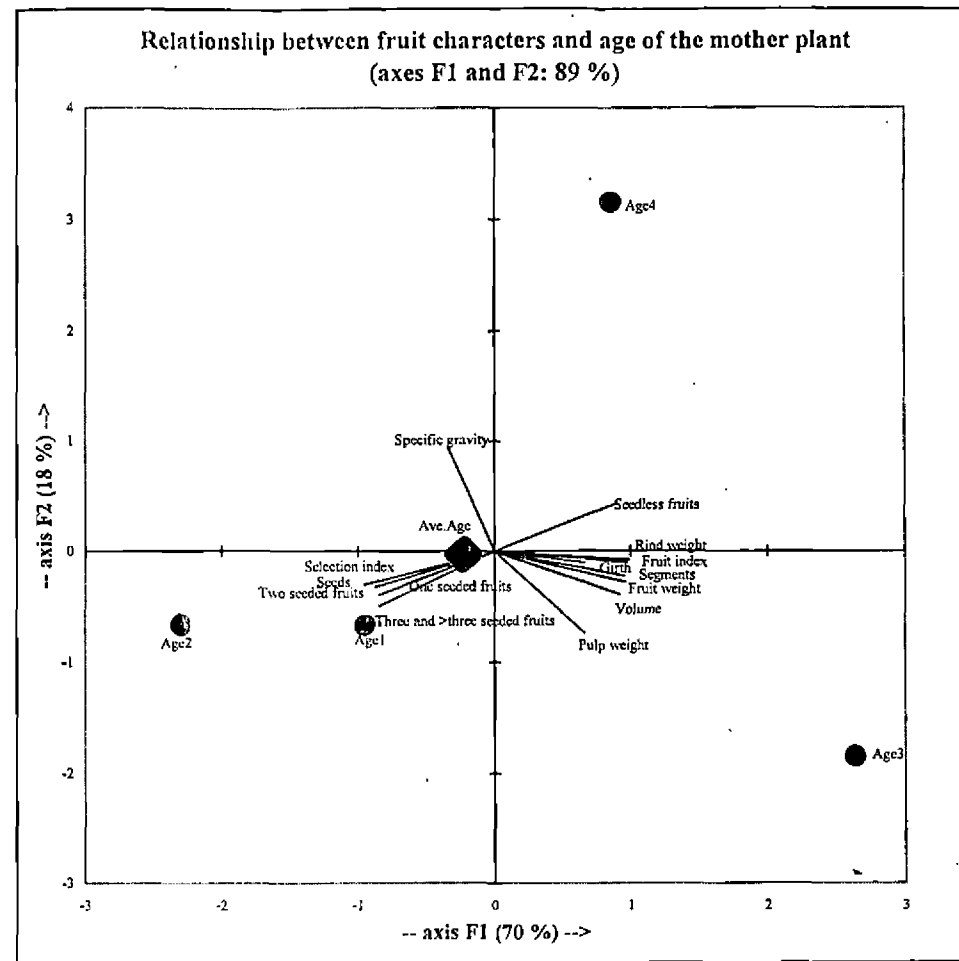
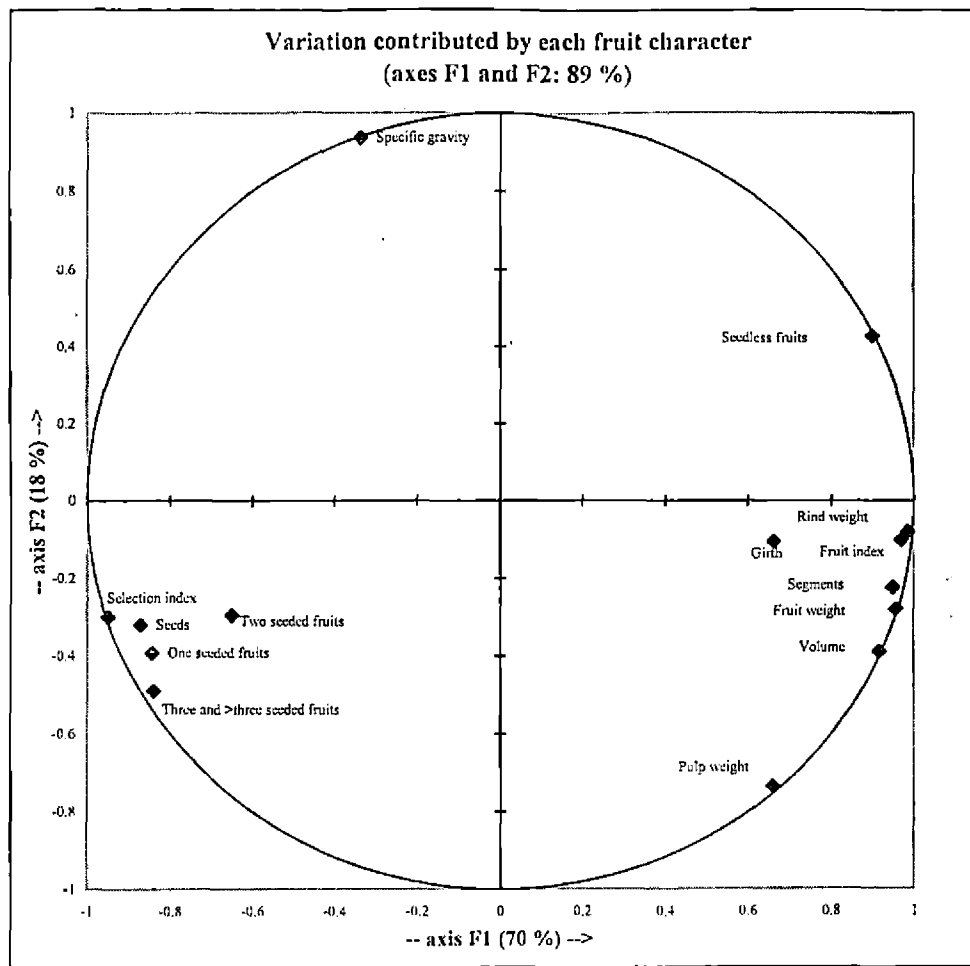


Fig. 7. Plot showing the percentage of variation contributed by each seed character and the relationship between age of the mother plant and seed characters in mangosteen (*Garcinia mangostana* L.)

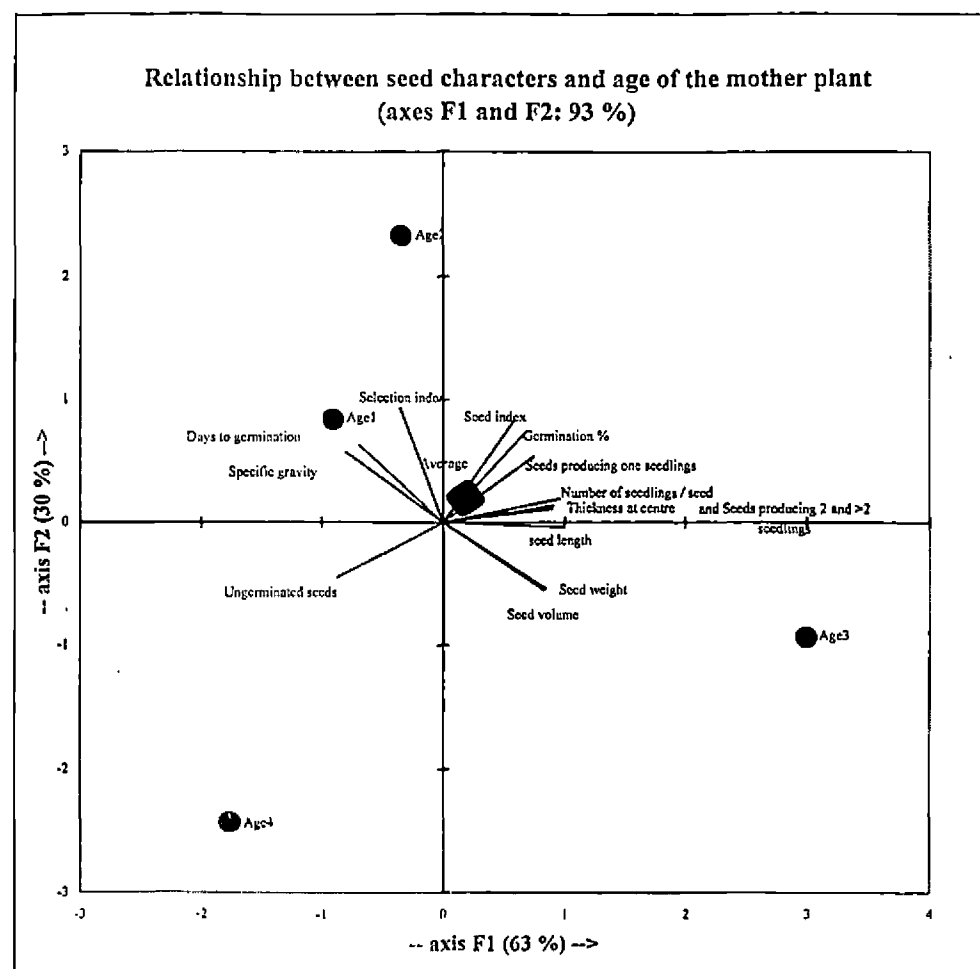
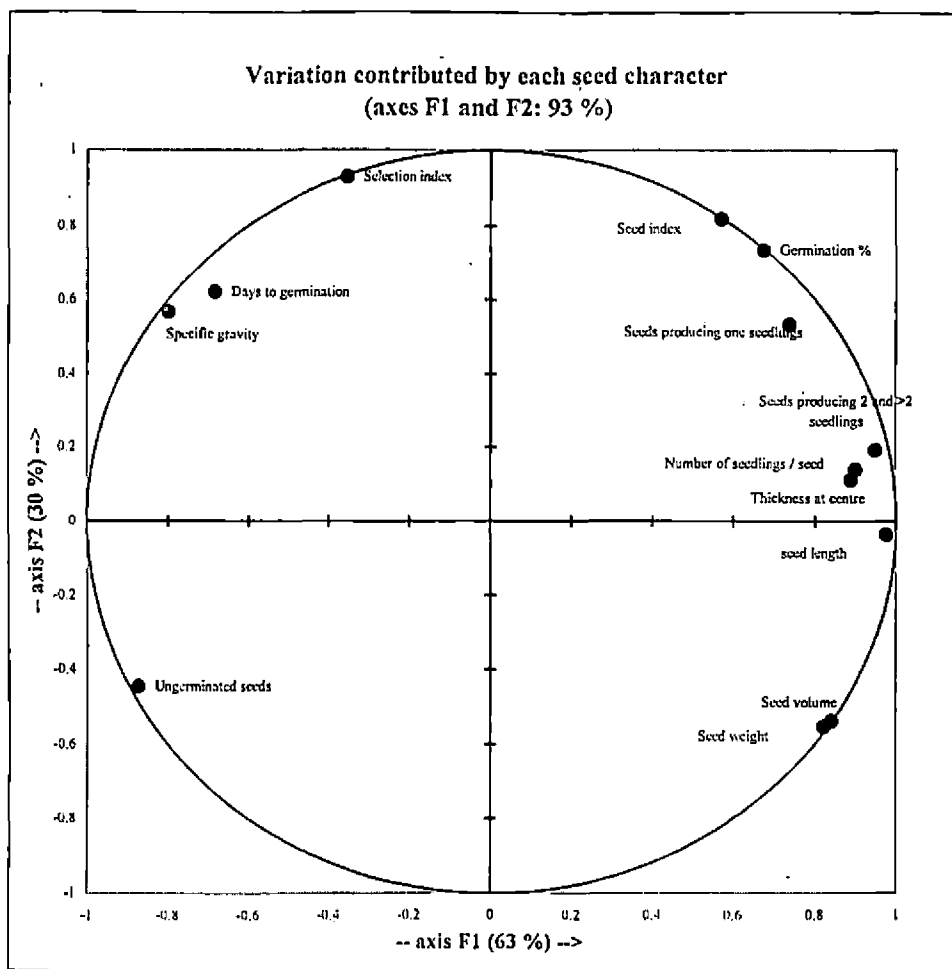
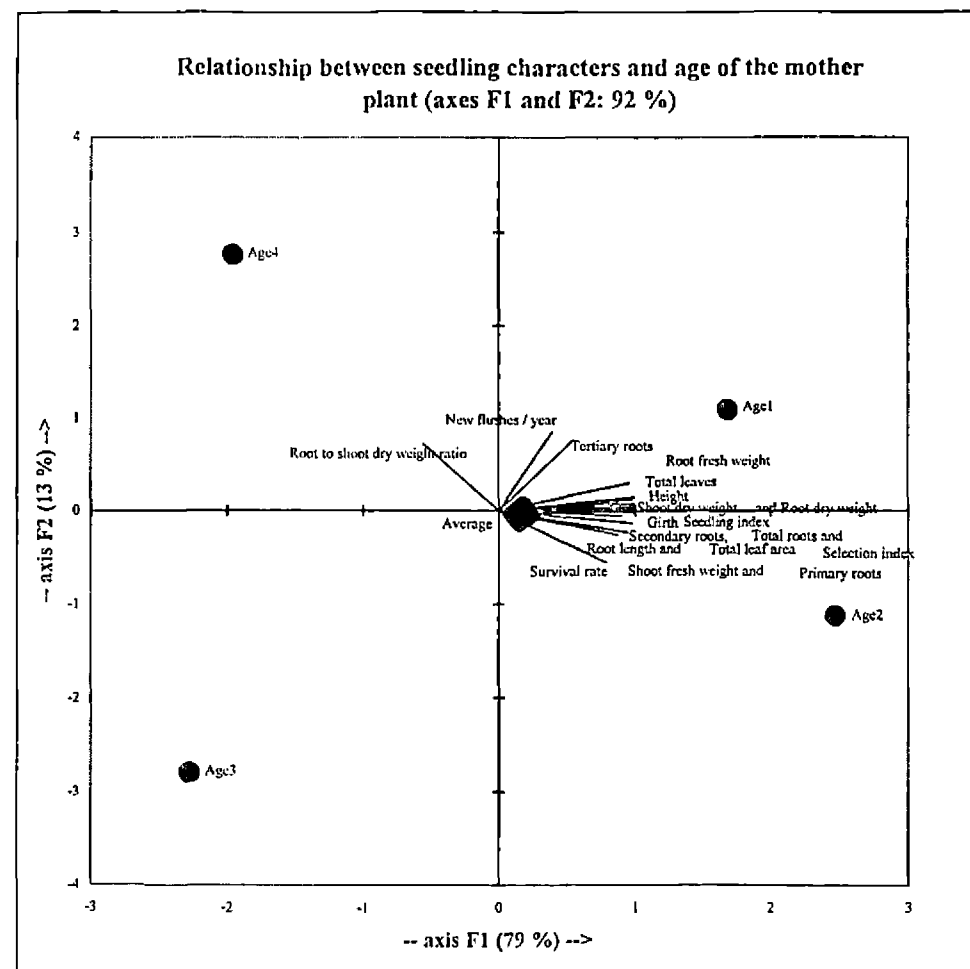
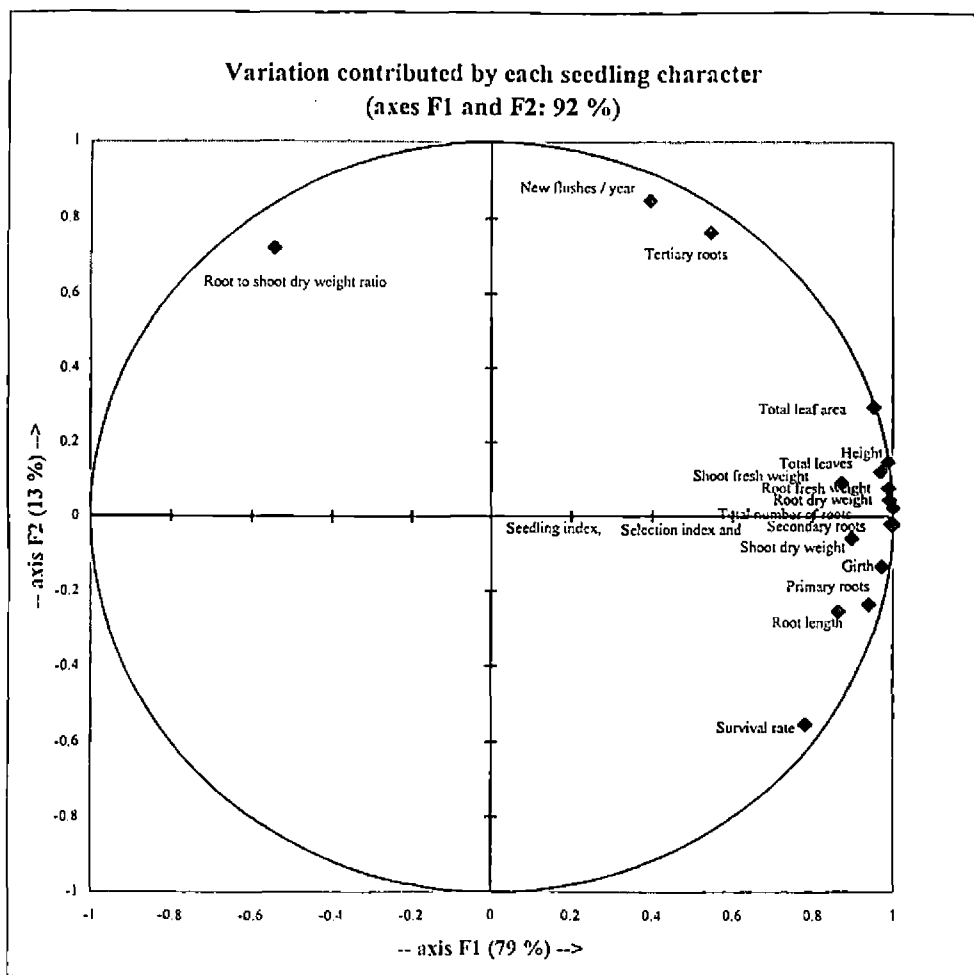


Fig. 8. Plot showing the percentage of variation contributed by each seedling character and the relationship between age of the mother plant and seedling characters in mangosteen (*Garcinia mangostana* L.)



characters whereas in age group four the dominant characters was the number of ungerminated seeds (Fig. 7).

In the case of seedling characters in factor I showed negative scores only for the root to shoot dry weight ratio whereas in factor II negative scores for girth, survival rate, shoot dry weight, root length and in number of roots (primary, secondary and tertiary), seedling index and selection index. All other characters showed positive factor scores. A study of the dominant characters of seedlings revealed that the major characters (seedling index, seedling girth, total number of roots, number of primary, secondary roots, survival rate, shoot fresh weight, dry weight, root dry weight, height of the seedlings and selection index were the dominant characters in the age group two. In the case of age group one root fresh weight, total number of leaves, number of tertiary roots and new flushes per shoot were the dominant characters. In the higher two age groups, no specific dominance were observed (Fig. 8).

The principal component analysis reduces only the dimensionality, but not the number of variables involved. Hence to reduce the number of variables and to find out the major variables that contribute more variation to the fruit, seed and seedling index, step-wise regression was performed.

#### **4.1.11. Step-wise regression**

Step-down regression of fruit index on 13 fruit characters, seed index on the same 13 fruit characters, seed index on the 12 seed characters separately and all the 25 fruit and seed character collectively, and seedling index on 13 fruit characters, 12 seed characters, 19 seed character including age separately and also collectively (all the 42 fruit, seed, seedling characters and age) were done, which finally gave the following regression equations with major variable, to each, indices on each group of characters.

##### **4.1.11.1. Fruit index on fruit characters alone:**

$$Y = 1.295 x_7 + 1.715 x_8 + 1.319 x_{14} - 4.17 \text{ with an } R^2 \text{ at } 0.993$$

Where Y - fruit index,  $x_7$  - pulp weight,  $x_8$  - rind weight,  $x_{14}$  - number of seedlings per fruit.

#### 4.1.11.2. Seed index on fruit characters alone

$Y = -0.282 x_2 + 0.427 x_3 + 14.416 x_5 + 22.368 x_{10} + 126.73$  with an  $R^2$  at 0.203. Where Y - seed index,  $x_2$  - age of the mother plant,  $x_3$  - fruit weight,  $x_5$  - fruit girth,  $x_{10}$  - number of seedless fruits.

#### 4.1.11.3. Seed index on seed characters alone

$$Y = -0.007 x_{15} - 0.004 x_{16} - 0.012 x_{17} + 0.009 x_{18} - 0.008 x_{19} + 0.002 x_{20} + 0.004 x_{21} + 0.015 x_{22} + 0.002 x_{24} + x_{25} + 0.01 \text{ with an } R^2 \text{ at } 1.00$$

Where Y - seed index,  $x_{15}$  - seed weight,  $x_{16}$  - seed length,  $x_{17}$  - seed thickness at centre,  $x_{18}$  - seed volume,  $x_{19}$  - seed specific gravity,  $x_{20}$  - number of seeds per fruit,  $x_{21}$  - number of seedling per seed,  $x_{22}$  - number of days to germination,  $x_{24}$  - number of seeds producing two or more than two seedlings,  $x_{25}$  - germination percentage.

#### 4.1.11.4. Seed index on fruit and seed index collectively

$$Y = -0.002 x_{11} - 0.006 x_{15} - 0.006 x_{17} + 0.006 x_{18} - 0.007 x_{19} + 0.005 x_{21} + 0.015 x_{22} - 0.002 x_{23} + x_{25} + 0.01 \text{ with an } R^2 \text{ at } 1.00$$

Where Y - seed index,  $x_{11}$  - number of one seeded fruits,  $x_{15}$  - seed weight,  $x_{17}$  - seed thickness at centre,  $x_{18}$  - seed volume,  $x_{19}$  - seed specific gravity,  $x_{21}$  - number of seedling per seed,  $x_{22}$  - number of days to germination,  $x_{23}$  - seed with one seedling,  $x_{25}$  - germination percentage.

#### 4.1.11.5. Seedling index on fruit characters including age

$$Y = -0.481 x_2 + 107.15 \text{ with an } R^2 \text{ of } 0.0388$$

Where, Y - seedling index,  $x_2$  - age of the mother plant.

#### 4.1.11.6. Seedling index on seed characters

$$Y = 136.67 x_{17} - 1083 \text{ with an } R^2 \text{ of } 0.1087$$

Where, Y - seedling index,  $x_{17}$  - seed thickness at centre.

#### 4.1.11.7. Seedling index on seedling characters

$$Y = 0.979 x_{30} + 0.037 x_{31} + 0.042 x_{32} + 0.027 x_{33} + 0.031 x_{39} + 0.202 x_{40} + 0.36 \text{ with an } R^2 \text{ of } 1.00$$

Where, Y - seedling index,  $x_{30}$  - total leaf area per seedling,  $x_{31}$  - survival rate at 12-months stage,  $x_{32}$  - shoot fresh weight,  $x_{33}$  - root fresh weight,  $x_{39}$  - root length,  $x_{40}$  - total number of roots.

#### 4.1.11.8. Seedling index on fruit, seed and seedling characters collectively including age of mother plant

$$Y = 0.026 x_{26} + 0.030 x_{28} + 0.977 x_{30} + 0.037 x_{31} + 0.0034 x_{32} + 0.029 x_{33} + 0.017 x_{35} + 0.009 x_{36} + 0.031 x_{39} + 0.031 x_{39} + 0.201 x_{40} \text{ with an } R^2 \text{ of } 1.00$$

Where, Y - seedling index,  $x_{26}$  - height of the seedling,  $x_{28}$  - total number of leaves,  $x_{30}$  - total leaf area,  $x_{31}$  - survival rate at twelve-months stage,  $x_{32}$  - shoot fresh weight,  $x_{33}$  - root fresh weight,  $x_{35}$  - shoot dry weight,  $x_{36}$  - root dry weight,  $x_{39}$  - root length,  $x_{40}$  - total number of roots.

#### 4.1.12. Cluster analysis

Cluster analysis was performed to find out the similarities and differences based on the fruit, seed and seedling characters separately and all characters collectively among the four age groups. Absolute euclidean distances between the four age groups were calculated based on the fruit, seed and seedling characters and are presented in the Table 17. The dendrogram showing the clusters (or similarities) based on the fruit, seed and seedling characters among the four age groups (Fig. 9).

Based on the fruit characters, closest distance was observed between age group of more than 25 years and 25 to 50 years followed by the age group of 25 to 50 years and more than 75 years and in all the remaining combinations higher distances were observed than the above, which indicates that the age group of more than 25 years and 25 to 50 years having nearly more similar characters of fruit.

Based on the seed characters closest distance was again observed between age group of more than 25 years and 25 to 50 years followed by the age group of more than 25 years and more than 75 years and in all the remaining combinations higher distances were observed than the above, which indicates that the age group of more than 25 years and 25 to 50 years are having nearly more similar characters of seed.

Based on the seedling characters closest distance was again observed between age group of more than 25 years and 25 to 50 years. All the remaining

combinations were observed at higher distances than the above, which indicate that, the age group of more than 25 years and 25 to 50 years having nearly more similar characters of seedling.

Based on the fruit, seed and seedling characters collectively, the closest distance was observed between age group of more than 25 years and 25 to 50 years followed by the age group of more than 25 years and more than 75 years and in all the remaining combinations higher distances were observed than the above. Finally it may be confirmed that based on the all the four dendrograms that maximum similarities of all the characters was between age group or less than 25 years and 25-50 years.

#### 4.1.13. Discriminant function analysis

Fruit index, seed index and seedling index of four age groups were discriminated using discriminant functional analysis. Discriminant functions were fitted for discrimination pairs of these age groups. The functions derived were as follows.

For groups 1 and 2

$$Z = 0.0004 \text{ FI} - 0.0547 \text{ SI} - 0.0004 \text{ SDLI with } D^2 = 0.4313$$

For groups 1 and 3

$$Z = -0.0483 \text{ FI} - 0.0313 \text{ SI} + 0.0075 \text{ SDLI with } D^2 = 2.381$$

For groups 1 and 4

$$Z = -0.0183 \text{ FI} - 0.0680 \text{ SI} + 0.0047 \text{ SDLI with } D^2 = 1.739$$

For groups 2 and 3

$$Z = -0.0406 \text{ FI} + 0.1264 \text{ SI} + 0.0137 \text{ SDLI with } D^2 = 2.782$$

For groups 2 and 4

$$Z = -0.0265 \text{ FI} + 0.3508 \text{ SI} + 0.0150 \text{ SDLI with } D^2 = 10.29$$

For groups 3 and 4

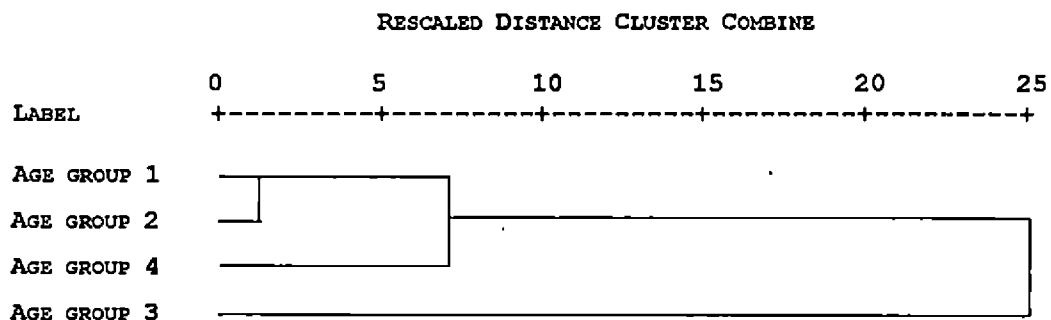
$$Z = 0.0024 \text{ FI} + 0.2152 \text{ SI} + 0.0004 \text{ SDLI with } D^2 = 4.064$$

Where FI - the fruit index, SI - the seed index and SDLI - the seedling index are the explanatory variables.

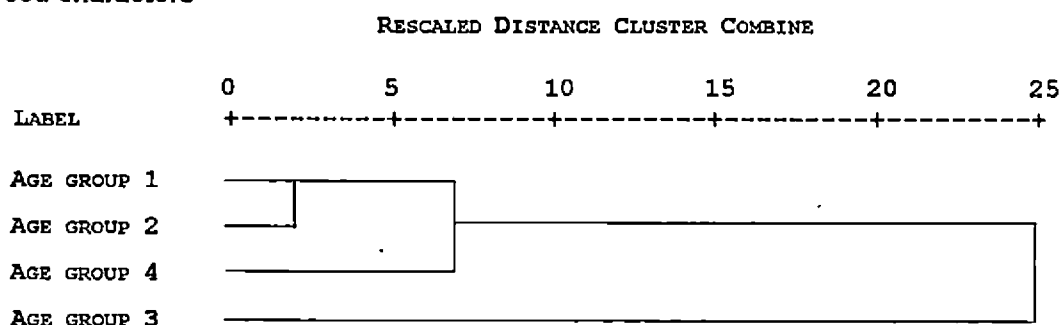
The average values of fruit index, seed index and seedling index for each age group were fitted in the equation and the discriminant values calculated for each pair of age groups. The direction of association of the discriminant

**FIG. 9. Dendrogram showing the similarity and proximity of the four age groups based on the fruit, seed and seedling characters individually and collectively in mangosteen (*Garcinia mangostana* L.)**

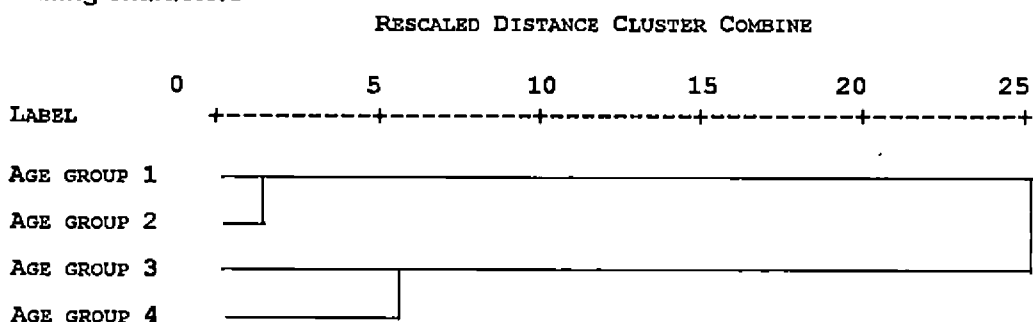
**Fruit characters**



**Seed characters**



**Seedling characters**



**All characters collectively**

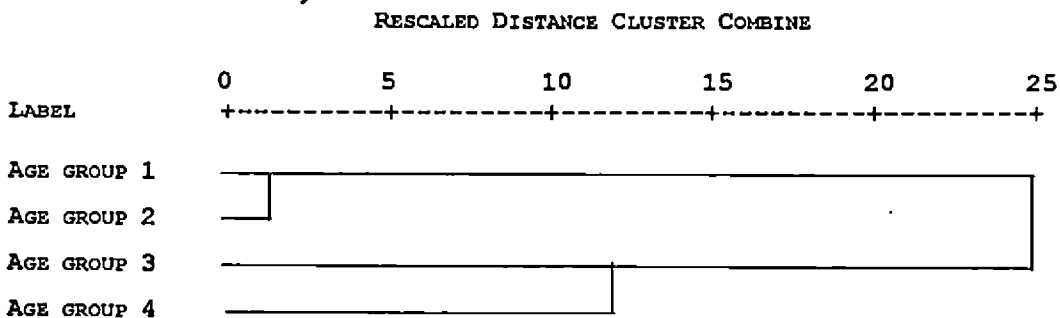


**Table 17. Proximity matrix showing the absolute squared euclidean distance between four age groups based on fruit, seed, seedling characters separately and collectively in mangosteen (*Garcinia mangostana* L.)**

| Characters and age groups | Absolute squared euclidean distance |        |        |       |
|---------------------------|-------------------------------------|--------|--------|-------|
|                           | 1                                   | 2      | 3      | 4     |
| <b>Fruit</b>              |                                     |        |        |       |
| 1                         | 0.00                                | 14.41  | 39.25  | 20.57 |
| 2                         | 14.41                               | 0.00   | 31.60  | 15.6  |
| 3                         | 39.25                               | 31.60  | 0.00   | 22.57 |
| 4                         | 20.57                               | 15.60  | 22.57  | 0.00  |
| <b>Seed</b>               |                                     |        |        |       |
| 1                         | 0.00                                | 13.14  | 30.09  | 13.24 |
| 2                         | 13.14                               | 0.00   | 21.58  | 20.37 |
| 3                         | 30.09                               | 21.58  | 0.00   | 33.59 |
| 4                         | 13.24                               | 20.37  | 33.59  | 0.00  |
| <b>Seedling</b>           |                                     |        |        |       |
| 1                         | 0.00                                | 5.65   | 29.97  | 35.44 |
| 2                         | 5.65                                | 0.00   | 26.48  | 34.63 |
| 3                         | 29.97                               | 26.48  | 0.00   | 11.83 |
| 4                         | 35.44                               | 34.63  | 11.83  | 0.00  |
| <b>All characters</b>     |                                     |        |        |       |
| 1                         | 0.00                                | 39.06  | 109.58 | 77.77 |
| 2                         | 39.06                               | 0.00   | 100.31 | 90.23 |
| 3                         | 109.58                              | 100.31 | 0.00   | 75.05 |
| 4                         | 77.77                               | 90.23  | 75.05  | 0.00  |

coefficients in each age group was given in the Table 18. In this maximum number of positive directions were observed in the age group of 25-50 years, when which was discriminated with other three age groups (Table 19). The corresponding discriminant values of each age group (criteria) and the mid values of the each pair of discriminant values were taken as in term and it was concluded that if the values is below the mid values it falls in the group I, if not it falls in the Group II. The criterion and criteria are presented in Table 20.

#### 4.1.14. Selection index

Principal component analysis was performed on all the fruit, seed and seedling characters collectively and first principal compound was taken as the index value (Fig. 10) for selection. The selection index was predicted using the multiple regression equation constant for each age group independently and also average of all age groups. The predictor equation was found to be

For group less than 25 years

$$Y = -0.0402 \text{ FI} + 0.0513 \text{ SI} + 0.9960 \text{ SDLI} - 0.4317 \text{ (adj. } R^2 = 0.99)$$

For group 25-50 years

$$Y = -0.0562 \text{ FI} + 0.0129 \text{ SI} + 0.9979 \text{ SDLI} + 4.331 \text{ (adj. } R^2 = 0.99)$$

For group 51-75 years

$$Y = -0.0479 \text{ FI} + 0.0115 \text{ SI} + 0.9967 \text{ SDLI} + 3.070 \text{ (adj. } R^2 = 0.99)$$

For group more than 75 years

$$Y = -0.0495 \text{ FI} + 0.0191 \text{ SI} + 0.9955 \text{ SDLI} + 2.247 \text{ (adj. } R^2 = 0.99)$$

For average of all age groups

$$Y = -0.0527 \text{ FI} + 0.0446 \text{ SI} + 0.9978 \text{ SDLI} + 1.056 \text{ (adj. } R^2 = 0.99)$$

Where FI- fruit index, SI- seed index and SDLI- seedling index.

The average of fruit index, seed index and seedling index values for each age group were fitted in the equation independently and the selection index values were determined. The average of all the age groups were marked out and are given in the Table 21.

#### 4.1.15. Index values

The highest index value was recorded in the age group of 25 to 50 years of mother plant, which was finally concluded as the best age group for selection of the mother plants. This was followed by age group of less than 25 years. The mean

**Table 18. Direction of association of six discriminant function coefficients involving the four age groups in mangosteen (*Garcinia mangostana* L.)**

| Pairs of compared age groups | Magnitude of the values |            |                |
|------------------------------|-------------------------|------------|----------------|
|                              | Fruit index             | Seed index | Seedling index |
| 1 and 2                      | +                       | -          | -              |
| 1 and 3                      | -                       | -          | +              |
| 1 and 4                      | -                       | +          | +              |
| 2 and 3                      | -                       | +          | +              |
| 2 and 4                      | -                       | +          | +              |
| 3 and 4                      | +                       | +          | -              |

**Table 19. Direction of association of six discriminant function coefficients when used to compare each age group with the remaining three age groups in mangosteen (*Garcinia mangostana* L.)**

| Discriminating pairs of age groups    |              | Magnitude of the values |            |                | Total number of positive values |
|---------------------------------------|--------------|-------------------------|------------|----------------|---------------------------------|
| Agegroup I                            | Age group II | Fruit index             | Seed index | Seedling index |                                 |
| 1                                     | 2            | +                       | -          | -              | 1                               |
| 1                                     | 3            | -                       | -          | +              | 1                               |
| 1                                     | 4            | -                       | +          | +              | 2                               |
| Total positive values for age group 1 |              |                         |            |                | 4                               |
| 2                                     | 1            | -                       | +          | +              | 2                               |
| 2                                     | 3            | -                       | +          | +              | 2                               |
| 2                                     | 4            | -                       | +          | +              | 2                               |
| Total positive values for age group 2 |              |                         |            |                | 6                               |
| 3                                     | 1            | +                       | +          | -              | 2                               |
| 3                                     | 2            | +                       | -          | -              | 1                               |
| 3                                     | 4            | +                       | +          | -              | 2                               |
| Total positive values for age group 3 |              |                         |            |                | 5                               |
| 4                                     | 1            | +                       | -          | -              | 1                               |
| 4                                     | 2            | +                       | -          | -              | 1                               |
| 4                                     | 3            | -                       | -          | +              | 1                               |
| Total positive values for age group 4 |              |                         |            |                | 3                               |

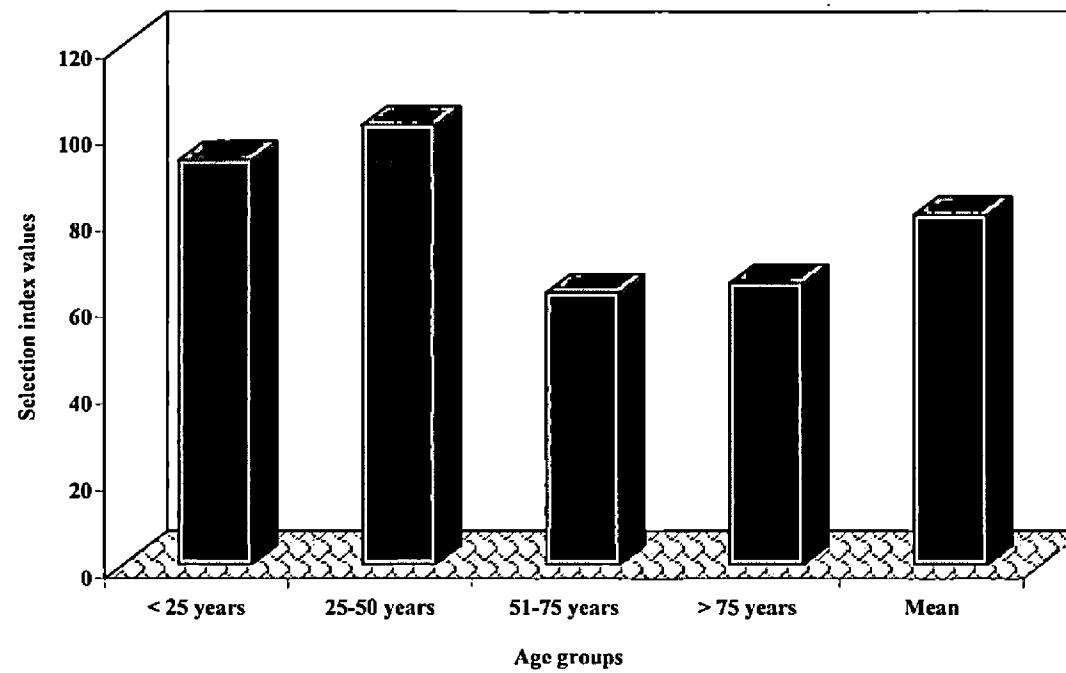
**Table 20. Criteria and criterion for discrimination of age groups in mangosteen (*Garcinia mangostana* L.)**

| S.No. | Age groups comparisons | Criteria 1 | Criteria 2 | Criterion | Conclusion                                                  |
|-------|------------------------|------------|------------|-----------|-------------------------------------------------------------|
| 1     | <25 and 25-50          | -4.41      | -4.84      | -4.62     | If the value is >-4.62 if falls in Group I, if not Group II |
| 2     | <25 and 51-75          | -6.19      | -8.57      | -7.38     | If the value is >-7.38 if falls in Group I, if not Group II |
| 3     | <25 and >75            | 4.26       | 2.52       | 3.39      | If the value is > 3.39 if falls in Group I, if not Group II |
| 4     | 25-50 and 51-75        | 8.96       | 6.17       | 7.57      | If the value is > 7.57 if falls in Group I, if not Group II |
| 5     | 25-50 and >75          | 30.17      | 19.87      | 25.02     | If the value is >25.02 if falls in Group I, if not Group II |
| 6     | 51-75 and >75          | 18.47      | 13.61      | 16.04     | If the value is >16.04 if falls in Group I, if not Group II |

**Table 21. Mean selection index or total index values of four age groups in mangosteen (*Garcinia mangostana* L.)**

| Age groups (Years) | Selection index values |
|--------------------|------------------------|
| Less than 25 years | 93.38                  |
| 25 – 50 years      | 101.45                 |
| 51 – 75 years      | 62.66                  |
| More than 75 years | 64.84                  |
| Mean               | 80.64                  |

**Fig. 10. Selection index or total index values of all the four age groups in mangosteen (*Garcinia mangostana* L.)**



values of the important characters in the best age group of 25-50 years were finally fixed to be the basis of the corresponding character for selection. Based on the particular character with seedling index, above average (if positively correlated) or below average (if negatively correlated) were selected as the indices of selection for obtaining increased growth in mangosteen.

Thus, it may be safely inferred that the age groups 25-50 years is best for obtaining best growth in mangosteen. In addition selection should be such that the fruits from this age group should have the fruit weight not less than 57.79 g, fruit girth not less than 4.51 cm, fruit volume not less than 50.87 ml, pulp weight not less than 15.73 g, rind weight not less than 41.40 g, number of segments not more than 5.66 numbers.

Seeds obtained from the fruits with above characters should have the seed weight not less than 0.66g, seed length not less than 1.61cm, seed thickness at centre not less than 0.66cm, seed volume not less than 0.44ml, seed specific gravity not less than 1.50, number of days to germination should less than 21.34 days, germination percentage not less than 86.98 % and number of seeds per fruit should not less than 1.29 numbers.

Further seedlings selected at one-year stage from this age group with the above-mentioned fruit and seed characters should have the height not less than 9.61cm, seedling girth at collar region not less than 2.00cm, total number of leaves per seedling should be not less than 8.88, number of new flushes per year not less than 1.33, total leaf area per seedling not less than 71.50 cm<sup>2</sup> and survival rate must be not less than 84.9 per cent.

## **4.2. Activation of seedling growth using various growth regulators**

### **4.2.1. Morphological characters of seedlings**

The mean data on morphological character of seedlings at two and four months stage is presented Table 22, sixth and eighth in Table 23, tenth months stage in Table 24 and twelve months stage in the Table 25.

#### **4.2.1.1. Height and increment in height at bimonthly intervals**

As maximum care was bestowed for uniformity of plants there was no much difference at the earliest two months stage. At the four-months stage plants treated with IAA 150 mg l<sup>-1</sup> recorded maximum height, which was at par with BA

**Table 22. Morphological characters of seedlings at two and four month stages (prior to and after treatment with growth regulators) in mangosteen (*Garcinia mangostana* L.)**

| Treatments<br>(mg l <sup>-1</sup> ) | Two month stage seedlings<br>(Just before the treatment) |               |                              | Four month stage seedlings<br>(Before second spray and two months after first spray) |                                |                    |                               |                              |                                              |
|-------------------------------------|----------------------------------------------------------|---------------|------------------------------|--------------------------------------------------------------------------------------|--------------------------------|--------------------|-------------------------------|------------------------------|----------------------------------------------|
|                                     | Height<br>(cm)                                           | Girth<br>(cm) | Total<br>number<br>of leaves | Height<br>(cm)                                                                       | Increment<br>in height<br>(cm) | Girth<br>(cm)      | Increment<br>in girth<br>(cm) | Total<br>number of<br>leaves | Increment<br>in total<br>number in<br>leaves |
| IAA 250                             | 1.75                                                     | 0.28          | 2.00                         | 3.73 <sup>bc</sup>                                                                   | 1.98 <sup>bc</sup>             | 0.79 <sup>a</sup>  | 0.51 <sup>a</sup>             | 3.50 <sup>ab</sup>           | 1.50 <sup>ab</sup>                           |
| IAA 150                             | 2.38                                                     | 0.28          | 2.50                         | 5.68 <sup>a</sup>                                                                    | 3.30 <sup>a</sup>              | 0.83 <sup>a</sup>  | 0.55 <sup>a</sup>             | 4.00 <sup>a</sup>            | 1.50 <sup>ab</sup>                           |
| IAA 50                              | 1.58                                                     | 0.23          | 2.00                         | 3.05 <sup>c</sup>                                                                    | 1.47 <sup>c</sup>              | 0.70 <sup>ab</sup> | 0.47 <sup>ab</sup>            | 3.50 <sup>ab</sup>           | 1.50 <sup>ab</sup>                           |
| GA 250                              | 2.08                                                     | 0.28          | 2.00                         | 3.88 <sup>bc</sup>                                                                   | 1.80 <sup>bc</sup>             | 0.84 <sup>a</sup>  | 0.56 <sup>a</sup>             | 4.00 <sup>a</sup>            | 2.00 <sup>a</sup>                            |
| GA 150                              | 2.43                                                     | 0.30          | 2.50                         | 4.40 <sup>abc</sup>                                                                  | 1.97 <sup>bc</sup>             | 0.86 <sup>a</sup>  | 0.56 <sup>a</sup>             | 4.00 <sup>a</sup>            | 1.50 <sup>ab</sup>                           |
| GA 50                               | 2.18                                                     | 0.23          | 2.00                         | 4.23 <sup>bc</sup>                                                                   | 2.05 <sup>abc</sup>            | 0.80 <sup>a</sup>  | 0.57 <sup>ab</sup>            | 4.00 <sup>a</sup>            | 2.00 <sup>a</sup>                            |
| BA 250                              | 2.03                                                     | 0.30          | 2.00                         | 4.45 <sup>abc</sup>                                                                  | 2.42 <sup>abc</sup>            | 0.83 <sup>a</sup>  | 0.53 <sup>ab</sup>            | 2.50 <sup>bc</sup>           | 0.50 <sup>b</sup>                            |
| BA 150                              | 1.75                                                     | 0.25          | 2.00                         | 4.63 <sup>ab</sup>                                                                   | 2.88 <sup>ab</sup>             | 0.82 <sup>a</sup>  | 0.57 <sup>ab</sup>            | 3.18 <sup>abc</sup>          | 1.18 <sup>ab</sup>                           |
| BA 50                               | 2.00                                                     | 0.23          | 2.00                         | 4.65 <sup>ab</sup>                                                                   | 2.65 <sup>abc</sup>            | 0.69 <sup>ab</sup> | 0.46 <sup>ab</sup>            | 3.00 <sup>abc</sup>          | 1.00 <sup>ab</sup>                           |
| Water spray                         | 1.83                                                     | 0.23          | 2.00                         | 3.65 <sup>bc</sup>                                                                   | 1.82 <sup>bc</sup>             | 0.78 <sup>ab</sup> | 0.55 <sup>a</sup>             | 2.25 <sup>c</sup>            | 0.25 <sup>b</sup>                            |
| Control                             | 1.45                                                     | 0.23          | 2.00                         | 1.68 <sup>d</sup>                                                                    | 0.23 <sup>d</sup>              | 0.58 <sup>b</sup>  | 0.35 <sup>b</sup>             | 2.50 <sup>bc</sup>           | 0.50 <sup>b</sup>                            |
| Mean values                         | 1.95                                                     | 0.23          | 2.09                         | 4.00                                                                                 | 2.05                           | 0.78               | 0.55                          | 3.31                         | 1.22                                         |
| C.D. (p < 0.05)                     | NS                                                       | NS            | NS                           | 1.24                                                                                 | 1.14                           | 0.182              | 0.14                          | 1.05                         | 1.22                                         |

Figures with same alphabets do not differ significantly at 5 % level.

IAA- Indole acetic acid, GA- Gibberellic acid, BA- Benzyl adenine.

150 and 50 mg l<sup>-1</sup>. At the six-months stage, again the treatments IAA 150 mg l<sup>-1</sup> recorded maximum height and was at par with plant receiving the treatments GA 250 and 150 mg l<sup>-1</sup>. At eighth and ten months stage again IAA 150 mg l<sup>-1</sup> recorded the maximum height but was followed by GA 150 and 50 mg l<sup>-1</sup> respectively. At final twelve-months stage GA 50 mg l<sup>-1</sup> followed by IAA 150 mg l<sup>-1</sup> recorded the maximum height. The next best treatments were the GA treatment at 50 mg l<sup>-1</sup> and 250 mg l<sup>-1</sup>.

The increment in height more or less followed a similar pattern to that observed at the bimonthly intervals. At the four-months stage the same treatments recorded maximum increments. At six months stage, GA 250 mg l<sup>-1</sup> followed by control of no spray, other GA treatments and all IAA treatments gave better increments, which was significantly superior and at par with each other. At the eight-months stage, though differences were not significant the relative influence of 150 mg l<sup>-1</sup> sprays of IAA and GA was visible. At ten-months stage, maximum increment was observed in the water spray, which was at par with all other treatments except IAA 250 mg l<sup>-1</sup>. At twelve-months stage, GA 150 mg l<sup>-1</sup> exhibited distinct increments in height followed by GA 50 and IAA 150 mg l<sup>-1</sup>. A perusal of the data revealed that general superiority of GA 150, 50 mg l<sup>-1</sup> followed by IAA 150 mg l<sup>-1</sup> and GA 50 mg l<sup>-1</sup>.

#### 4.2.1.2. Girth and increments at bimonthly intervals

The efficiency of secondary selection for uniformity of plants was evident at the two-months stage. There were no significant differences between plants. At four-months stage, GA 150 followed by GA 250 mg l<sup>-1</sup> recorded maximum values revealing the superiority of GA spray, in general followed by higher concentrations of IAA, but there were no significant difference. The data at tenth months revealed that GA 150 mg l<sup>-1</sup> followed by BA 250 mg l<sup>-1</sup> and IAA 150 mg l<sup>-1</sup> were the treatments in the order, recorded the higher values, whereas at the twelve months stage it was BA 250 mg l<sup>-1</sup> followed by GA 150 mg l<sup>-1</sup> and IAA 150 mg l<sup>-1</sup>. However, at the twelve months stage a shift was observed in the order with BA 250 mg l<sup>-1</sup> recording maximum girth.

In the case of increment at the four-months stage, higher doses of GA followed by higher doses of IAA showed maximum increment. At six-months

Table 23. Morphological characters at six and eight months stages of seedlings treated with growth regulators in mangosteen (*Garcinia mangostana* L.)

| Treatments<br>(mg l <sup>-1</sup> ) | Six month stage seedlings<br>(Before third spray and two months after second spray) |                                |               |                               |                              |                                              | Eight month stage seedlings<br>(Two months after third spray) |                                |                     |                               |                              |                                              |
|-------------------------------------|-------------------------------------------------------------------------------------|--------------------------------|---------------|-------------------------------|------------------------------|----------------------------------------------|---------------------------------------------------------------|--------------------------------|---------------------|-------------------------------|------------------------------|----------------------------------------------|
|                                     | Height<br>(cm)                                                                      | Increment<br>in height<br>(cm) | Girth<br>(cm) | Increment<br>in girth<br>(cm) | Total<br>number<br>of leaves | Increment<br>in total<br>number of<br>leaves | Height<br>(cm)                                                | Increment<br>in height<br>(cm) | Girth<br>(cm)       | Increment<br>in girth<br>(cm) | Total<br>number<br>of leaves | Increment<br>in total<br>number<br>of leaves |
| IAA 250                             | 4.90 <sup>bcd</sup>                                                                 | 1.17 <sup>ab</sup>             | 0.95          | 0.16                          | 4.50                         | 1.00                                         | 7.30 <sup>abc</sup>                                           | 2.40                           | 1.17 <sup>abc</sup> | 0.22 <sup>a</sup>             | 5.50                         | 1.00                                         |
| IAA 150                             | 6.83 <sup>a</sup>                                                                   | 1.15 <sup>ab</sup>             | 1.01          | 0.18                          | 4.65                         | 0.65                                         | 9.78 <sup>a</sup>                                             | 2.95                           | 1.23 <sup>ab</sup>  | 0.22 <sup>a</sup>             | 7.00                         | 2.35                                         |
| IAA 50                              | 4.10 <sup>cd</sup>                                                                  | 1.05 <sup>ab</sup>             | 0.83          | 0.13                          | 5.00                         | 1.50                                         | 5.63 <sup>c</sup>                                             | 1.53                           | 0.98 <sup>bc</sup>  | 0.15 <sup>ab</sup>            | 6.25                         | 1.25                                         |
| GA 250                              | 6.30 <sup>ab</sup>                                                                  | 2.45 <sup>a</sup>              | 0.99          | 0.15                          | 4.75                         | 0.75                                         | 7.95 <sup>abc</sup>                                           | 1.65                           | 1.21 <sup>ab</sup>  | 0.22 <sup>a</sup>             | 6.50                         | 1.75                                         |
| GA 150                              | 6.15 <sup>ab</sup>                                                                  | 1.75 <sup>ab</sup>             | 1.07          | 0.21                          | 4.83                         | 0.83                                         | 8.93 <sup>ab</sup>                                            | 2.78                           | 1.27 <sup>a</sup>   | 0.20 <sup>a</sup>             | 7.00                         | 2.17                                         |
| GA 50                               | 5.68 <sup>abc</sup>                                                                 | 1.45 <sup>ab</sup>             | 0.88          | 0.08                          | 5.25                         | 1.25                                         | 8.40 <sup>abc</sup>                                           | 2.72                           | 1.10 <sup>abc</sup> | 0.22 <sup>a</sup>             | 7.50                         | 2.25                                         |
| BA 250                              | 5.55 <sup>abc</sup>                                                                 | 1.10 <sup>ab</sup>             | 1.08          | 0.25                          | 3.75                         | 1.25                                         | 7.85 <sup>abc</sup>                                           | 2.30                           | 1.24 <sup>ab</sup>  | 0.16 <sup>ab</sup>            | 5.50                         | 1.75                                         |
| BA 150                              | 5.08 <sup>abcd</sup>                                                                | 0.45 <sup>b</sup>              | 0.95          | 0.13                          | 4.75                         | 1.57                                         | 6.65 <sup>abc</sup>                                           | 1.57                           | 1.15 <sup>abc</sup> | 0.20 <sup>a</sup>             | 6.25                         | 1.50                                         |
| BA 50                               | 5.28 <sup>abcd</sup>                                                                | 0.63 <sup>b</sup>              | 0.84          | 0.15                          | 4.50                         | 1.50                                         | 7.48 <sup>abc</sup>                                           | 2.20                           | 1.00 <sup>abc</sup> | 0.16 <sup>ab</sup>            | 6.75                         | 2.25                                         |
| Water spray                         | 4.23 <sup>cd</sup>                                                                  | 0.58 <sup>b</sup>              | 0.95          | 0.07                          | 4.00                         | 1.75                                         | 5.98 <sup>bc</sup>                                            | 1.75                           | 1.08 <sup>abc</sup> | 0.13 <sup>ab</sup>            | 5.50                         | 1.50                                         |
| Control                             | 3.55 <sup>d</sup>                                                                   | 1.87 <sup>ab</sup>             | 0.86          | 0.28                          | 3.75                         | 1.25                                         | 5.25 <sup>c</sup>                                             | 1.70                           | 0.91 <sup>c</sup>   | 0.05 <sup>b</sup>             | 5.25                         | 1.50                                         |
| Mean values                         | 5.24                                                                                | 1.24                           | 0.94          | 0.16                          | 4.52                         | 1.21                                         | 7.38                                                          | 2.14                           | 1.12                | 0.18                          | 6.27                         | 1.75                                         |
| C.D. (p < 0.05)                     | 1.60                                                                                | 1.46                           | NS            | NS                            | NS                           | NS                                           | 2.84                                                          | NS                             | 0.24                | 0.11                          | NS                           | NS                                           |

Figures with same alphabets do not differ significantly at 5 % level.

IAA- Indole acetic acid, GA- Gibberellic acid, BA- Benzyl adenine.

Table 24. Morphological characters at ten months stage of mangosteen (*Garcinia mangostana* L.) seedlings treated with growth regulators.

| Treatments<br>(mg l <sup>-1</sup> ) | Ten month stage seedlings<br>(Four months after third spray) |                                |                     |                               |                              |                                           |
|-------------------------------------|--------------------------------------------------------------|--------------------------------|---------------------|-------------------------------|------------------------------|-------------------------------------------|
|                                     | Height<br>(cm)                                               | Increment<br>in height<br>(cm) | Girth<br>(cm)       | Increment in<br>girth<br>(cm) | Total<br>number of<br>leaves | Increment of<br>total number<br>in leaves |
| IAA 250                             | 7.78 <sup>ab</sup>                                           | 0.48 <sup>b</sup>              | 1.29 <sup>abc</sup> | 0.12 <sup>ab</sup>            | 6.50 <sup>b</sup>            | 1.00 <sup>bc</sup>                        |
| IAA 150                             | 10.77 <sup>a</sup>                                           | 1.00 <sup>ab</sup>             | 1.38 <sup>ab</sup>  | 0.15 <sup>ab</sup>            | 8.00 <sup>ab</sup>           | 1.00 <sup>bc</sup>                        |
| IAA 50                              | 7.03 <sup>b</sup>                                            | 1.40 <sup>ab</sup>             | 1.11 <sup>bc</sup>  | 0.13 <sup>ab</sup>            | 6.75 <sup>ab</sup>           | 0.50 <sup>c</sup>                         |
| GA 250                              | 9.20 <sup>ab</sup>                                           | 1.25 <sup>ab</sup>             | 1.36 <sup>ab</sup>  | 0.15 <sup>ab</sup>            | 7.50 <sup>ab</sup>           | 1.00 <sup>bc</sup>                        |
| GA 150                              | 10.77 <sup>a</sup>                                           | 1.84 <sup>ab</sup>             | 1.43 <sup>a</sup>   | 0.16 <sup>ab</sup>            | 9.43 <sup>a</sup>            | 2.43 <sup>ab</sup>                        |
| GA 50                               | 9.65 <sup>ab</sup>                                           | 1.25 <sup>ab</sup>             | 1.24 <sup>abc</sup> | 0.13 <sup>ab</sup>            | 9.00 <sup>ab</sup>           | 1.50 <sup>abc</sup>                       |
| BA 250                              | 9.03 <sup>ab</sup>                                           | 1.18 <sup>ab</sup>             | 1.40 <sup>ab</sup>  | 0.15 <sup>ab</sup>            | 8.25 <sup>ab</sup>           | 2.75 <sup>a</sup>                         |
| BA 150                              | 7.80 <sup>ab</sup>                                           | 1.15 <sup>ab</sup>             | 1.30 <sup>abc</sup> | 0.13 <sup>ab</sup>            | 8.50 <sup>ab</sup>           | 2.25 <sup>abc</sup>                       |
| BA 50                               | 8.85 <sup>ab</sup>                                           | 1.37 <sup>ab</sup>             | 1.11 <sup>bc</sup>  | 0.10 <sup>b</sup>             | 7.50 <sup>ab</sup>           | 0.75 <sup>bc</sup>                        |
| Water spray                         | 8.05 <sup>ab</sup>                                           | 2.07 <sup>a</sup>              | 1.21 <sup>abc</sup> | 0.10 <sup>b</sup>             | 6.25 <sup>b</sup>            | 0.75 <sup>bc</sup>                        |
| Control                             | 6.93 <sup>b</sup>                                            | 1.68 <sup>ab</sup>             | 1.02 <sup>c</sup>   | 0.12 <sup>ab</sup>            | 7.25 <sup>ab</sup>           | 2.00 <sup>abc</sup>                       |
| Mean values                         | 8.71                                                         | 1.33                           | 1.26                | 0.13                          | 7.72                         | 1.45                                      |
| C.D. (p < 0.05)                     | 2.61                                                         | 1.22                           | 0.27                | 0.06                          | 2.39                         | 1.54                                      |

Figures with same alphabets do not differ significantly at 5 % level.

IAA- Indole acetic acid, GA- Gibberellic acid, BA- Benzyl adenine.

stage, BA 250 mg l<sup>-1</sup> followed by GA and IAA 150 mg l<sup>-1</sup> showed higher values though not significant. At eight-months stage the relative superiority higher doses of GA and IAA were explicit. At ten months stage GA 150 mg l<sup>-1</sup> followed by IAA 150 mg l<sup>-1</sup>, BA 250 mg l<sup>-1</sup> and GA 250 mg l<sup>-1</sup> revealed the maximum increment and the best treatment was significantly superior to all other treatments. At twelve-months stage, BA 250 mg l<sup>-1</sup> followed by GA 150 mg l<sup>-1</sup> recorded the maximum increments.

#### **4.2.1.3. Total number of leaves and increments at bimonthly intervals**

At the earliest stage differences in the means of increments were not significant revealing the efficiency of selection. At the four-months stage, all GA treatments and IAA at 150 mg l<sup>-1</sup> produced more and equal number of leaves. At six-months stage and eight months stage though difference was not significant GA 50 mg l<sup>-1</sup> registered maximum leaf count. This was followed by IAA 50 mg l<sup>-1</sup> at six-months stage whereas at eight-months stage, it was followed by GA and IAA 150 mg l<sup>-1</sup>, which registered equal leaf count. At ten months and twelve-months stage, GA 150 mg l<sup>-1</sup> recorded the maximum leaf count but results were significant, only in the former.

At four-months stage GA at the highest and lowest concentration excelled and were significantly superior to other treatments, whereas at the six and eight months stage, the difference were not significant. At six-months stage, BA 150 mg l<sup>-1</sup>, by and at eight-months stage, IAA 150 mg l<sup>-1</sup> showed maximum increment. At ten and twelve months stage, BA 250 and 50 mg l<sup>-1</sup>, respectively, recorded maximum increment and at par with GA 150 mg l<sup>-1</sup> in the former and GA, IAA and BA at 150 mg l<sup>-1</sup> in the latter.

#### **4.2.1.4. Number of new flushing/year**

The maximum number of flushes was recorded in the plants treated with GA 150 mg l<sup>-1</sup>, GA 50 mg l<sup>-1</sup> and BA 150 mg l<sup>-1</sup>, which were significantly at par. The least number of flushes were observed in the water sprayed plant.

#### **4.2.1.5. Number of leaves/flush**

There were no variation observed among the treatments with regard to the number of leaves/flush and all the treatments gave an average of two leaves.

Table 25. Morphological characters of twelve month old mangosteen (*Garcinia mangostana* L.) seedlings treated with growth regulators

| Treatments<br>(mg l <sup>-1</sup> ) | Twelve month stage<br>(Six months after third spray) |                                |               |                               |                              |                                           |                                    |                                |                                          |                         |
|-------------------------------------|------------------------------------------------------|--------------------------------|---------------|-------------------------------|------------------------------|-------------------------------------------|------------------------------------|--------------------------------|------------------------------------------|-------------------------|
|                                     | Height<br>(cm)                                       | Increment<br>in height<br>(cm) | Girth<br>(cm) | Increment<br>in girth<br>(cm) | Total<br>number of<br>leaves | Increment in<br>total number<br>of leaves | Number of<br>new flushes<br>/ year | Number of<br>leaves<br>/ flush | Total leaf<br>area<br>(cm <sup>2</sup> ) | Survival<br>rate<br>(%) |
| IAA 250                             | 8.78 <sup>ab</sup>                                   | 1.00 <sup>ab</sup>             | 1.42          | 0.13                          | 7.50                         | 1.00 <sup>ab</sup>                        | 1.20 <sup>b</sup>                  | 2.00                           | 56.42 <sup>abc</sup>                     | 100.0                   |
| IAA 150                             | 11.88 <sup>a</sup>                                   | 1.10 <sup>ab</sup>             | 1.48          | 0.10                          | 9.50                         | 1.50 <sup>ab</sup>                        | 1.60 <sup>ab</sup>                 | 2.00                           | 101.20 <sup>a</sup>                      | 100.0                   |
| IAA 50                              | 7.90 <sup>b</sup>                                    | 0.87 <sup>b</sup>              | 1.18          | 0.07                          | 7.50                         | 0.75 <sup>b</sup>                         | 1.40 <sup>ab</sup>                 | 2.00                           | 46.34 <sup>abc</sup>                     | 75.0                    |
| GA 250                              | 10.35 <sup>ab</sup>                                  | 1.15 <sup>ab</sup>             | 1.45          | 0.09                          | 8.00                         | 0.50 <sup>b</sup>                         | 1.50 <sup>ab</sup>                 | 2.00                           | 94.85 <sup>ab</sup>                      | 100.0                   |
| GA 150                              | 12.13 <sup>a</sup>                                   | 1.36 <sup>a</sup>              | 1.58          | 0.15                          | 10.50                        | 1.07 <sup>ab</sup>                        | 2.00 <sup>a</sup>                  | 2.00                           | 99.85 <sup>a</sup>                       | 100.0                   |
| GA 50                               | 10.88 <sup>ab</sup>                                  | 1.23 <sup>ab</sup>             | 1.29          | 0.05                          | 10.00                        | 1.00 <sup>ab</sup>                        | 2.00 <sup>a</sup>                  | 2.00                           | 58.83 <sup>abc</sup>                     | 75.0                    |
| BA 250                              | 10.13 <sup>ab</sup>                                  | 1.10 <sup>ab</sup>             | 1.60          | 0.20                          | 9.00                         | 0.75 <sup>b</sup>                         | 1.80 <sup>ab</sup>                 | 2.00                           | 48.40 <sup>abc</sup>                     | 100.0                   |
| BA 150                              | 8.75 <sup>ab</sup>                                   | 0.95 <sup>ab</sup>             | 1.35          | 0.05                          | 10.00                        | 1.50 <sup>ab</sup>                        | 2.00 <sup>a</sup>                  | 2.00                           | 61.56 <sup>abc</sup>                     | 75.0                    |
| BA 50                               | 9.98 <sup>ab</sup>                                   | 1.13 <sup>ab</sup>             | 1.19          | 0.08                          | 9.50                         | 2.00 <sup>a</sup>                         | 1.80 <sup>ab</sup>                 | 2.00                           | 41.53 <sup>abc</sup>                     | 100.0                   |
| Water spray                         | 9.03 <sup>ab</sup>                                   | 0.98 <sup>ab</sup>             | 1.26          | 0.05                          | 7.50                         | 1.25 <sup>ab</sup>                        | 1.10 <sup>b</sup>                  | 2.00                           | 30.79 <sup>c</sup>                       | 100.0                   |
| Control                             | 7.80 <sup>b</sup>                                    | 0.87 <sup>b</sup>              | 1.17          | 0.15                          | 8.25                         | 1.00 <sup>ab</sup>                        | 1.30 <sup>ab</sup>                 | 2.00                           | 37.22 <sup>bc</sup>                      | 100.0                   |
| Mean values                         | 9.78                                                 | 1.07                           | 1.36          | 0.10                          | 8.84                         | 1.12                                      | 1.61                               | 2.00                           | 61.55                                    | 93.18                   |
| C.D. (p < 0.05)                     | 3.08                                                 | 0.40                           | NS            | NS                            | NS                           | 0.91                                      | 0.64                               | NS                             | 52.85                                    | NS                      |

Figures with same alphabets do not differ significantly at 5 % level.

IAA- Indole acetic acid, GA- Gibberellic acid, BA- Benzyl adenine.

#### **4.2.1.6. Leaf area**

The maximum total leaf area per seedling was recorded in the plants treated with IAA 150 followed by GA 150 and 250 mg l<sup>-1</sup>, respectively. These three treatments were statistically at par with each other. But only the better two were significantly superior than the control.

#### **4.2.1.7. Survival rate**

Though the maximum of cent per cent survival rate was recorded in all the treatments except IAA 50, GA 50 and BA 150 mg l<sup>-1</sup>, no significant difference were observed between the treatment means.

#### **4.2.2. Shoot and root characters of one year old seedlings**

The data related to shoot and root characters are presented in Table 26.

##### **4.2.2.1. Shoot fresh weight**

Maximum shoot fresh weight was recorded in the plants treated with IAA 150 mg l<sup>-1</sup>, followed by GA 150 mg l<sup>-1</sup>. Both these treatments differed significantly between them and were superior to all other treatment means.

##### **4.2.2.2. Root fresh weight**

The highest fresh weight of roots was recorded in the plants treated with IAA 150 mg l<sup>-1</sup> followed by GA 150 and IAA 250 mg l<sup>-1</sup>. The best treatment was significantly superior to all other treatments.

##### **4.2.2.3. Shoot dry weight and root dry weight**

The maximum shoot dry weight and root dry weights were recorded in the plant treated with GA 250 mg l<sup>-1</sup> and IAA 150 mg l<sup>-1</sup> respectively. Which were significantly superior to the next best treatments in shoot and root dry weight were GA 150 mg l<sup>-1</sup> and GA 250 mg l<sup>-1</sup>.

##### **4.2.2.4. Root to shoot dry weight ratio**

Highest root to shoot dry weight ratio was recorded in the plants treated with IAA 150 mg l<sup>-1</sup>, followed by BA 50 mg l<sup>-1</sup>, which was at par with IAA 150 mg l<sup>-1</sup>, IAA 250 mg l<sup>-1</sup>, GA 50 mg l<sup>-1</sup> and the control. The ratio recorded in IAA 150 mg l<sup>-1</sup> treatment was significantly higher than all other treatments.

Table 26. Shoot and root characters of one year old mangosteen (*Garcinia mangostana* L.) seedlings treated with growth regulators.

| Treatments      | Shoot fresh weight (g) | Root fresh weight (g) | Shoot dry weight (g) | Root dry weight (g) | Root to shoot dry weight ratio | Root length (cm)    | Primary roots (No)  | Secondary roots (No) | Tertiary roots (No)  | Total roots (No)    |
|-----------------|------------------------|-----------------------|----------------------|---------------------|--------------------------------|---------------------|---------------------|----------------------|----------------------|---------------------|
| IAA 250         | 44.62 <sup>c</sup>     | 1.53 <sup>b</sup>     | 1.10 <sup>d</sup>    | 0.60 <sup>c</sup>   | 0.55 <sup>b</sup>              | 26.90 <sup>bc</sup> | 30.00 <sup>b</sup>  | 38.00 <sup>bc</sup>  | 20.00 <sup>de</sup>  | 88.00 <sup>c</sup>  |
| IAA 150         | 5.84 <sup>a</sup>      | 2.90 <sup>a</sup>     | 1.53 <sup>c</sup>    | 1.06 <sup>a</sup>   | 0.69 <sup>a</sup>              | 36.30 <sup>a</sup>  | 38.00 <sup>a</sup>  | 48.00 <sup>a</sup>   | 62.00 <sup>a</sup>   | 148.0 <sup>a</sup>  |
| IAA 50          | 1.80 <sup>ef</sup>     | 0.69 <sup>d</sup>     | 0.84 <sup>ef</sup>   | 0.35 <sup>de</sup>  | 0.42 <sup>c</sup>              | 12.30 <sup>c</sup>  | 10.00 <sup>c</sup>  | 18.00 <sup>de</sup>  | 10.00 <sup>b</sup>   | 38.00 <sup>ef</sup> |
| GA 250          | 4.74 <sup>c</sup>      | 1.05 <sup>c</sup>     | 2.20 <sup>a</sup>    | 0.69 <sup>b</sup>   | 0.31 <sup>c</sup>              | 15.20 <sup>de</sup> | 14.00 <sup>de</sup> | 20.00 <sup>d</sup>   | 12.00 <sup>fg</sup>  | 46.00 <sup>ef</sup> |
| GA 150          | 5.30 <sup>b</sup>      | 0.95 <sup>c</sup>     | 1.86 <sup>b</sup>    | 0.30 <sup>e</sup>   | 0.16 <sup>d</sup>              | 16.30 <sup>de</sup> | 20.00 <sup>c</sup>  | 31.00 <sup>c</sup>   | 18.00 <sup>def</sup> | 69.00 <sup>cd</sup> |
| GA 50           | 2.19 <sup>d</sup>      | 1.61 <sup>b</sup>     | 1.12 <sup>d</sup>    | 0.60 <sup>c</sup>   | 0.54 <sup>b</sup>              | 34.80 <sup>a</sup>  | 38.00 <sup>a</sup>  | 43.00 <sup>ab</sup>  | 40.00 <sup>b</sup>   | 121.00 <sup>b</sup> |
| BA 250          | 1.96 <sup>de</sup>     | 0.98 <sup>c</sup>     | 0.89 <sup>c</sup>    | 0.33 <sup>de</sup>  | 0.37 <sup>c</sup>              | 30.20 <sup>ab</sup> | 24.00 <sup>c</sup>  | 33.00 <sup>c</sup>   | 30.00 <sup>c</sup>   | 87.00 <sup>c</sup>  |
| BA 150          | 1.45 <sup>fg</sup>     | 0.69 <sup>d</sup>     | 0.77 <sup>f</sup>    | 0.32 <sup>de</sup>  | 0.41 <sup>c</sup>              | 15.60 <sup>de</sup> | 13.00 <sup>e</sup>  | 20.00 <sup>d</sup>   | 24.00 <sup>cd</sup>  | 57.00 <sup>de</sup> |
| BA 50           | 0.39 <sup>h</sup>      | 0.19 <sup>e</sup>     | 0.22 <sup>g</sup>    | 0.14 <sup>f</sup>   | 0.63 <sup>ab</sup>             | 16.40 <sup>de</sup> | 9.000 <sup>e</sup>  | 10.00 <sup>e</sup>   | 13.00 <sup>efg</sup> | 32.00 <sup>f</sup>  |
| Water spray     | 1.22 <sup>g</sup>      | 0.74 <sup>d</sup>     | 0.74 <sup>f</sup>    | 0.27 <sup>e</sup>   | 0.36 <sup>c</sup>              | 21.30 <sup>cd</sup> | 12.00 <sup>e</sup>  | 14.00 <sup>de</sup>  | 10.00 <sup>g</sup>   | 36.00 <sup>ef</sup> |
| Control         | 1.42 <sup>fg</sup>     | 0.86 <sup>cd</sup>    | 0.75 <sup>f</sup>    | 0.40 <sup>d</sup>   | 0.53 <sup>b</sup>              | 15.60 <sup>de</sup> | 19.00 <sup>cd</sup> | 20.00 <sup>d</sup>   | 8.000 <sup>g</sup>   | 47.00 <sup>ef</sup> |
| Mean values     | 2.81                   | 1.11                  | 1.09                 | 0.46                | 0.45                           | 21.90               | 20.64               | 26.89                | 22.46                | 69.91               |
| C.D. (p < 0.05) | 0.37                   | 0.186                 | 0.11                 | 0.08                | 0.11                           | 7.112               | 5.08                | 8.467                | 6.77                 | 20.32               |

Figures with same alphabets do not differ significantly at 5 % level.

IAA- Indole acetic acid, GA- Gibberellic acid, BA- Benzyl adenine.

#### **4.2.2.5. Root length**

The root length was highest in the plants treated with IAA 150 mg l<sup>-1</sup> followed by GA 50 mg l<sup>-1</sup>, but both were at par. Both of these treatment means were significantly higher than all other treatment means.

#### **4.2.2.6. Number of primary roots/seedling**

Maximum number of primary roots was recorded in the plants treated with IAA 50 and GA 50 mg l<sup>-1</sup>. These treatment means were at par with each other and significantly superior to all other treatments.

#### **4.2.2.7. Number of secondary roots**

Highest number of secondary roots was observed in the plants treated with IAA 150 mg l<sup>-1</sup>, followed by GA 50 mg l<sup>-1</sup> and IAA 250 mg l<sup>-1</sup>. The mean of the treatment IAA 150 mg l<sup>-1</sup> was statistically at par with GA 50 mg l<sup>-1</sup> and GA 50 mg l<sup>-1</sup> was at par with IAA 250 mg l<sup>-1</sup>.

#### **4.2.2.8. Number tertiary roots**

The mean number of tertiary roots was highest in the plants treated with IAA 150 mg l<sup>-1</sup>, which differed significantly with GA 50 mg l<sup>-1</sup> the next best treatment, other treatments and also the control.

#### **4.2.2.9. Total number of roots**

The means of total number of roots of IAA 150 mg l<sup>-1</sup> treated plants were significantly higher than all other treatments. This was followed by GA 150 mg l<sup>-1</sup> was also significantly superior to all other treatment means.

### **4.2.3. Biochemical characters of one year old seedlings**

The bio-chemical characters of growth regulators treated plants showing best, intermediate and least growth (Plate 5) at twelve-months stage are presented in the Table 27

#### **4.2.3.1. Nitrogen content**

Though the differences of the treatment means were not significant, a distinct trend was observed in the case of nitrogen content. A gradual decrease was

**Table 27. Biochemical characters in the leaves of one year old mangosteen (*Garcinia mangostana* L.) seedlings treated with growth regulators.**

| Plant growth of growth regulators treated plants | N (%) | P (%)             | K (%) | Crude protein (%)   | Na (%) | Chlorophyll a (mg/g) | Chlorophyll b (mg/g) | Chlorophyll a / b ratio | Total chlorophyll (mg/g) | Total phenols (mg/g) | Total carbohydrates (mg/g) | Absciscic acid (mg/g) |
|--------------------------------------------------|-------|-------------------|-------|---------------------|--------|----------------------|----------------------|-------------------------|--------------------------|----------------------|----------------------------|-----------------------|
| Best (GA 150 mg l <sup>-1</sup> )                | 2.11  | 0.19 <sup>a</sup> | 0.31  | 13.17 <sup>a</sup>  | 0.31   | 0.82 <sup>a</sup>    | 0.50 <sup>a</sup>    | 1.67                    | 1.32 <sup>a</sup>        | 0.62                 | 6.60 <sup>a</sup>          | 0.20                  |
| Intermediate (BA 250 mg l <sup>-1</sup> )        | 1.89  | 0.12 <sup>b</sup> | 0.36  | 11.81 <sup>ab</sup> | 0.36   | 0.48 <sup>b</sup>    | 0.26 <sup>b</sup>    | 1.84                    | 0.74 <sup>b</sup>        | 0.59                 | 4.43 <sup>b</sup>          | 0.16                  |
| Least (IAA 50 mg l <sup>-1</sup> )               | 1.66  | 0.11 <sup>b</sup> | 0.33  | 10.40 <sup>b</sup>  | 0.33   | 0.33 <sup>b</sup>    | 0.20 <sup>b</sup>    | 1.69                    | 0.53 <sup>b</sup>        | 0.56                 | 4.16 <sup>b</sup>          | 0.14                  |
| Control (No spray)                               | 1.78  | 0.11 <sup>b</sup> | 0.35  | 11.11 <sup>b</sup>  | 0.35   | 0.40 <sup>b</sup>    | 0.23 <sup>b</sup>    | 1.74                    | 0.63 <sup>b</sup>        | 0.58                 | 4.30 <sup>b</sup>          | 0.15                  |
| Mean values                                      | 1.86  | 0.13              | 0.34  | 11.62               | 0.34   | 0.51                 | 0.30                 | 1.73                    | 0.80                     | 0.59                 | 4.87                       | 0.16                  |
| C.D.(p<0.05)                                     | NS    | 0.07              | NS    | 1.45                | NS     | 0.21                 | 0.13                 | NS                      | 0.37                     | NS                   | 2.00                       | NS                    |

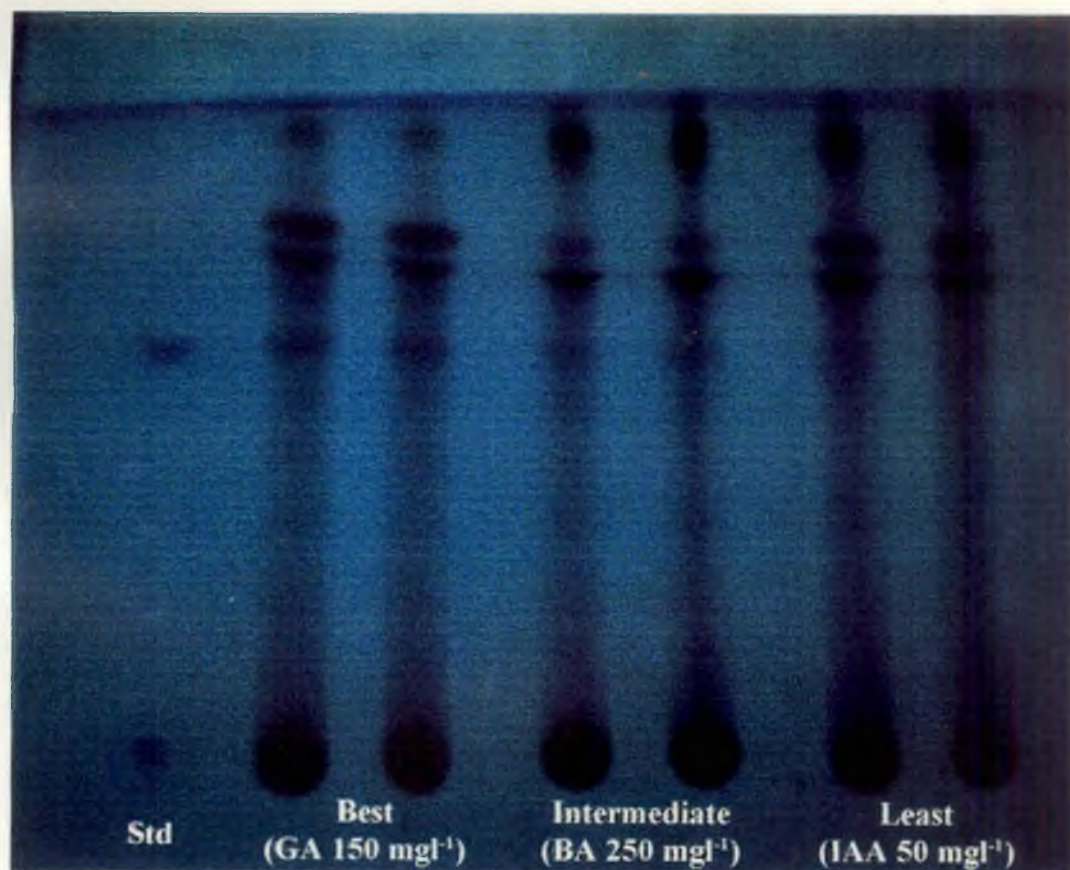
Figures with same alphabets do not differ significantly at 5 % level.

IAA- Indole acetic acid, GA- Gibberellic acid, BA- Benzyl adenine.

**Plate 5. Seedlings of treatments, showing the best, the intermediate and the least growth response to various growth regulators in mangosteen (*Garcinia mangostana* L.)**



**Plate 6. Banding pattern observed in TLC used to quantify abscisic acid content in various treatments using growth regulators in mangosteen (*Garcinia mangostana* L.)**



observed in the nitrogen content from the plants showing the best growth (GA 150  $\text{mg l}^{-1}$ ) to the intermediate (BA 250  $\text{mg l}^{-1}$ ) to the least growth (IAA 50  $\text{mg l}^{-1}$ ).

#### **4.2.3.2. Phosphorus content**

As in the case of the nitrogen content, the phosphorus content recorded was also highest in the plant showing best growth and decreased gradually towards the plant showing intermediate and then to the least growth. The means of content of best treatment was significantly higher than all other treatments including the control. Other treatments were at par with the control.

#### **4.2.3.3. Potassium content**

The highest potassium content was observed in the treatment, which showed intermediate growth (BA 250  $\text{mg l}^{-1}$ ). The treatments, which showed highest growth, recorded the lowest potassium content. However, there were no significant differences observed between means of all treatments including the control.

#### **4.2.3.4. Crude protein**

The highest crude protein content was recorded in the plants that showed the best growth and the content gradually decreased gradually towards the treatments, which showed intermediate, and to the treatment showing least. The best treatment plants had significantly higher crude protein content than the treatment, which showed least growth, and the control plants but were at par with the intermediate plants.

#### **4.2.3.5. Sodium content**

There were no significant differences observed between the treatments means including the control. The highest content was found in plants sprayed with BA 250  $\text{mg l}^{-1}$  and the lowest was in the plant receiving IAA 50  $\text{mg l}^{-1}$  treatments.

#### **4.2.3.6. Chlorophyll content**

Maximum chlorophyll a, chlorophyll b and total chlorophyll content were recorded in treatment, which showed the best growth. The content gradually decreased towards the intermediate and least growth plants. The content in the best

treatment was higher than the control, whereas the content in intermediary and the least treatments were at par with the control.

#### **4.2.3.7. Total phenols**

The highest total phenol content was observed in treatment showing the best growth. This gradually decreased towards intermediate and lowest observed in the least effective plants. However, no significant differences were observed between the treatment means (Fig. 11).

#### **4.2.3.8. Total carbohydrates**

Significantly higher carbohydrates content were recorded in the treatment, which showed maximum growth. The mean of all other treatments were statistically at par with each other.

#### **4.2.3.9. Absciscic acid content**

The content of absciscic acid, which normally goes hand and in hand with growth inhibition, was also contrary to the normal lines of thought. However like in the case of the phenol content, the ABA content was found to be highest in the treatment in treatments showing maximum growth and this plants decreased gradually to the treatments showing intermediate growth and to least effective treatment plants (Fig. 11). However, the difference between treatments means were not significant. The Rf value of the ABA was found to as 0.44. The banding pattern observed is presented in Plate 6.

### **4.3. Activation of seedling growth using arbuscular mycorrhizal fungi (AMF) and Azospirillum**

#### **4.3.1. Morphological characters of seedlings**

The mean data on morphological characters of seedlings at three and six months stages are presented in Table 28 and nine months stage in Table 29 and twelve months are presented in the Table 30.

##### **4.3.1.1. Height and increments at quarterly intervals**

There were no significant differences observed in height at third month stage as plants were selected based on uniformity. At six months stage, maximum and significantly higher height were recorded in the plants inoculated with *Glomus*

**Fig. 11. Total phenols and abscisic acid content of the various growth regulators treated plants showing best, intermediate and least growth in mangosteen (*Garcinia mangostana* L.)**

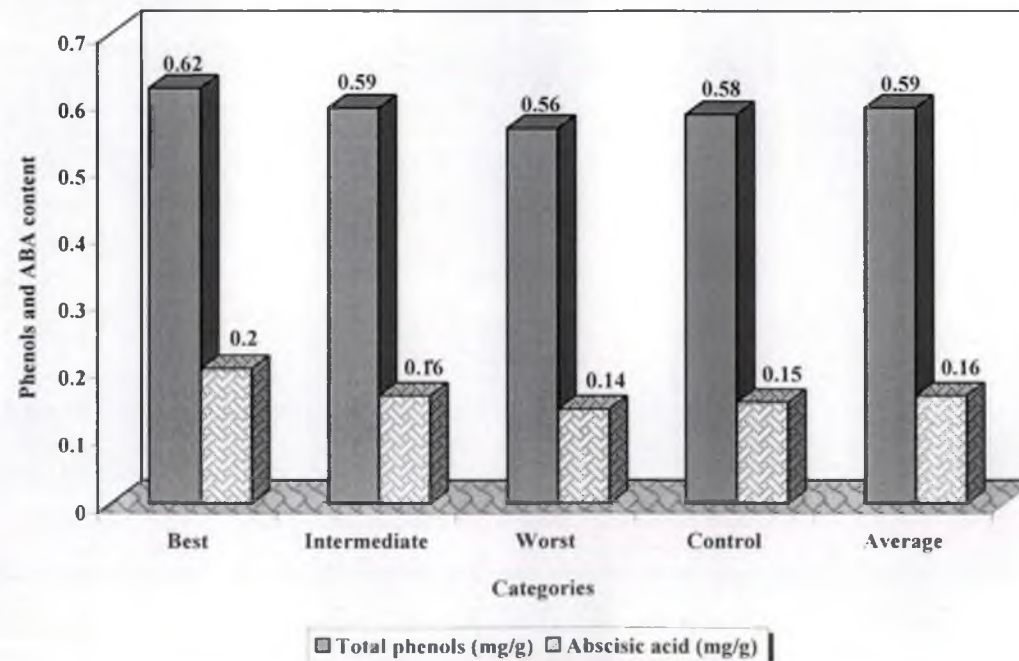


Table 28. Morphological characters of three and six month old mangosteen (*Garcinia mangostana* L.) seedlings inoculated with arbuscular mycorrhizal fungi (AMF) and *Azospirillum*.

| Treatments     | Three month stage<br>(Before the treatment) |               |                              | Six month stage<br>(Three months after inoculation) |                                |                    |                               |                                 |                                              |
|----------------|---------------------------------------------|---------------|------------------------------|-----------------------------------------------------|--------------------------------|--------------------|-------------------------------|---------------------------------|----------------------------------------------|
|                | Height<br>(cm)                              | Girth<br>(cm) | Total<br>number<br>of leaves | Height<br>(cm)                                      | Increment<br>of height<br>(cm) | Girth<br>(cm)      | Increment<br>of girth<br>(cm) | Total<br>number<br>of<br>leaves | Increment<br>of total<br>number of<br>leaves |
| G.m 5          | 4.03                                        | 0.99          | 4.00                         | 5.67 <sup>ab</sup>                                  | 1.63 <sup>ab</sup>             | 1.11 <sup>b</sup>  | 0.12                          | 6.00                            | 2.00                                         |
| G.m 10         | 3.93                                        | 1.20          | 3.67                         | 5.60 <sup>ab</sup>                                  | 1.67 <sup>ab</sup>             | 1.35 <sup>ab</sup> | 0.15                          | 5.67                            | 2.00                                         |
| G.m 20         | 6.23                                        | 1.10          | 3.33                         | 8.63 <sup>ab</sup>                                  | 2.40 <sup>ab</sup>             | 1.35 <sup>ab</sup> | 0.26                          | 6.33                            | 3.00                                         |
| G.f 5          | 4.73                                        | 1.02          | 2.67                         | 6.27 <sup>ab</sup>                                  | 1.53 <sup>ab</sup>             | 1.20 <sup>ab</sup> | 0.17                          | 6.67                            | 4.00                                         |
| G.f 10         | 5.57                                        | 1.04          | 4.33                         | 8.23 <sup>ab</sup>                                  | 2.67 <sup>ab</sup>             | 1.36 <sup>ab</sup> | 0.32                          | 8.00                            | 3.67                                         |
| G.f 20         | 3.57                                        | 1.04          | 3.33                         | 4.83 <sup>b</sup>                                   | 1.27 <sup>ab</sup>             | 1.22 <sup>ab</sup> | 0.18                          | 5.67                            | 2.33                                         |
| Az. 5          | 4.33                                        | 1.18          | 3.00                         | 6.00 <sup>ab</sup>                                  | 1.67 <sup>ab</sup>             | 1.25 <sup>ab</sup> | 0.07                          | 6.33                            | 3.33                                         |
| Az. 10         | 5.53                                        | 1.05          | 4.00                         | 7.47 <sup>ab</sup>                                  | 1.93 <sup>ab</sup>             | 1.30 <sup>ab</sup> | 0.25                          | 6.67                            | 2.67                                         |
| Az. 20         | 4.43                                        | 1.04          | 3.33                         | 7.07 <sup>ab</sup>                                  | 2.63 <sup>ab</sup>             | 1.26 <sup>ab</sup> | 0.22                          | 7.67                            | 4.33                                         |
| Az.5 + G.m 5   | 3.27                                        | 1.06          | 3.33                         | 4.90 <sup>b</sup>                                   | 1.63 <sup>ab</sup>             | 1.18 <sup>ab</sup> | 0.11                          | 6.00                            | 2.67                                         |
| Az10 + G.m5    | 3.50                                        | 1.15          | 4.67                         | 5.67 <sup>ab</sup>                                  | 2.17 <sup>ab</sup>             | 1.22 <sup>ab</sup> | 0.07                          | 7.33                            | 2.67                                         |
| Az.20 + G.m5   | 2.97                                        | 1.01          | 3.67                         | 4.77 <sup>b</sup>                                   | 1.80 <sup>ab</sup>             | 1.16 <sup>ab</sup> | 0.15                          | 7.33                            | 3.67                                         |
| Az.5 + G.m10   | 4.37                                        | 1.17          | 4.00                         | 6.37 <sup>ab</sup>                                  | 2.00 <sup>ab</sup>             | 1.35 <sup>ab</sup> | 0.18                          | 7.33                            | 3.33                                         |
| Az.10 + G.m10  | 3.98                                        | 1.03          | 4.00                         | 5.97 <sup>ab</sup>                                  | 1.98 <sup>ab</sup>             | 1.26 <sup>ab</sup> | 0.22                          | 6.67                            | 2.67                                         |
| Az.20 + G.m10  | 4.40                                        | 1.03          | 4.00                         | 7.47 <sup>ab</sup>                                  | 3.07 <sup>a</sup>              | 1.32 <sup>ab</sup> | 0.29                          | 8.00                            | 4.00                                         |
| Az.5 + G.m20   | 4.07                                        | 1.02          | 4.67                         | 6.73 <sup>ab</sup>                                  | 2.67 <sup>ab</sup>             | 1.39 <sup>ab</sup> | 0.37                          | 8.67                            | 4.00                                         |
| Az.10 + G.m20  | 4.33                                        | 1.03          | 4.00                         | 7.17 <sup>ab</sup>                                  | 2.83 <sup>a</sup>              | 1.31 <sup>ab</sup> | 0.28                          | 8.00                            | 4.00                                         |
| Az.20 + G.m20  | 4.10                                        | 0.90          | 3.33                         | 5.87 <sup>ab</sup>                                  | 1.77 <sup>ab</sup>             | 1.11 <sup>b</sup>  | 0.21                          | 7.33                            | 4.00                                         |
| Az.5 + G.f 5   | 5.43                                        | 0.90          | 2.33                         | 7.23 <sup>ab</sup>                                  | 1.80 <sup>ab</sup>             | 1.16 <sup>ab</sup> | 0.26                          | 7.33                            | 5.00                                         |
| Az.10 + G.f 5  | 6.37                                        | 1.19          | 4.00                         | 9.33 <sup>a</sup>                                   | 2.97 <sup>a</sup>              | 1.48 <sup>a</sup>  | 0.29                          | 8.00                            | 4.00                                         |
| Az. 20 + G.f 5 | 4.33                                        | 1.02          | 3.67                         | 7.07 <sup>ab</sup>                                  | 2.73 <sup>ab</sup>             | 1.34 <sup>ab</sup> | 0.32                          | 7.67                            | 4.00                                         |
| Az. 5 + G.f 10 | 3.63                                        | 1.17          | 4.67                         | 6.00 <sup>ab</sup>                                  | 2.37 <sup>ab</sup>             | 1.35 <sup>ab</sup> | 0.19                          | 7.33                            | 2.67                                         |
| Az.10 + G.f 10 | 4.93                                        | 1.15          | 4.00                         | 7.73 <sup>ab</sup>                                  | 2.80 <sup>ab</sup>             | 1.27 <sup>ab</sup> | 0.12                          | 6.33                            | 2.33                                         |
| Az.20 + G.f 10 | 4.23                                        | 1.11          | 3.33                         | 5.13 <sup>ab</sup>                                  | 0.90 <sup>b</sup>              | 1.35 <sup>ab</sup> | 0.24                          | 6.67                            | 3.33                                         |
| Az.5 + G.f 20  | 4.57                                        | 1.03          | 3.33                         | 7.70 <sup>ab</sup>                                  | 3.13 <sup>a</sup>              | 1.27 <sup>ab</sup> | 0.24                          | 6.33                            | 3.00                                         |
| Az.10 + G.f 20 | 3.90                                        | 1.17          | 4.00                         | 6.87 <sup>ab</sup>                                  | 2.97 <sup>a</sup>              | 1.44 <sup>ab</sup> | 0.27                          | 8.00                            | 4.00                                         |
| Az.20 + G.f 20 | 4.10                                        | 0.88          | 3.00                         | 5.83 <sup>ab</sup>                                  | 1.73 <sup>ab</sup>             | 1.11 <sup>b</sup>  | 0.22                          | 6.67                            | 3.67                                         |
| SSP10 alone    | 3.33                                        | 1.04          | 2.00                         | 5.60 <sup>ab</sup>                                  | 2.27 <sup>ab</sup>             | 1.32 <sup>ab</sup> | 0.28                          | 6.00                            | 4.00                                         |
| Control        | 5.50                                        | 1.18          | 2.67                         | 7.63 <sup>ab</sup>                                  | 2.13 <sup>ab</sup>             | 1.38 <sup>ab</sup> | 0.20                          | 6.67                            | 4.00                                         |
| Mean values    | 4.40                                        | 1.07          | 3.60                         | 6.58                                                | 2.18                           | 1.28               | 0.22                          | 6.99                            | 3.39                                         |
| CD. (p< 0.05)  | NS                                          | NS            | NS                           | 3.40                                                | 1.55                           | 0.29               | NS                            | NS                              | NS                                           |

Figures with same alphabets do not differ significantly at 5% level.

G.m- *Glomus mosseae*, G.f- *Glomus fasciculatum*, Az.- *Azospirillum*

*fasciculatum* (G.f.) 5 g + Azospirillum (Az.) 10 g + single super phosphate (SSP) 10 g. All other treatments were at par with each other including the control, except the two treatments *Glomus mosseae* (G.m.) 5g + Az. 5 g + SSP 10 g and G.m. 5g + Az. 20 g + SSP 10 g, which recorded very low values. At nine months stage, maximum significantly superior height was recorded in the plants inoculated with G.f. 5g + Az. 10 g + SSP 10 g, all other treatments were at par with each other. At twelve months stage, maximum height was observed in the plants inoculated with G.f. 5g + Az. 10 g + SSP 10 g which was significantly superior to all other treatments except the next best combination of inoculation with G.f. 5g + Az. 20g + SSP 10 g.

With regard to the increment in height at various intervals, it was observed that at six months stage significantly higher increment was recorded in the plants inoculated with G.f. 20g + Az. 5 g + SSP 10 g and at which was at par with the treatments G.m. 10 g + Az. 20 g + SSP 10 g, G.f. 20g + Az. 10 g + SSP 10 g and G.m. 20g + Az. 10 g + SSP 10 g. At nine months stage, maximum and higher increment in height were recorded in the plants inoculated with G.f. 5g + Az. 20 g + SSP 10 g all other treatments were at par with each other. At twelve-months stage, significantly the highest increment in height was recorded in the plants inoculated with same treatment as in the six-months stage followed by SSP 10 g alone treated plants. These treatments were statistically superior in rate of increments in height than other treatments.

#### 4.3.1.2. Girth and increments at quarterly intervals

Since maximum care was bestowed in the selection of uniform plants there were no significant differences observed at the early stage. At sixth, ninth and twelve months stage, maximum girth was recorded in the same treatment combination of G.f. 5g + Az. 10g + SSP 10 g, followed by G.m. 20g + Az. 5 g + SSP 10 g at six months stage, G.f. 20g + Az. 10 g + SSP 10 g at nine months stage and G.f. 5g + Az. 20g + SSP 10 g at twelve months stage. At six months stage, G.f. 5g + Az. 10g + SSP 10 g was at par with all other treatments including control except G.m. 5g + SSP 10 g, G.m. 20g + Az. 20g + SSP 10 g and G.f. 20g + Az. 20g + SSP 10 g. At the nine months and twelve-months stages the best treatment was significantly superior to all other treatments.

Table 29. Morphological characters of nine months old mangosteen (*Garcinia mangostana* L.) seedlings inoculated with Arbuscular mycorrhizal fungi (AMF) and *Azospirillum*.

| Treatments<br>(g) | Nine month stage<br>(Six months after inoculation) |                                |                      |                               |                              |                                           |
|-------------------|----------------------------------------------------|--------------------------------|----------------------|-------------------------------|------------------------------|-------------------------------------------|
|                   | Height<br>(cm)                                     | Increment<br>in height<br>(cm) | Girth<br>(cm)        | Increment<br>in girth<br>(cm) | Total<br>number of<br>leaves | Increment in<br>total number<br>of leaves |
| G.m 5             | 7.70 <sup>ab</sup>                                 | 2.03 <sup>abc</sup>            | 1.23 <sup>cd</sup>   | 0.11 <sup>abcd</sup>          | 10.67 <sup>ab</sup>          | 4.67 <sup>ab</sup>                        |
| G.m 10            | 6.40 <sup>b</sup>                                  | 0.80 <sup>bc</sup>             | 1.51 <sup>abcd</sup> | 0.16 <sup>abcd</sup>          | 6.67 <sup>b</sup>            | 1.00 <sup>c</sup>                         |
| G.m 20            | 9.90 <sup>ab</sup>                                 | 1.27 <sup>abc</sup>            | 1.51 <sup>abcd</sup> | 0.16 <sup>abcd</sup>          | 9.00 <sup>ab</sup>           | 2.67 <sup>abc</sup>                       |
| G.f 5             | 7.67 <sup>ab</sup>                                 | 1.40 <sup>abc</sup>            | 1.30 <sup>bcd</sup>  | 0.11 <sup>bcd</sup>           | 9.33 <sup>ab</sup>           | 2.67 <sup>abc</sup>                       |
| G.f 10            | 9.90 <sup>ab</sup>                                 | 1.67 <sup>abc</sup>            | 1.47 <sup>abcd</sup> | 0.11 <sup>abcd</sup>          | 12.67 <sup>a</sup>           | 4.67 <sup>ab</sup>                        |
| G.f 20            | 6.83 <sup>ab</sup>                                 | 2.00 <sup>abc</sup>            | 1.28 <sup>bcd</sup>  | 0.06 <sup>d</sup>             | 8.00 <sup>ab</sup>           | 2.33 <sup>abc</sup>                       |
| Az. 5             | 7.75 <sup>ab</sup>                                 | 1.75 <sup>abc</sup>            | 1.42 <sup>abcd</sup> | 0.17 <sup>abcd</sup>          | 9.67 <sup>ab</sup>           | 3.33 <sup>abc</sup>                       |
| Az. 10            | 8.40 <sup>ab</sup>                                 | 0.93 <sup>abc</sup>            | 1.63 <sup>abcd</sup> | 0.33 <sup>a</sup>             | 9.33 <sup>ab</sup>           | 2.67 <sup>abc</sup>                       |
| Az. 20            | 8.03 <sup>ab</sup>                                 | 0.97 <sup>abc</sup>            | 1.43 <sup>abcd</sup> | 0.16 <sup>abcd</sup>          | 8.67 <sup>ab</sup>           | 1.00 <sup>c</sup>                         |
| Az 5 + G.m 5      | 5.07 <sup>b</sup>                                  | 0.17 <sup>c</sup>              | 1.33 <sup>bcd</sup>  | 0.15 <sup>abcd</sup>          | 8.00 <sup>ab</sup>           | 2.00 <sup>abc</sup>                       |
| Az 10 + G.m 5     | 8.13 <sup>ab</sup>                                 | 2.47 <sup>ab</sup>             | 1.46 <sup>abcd</sup> | 0.24 <sup>abcd</sup>          | 11.00 <sup>ab</sup>          | 3.67 <sup>abc</sup>                       |
| Az 20 + G.m 5     | 6.13 <sup>b</sup>                                  | 1.37 <sup>abc</sup>            | 1.34 <sup>bcd</sup>  | 0.18 <sup>abcd</sup>          | 9.33 <sup>ab</sup>           | 2.00 <sup>abc</sup>                       |
| Az 5 + G.m 10     | 7.73 <sup>ab</sup>                                 | 1.37 <sup>abc</sup>            | 1.49 <sup>abcd</sup> | 0.14 <sup>abcd</sup>          | 12.67 <sup>a</sup>           | 5.33 <sup>a</sup>                         |
| Az 10 + G.m 10    | 7.33 <sup>ab</sup>                                 | 1.37 <sup>abc</sup>            | 1.41 <sup>abcd</sup> | 0.15 <sup>abcd</sup>          | 10.00 <sup>ab</sup>          | 3.33 <sup>abc</sup>                       |
| Az 20 + G.m 10    | 10.20 <sup>ab</sup>                                | 2.73 <sup>ab</sup>             | 1.60 <sup>abcd</sup> | 0.29 <sup>abc</sup>           | 13.33 <sup>a</sup>           | 5.33 <sup>a</sup>                         |
| Az 5 + G.m 20     | 9.27 <sup>ab</sup>                                 | 2.53 <sup>ab</sup>             | 1.53 <sup>abcd</sup> | 0.15 <sup>abcd</sup>          | 12.67 <sup>a</sup>           | 4.00 <sup>abc</sup>                       |
| Az 10 + G.m 20    | 9.50 <sup>ab</sup>                                 | 2.33 <sup>ab</sup>             | 1.54 <sup>abcd</sup> | 0.22 <sup>abcd</sup>          | 12.67 <sup>a</sup>           | 4.67 <sup>ab</sup>                        |
| Az 20 + G.m 20    | 8.00 <sup>ab</sup>                                 | 2.13 <sup>abc</sup>            | 1.29 <sup>bcd</sup>  | 0.18 <sup>abcd</sup>          | 10.33 <sup>ab</sup>          | 3.00 <sup>abc</sup>                       |
| Az 5 + G.f 5      | 8.73 <sup>ab</sup>                                 | 1.50 <sup>abc</sup>            | 1.41 <sup>abcd</sup> | 0.26 <sup>abcd</sup>          | 9.33 <sup>ab</sup>           | 2.00 <sup>abc</sup>                       |
| Az 10 + G.f 5     | 11.83 <sup>a</sup>                                 | 2.50 <sup>ab</sup>             | 1.81 <sup>a</sup>    | 0.33 <sup>a</sup>             | 12.00 <sup>ab</sup>          | 4.00 <sup>abc</sup>                       |
| Az 20 + G.f 5     | 10.00 <sup>ab</sup>                                | 2.93 <sup>a</sup>              | 1.65 <sup>abc</sup>  | 0.31 <sup>ab</sup>            | 13.00 <sup>a</sup>           | 5.33 <sup>a</sup>                         |
| Az 5 + G.f 10     | 8.43 <sup>ab</sup>                                 | 2.43 <sup>ab</sup>             | 1.49 <sup>abcd</sup> | 0.14 <sup>abcd</sup>          | 12.00 <sup>ab</sup>          | 4.67 <sup>ab</sup>                        |
| Az 10 + G.f 10    | 9.23 <sup>ab</sup>                                 | 1.50 <sup>abc</sup>            | 1.41 <sup>abcd</sup> | 0.14 <sup>abcd</sup>          | 10.67 <sup>ab</sup>          | 4.33 <sup>abc</sup>                       |
| Az 20 + G.f 10    | 7.23 <sup>ab</sup>                                 | 2.10 <sup>abc</sup>            | 1.51 <sup>abcd</sup> | 0.16 <sup>abcd</sup>          | 10.00 <sup>ab</sup>          | 3.33 <sup>abc</sup>                       |
| Az 5 + G.f 20     | 8.37 <sup>ab</sup>                                 | 0.67 <sup>bc</sup>             | 1.36 <sup>abcd</sup> | 0.10 <sup>bcd</sup>           | 8.00 <sup>ab</sup>           | 1.67 <sup>bc</sup>                        |
| Az 10 + G.f 20    | 9.17 <sup>ab</sup>                                 | 2.30 <sup>ab</sup>             | 1.70 <sup>ab</sup>   | 0.26 <sup>abcd</sup>          | 10.67 <sup>ab</sup>          | 2.67 <sup>abc</sup>                       |
| Az 20 + G.f 20    | 8.33 <sup>ab</sup>                                 | 2.50 <sup>ab</sup>             | 1.17 <sup>d</sup>    | 0.07 <sup>cd</sup>            | 10.33 <sup>ab</sup>          | 3.67 <sup>abc</sup>                       |
| SSP10 alone       | 7.97 <sup>ab</sup>                                 | 2.37 <sup>ab</sup>             | 1.56 <sup>abcd</sup> | 0.24 <sup>abcd</sup>          | 10.67 <sup>ab</sup>          | 4.67 <sup>ab</sup>                        |
| Control           | 9.67 <sup>ab</sup>                                 | 2.03 <sup>abc</sup>            | 1.51 <sup>abcd</sup> | 0.13 <sup>abcd</sup>          | 10.00 <sup>ab</sup>          | 3.33 <sup>abc</sup>                       |
| Mean values       | 8.38                                               | 1.08                           | 1.46                 | 0.18                          | 10.37                        | 3.38                                      |
| CD. (p< 0.05)     | 4.20                                               | 1.70                           | 0.38                 | 0.18                          | 4.49                         | 2.96                                      |

Figures with same alphabets do not differ significantly at 5% level.

G.m - *Glomus mosseae*, G.f- *Glomus fasciculatum*, Az - *Azospirillum*

With regard to the increment in girth at six months stage, maximum increment in girth was recorded in the plants inoculated with G.m. 20 g + Az. 5 g + SSP 10 g followed by treatments G.f. 5 g + Az. 20 g + SSP 20 g and G.f. 10 g + SSP 10 g, which gave the same values. However, there were no significant differences observed among the treatments. At nine months stage, maximum increment in girth were observed in treatment combination Az. 10 g + SSP 10 g and G.f. 5g + Az. 10 g which were at par with each other and significantly higher than all the treatment G.f. 5g + Az. 20 g + SSP 10 g. These three treatments were significantly higher than other treatments including control. At twelve months stage, maximum increment was observed in the treatment combination of G.f. 5g + Az. 20 g + SSP 10 g and this was significantly superior to G.m. 10g + Az. 20 g + SSP 10 g. These two treatments were significantly superior to all other treatments including the control.

#### 4.3.1.3. Total number of leaves

Maximum care was taken to select plants with uniform number of leaves prior to application of the treatments and hence no significant differences were observed in the leaf count at the early stage. At six months stage, maximum leaf count was recorded in the plants inoculated with G.m. 20g + Az. 5 g + SSP 10 g followed by the treatments, G.m. 10g + Az. 20 g + SSP 10 g, G.f. 10g + SSP 10 g, G.f. 5g + Az. 10g + SSP 10 g and G.f. 20g + Az. 10 g + SSP 10 g, which gave the same leaf count. However, there were no significant differences observed between the treatment means. At nine months stage, maximum leaf count was recorded in the plants treated at par with the treatments G.m. 20g + Az. 10 g + SSP 10 g, G.m. 20g + Az. 20 g + SSP 10 g, G.m. 10g + Az. 5 g + SSP 10 g and G.f. 10 g + SSP 10 g. At twelve months stage, maximum leaf count was recorded in the treatment G.m. 10g + Az. 20g + SSP 10 g which was significantly higher than G.f. 5g + Az. 20g + SSP 10 g. These two treatments were significantly superior to all other treatments including the control.

Maximum increment at six months stage was recorded in the plants treated with G.f. 5g + Az. 5 g + SSP 10 g followed by Az. 20 g + SSP 10 g. However, the treatment effects did not differ significantly. At nine months stage, maximum increment was recorded in the treatment G.m. 10g + Az. 5 g + SSP 10 g,

**Table 30. Morphological characters of twelve months old mangosteen (*Garcinia mangostana* L.) seedlings inoculated with arbuscular mycorrhizal fungi (AMF) and Azospirillum.**

| Treatments (g) | Twelve month stage<br>(Nine months after inoculation) |                          |                      |                         |                        |                                     |                         |                     |                                    |                     |
|----------------|-------------------------------------------------------|--------------------------|----------------------|-------------------------|------------------------|-------------------------------------|-------------------------|---------------------|------------------------------------|---------------------|
|                | Height (cm)                                           | Increment in height (cm) | Girth (cm)           | Increment in girth (cm) | Total number of leaves | Increment in total number of leaves | New flushes / year (No) | Leaves / flush (No) | Total leaf area (cm <sup>2</sup> ) | Survival rate (%)   |
| G.m 5          | 10.13 <sup>c</sup>                                    | 2.43 <sup>bcd</sup>      | 1.31 <sup>d</sup>    | 0.09 <sup>d</sup>       | 12.67 <sup>abcde</sup> | 2.00 <sup>abcd</sup>                | 1.57 <sup>ab</sup>      | 2.00                | 82.61 <sup>bc</sup>                | 100.00 <sup>a</sup> |
| G.m 10         | 7.73 <sup>c</sup>                                     | 1.33 <sup>d</sup>        | 1.62 <sup>abcd</sup> | 0.11 <sup>cd</sup>      | 8.00 <sup>e</sup>      | 1.33 <sup>abcd</sup>                | 1.12 <sup>b</sup>       | 2.00                | 18.93 <sup>c</sup>                 | 100.00 <sup>a</sup> |
| G.m 20         | 11.23 <sup>bc</sup>                                   | 1.33 <sup>d</sup>        | 1.77 <sup>abcd</sup> | 0.25 <sup>abcd</sup>    | 12.33 <sup>abcde</sup> | 3.33 <sup>ab</sup>                  | 1.67 <sup>ab</sup>      | 2.00                | 31.66 <sup>c</sup>                 | 100.00 <sup>a</sup> |
| G.f 5          | 8.93 <sup>c</sup>                                     | 1.27 <sup>d</sup>        | 1.38 <sup>cd</sup>   | 0.08 <sup>d</sup>       | 11.00 <sup>abcde</sup> | 1.67 <sup>abcd</sup>                | 1.54 <sup>ab</sup>      | 2.00                | 42.43 <sup>bc</sup>                | 100.00 <sup>a</sup> |
| G.f 10         | 11.57 <sup>bc</sup>                                   | 1.67 <sup>d</sup>        | 1.68 <sup>abcd</sup> | 0.21 <sup>abcd</sup>    | 14.33 <sup>abcd</sup>  | 1.67 <sup>abcd</sup>                | 2.00 <sup>a</sup>       | 2.00                | 107.00 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| G.f 20         | 8.43 <sup>c</sup>                                     | 1.60 <sup>d</sup>        | 1.52 <sup>abcd</sup> | 0.23 <sup>abcd</sup>    | 8.67 <sup>de</sup>     | 0.67 <sup>cd</sup>                  | 1.22 <sup>ab</sup>      | 2.00                | 40.29 <sup>c</sup>                 | 100.00 <sup>a</sup> |
| Az. 5          | 10.50 <sup>c</sup>                                    | 2.75 <sup>bcd</sup>      | 1.65 <sup>abcd</sup> | 0.24 <sup>abcd</sup>    | 11.00 <sup>abcde</sup> | 1.33 <sup>abcd</sup>                | 1.60 <sup>ab</sup>      | 2.00                | 111.10 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Az. 10         | 10.47 <sup>c</sup>                                    | 2.07 <sup>d</sup>        | 2.13 <sup>abcd</sup> | 0.50 <sup>abcd</sup>    | 9.67 <sup>bcd</sup>    | 0.33 <sup>d</sup>                   | 1.42 <sup>ab</sup>      | 2.00                | 84.49 <sup>bc</sup>                | 100.00 <sup>a</sup> |
| Az. 20         | 10.33 <sup>c</sup>                                    | 2.30 <sup>bcd</sup>      | 1.60 <sup>abcd</sup> | 0.18 <sup>bcd</sup>     | 10.33 <sup>abcde</sup> | 1.67 <sup>abcd</sup>                | 1.55 <sup>ab</sup>      | 2.00                | 47.77 <sup>bc</sup>                | 100.00 <sup>a</sup> |
| Az.5 + G.m 5   | 8.70 <sup>c</sup>                                     | 3.63 <sup>bcd</sup>      | 1.51 <sup>abcd</sup> | 0.18 <sup>bcd</sup>     | 9.00 <sup>cde</sup>    | 1.00 <sup>bcd</sup>                 | 1.21 <sup>ab</sup>      | 2.00                | 20.00 <sup>c</sup>                 | 100.00 <sup>a</sup> |
| Az.10 + G.m5   | 11.23 <sup>bc</sup>                                   | 3.10 <sup>bcd</sup>      | 1.76 <sup>abcd</sup> | 0.30 <sup>abcd</sup>    | 13.00 <sup>abcde</sup> | 2.00 <sup>abcd</sup>                | 1.80 <sup>ab</sup>      | 2.00                | 89.48 <sup>abc</sup>               | 100.00 <sup>a</sup> |
| Az.20 + G.m5   | 8.83 <sup>c</sup>                                     | 2.70 <sup>bcd</sup>      | 1.54 <sup>abcd</sup> | 0.20 <sup>abcd</sup>    | 11.33 <sup>abcde</sup> | 2.00 <sup>abcd</sup>                | 1.68 <sup>ab</sup>      | 2.00                | 63.95 <sup>bc</sup>                | 100.00 <sup>a</sup> |
| Az.5 + G.m10   | 11.73 <sup>abc</sup>                                  | 4.00 <sup>abcd</sup>     | 1.80 <sup>abcd</sup> | 0.31 <sup>abcd</sup>    | 14.33 <sup>abcd</sup>  | 1.67 <sup>abcd</sup>                | 1.93 <sup>ab</sup>      | 2.00                | 119.80 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Az.10+ G.m10   | 9.33 <sup>c</sup>                                     | 2.00 <sup>d</sup>        | 1.64 <sup>abcd</sup> | 0.23 <sup>abcd</sup>    | 12.00 <sup>abcde</sup> | 2.00 <sup>abcd</sup>                | 1.75 <sup>ab</sup>      | 2.00                | 76.21 <sup>bc</sup>                | 100.00 <sup>a</sup> |
| Az.20+ G.m10   | 14.10 <sup>abc</sup>                                  | 3.90 <sup>abcd</sup>     | 2.18 <sup>abc</sup>  | 0.58 <sup>ab</sup>      | 16.33 <sup>a</sup>     | 3.00 <sup>abc</sup>                 | 2.00 <sup>a</sup>       | 2.00                | 181.90 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Az.5 + G.m20   | 13.27 <sup>abc</sup>                                  | 4.00 <sup>abcd</sup>     | 1.91 <sup>abcd</sup> | 0.38 <sup>abcd</sup>    | 14.67 <sup>abcd</sup>  | 2.00 <sup>abcd</sup>                | 1.64 <sup>ab</sup>      | 2.00                | 205.20 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Az.10+ G.m20   | 13.07 <sup>abc</sup>                                  | 3.57 <sup>bcd</sup>      | 1.91 <sup>abcd</sup> | 0.37 <sup>abcd</sup>    | 14.67 <sup>abcd</sup>  | 2.00 <sup>abcd</sup>                | 1.68 <sup>ab</sup>      | 2.00                | 168.50 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Az.20+ G.m20   | 11.00 <sup>bc</sup>                                   | 3.00 <sup>bcd</sup>      | 1.43 <sup>bcd</sup>  | 0.14 <sup>cd</sup>      | 12.00 <sup>abcde</sup> | 1.67 <sup>abcd</sup>                | 1.34 <sup>ab</sup>      | 2.00                | 70.01 <sup>bc</sup>                | 100.00 <sup>a</sup> |
| Az.5 + G.f 5   | 11.70 <sup>abc</sup>                                  | 2.97 <sup>bcd</sup>      | 1.82 <sup>abcd</sup> | 0.41 <sup>abcd</sup>    | 12.33 <sup>abcde</sup> | 3.00 <sup>abc</sup>                 | 1.43 <sup>ab</sup>      | 2.00                | 133.40 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Az.10 + G.f 5  | 18.30 <sup>a</sup>                                    | 6.47 <sup>abc</sup>      | 2.32 <sup>a</sup>    | 0.52 <sup>abcd</sup>    | 15.00 <sup>abc</sup>   | 3.00 <sup>abc</sup>                 | 2.00 <sup>a</sup>       | 2.00                | 287.50 <sup>a</sup>                | 100.00 <sup>a</sup> |
| Az. 20 + G.f 5 | 17.77 <sup>ab</sup>                                   | 7.77 <sup>a</sup>        | 2.28 <sup>ab</sup>   | 0.63 <sup>a</sup>       | 15.33 <sup>ab</sup>    | 2.33 <sup>abcd</sup>                | 2.00 <sup>a</sup>       | 2.00                | 211.60 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Az. 5 + G.f 10 | 11.43 <sup>bc</sup>                                   | 3.00 <sup>bcd</sup>      | 1.81 <sup>abcd</sup> | 0.32 <sup>abcd</sup>    | 14.00 <sup>abcde</sup> | 2.00 <sup>abcd</sup>                | 1.99 <sup>a</sup>       | 2.00                | 106.90 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Az.10 + G.f 10 | 11.80 <sup>abc</sup>                                  | 2.57 <sup>bcd</sup>      | 1.67 <sup>abcd</sup> | 0.25 <sup>abcd</sup>    | 13.00 <sup>abcde</sup> | 2.33 <sup>abcd</sup>                | 1.83 <sup>ab</sup>      | 2.00                | 246.60 <sup>ab</sup>               | 100.00 <sup>a</sup> |
| Az.20 + G.f 10 | 9.47 <sup>c</sup>                                     | 2.23 <sup>cd</sup>       | 1.64 <sup>abcd</sup> | 0.13 <sup>cd</sup>      | 11.33 <sup>abcde</sup> | 1.33 <sup>abcd</sup>                | 1.75 <sup>ab</sup>      | 2.00                | 78.29 <sup>bc</sup>                | 100.00 <sup>a</sup> |
| Az.5 + G.f 20  | 9.47 <sup>c</sup>                                     | 1.10 <sup>d</sup>        | 1.59 <sup>abcd</sup> | 0.23 <sup>abcd</sup>    | 11.00 <sup>abcde</sup> | 3.00 <sup>abc</sup>                 | 1.54 <sup>ab</sup>      | 2.00                | 143.70 <sup>abc</sup>              | 66.67 <sup>b</sup>  |
| Az.10 + G.f 20 | 13.17 <sup>abc</sup>                                  | 4.00 <sup>abcd</sup>     | 2.23 <sup>abc</sup>  | 0.53 <sup>abc</sup>     | 14.33 <sup>abcd</sup>  | 3.67 <sup>a</sup>                   | 2.00 <sup>a</sup>       | 2.00                | 223.30 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Az.20 + G.f 20 | 10.23 <sup>c</sup>                                    | 1.90 <sup>d</sup>        | 1.44 <sup>bcd</sup>  | 0.27 <sup>abcd</sup>    | 11.67 <sup>abcde</sup> | 1.33 <sup>abcd</sup>                | 2.00 <sup>a</sup>       | 2.00                | 54.21 <sup>bc</sup>                | 100.00 <sup>a</sup> |
| SSP10 alone    | 14.50 <sup>abc</sup>                                  | 6.53 <sup>ab</sup>       | 2.08 <sup>abcd</sup> | 0.52 <sup>abcd</sup>    | 14.00 <sup>abcde</sup> | 3.33 <sup>ab</sup>                  | 1.68 <sup>ab</sup>      | 2.00                | 123.90 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Control        | 12.30 <sup>abc</sup>                                  | 2.63 <sup>bcd</sup>      | 1.83 <sup>abcd</sup> | 0.32 <sup>abcd</sup>    | 12.33 <sup>abcde</sup> | 2.33 <sup>abcd</sup>                | 1.12 <sup>b</sup>       | 2.00                | 169.60 <sup>abc</sup>              | 100.00 <sup>a</sup> |
| Mean values    | 11.41                                                 | 3.03                     | 1.76                 | 0.30                    | 12.40                  | 2.03                                | 1.66                    | 2.00                | 115.19                             | 97.70               |
| CD. (p < 0.05) | 5.63                                                  | 3.51                     | 0.69                 | 0.35                    | 5.03                   | 1.96                                | 0.69                    | NS                  | 166.20                             | 24.78               |

Figures with same alphabets do not differ significantly at 5% level.

G.m- *Glomus mosseae*, G.f- *Glomus fasciculatum*, Az. - *Azospirillum*

which was at par with the treatments G.m. 10g + Az. 20 g + SSP 10 g and G.f. 5g + Az. 20g + SSP 10 g. At twelve months stage, maximum increment was observed in the treatment G.f. 20g + Az. 10 g + SSP 10 g.

#### **4.3.1.3. Number of new flushes/year**

Maximum number of new flushes/year were recorded in the plants inoculated with G.f. 10 g + SSP 10 g, G.m. 10g + Az. 20 g + SSP 10 g, G.f. 5g + Az. 10 g + SSP 10 g, G.f. 5g + Az. 20 g + SSP 10 g, G.f. 20g + Az. 10 g + SSP 10 g and G.f. 20g + Az. 20 g + SSP 10 g which gave the same number of flush count, followed by G.f. 10 g + Az. 5 g + SSP 10 g. All the above treatments were significantly superior to the other treatments.

#### **4.3.1.4. Number of leaves/flush**

There were no variation observed among the treatments with regard to the number of leaves/flush and all the treatments gave an average of two leaves.

#### **4.3.1.5. Leaf area**

Maximum leaf area was recorded in the plants inoculated with G.f. 5g + Az. 10 g + SSP 10 g followed by G.f. 10g + Az. 10 g + SSP 10 g. These two treatments were at par with each other and were relatively superior to all other treatments, including the control.

#### **4.3.1.6. Survival rate**

Cent per cent survival rate was observed in all the treatments except G.f. 20 g + Az. 5g + SSP 10 g, which gave only 66.67 per cent survival rate.

### **4.3.2. Shoot and root morphological characters**

The mean data related to the characters of shoot and root of one-year-old mangosteen seedlings are presented in the Table 31.

#### **4.3.2.1. Fresh weight of shoot and root**

Maximum fresh weight of the shoot was recorded in the plants inoculated with G.f. 20 g + Az. 10 g + SSP 10 g, which was significantly superior to all other treatments. This was followed by G.f. 5g + Az. 10g + SSP 10 g, G.f. 10g + Az. 10 g + SSP 10 g and G.f. 5g + Az. 20 g + SSP 10 g. These three

treatments were at par with each other and significantly superior to all the other treatments including the control.

Highest fresh weight of the root was recorded in the treatment G.f. 5g + Az. 10 g + SSP 10 g followed by G.f. 20g + Az. 20g + SSP 10 g. The differences between the treatment means were significant and both the above treatments were also significantly superior to all other treatments including control.

#### **4.3.2.2. Dry weight of shoot and roots**

Maximum dry weight of shoot and root were recorded in the plants inoculated with G.f. 20g + Az. 10 g + SSP 10 g and G.f. 5g + Az. 10g + SSP 10 g respectively followed by G.f. 5g + Az. 10g + SSP 10 g and G.f. 20g + Az. 10 g + SSP 10 g. In both cases i.e., dry weight of shoot and root, the means of the two treatments, which gave maximum dry weight, not only significantly differed between them but also was also superior to all other treatments. A critical analysis reveals that only the relative positions of the best and second best treatments in the case of root and shoot dry weight inter changed.

#### **4.3.2.3. Dry weight ratio of root to shoot**

Maximum dry weight ratio of roots and shoots was recorded in the plants inoculated with G.m. 20g + SSP 10 g, which was significantly superior to all other treatments. All other treatments were at par with each other including the control.

#### **4.3.2.4. Root length**

The maximum root length was observed in the plants inoculated with G.f. 5g + Az. 10g + SSP 10 g, which was significantly superior to all other treatments. This was followed by SSP 10 g alone treated plants and G.f. 20g + Az. 10g + SSP 10 g, which were statistically at par. The above treatments produced roots with length, which were significantly superior to all other remaining treatments including the control.

#### **4.3.2.5. Number of primary, secondary, tertiary and total roots**

Maximum and significantly higher primary root count was recorded in the plants inoculated with G.f. 5 g + Az. 20 g + SSP 10 g followed by SSP 10 g

alone treated plants. The treatments G.m. 10 g + Az. 10 g + SSP 10 g, G.f. 20g + Az. 5 g + SSP 10 g, G.m. 20 g + SSP 10 g, G.f. 20g + Az. 10 g + SSP 10 g, G.m. 10g + Az. 20 g + SSP 10 g, G.f. 20 g + Az. 20 g + SSP 10 g and G.m. 10 g + Az. 5g + SSP 10 g produced more number of primary roots.

Maximum number of secondary roots was registered in the plants inoculated with G.m. 10 g + Az. 10 g + SSP 10 g, which was at par with G.m. 10 g + Az. 5 g + SSP 10 g the neat best treatment and significantly superior to all other treatments. This was followed by G.f. 5g + Az. 10 g + SSP 10 g and G.m. 5g + Az. 20 g + SSP 10 g. The means of the latter two treatments were at par with each other.

Highest tertiary root count was observed in the treatment G.f. 5g + Az. 10 g + SSP 10 g which was statistically at par with treatment combination G.m. 10 g + Az. 10 g + SSP g and SSP 10 g alone treated plants. The latter two treatments were at par with G.f. 20 g + Az. 10 g + SSP 10 g. The above treatments were significantly higher than all other treatments including control.

Maximum count of total number of roots was observed in plants inoculated with G.m. 10 g + Az. 10 g + SSP 10 g , which was superior to all other treatments. This was followed by G.m. 10 g + Az. 5 g + SSP 10 g, which was at par with G.f. 5 g + Az. 10 g + SSP 10 g and SSP 10 g alone treated plants. The means of all the above treatments were significantly superior to the means of all other treatments including the control.

#### **4.3.3. Biochemical characters of seedling leaves**

For the purpose of analyzing the biochemical characters the treatments were categorized as those showing the best growth, those showing intermediary growth and those enabled the least growth (Plate 7). The typical of the group were selected (for best growth: G.f. 5 g + Az. 10 g + SSP 10 g, for intermediate growth: G.m. 10 g + SSP 10 g, and for least growth: G.m. 20 g + Az. 10 g + SSP 10 g) for the study and the data are presented in the Table 32.

##### **4.3.3.1. Nitrogen content**

The nitrogen content was highest in the treatments, which showed maximum growth (G.f. 5 g + Az. 10 g + SSP 10 g). A distinct trend was noticed with the treatment, which showed best growth showing maximum values, the

**Table 31. Morphological characters of twelve month stage mangosteen (*Garcinia mangostana* L.) seedlings inoculated with arbuscular mycorrhizal fungi (AMF) and Azospirillum.**

| Treatments (g) | Shoot fresh weight (g) | Root fresh weight (g) | Shoot dry weight (g) | Root dry weight (g)   | Root to shoot dry weight ratio | Root length (cm)       | Primary roots (No)      | Secondary roots (No)  | Tertiary roots (No)   | Total roots (No)       |
|----------------|------------------------|-----------------------|----------------------|-----------------------|--------------------------------|------------------------|-------------------------|-----------------------|-----------------------|------------------------|
| G.m 5          | 6.00 <sup>ij</sup>     | 1.00 <sup>lmn</sup>   | 3.13 <sup>kl</sup>   | 0.65 <sup>ij</sup>    | 0.21 <sup>b</sup>              | 10.2 <sup>k</sup>      | 12.0 <sup>kl</sup>      | 16.0 <sup>g</sup>     | 9.0 <sup>no</sup>     | 37.0 <sup>l</sup>      |
| G.m 10         | 3.05 <sup>lmn</sup>    | 0.89 <sup>mno</sup>   | 0.97 <sup>r</sup>    | 0.35 <sup>mno</sup>   | 0.36 <sup>b</sup>              | 23.2 <sup>efgh</sup>   | 21.0 <sup>fghijk</sup>  | 36.0 <sup>d</sup>     | 15.0 <sup>ijklm</sup> | 72.0 <sup>ghij</sup>   |
| G.m 20         | 4.79 <sup>ikl</sup>    | 1.08 <sup>lm</sup>    | 0.22 <sup>t</sup>    | 0.51 <sup>ijklm</sup> | 2.62 <sup>a</sup>              | 22.8 <sup>efgh</sup>   | 31.0 <sup>abcde</sup>   | 43.0 <sup>cd</sup>    | 19.0 <sup>ijk</sup>   | 93.0 <sup>efgh</sup>   |
| G.f 5          | 3.09 <sup>lmn</sup>    | 0.70 <sup>op</sup>    | 1.20 <sup>q</sup>    | 0.31 <sup>nop</sup>   | 0.26 <sup>b</sup>              | 20.7 <sup>hi</sup>     | 14.0 <sup>kl</sup>      | 31.0 <sup>def</sup>   | 12.0 <sup>lmno</sup>  | 57.0 <sup>ijkl</sup>   |
| G.f 10         | 10.54 <sup>f</sup>     | 2.05 <sup>g</sup>     | 4.74 <sup>h</sup>    | 0.86 <sup>g</sup>     | 0.18 <sup>b</sup>              | 23.2 <sup>efgh</sup>   | 22.0 <sup>efghij</sup>  | 38.0 <sup>cd</sup>    | 10.0 <sup>mno</sup>   | 70.0 <sup>ghijk</sup>  |
| G.f 20         | 7.54 <sup>hi</sup>     | 1.56 <sup>i</sup>     | 3.27 <sup>k</sup>    | 0.68 <sup>hi</sup>    | 0.21 <sup>b</sup>              | 24.6 <sup>cdefgh</sup> | 26.0 <sup>defghi</sup>  | 39.0 <sup>cd</sup>    | 26.0 <sup>gh</sup>    | 91.0 <sup>efgh</sup>   |
| Az. 5          | 1.53 <sup>n</sup>      | 0.42 <sup>qr</sup>    | 0.67 <sup>s</sup>    | 0.21 <sup>opq</sup>   | 0.30 <sup>b</sup>              | 17.6 <sup>ij</sup>     | 19.0 <sup>hijkl</sup>   | 28.0 <sup>defg</sup>  | 11.0 <sup>lmno</sup>  | 58.0 <sup>ijkl</sup>   |
| Az. 10         | 3.94 <sup>klm</sup>    | 1.06 <sup>lm</sup>    | 1.81 <sup>op</sup>   | 0.50 <sup>ijklm</sup> | 0.28 <sup>b</sup>              | 21.2 <sup>ghi</sup>    | 20.0 <sup>ghijk</sup>   | 32.0 <sup>def</sup>   | 15.0 <sup>ijklm</sup> | 67.0 <sup>hijkl</sup>  |
| Az. 20         | 3.36 <sup>lm</sup>     | 0.58 <sup>pq</sup>    | 1.19 <sup>q</sup>    | 0.17 <sup>pq</sup>    | 0.14 <sup>b</sup>              | 20.3 <sup>hi</sup>     | 15.0 <sup>kl</sup>      | 19.0 <sup>cfg</sup>   | 8.0 <sup>o</sup>      | 42.0 <sup>kl</sup>     |
| Az.5 + G.m 5   | 5.57 <sup>jk</sup>     | 1.13 <sup>kl</sup>    | 1.94 <sup>a</sup>    | 0.38 <sup>lmn</sup>   | 0.20 <sup>b</sup>              | 18.3 <sup>ij</sup>     | 20.0 <sup>ghijk</sup>   | 32.0 <sup>def</sup>   | 14.0 <sup>klmn</sup>  | 66.0 <sup>hijkl</sup>  |
| Az.10 + G.m.5  | 8.32 <sup>gh</sup>     | 1.83 <sup>h</sup>     | 3.77 <sup>j</sup>    | 0.90 <sup>g</sup>     | 0.24 <sup>b</sup>              | 21.5 <sup>ghi</sup>    | 23.0 <sup>defghij</sup> | 38.0 <sup>cd</sup>    | 24.0 <sup>hi</sup>    | 85.0 <sup>fghi</sup>   |
| Az.20 + G.m.5  | 6.42 <sup>ij</sup>     | 1.37 <sup>ij</sup>    | 2.55 <sup>m</sup>    | 0.55 <sup>ijk</sup>   | 0.22 <sup>b</sup>              | 14.6 <sup>j</sup>      | 19.0 <sup>hijkl</sup>   | 52.0 <sup>bc</sup>    | 30.0 <sup>g</sup>     | 101.0 <sup>cdefg</sup> |
| Az.5 + G.m.10  | 11.04 <sup>ef</sup>    | 2.51 <sup>f</sup>     | 4.79 <sup>h</sup>    | 1.10 <sup>f</sup>     | 0.23 <sup>b</sup>              | 20.3 <sup>hi</sup>     | 29.0 <sup>bcddefg</sup> | 86.0 <sup>a</sup>     | 46.0 <sup>de</sup>    | 161.0 <sup>b</sup>     |
| Az.10+G.m.10   | 5.56 <sup>jk</sup>     | 1.49 <sup>ij</sup>    | 2.21 <sup>n</sup>    | 0.57 <sup>ijk</sup>   | 0.26 <sup>b</sup>              | 26.8 <sup>bcde</sup>   | 36.0 <sup>abc</sup>     | 94.0 <sup>a</sup>     | 58.0 <sup>ab</sup>    | 188.0 <sup>a</sup>     |
| Az.20+G.m.10   | 12.52 <sup>de</sup>    | 2.40 <sup>f</sup>     | 5.90 <sup>f</sup>    | 1.16 <sup>f</sup>     | 0.20 <sup>b</sup>              | 27.4 <sup>bcd</sup>    | 30.0 <sup>bcddef</sup>  | 59.0 <sup>b</sup>     | 38.0 <sup>f</sup>     | 127.0 <sup>cd</sup>    |
| Az.5 + G.m.20  | 2.49 <sup>mno</sup>    | 0.26 <sup>r</sup>     | 0.92 <sup>r</sup>    | 0.11 <sup>q</sup>     | 0.11 <sup>b</sup>              | 16.2 <sup>j</sup>      | 10.0 <sup>l</sup>       | 18.0 <sup>fg</sup>    | 12.0 <sup>lmno</sup>  | 40.0 <sup>kl</sup>     |
| Az.10+G.m.20   | 4.08 <sup>klm</sup>    | 0.83 <sup>no</sup>    | 1.68 <sup>p</sup>    | 0.36 <sup>lmno</sup>  | 0.21 <sup>b</sup>              | 21.7 <sup>fghi</sup>   | 22.0 <sup>efghij</sup>  | 33.0 <sup>def</sup>   | 14.0 <sup>klmn</sup>  | 69.0 <sup>hijk</sup>   |
| Az.20+G.m.20   | 8.47 <sup>gh</sup>     | 1.95 <sup>gh</sup>    | 3.69 <sup>j</sup>    | 0.81 <sup>gh</sup>    | 0.22 <sup>b</sup>              | 28.4 <sup>bc</sup>     | 16.0 <sup>kl</sup>      | 44.0 <sup>cd</sup>    | 16.0 <sup>kl</sup>    | 76.0 <sup>ghi</sup>    |
| Az.5 + G.f 5   | 7.72 <sup>hi</sup>     | 1.30 <sup>jk</sup>    | 3.00 <sup>l</sup>    | 0.52 <sup>ijkl</sup>  | 0.17 <sup>b</sup>              | 22.5 <sup>fgh</sup>    | 20.0 <sup>ghijk</sup>   | 34.0 <sup>de</sup>    | 20.0 <sup>ij</sup>    | 74.0 <sup>ghi</sup>    |
| Az.10 + G.f 5  | 19.72 <sup>b</sup>     | 6.31 <sup>a</sup>     | 10.55 <sup>b</sup>   | 3.03 <sup>a</sup>     | 0.29 <sup>b</sup>              | 36.4 <sup>a</sup>      | 40.0 <sup>a</sup>       | 58.0 <sup>b</sup>     | 60.0 <sup>a</sup>     | 158.0 <sup>b</sup>     |
| Az. 20 + G.f 5 | 18.60 <sup>b</sup>     | 3.32 <sup>de</sup>    | 6.20 <sup>c</sup>    | 1.42 <sup>c</sup>     | 0.23 <sup>b</sup>              | 23.2 <sup>efgh</sup>   | 18.0 <sup>ijkl</sup>    | 28.0 <sup>cdefg</sup> | 30.0 <sup>g</sup>     | 76.0 <sup>ghi</sup>    |
| Az. 5 + G.f 10 | 11.36 <sup>ef</sup>    | 2.49 <sup>f</sup>     | 5.39 <sup>g</sup>    | 1.36 <sup>c</sup>     | 0.25 <sup>b</sup>              | 25.8 <sup>cdef</sup>   | 28.0 <sup>cdefgh</sup>  | 40.0 <sup>cd</sup>    | 47.0 <sup>de</sup>    | 115.0 <sup>cde</sup>   |
| Az.10+ G.f 10  | 19.65 <sup>b</sup>     | 2.49 <sup>f</sup>     | 8.76 <sup>c</sup>    | 2.15 <sup>c</sup>     | 0.25 <sup>b</sup>              | 18.2 <sup>ij</sup>     | 15.0 <sup>kl</sup>      | 33.0 <sup>def</sup>   | 42.0 <sup>ef</sup>    | 90.0 <sup>efgh</sup>   |
| Az.20+ G.f 10  | 9.80 <sup>fg</sup>     | 3.97 <sup>c</sup>     | 4.49 <sup>i</sup>    | 1.82 <sup>d</sup>     | 0.41 <sup>b</sup>              | 23.2 <sup>efgh</sup>   | 16.0 <sup>kl</sup>      | 30.0 <sup>cdefg</sup> | 18.0 <sup>jk</sup>    | 64.0 <sup>hijkl</sup>  |
| Az.5 + G.f 20  | 16.95 <sup>c</sup>     | 4.01 <sup>c</sup>     | 6.92 <sup>d</sup>    | 1.67 <sup>d</sup>     | 0.24 <sup>b</sup>              | 26.8 <sup>bcde</sup>   | 32.0 <sup>abcd</sup>    | 43.0 <sup>cd</sup>    | 50.0 <sup>cd</sup>    | 125.0 <sup>cd</sup>    |
| Az.10+ G.f 20  | 25.53 <sup>a</sup>     | 3.39 <sup>d</sup>     | 11.09 <sup>a</sup>   | 2.56 <sup>b</sup>     | 0.23 <sup>b</sup>              | 30.2 <sup>b</sup>      | 30.0 <sup>bcddef</sup>  | 42.0 <sup>cd</sup>    | 53.0 <sup>bc</sup>    | 125.0 <sup>cd</sup>    |
| Az.20+ G.f 20  | 13.91 <sup>d</sup>     | 5.23 <sup>b</sup>     | 5.43 <sup>g</sup>    | 1.35 <sup>c</sup>     | 0.25 <sup>b</sup>              | 23.8 <sup>defgh</sup>  | 29.0 <sup>bcddefg</sup> | 38.0 <sup>cd</sup>    | 43.0 <sup>ef</sup>    | 110.0 <sup>def</sup>   |
| SSP10 alone    | 16.27 <sup>c</sup>     | 3.15 <sup>c</sup>     | 6.89 <sup>d</sup>    | 1.79 <sup>d</sup>     | 0.26 <sup>b</sup>              | 30.4 <sup>b</sup>      | 38.0 <sup>ab</sup>      | 44.0 <sup>cd</sup>    | 58.0 <sup>ab</sup>    | 140.0 <sup>bc</sup>    |
| Control        | 10.54 <sup>f</sup>     | 3.91 <sup>c</sup>     | 3.65 <sup>j</sup>    | 0.45 <sup>klmn</sup>  | 0.12 <sup>b</sup>              | 25.4 <sup>cdefg</sup>  | 28.0 <sup>cdefgh</sup>  | 32.0 <sup>def</sup>   | 18.0 <sup>jk</sup>    | 78.0 <sup>ghi</sup>    |
| Mean values    | 9.60                   | 2.16                  | 4.04                 | 0.98                  | 0.31                           | 22.93                  | 23.41                   | 40.0                  | 28.138                | 91.552                 |
| C.D.(p<0.05)   | 1.63                   | 0.19                  | 0.19                 | 0.15                  | 0.33                           | 3.60                   | 8.17                    | 13.08                 | 4.903                 | 26.15                  |

Figures with same alphabets do not differ significantly at 5% level.

G.m- *Glomus mosseae*, G.f- *Glomus fasciculatum*, Az - Azospirillum

**Table 32. Biochemical characters in the leaf samples of one year old mangosteen (*Garcinia mangostana* L.) seedlings treated with arbuscular mycorrhizal fungi and Azospirillum.**

| AMF and Azospirillum inoculated plants | N (%) | P (%)             | K (%) | Crude protein (%)   | Na (%) | Chlorophyll a (mg/g) | Chlorophyll b (mg/g) | Chlorophyll a / b ratio | Total chlorophyll (mg/g) | Total phenols (mg/g) | Total carbohydrates (mg/g) | Abscissic acid (mg/g) |
|----------------------------------------|-------|-------------------|-------|---------------------|--------|----------------------|----------------------|-------------------------|--------------------------|----------------------|----------------------------|-----------------------|
| Best (Az 10 + G.f 5)                   | 2.35  | 0.19 <sup>a</sup> | 0.34  | 14.67 <sup>a</sup>  | 0.34   | 0.95 <sup>a</sup>    | 0.42 <sup>a</sup>    | 2.30                    | 1.37 <sup>a</sup>        | 0.64                 | 7.85 <sup>a</sup>          | 0.21 <sup>a</sup>     |
| Intermediate (G.m 10 g)                | 2.08  | 0.05 <sup>b</sup> | 0.30  | 12.99 <sup>b</sup>  | 0.34   | 0.66 <sup>b</sup>    | 0.29 <sup>a</sup>    | 2.38                    | 0.95 <sup>ab</sup>       | 0.46                 | 6.59 <sup>ab</sup>         | 0.16 <sup>ab</sup>    |
| Least (Az 10+G.m20)                    | 1.79  | 0.04 <sup>b</sup> | 0.28  | 11.22 <sup>c</sup>  | 0.34   | 0.17 <sup>c</sup>    | 0.11 <sup>b</sup>    | 1.88                    | 0.27 <sup>b</sup>        | 0.47                 | 4.85 <sup>b</sup>          | 0.08 <sup>b</sup>     |
| Control                                | 1.94  | 0.04 <sup>b</sup> | 0.29  | 12.10 <sup>bc</sup> | 0.34   | 0.41 <sup>c</sup>    | 0.20 <sup>ab</sup>   | 2.05                    | 0.61 <sup>ab</sup>       | 0.46                 | 5.72 <sup>ab</sup>         | 0.14 <sup>ab</sup>    |
| Mean values                            | 2.04  | 0.08              | 0.30  | 12.75               | 0.34   | 0.55                 | 0.25                 | 2.15                    | 0.80                     | 0.51                 | 6.25                       | 0.15                  |
| C.D .(p<0.05)                          | NS    | 0.09              | NS    | 1.46                | NS     | 0.25                 | 0.17                 | NS                      | 0.80                     | NS                   | 2.13                       | 0.096                 |

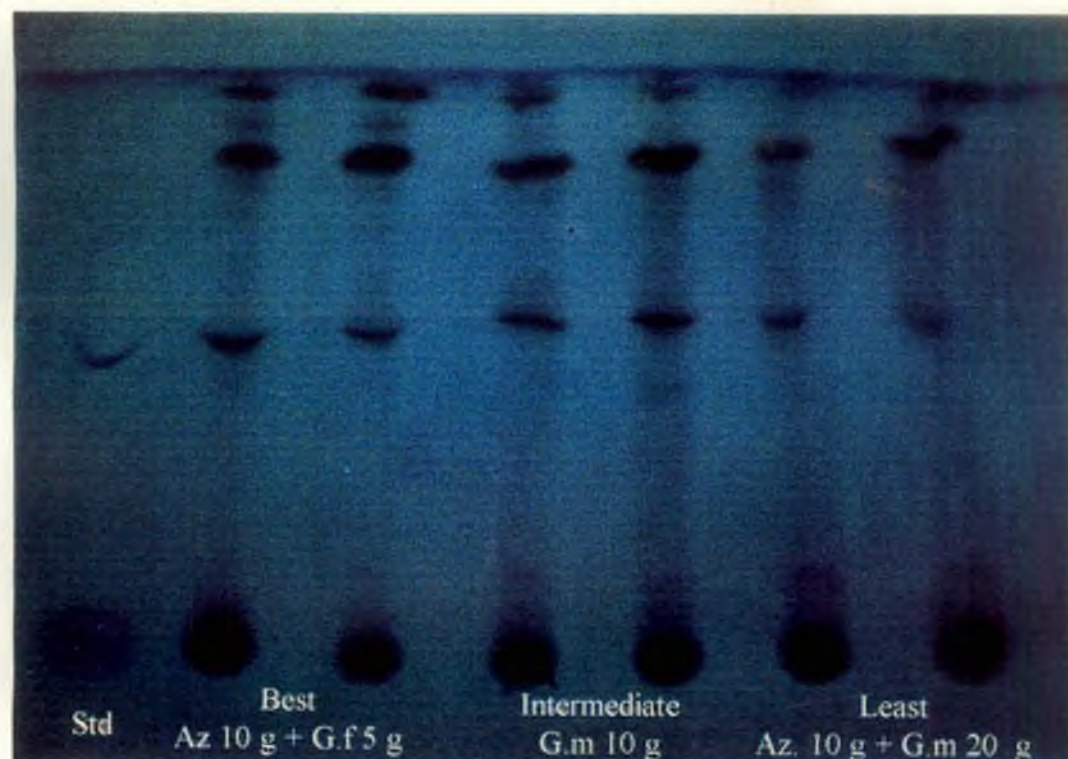
Figures with same alphabets do not differ significantly at 5 %

G.m- *Glomus mosseae*, G.f- *Glomus fasciculatum*, Az- Azospirillum

**Plate 7. Seedlings of treatments, showing the best, the intermediate and the least growth response to arbuscular mycorrhizal fungi (AM fungi) and azospirillum in mangosteen (*Garcinia mangostana* L.)**



**Plate 8. Banding pattern observed in TLC used to quantify abscisic acid content in various treatments using arbuscular mycorrhizal fungi (AM fungi) and azospirillum in mangosteen (*Garcinia mangostana* L.)**



intermediary values being recorded in the treatments showing intermediate growth and the lowest values in the treatment showing least growth. However, there were no significant differences observed between the treatment means.

#### **4.3.3.2. Phosphorus content**

A pattern almost similar to that observed in case of N was observed in the case of phosphorus content also. However, the mean content in the treatment, which showed the best growth, was significantly superior to other treatments including the control.

#### **4.3.3.3. Potassium content**

The potassium content also revealed similar trend with the treatment showing maximum growth having highest potassium content. However, there was no significant difference observed between the various treatments means including the control. The control treatment recorded the values between the treatments showing intermediary growth and least values.

#### **4.3.3.4. Crude protein content**

The highest crude protein content was also observed in the treatment, which showed best growth. It was significantly superior to other treatments and also the control. The treatments, which showed intermediate growth also showed higher values, which were significantly higher than the treatment showing least growth and control plants.

#### **4.3.3.5. Sodium content**

Same level of sodium content was recorded in the treatment showing best, intermediate and least growth and this same as control plants.

#### **4.3.3.6. Chlorophyll content**

Maximum chlorophyll a, b and total content were observed in the treatment showing maximum growth, itself. In case of chlorophyll a this was significantly superior than the means of content observed in plants of other categories and the control. The content of the plant with least growth was at par with control. In the case of chlorophyll b content the trend observed was similar to that of growth. The treatment with maximum growth had highest chlorophyll b

content, which was on par with the treatment showing intermediate growth. These two levels were significantly superior to the level observed in the plants, which showed the least growth, but it was statistically at par with the control.

#### **4.3.3.7. Total phenols**

Contrary to the normal lines of thinking the total phenol content was highest in the treatments with maximum growth (Fig. 12). However, there were no significant differences observed between treatment means and the control.

#### **4.3.3.8. Total carbohydrates**

The total carbohydrate recorded was highest in the treatment, which recorded the maximum growth. It was at par with the treatment means that showed intermediate growth and also with the control.

#### **4.3.3.9. Absciscic acid content**

The content of abscisic acid, which normally goes hand and in hand with growth inhibition was also contrary to the normal lines of thought. The treatments, which revealed more growth, also had the highest abscisic acid content. The means of treatment group, which showed the highest abscisic acid content, was also at par with that of the treatment, which showed intermediary growth and also with the control but the treatment means of the first group was significantly superior to the category which showed the least growth (Fig. 12 and Plate 8).

#### **4.3.4. Microbial population and percentage of root infection**

The mean data related to microbial population and percentages of root infection are presented in the Table 33.

##### **4.3.4.1. Spore population of arbuscular mycorrhizal fungi (AMF)**

The highest number of spores were counted in the rhizosphere of the plants inoculated with G.f. 20 g + SSP 10 g followed by G.f. 20 g + Az. 20 g + SSP 10 g. These two treatments were on par with all other treatments except the control proving the superiority in colonization.

**Fig. 12. Total phenols and abscisic acid content of the AM fungi and Azospirillum treated plants showing best, intermediate and least growth in mangosteen (*Garcinia mangostana* L.)**

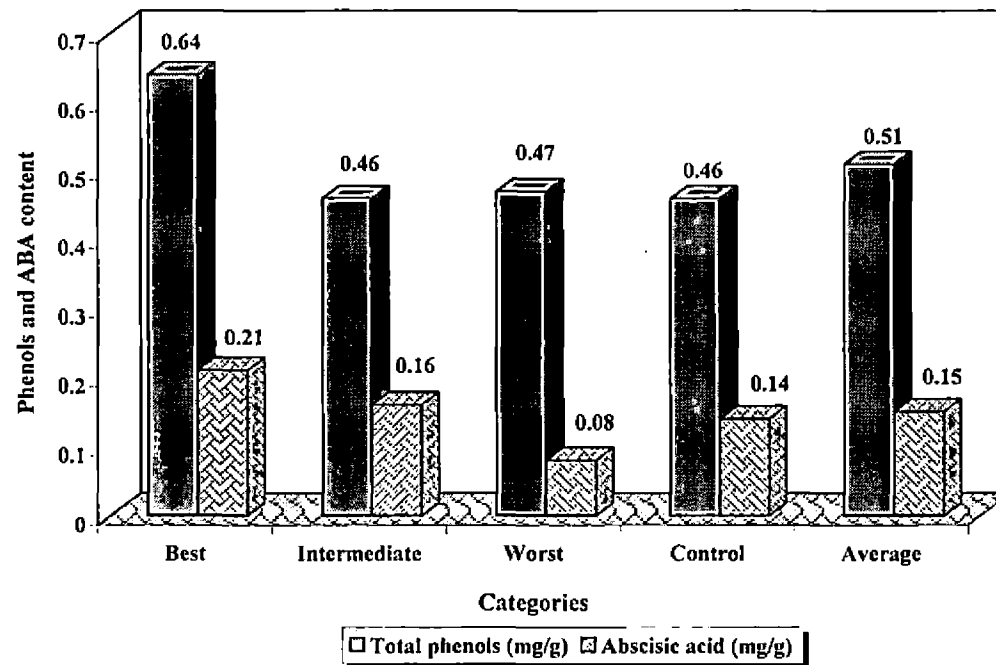


**Table - 33. Microbial population and infectivity in twelve month old mangosteen (*Garcinia mangostana* L.) seedlings rhizosphere and roots inoculated with Arbuscular mycorrhizal fungi (AMF) and Azospirillum.**

| Treatments     | Spores<br>(No. / 100 g of soil) | Infection<br>(%)        | Azospirillum<br>population<br>( $\times 10^6$ cells<br>/ g of soil) |
|----------------|---------------------------------|-------------------------|---------------------------------------------------------------------|
| G.m 5          | 198.00 <sup>ab</sup>            | 40.00 <sup>cdef</sup>   | 0.22 <sup>bc</sup>                                                  |
| G.m 10         | 214.00 <sup>ab</sup>            | 55.00 <sup>abcdef</sup> | 0.24 <sup>bc</sup>                                                  |
| G.m 20         | 219.00 <sup>ab</sup>            | 65.00 <sup>abcde</sup>  | 0.26 <sup>abc</sup>                                                 |
| G.f 5          | 206.00 <sup>ab</sup>            | 40.00 <sup>cdef</sup>   | 0.27 <sup>ab</sup>                                                  |
| G.f 10         | 222.00 <sup>ab</sup>            | 60.00 <sup>abcdef</sup> | 0.28 <sup>ab</sup>                                                  |
| G.f 20         | 228.00 <sup>a</sup>             | 70.00 <sup>abcd</sup>   | 0.30 <sup>ab</sup>                                                  |
| Az. 5          | 136.00 <sup>bc</sup>            | 35.00 <sup>def</sup>    | 0.34 <sup>ab</sup>                                                  |
| Az. 10         | 142.00 <sup>abc</sup>           | 40.00 <sup>cdef</sup>   | 0.35 <sup>ab</sup>                                                  |
| Az. 20         | 148.00 <sup>abc</sup>           | 30.00 <sup>ef</sup>     | 0.37 <sup>ab</sup>                                                  |
| Az.5 + G.m 5   | 200.00 <sup>ab</sup>            | 45.00 <sup>bcdef</sup>  | 0.31 <sup>ab</sup>                                                  |
| Az.10 + G.m5   | 213.00 <sup>ab</sup>            | 55.00 <sup>abcdef</sup> | 0.36 <sup>ab</sup>                                                  |
| Az.20 + G.m5   | 215.00 <sup>ab</sup>            | 50.00 <sup>abcdef</sup> | 0.37 <sup>ab</sup>                                                  |
| Az.5 + G.m10   | 204.00 <sup>ab</sup>            | 50.00 <sup>abcdef</sup> | 0.33 <sup>ab</sup>                                                  |
| Az.10 + G.m10  | 218.00 <sup>ab</sup>            | 65.00 <sup>abcde</sup>  | 0.37 <sup>ab</sup>                                                  |
| Az.20 + G.m10  | 222.00 <sup>ab</sup>            | 70.00 <sup>abcd</sup>   | 0.34 <sup>ab</sup>                                                  |
| Az.5 + G.m20   | 206.00 <sup>ab</sup>            | 60.00 <sup>abcdef</sup> | 0.32 <sup>ab</sup>                                                  |
| Az.10 + G.m20  | 220.00 <sup>ab</sup>            | 75.00 <sup>abc</sup>    | 0.38 <sup>ab</sup>                                                  |
| Az.20 + G.m20  | 224.00 <sup>ab</sup>            | 55.00 <sup>abcdef</sup> | 0.39 <sup>ab</sup>                                                  |
| Az.5 + G.f 5   | 204.00 <sup>ab</sup>            | 80.00 <sup>ab</sup>     | 0.32 <sup>ab</sup>                                                  |
| Az.10 + G.f 5  | 216.00 <sup>ab</sup>            | 90.00 <sup>a</sup>      | 0.36 <sup>ab</sup>                                                  |
| Az.20 + G.f 5  | 219.00 <sup>ab</sup>            | 85.00 <sup>ab</sup>     | 0.40 <sup>a</sup>                                                   |
| Az.5 + G.f 10  | 210.00 <sup>ab</sup>            | 80.00 <sup>ab</sup>     | 0.33 <sup>ab</sup>                                                  |
| Az.10 + G.f 10 | 220.00 <sup>ab</sup>            | 85.00 <sup>ab</sup>     | 0.37 <sup>ab</sup>                                                  |
| Az.20 + G.f 10 | 224.00 <sup>ab</sup>            | 85.00 <sup>ab</sup>     | 0.38 <sup>ab</sup>                                                  |
| Az.5 + G.f 20  | 213.00 <sup>ab</sup>            | 85.00 <sup>ab</sup>     | 0.37 <sup>ab</sup>                                                  |
| Az.10 + G.f 20 | 224.00 <sup>ab</sup>            | 90.00 <sup>a</sup>      | 0.35 <sup>ab</sup>                                                  |
| Az.20 + G.f 20 | 226.00 <sup>ab</sup>            | 80.00 <sup>ab</sup>     | 0.39 <sup>ab</sup>                                                  |
| SSP10 alone    | 150.00 <sup>abc</sup>           | 30.00 <sup>ef</sup>     | 0.23 <sup>bc</sup>                                                  |
| Control        | 90.00 <sup>c</sup>              | 25.00 <sup>f</sup>      | 0.12 <sup>c</sup>                                                   |
| Mean values    | 201.10                          | 61.21                   | 0.32                                                                |
| C.D. (p<0.05)  | 73.55                           | 32.69                   | 0.14                                                                |

Figures with same alphabets do not differ significantly at 5 % level.

G.m- *Glomus mosseae*, G.f- *Glomus fasciculatum*, Az.- *Azospirillum*

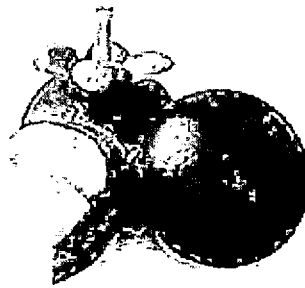
#### **4.3.4.2. Percentage of root infection**

The root infection, which gave a clear picture of the colonization, was also studied. The highest percentage of root infection was recorded in the plants inoculated with G.f. 5 g + Az. 10 g + SSP 10 g and G.f. 20 g + Az. 10 + SSP 10 g with both registering the higher values of mean percentage of infection. These treatments were at par with all other treatments except G.m. 5 g + SSP 10 g, G.f. 5 g + SSP 10 g, all the Azospirillum + SSP alone treated plants, G.m. 5 g + Az. 5 g + SSP 10 g, SSP 10 g also and the control.

#### **4.3.4.3. Azospirillum population**

The maximum Azospirillum population was recorded in the rhizosphere of the plants inoculated with G.f. 10g + Az. 20 g + SSP 10 g, which was on par with all other treatments except combination of G.m. 5 g and 10 g alone with SSP 10 g absolute control of SSP 10 g alone and the control plants.

## *DISCUSSION*



## CHAPTER - V

### DISCUSSION

Results of the study on “Selection index and activation of seedling growth in Mangosteen (*Garcinia mangostana* L.)” are discussed under the following sub headings.

#### 5.1.1. Selection index

The discussion of the selection index experiment is presented in the following captions.

##### 5.1.1.1. Age of the mother plant and morphological characters of fruit, seed and seedlings

The results emanating from the study revealed that plants of age group 25-50 years were observed to be the best for the selection as mother plant to obtain maximum seedling growth. This finding can be argued from many directions. Firstly, a perusal of the data on the morphological characters of fruit with the seedling index shows that most of the characters were negatively correlated. On the contrary, the seed characters were found to be positively correlated with the seedling index revealing that the seed characters are much more important than the fruit characters in determining the seedling growth. Though the reflection of growth cannot be said to be an exclusive function of seed characters, it is clear from the findings that this is more important than characters of fruit. In the present study all the fruit characters belonging to the age group of 25-50 years recorded the least values, whereas visually the seed characters such as seed weight and other characters were comparatively less but number of seeds per fruit, number of seedlings per seed, germination percentage and number of days taken to germination were highest in the age group of 51-75 years. Nevertheless, a critical analysis of the data revealed that the seed weight as a fraction of the total fruit weight is an underlying key factor. The age group of 25-50 years recorded the highest percentage of seed weight expressed as a fraction of the whole fruit weight (Fig. 1) and though the differences are negligible, the external manifestation of this minor difference on seedling growth is glaring and explicit. Secondly, the data

revealed that the number of seeds per fruit, number of seedlings per seed, germination percentage and number of days taken to germination recorded were also highest in the age group 25-50 years. This should have been one of the paramount reasons as to why this age group gave better seedling index. Thirdly, this age group is the stage of actual physiological maturity of the tree and the stage of constant bearing and returns, while the first group represents the stage of ontogenic transformation from juvenile tree to adult phase. The third and fourth age groups represent a stage of aging and senescence, which can be confirmed by the high percentage of seedlessness observed in these two groups. Identical results on these lines are available on other crops, like coconut where in the middle aged trees (25-60 years) has been found to be produce quality seedlings (Menon and Pandalai, 1960). In cashew wherein varieties with comparable age were grouped on the basis of colour and shape of the apples (Falade, 1981) and in citrus, who reported pedigree performance as a function of age of the tree (Reddy 1997).

#### **5.1.1.2. Biochemical characters**

Biochemical characters of the mother plants (all characters undertaken in this study) gave intermediately values with highest in the lowest age group, and a gradual gradation with increase in age groups. The possible reason for this is that the trees belonging to the age group of below 25 years were at their maximum active growing stage to develop into the whole plant structure. Hence, the nutrient uptake was highest in this age group. The higher values in the lower age group should be one of excesses and the lower values in the higher age group should be one nearing to the point of the deficiencies. Only a study involving ratios of different nutrients in the age groups and levels of productivity as in the diagnosis and recommendation integrated system (DRIS) can confirm this debatable point and is suggested as a future line of work.

The results generated reveal that the content of N, P, K, crude protein, total phenols, total carbohydrates and total sugars in the seeds were highest in the 25-50 year age group, whereas sodium and abscisic acid were highest in less than 25 years age group and in both cases it was lowest in the aged group. The results can be rationalised from different angles. On one side it presents a picture of physiological maturity. The age group of less than 25 years represents the stage,

which has just switched over to the reproduction phase or is in the ontogenic transformation from the vegetative to the reproductive phase. The next stage (25-50 year group) represents an age group in steady bearing phase whereas the later two stages represents an advanced stage of crop wherein senility due to ageing shows its marked effects. The higher degree of seedlessness observed in such cases proves this beyond doubt.

Another major interpretation of the result is that the compactness of the seed has a bearing on the higher content of biochemical characters. Though the seed weight, length, volume and thickness are highest in the third age group the specific gravity (i.e., weight/volume), which reflects the correct nature of the compactness of the seed is highest in the age group in 25-50 year age group and this in turn is reflected on better attributes like germination, growth and survival rate. The importance of age group has been established in palms like coconut (Menon and Pandalai, 1960) but in the phase studies it has not been linked with biochemical characters.

A scrutiny of the results reveals very interesting trends. The N and crude protein content of the seedling leaves was highest in the age group of less than 25 years whereas P, K, chlorophyll a, b, total chlorophyll, total carbohydrate and total phenol and ABA were highest in 25-50 year age group. Logical reasons for such results stem from the fact that the seedlings produced from seeds in the lowest age group was in the early phase of transformation from the juvenile to reproductive phase and this should be the cause for the high N and crude protein. All the root characters and the root to shoot dry weight ratio are highest in the second age group and this should be the reason for higher P and K content. The highest number of leaves per flush and total leaf area is the reason for the high chlorophyll a, b and total chlorophyll content. This in turn led to a better light harvest resulting in higher carbohydrate content.

The higher amount of the inhibitor complex of total phenol and abscisic acid can only be explained in terms of correlative inhibition and such reports already exist (White and Mansfield, 1977 and Wilkins, 1987). Only an exhaustive study covering all growth regulators and their balance can confirm this aspect and which could be a worth of line for future investigations.

### **5.1.1.3. Mother plant biochemical characters and fruit, seed and seedling morphological characters**

The study on the mother plant biochemical characters revealed that the leaf N, P, K, Na, protein, total phenol and abscisic acid were maximum in the age group less than 25 years. On the other hand all the morphological characters of the fruit like weight, volume, girth etc. were maximum in the age group of 51-75 years. The fruit index of the age group of less than 25 years and 25-50 years were comparatively less. The nutrients N, P, K, and protein were higher in the younger age groups as the plants were in their active vegetative phase. The second age group (25-50 years), which represents a steady bearing phase and a stage of complete transition was probably the reason as to why the nutrient content was comparatively less. The study also revealed that this age group yielded the most seeded fruits and hence the seed, which is normally the biggest physiological sink should have drawn in all the required nutrients and photosynthates. In the higher age group which account for more than 40 percentage of seedlessness, the fruits should have acted as a better physiological sink and hence the bigger size. Cannel's (1985) findings support the first contention of seeded fruits and Kurien *et al.*, (2000) study on the sink mechanisms of various tissues in the bearing phase of parthenocarpic fruits give logical support in the case of seedless fruits.

The seedling characters on the other hand has been proven to be a more important factor related to the characters of seeds as proven in the aspects contributing to the principal component analysis and discriminant functional analysis. Hence the age group of 25-50 years gave better seedling characters also confirming a lesser contribution of the mother plant biochemical characters, which was comparatively less in this age group. A full fledged study on the sink mechanism and the carbon partitioning in the bearing phase encompassing both seeded and seedless fruits can only answer this vital question and is yet another direction worth to be probed in depth and is suggested as a line for future work.

### **5.1.1.4. Fruit morphological characters and biochemical characters of seed and seedling**

The fruit morphological characters were observed to be highest in the 51-75 years group whereas for most biochemical characters of seed (except Na and

ABA) and seedling (except N and crude protein) the 25-50 year age group recorded highest content.

The above results can be rationalised only on the basis of phasic development and as a consequence of sink activity. In the very early stages most of the energy source has been directed to the structural make up of the plants and hence the resultant high N and crude protein. On the other hand, in the steady bearing phase the seeds should have acted as the most potent sink and hence the highest biochemical content. Beyond this age group, maximum seedlessness has been observed and hence the fruit must have been the highest physiological sink.

Cannel (1985) found out that the seed is the most potent sink of all tissues in seeded plants and the finding in banana (parthenocarpic fruit) that the male flower is the most potent sink (Kurien *et al.*, 2000) actually sums up the finding that it is the presence or absence of the seed in the present study which was responsible for such a result.

#### **5.1.1.5. Seed morphological characters in relation to seed and seedling biochemical characters**

Most of the seed morphological characters (seed weight, length, thickness at centre and volume) almost coincided with that of the fruit due to the positive correlation. All seed biochemical characters except for the sodium and the abscisic acid and in case of the seedlings except N and crude protein were highest in the 25-50 years age groups.

In the case of seeds, two vital aspects should have contributed to the higher values, which can be explained from the results itself. The higher seed characters should have been primarily due to a higher level of sugar, which is a pre-requisite for the energy requirement in germination. A high level of total carbohydrates as observed in the study acts as a resource pools for the constant supply of sugars by its basic break down. This is normally achieved by the enzymatic (amylase) action normally with increase in Gibberellins (Varner and Ho, 1976; Locy and Kende, 1978; Jacobsen *et al.*, 1979 and Jones, 1980). The gibberellins were not quantified in the study but the high levels of sugars point to this direction. Another striking feature is the least levels of abscisic acid in the seeds of this age group. These two factors individually and collectively must have

been responsible for the high germination. The higher amount of total chlorophyll and its fractions along with the higher leaf area should be the underlying cause for more carbohydrate in this group.

#### **5.1.1.6. Seedling morphological characters in relation to biochemical characters of seed and seedling**

The seedling morphological characters except for fresh and dry weight of shoots was highest in less than 25 year age group whereas all other characters were highest in 25-50 year age group. All seed biochemical characters (except Na and ABA) and seedling biochemical characters (except N and crude protein) were highest in 25-50 year age group.

Mangosteen plants have a magnolioid rooting system and hence characters of roots such as an effective foraging system, which is determined by the length of largest roots, the total number of roots and the number of primary, secondary and tertiary roots are of utmost significance.

Higher quantity of carbohydrates and sugars in seeds are observed in the 25-50 year age group and hence this age group showed higher germination, better survival rate, as the plants in the early years were better sustained by the reserves in the seed. Higher amount of chlorophyll and the more leaf area naturally resulted in more total carbohydrates in the seedlings. Correlation among fruit, seed and seedling morphological characters confirmed that the seed morphological characters are positively and significantly correlated with seedling morphological characters. The specific factor of seed specific gravity discussed as compactness in the age group 25-50 years needs to be more emphasized. Even though the seed weight was higher in above 50-years age group, the improved seed germination and seedling characters can only be as a result of the higher carbohydrates and sugar level in the seeds. The finding by Campbell (1966) that selection for seedlings based on seed weight of not less than one gram has overlooked this important seed specific gravity factor. Neither has a seed weight of one gram been observed in our samples. This higher seed weight is probably because the above workers based their study in Southern Florida and generally mangosteen plants in the above area produce bigger fruits. In Southeast Asiatic countries, it is reported that individual fruit weight often exceeds more than 100 g (Jarimopas *et al.*, 1988).

Results in our study are in terms with the observation of Bedell and Vijayachandran (1994) in teak. They reported that large fruits can be seedless and small and medium fruits contain well-formed seeds.

#### **5.1.1.7. Mother plant, seed and seedling biochemical characters**

The mother plant biochemical characters were highest in least age group whereas the seed and seedling biochemical characters were highest in 25-50 year age group. The above finding can only be explained based on the maturity. The mother plants of less than 25-year group were the plants, which had entered the reproductive phase but still in the active stage of growth and hence contained higher content of most characters. On the contrary, the biochemical characters of the seed (except Na and ABA) and seedling (except N and crude protein) were highest in the age group of 25-50 years. The seeds in this age group were from plants that had reached a steady-bearing phase and hence had a high level of physiological maturity. Such seeds had low ABA content, which is a known growth inhibitor and the high amount of carbohydrates was the two important aspects responsible for the higher germination and better growth rate. The higher ABA content in the higher age group should have been the cause of seedlessness, poor germination and the very low survival rate.

The higher P content observed in seedlings of 25-50 year age group must be the major reason for a better rooting system, as its role in rooting is an established fact. The higher chlorophyll and leaf area was the reason for the more amount of carbohydrate.

#### **5.1.2. Association of morphological characters of fruit, seed and seedling**

Results revealed that the fruit index was positively correlated with most of the fruit and seed characters except fruit specific gravity, number of one seeded fruit, seed thickness at centre, seed specific gravity, number of seedlings per fruit, germination percentage, and all the seedling characters were negatively correlated. An introspection of the age group variations revealed that the maximum values of all the morphological characters of fruit and seed were recorded in 51-75 years and the lowest values were recorded in 25-50 years. As fruit index is a function, which is derived from all the morphological characters of fruit the characters ought to be naturally correlated. But the negative correlations observed were due to the lowest

values of fruit characters recorded in the 25-50 years age group, which in turn gave maximum seeded fruits, maximum germination of seeds, maximum survival rate and the best quality seedlings as revealed by the improved morphological characters.

The seed index was observed to be negatively correlated with all the fruit characters. Though the pattern of gradation observed in the values of seed characters in the various age groups were the same as that observed for fruit characters in the same age group, the corresponding size or weight of the seed was not observed. The relative differences observed at the seed level are not as explicit as in the case of fruits and this could be the reason for the negative correlation observed between seed index and fruit characters. This is more evidenced if a ratio of the seed weight to fruit weight is computed. The second age group registered the highest values, in the ratio, which again reveals that the seed weight expressed as a fraction of the fruit weight is a more important character. Similarly, the differences are most clear in seed thickness to fruit girth ratio, where the second age group revealed a very high ratio in spite of the fact that for both of the above characters, age group less than 25 years recorded the highest values individually.

The positive correlations of seed index with all seedling characters once again confirm that the seedling characters are more governed by both the individual as well as collective characters of the seed. Though in the standard methodology that was adopted, equal importance (weightage) were given to the seed, fruit, seedling characters and age of the mother plant, the results confirm that it is the seed characters, which have a more say in determining the better seedling characters.

Seedling index, which was computed as a total variation of all the seedling characters collectively, was negatively correlated with number of seedlings per seed, number of days to germination, and seeds producing more than two seedlings. This is basically due to the fact that as a consequence of an increase in the number of seedlings per seed, the growth characters of the seedling are affected. The number of days taken to germinate was negatively correlated with seedling index. This is due to the reason that the seed characters were positively correlated with seedling characters and the age groups that recorded higher values of seed morphological characters also recorded the least number of days to

germination. The number of seeds producing more than two seedlings were negatively correlated with the seedling index as the positive aspect of more number of seedlings produced per seed was negated by the character of comparatively slower growth.

In general, most of the fruit characters are positively correlated with seed characters and negatively correlated with seedling characters. Most of seed characters are positively correlated with seedling characters. The typical reason for this is the values of fruit characters increase with mother plant age group. But this increase is not matched by a corresponding increase in the seed characters. In the case of seedling, the age groups with increased fruit characters are giving only weaker seedlings as revealed by the lower seedling index. The increase generally observed in the seed characters lead to increased seedling growth and hence over emphasizes the absolute command of the characters of seed in determining the quality attributes of seedlings.

### **5.1.3. Principal component analysis**

#### **5.1.3.1. Fruit characters and index**

A figurative plot of the principal components of the fruit characters are presented in Fig. 6 showing very narrow angles among the fruit characters such as rind weight, pulp weight, fruit weight, fruit index, number of segments, fruit girth and fruit volume, which describes actually the high positive correlation that exist between them. The principal component analysis of fruit characters and age of the mother plant showed that the factor I and factor II account for 88.76 percentage of the cumulative variance. A critical analysis of the plot reveals that for all major characters of the fruit, the age group three showed narrow angles, which highlights that most of the improved fruit morphological characters are observed in this group. On the other hand seedlessness showed narrow angles to age group three and four confirming that it is a factor that goes hand in hand with increased age. Seedlessness in fruits and seediness (one seeded, two seeded & more than three seeded) are at opposite directions showing that they are negatively correlated. A similar position at opposite ends is observed in the case of specific gravity and pulp weight, which reconfirms the negative correlation.

### 5.1.3.2. Seed characters and index

Principal component analysis of the seed characters and age of the mother plant showed that factor I and factor II account for 92.94 percentage of the cumulative variance. A critical perusal of the plot (Fig. 7) of the seed characters showed that maximum seed characters (Seed index, selection index, germination percentage, seed producing one seedling, number of seedling per seed and seed thickness at centre) were in close proximity and with very narrow angles to age group two, which clearly establishes the distinct superiority of age group two. The number of ungerminated seeds was in close proximity to age group four and positioned at opposite to germination percentage showing the negative correlation. Similarly the seed weight and volume are positioned at opposite end to the days to germination and specific gravity, which confirm the high significant negative correlation observed in the study.

### 5.1.3.3. Seedling characters and index

Principal component analysis of the fruit characters and age of the mother plant showed that factor I and factor II account for 92.49 percentage of the cumulative variance. The most important or major characters of the seedling and the selection index are in close proximity to age group two (Fig. 8), which clearly establishes that age group two seedlings are superior in all characters. The narrow angles between the various characters and this age group also establishes the high positive correlations of the characters with this age group. The placement of survival rate and root to shoot dry weight ratio at opposite ends not only reveals the negative correlation but on the more important side, the importance of roots which is very important in the case of mangosteen.

### 5.1.4. Step-wise regression

The step-wise regression was done to identify the variables contributing maximum variations and to reduce the number of variables showed no explicitness or clear-cut influence of attributes with respect to fruit characters. In case of seed characters, the thickness of the seed at the centre was found to be the most important factor. This is supported by the highest seed specific gravity, which was maximum in the best age group. In the case of seedling index, the important

characters were height of seedling, total number of leaves, total leaf area, survival rate, shoot and root fresh weight and dry weight, root length and total number of roots. In case of seedlings the root characters are found to be important and this is logical as the root system in mangosteen is magnolioid but cannot be recommended as indices for selection as they are underground, mangosteen plants are very sensitive and even removal of bits of leaves for chemical analysis normally resulted in death of plants.

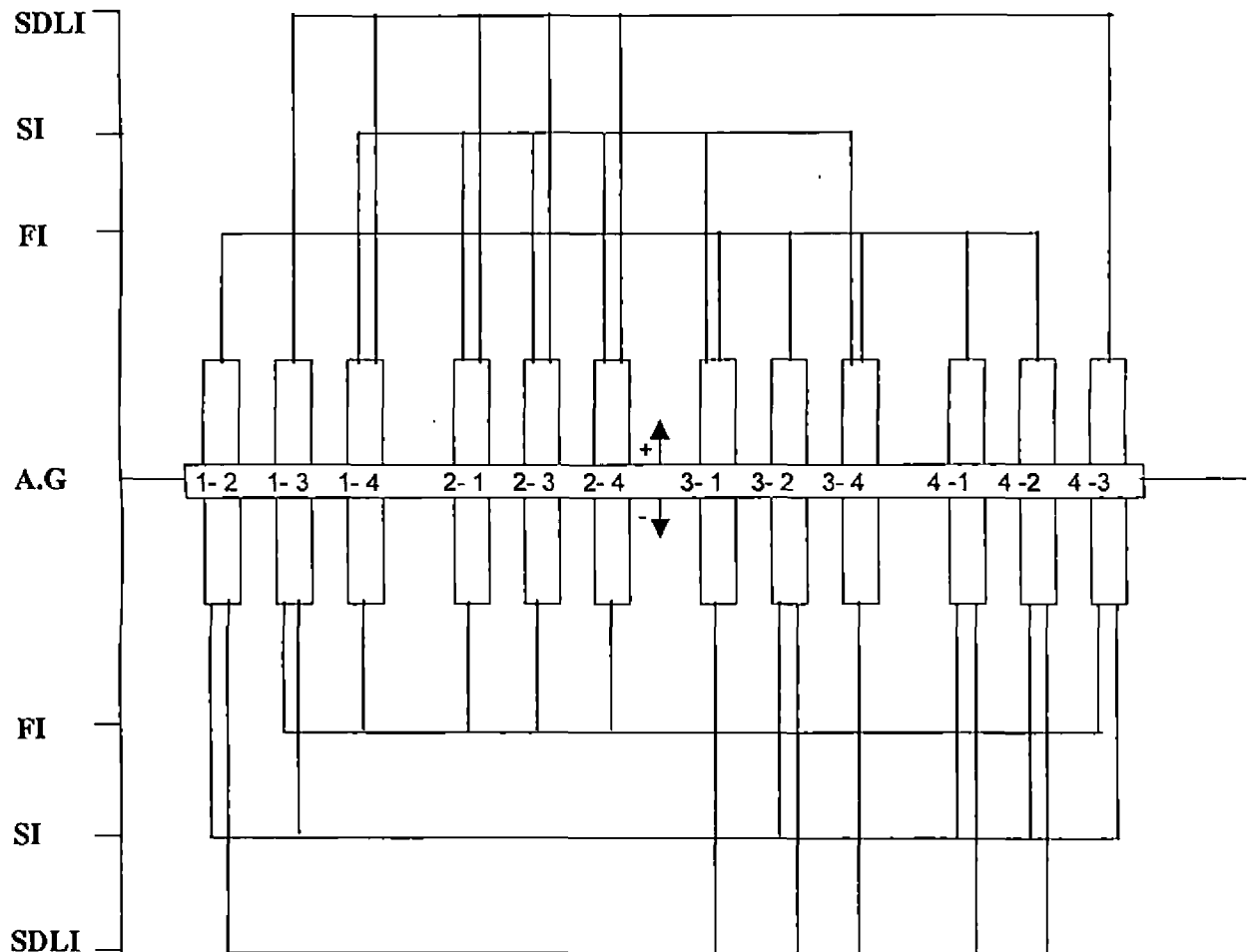
#### **5.1.5. Similarities between age groups based on the fruit, seed and seedling characters.**

A critical analysis of the various age groups point to a very important conclusion i.e., in most of the fruit characters the age group one and two gave comparatively lesser values, whereas the higher age groups gave maximum values and have higher fruit index. Like wise in the case of seeds the higher age groups were of better size but the lower age group gave more seeded fruits and gave better germination and more number of seedlings per seed. These characters though were highest in the age group two were equally high in the youngest age group and thus the similarity between these two younger age groups were higher resulting in more closer distance in the dendrogram showing hierarchical clusters based on the euclidean distance. In the case of seedling characters also a comparative study reveals more similarity and when all fruit, seed and seedling characters collectively were also taken. There was more similarity between the younger two age groups and this should be the reason for the very close distance between these age groups of less than 25 years and 25 – 50 years and the close proximity in the dendrogram (Fig. 9).

#### **5.1.6. Discriminant function**

Further extrapolation of the coefficients (Table 19) used in discrimination of various groups were critically analysed and presented as in Table 20. The directions of coefficients were used to prepare the dendrogram presented in Fig. 13 showing both the positive and negative direction of the coefficient of fruit index, seed index and seedling index. It is again obvious from the table and the dendrogram that maximum coefficients were positively linked in case of age group two when two specific pairs of age groups were discriminated as envisaged

**Fig. 13. Dendrogram showing the directions of discriminant coefficients of fruit, seed and seedling indices of each age group when compared to the remaining three age groups in mangosteen (*Garcinia mangostana* L.)**



**FI- Fruit index, SI- Seed index, SDLI- seedling index, A.G – Age groups for discrimination.**

in this study. This was actually a reflection of the higher seed and seedling characters in the age group two compared to the other age groups, which reconfirms that this group is the best age group for selection as mother plants.

#### **5.1.7. Selection index**

Based upon the equation, the selection index worked out revealed that the age group of 25-50 years was the best. This is actually more a reflection of the improved seedling characters particularly the germination percentage, survival rate and other morphological characters. The seed characters as revealed by the seed index were also highest in this particular age group. In the selection index equation the seed characters were given equal weightage with all characters and hence this age group which showed better seed characters gave more index values. Though the fruit characters were for better in the higher aged groups, seedlessness, low germination percentage and poor survival rate were the main reasons for the lower selection index values. Root characters cannot be taken as indices for selection as they are below ground, and hence not visible. Further any attempt to lift the bare seedlings normally ends up with death of the plants, as the plant is highly sensitive. As the root characters are positively correlated with shoot characters the selection based on the shoot characters is the reflection of the root characters as well.

Having identified the best age group the mid value of the dominant characters were chosen as viable indices for the selection. The mid values of seedling characters were fixed such that destructive procedures were to be avoided. Considering all the above results obtained in the study, the following characters with the mid values were selected as indices for selection.

The selection should be such that the fruits from mother plants of the age group of 25-50 years should have the fruit weight not less than 58 g, fruit girth not less than 5 cm, fruit volume not less than 51 ml, pulp weight not less than 16 g, rind weight not less than 41 g, number of segments less than 5 numbers.

Seeds obtained from the fruits with above characters, should have the seed weight not less than 0.66g, seed length not less than 1.61cm, seed thickness at centre not less than 0.66cm, seed volume not less than 0.44ml, seed specific gravity not less than 1.50, number of days to germination should not be less than

21 days, germination percentage not less than 87 per cent and preferably having the number of seeds per fruit more than one.

Further, seedlings at one-year stage from this age group with the above mentioned fruit and seed characters should have height not less than 10 cm, seedling girth at collar region not less than 2 cm, total number of leaves per seedling should be not less than 9, number of new flushes per year more than one, total leaf area per seedling not less than 72 cm<sup>2</sup> and survival rate must be not less than 85 per cent.

Finally sum up the work on selection indices it can be inferred that the study has generated results of immense practical relevance, which will directly aid in selection or act as a potent tool for selection of mother plant. Fruit, seed and seedling characters for improved seedling growth.

## **5.2. Growth regulators and activation of seedling growth**

The results of the studies on activation of growth using growth regulators revealed the overall superiority of GA 150 mg l<sup>-1</sup>.

One of the first proposals advanced to explain the biophysical mechanism of GA stimulated growth is that GA stimulated growth by lowering the osmotic potential by increasing the solute concentration of the cell sap (Wilkins, 1987). Changes in osmotic potential consequent to GA treatment due to increase in uptake leads to an increase in growth (Stuart and Jones, 1977). They observed higher uptake of K<sup>+</sup>, which was one of the prime reasons for increase in growth. The higher or altered levels of P observed in the study at this concentration should have been the reason for better root characters like number of roots which together with change in osmotic potential should have caused an increase in K<sup>+</sup> uptake.

Another qualitative aspect is the levels of chlorophyll which along with the increased leaf number and area collectively would have been responsible for higher amount of photosynthesis, finally leading to higher levels of carbohydrates and thereby better growth parameters like height girth etc. as observed in the present study. A study involving the changes in the polysaccharides or simple sugar levels with prior to and after flushing which is the major form of growth in perennials can only conclusively reveal the correct picture.

The positive effects of GA / Auxins on cell expansion and growth can be described even in biophysical terms. The most widely held ideas are that either newly synthesized wall polymers move into the wall or cell wall loosening factors are involved. Numerous demonstrations that GA treated elongation is paralleled by an increase in the synthesis of cell wall polymers (Montague and Ihuma, 1975 and Srivastava *et al.*, 1975; Kaufman and Dayanandan, 1983). The plant cell walls contain protein and inorganic ions in addition to complex polysaccharides and that both protein and ions especially  $\text{Ca}^{++}$  play a role in cell wall extensibility. The higher levels of crude protein observed in this treatment convincingly prove that protein synthesis was enhanced as a result of the exogenous application of GA at  $150 \text{ mg l}^{-1}$ .

The role of protons ( $\text{H}^+$ ) is described by the acid growth hypothesis (Hebard *et al.*, 1976) proposed both in the case of auxins and gibberellins. They observed the releases of  $\text{H}^+$  but the magnitude of its effects were quantified as only seventeen per cent above the control. In their study the implication of protons in the GA induced growth was because acidic buffers promote elongation only at optimal  $\text{GA}_3$  concentration. In the present study also, though three concentrations of GA and IAA were studied only GA  $150 \text{ mg l}^{-1}$  and IAA  $150 \text{ mg l}^{-1}$  were found efficient in promoting growth as both GA and auxin have roles in both cell wall loosening and extensibility factors. Such reports have also been made by Jones and Macmillan (1984) and Takahashi *et al.* (1986).

The proven effect of overcoming the dormancy imposed by abscisic acid is another method of action of GA's. The higher content of ABA in mangosteen could probably be counteracted only at the optimal concentration of GA. Taylor and Wareing (1979) have reported that GA's are antagonist to ABA and hence promote the growth.

One very interesting feature of the study is that both in case of total phenols and abscisic acid the highest amount were observed in the treatments showing the best growth and the lowest amount in the least effective treatment, which suggest that it is a case of correlative inhibition. White and Mansfield (1977) reported that the content is the same in inhibited buds as well as buds released from dormancy. Growth can only be visualized as sum of many positive factors favouring growth in relation to the factors affecting growth inhibition. On

the hormonal side, only the balance between growth promoters and growth inhibitors can reveal the correct situation. Based on the fact that maximum growth was observed only in GA  $150 \text{ mg l}^{-1}$  and IAA  $150 \text{ mg l}^{-1}$ , it should be presumed that the endogenous levels of growth promoters in relation to growth inhibitors or their ratio should have also been relatively high. Results generated in the studies of (Lassoie and Hinckley, 1991) point to this direction. Only a systematic and detailed study involving endogenous levels of all growth regulators at different stages in mangosteen should throw more light on this complex situation.

### **5.3. Arbuscular mycorrhizal fungi and activation of seedling growth**

The best treatments in case of microbial inoculation was a combination of G.f. 5 g + Az. 10 g + 10 SSP followed by G.f. 5 g + Az. 20 g + 10 SSP.

Critical analysis of the data reveal that the percentage of AM fungi infection was maximum in the treatments, which showed maximum growth. The next best also showed high percentage of infection. Though not the highest the same treatments showed high AM fungi spore count. These two-treatment combinations also showed high *Azospirillum* population. These three characters prove beyond doubt that the combination was best in the treatment, which gave maximum growth. This is a reflection of mycelial mat formation on absorbing roots, which in turn lead to a higher P, N and K uptake as observed in the study. The effects were most pronounced in case of P as the content registered a three-fold increase. This should have been due to two factors namely the external apply of 10 g SSP and a proven concept that mycorrhiza gives out an organic acid secretion which is capable of solubilising the acid soluble phosphate (i.e., semi soluble phosphate) into soluble form. Some of the previous reports substantiate these findings (Bartlett and Lewis, 1973). Increase in selective uptake of major nutrients has also been reported by several workers (Hatch, 1937; Umesh *et al.*, 1988 and Rizzardi, 1990). The capability of transferring it into the soluble form has also been reported (Bolan *et al.*, 1972). Another possible reason is that they can enhance the storage capacity and the continuous disintegration of arbuscules leads to the availability of more mineral nutrients to the host (Gerdemann, 1968).

The higher levels of P, which was near to the three times, should have been the reason for quantitative improvement of the root characters. This can be

observed in the best treatment in the study also induced the highest fresh and dry weight of roots, characters such as length of longest root and improved characters of number of roots. In mangosteen, Masri and Azizah (1998) had reported alternation of root characters such as root density and branching density which lead to 67-88 per cent higher uptake of P. Studies on alteration of rooting density is of paramount importance in mangosteen owing to the fact that the crop produces only magnolioid roots, which is an unique feature of mangosteen among all fruit crops. Due to lack or impaired production of root hairs, absorption of nutrients and water is less and even survival at nature's mercy or benevolence. As such any treatment, which improves the qualitative aspects of rooting such as root length, root branching and root density certainly will influence all aspects of growth and productivity and should be the prime consideration.

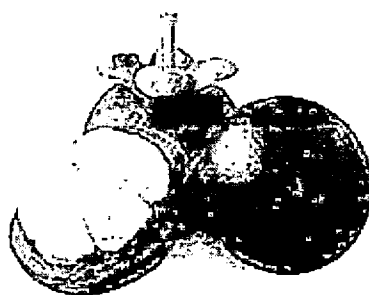
The production of growth promoting substances by *Glomus mosseae* and *Glomus fasciculatum* is well documented (Miller, 1971, Crafts and Miller, 1974 and Slankis, 1975). Higher nutrient uptake and growth promoting substances should have been the reason for the more chlorophyll content, and higher leaf area, which together accounted for higher carbon assimilation (Estrada-Luna, 2000) leading to higher carbohydrate content as observed in the study. Higher crude protein content also points to the level of protein synthesis due to AM fungi inoculation, which is a new area to catch up both imagination and investigation.

The higher nutrient uptake and carbohydrate accumulation resulted in higher shoot and root biomass and dry weight content. Differences observed in growth increment during intervals of observation are basically due to infectivity and colonization of AM fungi on feeder roots. This is partly an efficiency factor of the fungi and secondly is influenced by soil ecological factors as well as the host. In mangosteen, Masri *et al.* (1998) observed growth increase due to AM fungi inoculation and thereby reducing nursery period of mangosteen. Improved growth has also been reported by Masri *et al.* (1998).

As in the case of activation of growth using bioregulators, here also the content of inhibitors namely phenols and ABA were higher in the best treatment and a general decrease was observed to the treatment, which showed the least growth. This can also be argued only on the lines of correlative inhibition. The content being higher did not inhibit the growth, as the balance of various growth

regulators should have been more towards the plant growth promoters than growth inhibitors. More detailed investigation encompassing the whole endogenous levels of plant hormones at the critical stages of bud dormancy, bud activation, flushing and post flushing can only answer this vital question.

## *SUMMARY*



## CHAPTER - VI

### SUMMARY

The experiments on "Selection index and activation of seedling growth in mangosteen (*Garcinia mangostana* L.)" were conducted in the central orchard attached to the department of pomology and floriculture of the college of horticulture, vellanikara from March 2000 to February 2002.

The study was taken with the main aim of identifying some of the basic reasons responsible for the slow growth, and also to address this problem by evolving and identifying a criterion involving selection in age of the mother plant, fruit, seed and seedling characters or evolving direct selection indices at all four stages with respect to seedling growth. Activation of seedling growth by breaking the barrier of slow growth involved in this investigation in two directions, the first a hormonal approach to using growth regulator sprays (indole acetic acid, gibberellic acid and benzyl adenine) at defined concentrations and the second is use of arbuscular micorrhizal fungi (*Glomus mosseae* and *Glomus fasciculatum*) and *Azospirillum* individually and in combinations.

The important results obtained and the conclusions drawn out from the investigation are summarized hereunder.

1. Among the leaf biochemical characters of mother plant, nitrogen, phosphorus, potassium, crude protein, sodium, total phenols and total carbohydrates were highest in the lowest age group. Lowest values of nitrogen, phosphorus, potassium and crude protein were in the highest age group, whereas the content of sodium, total phenols and total carbohydrates was maximum in the age group of 51-75 years of mother plant.
2. All the morphological characters of the fruits and seedlessness recorded were maximum in the age group 51-75 years. Differences were observed between age groups in the case of number of one seeded, two seeded and three and more than three seeded fruit.

3. All morphological characters of the seed were maximum in the age group 51-75 years. The ungerminated seeds were maximum in the case of >75 years, whereas earliness in germination was best in 51-75 years and the percentage of germination was highest in the age group 25-50 years. Nitrogen, phosphorus, potassium, crude protein, total carbohydrates, total sugar, total phenol in seeds were highest in the age group 25-50 years, whereas sodium content was highest in <25 years and abscisic acid content was highest in >75 years.

4. Height, girth, number of leaves per seedling, total leaf area, survival rate and root characters were highest in 25-50 years age group, whereas root and shoot dry weight were maximum in the <25 years. The content of nitrogen, phosphorus, potassium, crude protein and sodium content was highest in the less than 25 years group, whereas chlorophyll a, b, total phenol, total carbohydrates and abscisic acid content were highest in the age group of 25-50 years.

5. New variables were generated using all the fruit, seed and seedling characters as fruit index, seed index and seedling index by principle component analysis.

6. Maximum fruit characters (fruit weight, fruit volume, fruit girth, pulp weight, rind weight) were positively correlated with seed characters such as seed weight, seed length, seed volume, number of seeds, number of seedlings per seed and number of seeds producing two and more than two seedlings.

7. Seed characters such as seed weight, seed length, seed thickness at centre, seed volume, number of seeds producing one seedling, number of seeds per fruit, germination percentage and seed index were positively correlated with the seedling characters such as height and girth of the seedlings, total number of leaves, total leaf area and seedling index. Number of seeds per fruit was positively correlated with number of flushes per year. Number of days taken to germinate was positively correlated with root length of the seedlings. Germination percentage and seed index were positively correlated with root fresh weight, number of primary, secondary and total number of roots.

8. Maximum fruit characters (fruit weight, fruit volume, fruit girth, pulp weight, rind weight, number of seedless fruits, number of one, two and three & more than



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three seeded fruits) were negatively correlated with seedling characters such as height, girth, total number of leaves, total number of new flushes per year, total leaf area, survival rate, fresh and dry weight of shoot and root, root length, number of primary, secondary, tertiary and total number of roots.

9. Using the principle component analysis and multiple regression analysis, prediction models for fruit index, seed index and seedling index were fitted. The prediction models had the corresponding adjusted  $R^2$  values, as follows

$$\text{Fruit index } Y = 0.0695 P_1 - 0.1283 P_2 - 0.0197 \quad (\text{adj. } R^2 = 0.99)$$

$$\text{Seed index } Y = 0.3198 P_1 - 0.6307 P_2 - 0.0135 \quad (\text{adj. } R^2 = 1.00)$$

$$\text{Seedling index } Y = 0.7003 P_1 - 0.0703 P_2 - 32.63 \quad (\text{adj. } R^2 = 0.99)$$

Where  $P_1$  and  $P_2$  are principle components 1 and 2.

10. To find out the dominant characters among fruit, seed and seedling characters and also all characters, a principal component analysis was performed. Figurative plots of PCA based on morphological data of fruit, seed, seedling and all characters collectively were made. The spread of the age groups and morphological characters on the plain defined by the first two principle components were figuratively represented.

11. No major fruit characters were identified when step-wise regression were performed for seedling index and the prediction model was

$$Y = 0.481 x_2 + 107.15 \quad (\text{adj. } R^2 = 0.038), \text{ where } x_2 - \text{age of the mother plant}$$

Major seed characters identified when step-wise regression were performed for seedling index were seed thickness at centre ( $x_{17}$ ), and the prediction model was

$$Y = 136.67 x_{17} + 10.83 \quad (\text{adj. } R^2 = 0.1087)$$

Where  $x_{17}$  - seed thickness at centre

Major seedling characters identified when step-wise regression were performed for seedling index were total leaf area ( $x_{30}$ ), survival rate ( $x_{31}$ ), fresh weight of shoot ( $x_{32}$ ) and root ( $x_{33}$ ), root length ( $x_{39}$ ) and total number of roots ( $x_{40}$ ) and the prediction model was

$$Y = 0.979 x_{30} + 0.037 x_{31} + 0.042 x_{32} + 0.027 x_{33} + 0.031 x_{39} + 0.202 x_{40} + 0.36 \quad (\text{adj. } R^2 = 1.00)$$

12. Hierarchical cluster analysis performed based on absolute euclidean distance to find out the similarities (or dissimilarities) of all characters between the four age groups revealed the closest and distance between < 25 years and 25- 50 year age groups.

13. Discriminant functional analysis was performed and six discriminant functions were fitted with corresponding  $D^2$  values to discriminate the six pairs involving the four age groups (1 and 2, 1 and 3, 1 and 4, 2 and 3, 2 and 4, 3 and 4) involving the four age groups envisaged in the study. The discriminate functions are

For discriminating group 1 and 2

$$Y = 0.0004 \text{ FI} - 0.0547 \text{ SI} - 0.0004 \text{ SDLI} \quad (D^2 = 0.431)$$

For discriminating group 1 and 3

$$Y = -0.0483 \text{ FI} - 0.0313 \text{ SI} + 0.0075 \text{ SDLI} \quad (D^2 = 2.381)$$

For discriminating group 1 and 4

$$Y = -0.0183 \text{ FI} - 0.0680 \text{ SI} + 0.0047 \text{ SDLI} \quad (D^2 = 1.739)$$

For discriminating group 2 and 3

$$Y = -0.0406 \text{ FI} + 0.1264 \text{ SI} + 0.0137 \text{ SDLI} \quad (D^2 = 2.782)$$

For discriminating group 2 and 4

$$Y = -0.0265 \text{ FI} + 0.3508 \text{ SI} + 0.0150 \text{ SDLI} \quad (D^2 = 10.29)$$

For discriminating group 3 and 4

$$Y = 0.0024 \text{ FI} + 0.2120 \text{ SI} - 0.0004 \text{ SDLI} \quad (D^2 = 4.064)$$

**Criteria and criterion** were determined to find the age groups of selected fruit, seed and seedlings collectively are

|                                  | <b>Criteria 1</b> | <b>Criteria 2</b> | <b>Criterion</b> |
|----------------------------------|-------------------|-------------------|------------------|
| For discriminating group 1 and 2 | -4.41             | -4.84             | -4.62            |
| For discriminating group 1 and 3 | -6.19             | -8.57             | -7.38            |
| For discriminating group 1 and 4 | 4.26              | 2.52              | 3.39             |
| For discriminating group 2 and 3 | 8.96              | 6.17              | 7.59             |
| For discriminating group 2 and 4 | 30.17             | 19.87             | 25.02            |
| For discriminating group 3 and 4 | 18.47             | 13.61             | 16.04            |

14. Selection index was worked out separately for each of the four age groups by giving equal importance to fruit index, seed index, seedling index and age of the mother plant. Selection index models and the values for each age group are

For group < 25 years: index values = 93.73

$$Y = -0.0402 \text{ FI} + 0.0513 \text{ SI} + 0.9960 \text{ SDLI} - 0.4317 \text{ (adj. } R^2 = 0.99)$$

For group 25-50 years: index values = 101.17

$$Y = -0.0562 \text{ FI} + 0.0129 \text{ SI} + 0.9979 \text{ SDLI} + 4.331 \text{ (adj. } R^2 = 0.99)$$

For group 51-75 years: index values = 65.20

$$Y = -0.0479 \text{ FI} + 0.0115 \text{ SI} + 0.9967 \text{ SDLI} + 3.070 \text{ (adj. } R^2 = 0.99)$$

For group > 75 years: index values = 67.20

$$Y = -0.0495 \text{ FI} + 0.0191 \text{ SI} + 0.9955 \text{ SDLI} + 2.247 \text{ (adj. } R^2 = 0.99)$$

Where FI, SI and SDLI are fruit index, seed index and seedling index.

15. Based on the above selection index values, the best age group for growth was identified as the mother plants belonging to 25-50 years age group. In this best age group, the average i.e. mid values of the each attribute of fruit, seed and seedling character were fixed as the index of selection criteria of that attribute. Further based on the correlations, for each attributes in fruit, seed and seedling characters, the above values or below values of the mid values served as the basis of the selection criteria. The important attributes and the selection values were given below, as

The selection should be such that the fruits from mother plants of the age group of 25-50 years should have the fruit weight not less than 58 g, fruit girth not less than 5 cm, fruit volume not less than 51 ml, pulp weight not less than 16 g, rind weight not less than 41 g, number of segments less than 5 numbers.

Seeds obtained from the fruits with above characters, should have the seed weight not less than 0.66g, seed length not less than 1.61cm, seed thickness at centre not less than 0.66cm, seed volume not less than 0.44ml, seed specific gravity not less than 1.50, number of days to germination should not be less than 21 days, germination percentage not less than 87 % and preferably having the number of seeds per fruit more than one.

Further seedlings at one-year stage from this age group with the above-mentioned fruit and seed characters should have height not less than 10 cm, seedling girth at collar region not less than 2 cm, total number of leaves per seedling should be not less than 9, number of new flushes per year more than one,

total leaf area per seedling not less than 72 cm<sup>2</sup> and survival rate must be not less than 85 %.

16. In the experiment on activation of growth using growth regulators, the best treatment for activation of the growth in mangosteen was GA 150 mg l<sup>-1</sup> followed by IAA 250 mg l<sup>-1</sup>.

17. The mean values of various morphological character of the seedlings treated with GA 150 mg l<sup>-1</sup>, IAA 250 mg l<sup>-1</sup> and control plants with no spray at twelve months stage as were follows. The mean values of height were 12.13 cm, 11.88 cm and 7.80 cm, girth were 1.58 cm, 1.48 cm and 1.17 cm, total number of leaves were 10.50, 9.50 and 8.25, number of flushes per year were 2.00, 1.60 and 1.30, number of leaves per flush were 2.00, 2.00 and 2.00, total leaf area were 99.85, 101.20 and 37.22 cm<sup>2</sup>, survival rate at twelfth months were 100, 100 and 100%, total fresh weight were 6.25, 8.74 and 2.28 g, total dry weight were 2.16, 2.59 and 1.15 g, dry weight ratio of root to shoot were 0.16, 0.69 and 0.53, root length were 16.30, 36.30 and 15.60 cm, number of primary roots were 20.00, 38.00 and 19.00, secondary roots were 31.00, 48.00 and 20.00 and tertiary roots were 18.00, 62.00 and 8.00 roots and the total number of roots were 69.00, 148.00 and 47.00 respectively.

18. The studies on biochemical characters (nitrogen, phosphorus, potassium, crude protein, chlorophyll a, b and total chlorophyll, total phenols, total carbohydrates and abscisic acid content) in the experiment on activation of seedling growth using plant growth regulators revealed a rhythmic pattern with the treatments that showed best growth registering higher values followed by the intermediate treatments (BA 250 mg l<sup>-1</sup>) and the lowest in the treatment showing least growth. On the contrary sodium content was maximum in plant having intermediate growth. The control plant (no spray) showed intermediate values between the treatment showing intermediary and least growth.

19. In the experiment on activation of growth using AM fungi and Azospirillum, it was found that the best treatment for the activation of seedling growth in mangosteen was a combination of *Glomus fasciculatum* 5 g + Azospirillum 10 g +

single super phosphate 10 g followed by *Glomus fasciculatum* 5 g + Azospirillum 20 g + single super phosphate 10 g.

20. The mean values of the morphological characters in the seedlings inoculated with a combination of *Glomus fasciculatum* 5 g + Azospirillum 10 g + single super phosphate 10 g, *Glomus fasciculatum* 5 g + Azospirillum 20 g + single super phosphate 10 g and control plants (no inoculation) at twelve months stage were as follows. The values of height were 18.30, 17.77 and 12.30 cm, girth were 2.32, 2.28 and 1.83 cm, total number of leaves were 15.00, 15.33 and 12.33, number of new flushes per year were 2.00, 2.00 and 1.12, number of leaves per flush were 2.00, 2.00 and 2.00, total leaf area were 287.50, 211.60 and 169.60 cm<sup>2</sup>, survival rate were 100, 100 and 100%, total fresh weight were 26.03, 21.92 and 14.45 g, total dry weight were 13.58, 7.62 and 4.10 g, root to shoot dry weight ratio were 0.29, 0.23 and 0.12, root length were 36.4, 23.2 and 25.4, number of primary roots were 40.00, 18.00 and 28.00, secondary roots were 58.00, 28.00 and 32.00 and tertiary roots were 60.00, 30.00 and 18.00 and total number of roots were 158.00, 76.00 and 78.00 respectively.

21. Studies on the biochemical characters (nitrogen, phosphorus, potassium, crude protein, chlorophyll a, b and total chlorophyll, total phenols, total carbohydrates and abscisic acid content) of the experiment for activation of seedling growth using a combination arbuscular mycorrhizal fungi and Azospirillum + single super phosphate, revealed that a rhythmic pattern. The best treatment (*Glomus fasciculatum* 5 g + Azospirillum 10 g + single super phosphate 10 g) regarding highest values followed by the intermediate (*Glomus mosseae* 10 g + single super phosphate 10 g) recording intermediate values, and least (*Glomus mosseae* 20 g + Azospirillum 10 g + single super phosphate 10 g) growth recording least values. The sodium content were equal in all the above three categories. The control plants (no inoculations) showed intermediate values between treatments showing intermediate and least growth.

22. The maximum spore count was recorded in the treatment *Glomus fasciculatum* 20g + single super phosphate 10g (228.0) followed by *Glomus fasciculatum* 20g + Azospirillum 20g + single super phosphate 10g (226.0). These values were

significantly nearly two and half times higher than the control (90.0). The data revealed that with increasing doses of inoculums and higher spore count was observed.

Highest percentage (80-90%) of root infection were observed in all the treatments with the combinations of *Glomus fasciculatum* + Azospirillum + single super phosphate followed by the combinations of *Glomus mosseae* + Azospirillum treated plants. Maximum infection was observed in the treatment combinations with low level and high levels of *Glomus fasciculatum* (5 and 20 g) and medium level of Azospirillum (10g).

Azospirillum populations were observed to be highest in the combinations of *arbuscular mycorrhizal* fungi + Azospirillum rather than each of the AM fungi alone inoculated treatment. Maximum population ( $0.4 \times 10^6$  cfu /g of soil) were recorded in *Glomus fasciculatum* 5 g + Azospirillum 10 g + single super phosphate 10 g followed by *Glomus mosseae* 20g + Azospirillum 20g + single super phosphate 10 g and *Glomus mosseae* 20g + Azospirillum 20 g + single super phosphate 10 g which recorded equal values of  $0.39 \times 10^6$  cfu /g of soil. The control with no inoculation showed least ( $0.12 \times 10^6$  cfu / g of soil).

23. Standard procedure (Little *et al.*, 1972) for identification and quantification of Absciscic acid was modified, as the banding pattern in mangosteen could not be obtained. A modified procedure from the above was standardized and the banding pattern corresponding to Rf values of ABA was obtained. Samples belonging to the four age groups, the experiment on growth regulator sprays and the plants inoculated with the combination of Arbuscular mycorrhizal fungi + Azospirillum + single super phosphates and standard samples were run and banding pattern as obtained. The bands were scraped carefully and ABA in each age group and treatments quantified. The study on identification and quantification of ABA in mangosteen is a basic and original contribution from the thesis work.

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\* Originals not seen

# **SELECTION INDEX AND ACTIVATION OF SEEDLING GROWTH IN MANGOSTEEN**

*(Garcinia mangostana L.)*

By

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## **ABSTRACT OF THE TH**

*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 - 680 654

KERALA, INDIA

**2002**

## ABSTRACT

The experiments on "Selection index and activation of seedling growth in Mangosteen (*Garcinia mangostana* L.) were conducted in the central orchard attached to the Department of Pomology and Floriculture of the College of Horticulture from March 2000 to February 2002 with the broad aims of standardizing selection indices as well as activation of the seedling growth in mangosteen. Two separate experiments, one approach envisaging growth regulators and the other involving arbuscular mycorrhizal fungi (*Glomus mosseae* and *Glomus fasciculatum* and Azospirillum with single super phosphate were taken up. The important results are as follows.

Analysis of leaf biochemical characters of the mother plants belonging to different age groups (<25, 25-50, 51-75 and >75 years) revealed that nitrogen, phosphorus, potassium and crude protein, were highest in the lowest (<25 years) age group and least values were in the highest (>75 years) age group, except sodium, total phenols and total carbohydrates, which were maximum in the age group of 51-75 years.

The number of seedless fruits and almost all the morphological characters of the fruit were highest in the age group of 51-75 years. Number of one seeded, two seeded and three and more than three seeded fruits were also varying among the four age groups.

All seed morphological characters and number of ungerminated seeds showed maximum values in the age group of 51-75 years and >75 years. Seeds obtained from the age group of 51-75 years showed earliness in germination but the percentage of germination was highest in the age group of 25-50 years.

The biochemical characters of seed revealed that nitrogen, phosphorus, potassium, crude protein, total carbohydrates, total sugar and total phenols were maximum in the age group of 25-50 years, whereas sodium and abscisic acid were highest in the age groups of less than 25 and more than 75 years, respectively.

The morphological characters of seedling such as, height, girth, total number of leaves per seedling, total leaf area, survival rate at twelve months stage and root characters were highest in 25-50 years age group whereas the root and shoot dry weight were maximum in the less than 25 years group.

Nitrogen, phosphorus, potassium, crude protein and sodium levels in the leaves of the seedling were highest in the age group of less than 25 years. Chlorophyll a, b, total phenols, total carbohydrates and abscisic acid contents were higher in the age group of 25-50 years.

Maximum fruit index was observed in the age group of 51-75 years but seed and seedling index were highest in 25-50 years age group.

Most of the seed characters were positively correlated with seedling characters. Though all the fruit characters were positively correlated with seed characters they were negatively correlated with seedling characters.

Fruit index, seed index and seedling index were separately predicted using the prediction models fitted by multiple regression equations of principle components one and two with corresponding adjusted  $R^2$  values.

Dominant characters among the age of mother plant, fruit, seed and seedling characters separately were found out by figurative plot principal component analysis based on morphological data of the above characters individually.

Using stepwise regression major characters contributing to seedling index were identified as age of the mother plant, seed thickness at centre, total leaf area, survival rate, fresh weight of root and plant, root length and total number of roots, which contributed maximum variation to seedling morphological characters and prediction model for fruit index, seed index and seedling index were fitted.

To establish the similarities (or dissimilarities) between the four age groups, hierarchical cluster analysis using euclidean distance was performed which revealed that the younger two age groups (less than 25 years and 25-50 years) of the mother plants were the closest groups with respect to all characters.

The four using discriminant functions were fitted to discriminate the four age groups with corresponding  $D^2$  values. The criteria and criterion were determined to describe the age groups of selected fruit, seed and seedlings collectively.

By giving equal importance to age of the mother plant, fruit index, seed index and seedling index the selection index was worked out and the best age group of the mother plant for obtaining maximum growth of seedlings was identified as 25-50 years. Based on the correlations between various characters and

growth index, the above or below average values with respect to each of the attribute (important and visual) belonging to the fruit, seed and seedling characters were identified. The mid values of the each attribute in the best age group were fixed as the index for selection.

Among the growth regulator sprays for activating the slow growth in mangosteen, the best treatments were GA 150 mg l<sup>-1</sup> followed by IAA 250 mg l<sup>-1</sup>.

Biochemical studies on the growth regulators treated plants revealed that the treatment that showed maximum growth also recorded the highest values of nitrogen, phosphorus, potassium, crude protein, chlorophyll a, b, total chlorophyll, total phenols, total carbohydrates and abscisic acid content. The treatment, which showed intermediate growth recorded intermediate values except for sodium, where it was maximum. The least content was observed in the treatments with least growth. The control plant showed intermediate values between the values of plant with intermediate and least growth.

Best treatment for activating the seedling growth among the treatments with arbuscular mycorrhizal fungi and Azospirillum inoculations were identified as, the combinations of *Glomus fasciculatum* 5 g + Azospirillum 10 g + single super phosphate 10 g followed by *Glomus fasciculatum* 5 g + Azospirillum 20 g + single super phosphate 10 g.

A rhythmic pattern was observed with the treatments showing best seedling growth also recording higher values of nitrogen, phosphorus, potassium, crude protein, chlorophyll a, b, total chlorophyll, total phenol total carbohydrates and the abscisic acid content, and the treatments showing in intermediate growth recording intermediate values except sodium. The least values were in treatments that showed least growth. The control plant showed intermediate values between the values of the plant with intermediately and least growth.

The highest spore count was observed in the plants inoculated with *Glomus fasciculatum* 20g + single super phosphate 10 g followed by *Glomus fasciculatum* 20 g + Azospirillum 20 g + single super phosphate 10 g. With regard to the root infection, plants inoculated with *Glomus fasciculatum* 5 g + Azospirillum 20 g + single super phosphate 10 g. and *Glomus fasciculatum* 20 g + Azospirillum 10 g + single super phosphate 10 g revealed maximum percentage of infection. The Azospirillum population was maximum in the plants inoculated

*Glomus fasciculatum* 5 g + Azospirillum 10 g + followed by *Glomus mosseae* 20 g + Azospirillum 20 g + single super phosphate 10 g.

The standard procedure for identification and quantification of abscisic acid (Little *et al.*, 1972) was modified, as clear banding patterns were not obtained. Using the modified procedure, the characteristic-banding pattern corresponding to standard abscisic acid was obtained and confirmed when standards of abscisic acid were also simultaneously run with samples.

Banding patterns and quantification of samples in each of the four age groups, the growth regulator treatments and the treatment with arbuscular mycorrhizal fungi and Azospirillum inoculated plants were also successfully conducted.