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Preliminary studies on selection indices for activating seedling growth in mangosteen (*Garcinia mangostana* L.)

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Abstract: Studies on selection indices for activating seedling growth in mangosteen were conducted in the central orchard at the main campus of Kerala Agricultural University. The present investigation was undertaken with the main aim of identifying some of the basic reasons for slow growth in mangosteen, and to address this problem by developing and identifying criteria to select the age of the mother plant, fruit, seed and seedling characters or direct selection indices at all four stages with respect to seedling growth. Mother plants of four distinct age groups were used in the study. Variables were generated using all fruit, seed and seedling characters such as fruit index, seed index and seedling index by principal component analysis (PCA). Using PCA and multiple regression analysis, prediction models was fitted for the three indices. Major fruit, seed and seedling characters were identified by stepwise regression. Hierarchial analysis was performed based on Euclidean distance to find the similarities between the four age groups. Discriminant function analysis was performed and six discriminant functions were fitted with corresponding D^2 values to discriminate the six pairs involving the four age groups of the mother plants. For practical purposes, selection indices and best age group of mother plants are described in the work.

1. Introduction

Mangosteen (*Garcinia mangostana* L.), the queen of tropical fruits (Almeda and Martin, 1976; IBPGR, 1986; Kusumo and Verheij, 1994), is a very important crop of the warm humid tropics. The crop like other polyaxial tropical and sub tropical trees such as rubber, mango, cashew and citrus, exhibits a rhythmic growth habit under the relatively constant environmental conditions of the tropics (Alvim, 1964; Borchert, 1973). It bears profusely and fits very well as a component of home gardens of Kerala. Though it is a fruit crop with immense potential, both as a monocrop and as a mixed crop in 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*., 1992 b).

The apomictic mangosteen (Richards, 1990; Normah *et al*., 1992) seedlings used for commercial planting are extremely slow growing, both at nursery stage and in orchards (Hume, 1947; Almeda and Martin, 1976; Wiebel *et al*., 1991, 1992 a). The slow growth rate and consequent long pre-bearing phase have been a cause for concern wherever mangosteen is grown. Though the long gestation period, ranging from 10-15 years (Lim, 1984; Richards, 1990; 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*., 1992 b, 1995). This crop lacks root hair (Richards, 1990) and this reduced vital link responsible for absorption of nutrients and water may be one of the prime reasons for slow growth. 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).

A critical review of the literature has revealed that only very few references to the crop exist. Selection index studies are available in palms but the aims differ as the thrust of the present work is directed toward the growth rate. This study was undertaken with the objectives of identifying some of the basic reasons for the slow growth rate and, secondly, to address this problem by identifying the mother plant, fruit and seed characters in relation to seedling growth and formulating the selection indices at these three basic levels. Accelerating the growth rate of mangosteen trees and thereby reducing the gestation period is one of the pre-requisites for an extensive commercialization of this crop.

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2. Materials and Methods

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

Identification of mother plants belonging to various age groups

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

The required number of plants belonging to different age groups could have been located in different regions, but the 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 fruit collection were centered on this area. Furthermore this approach aided in eliminating possible errors from an ecological point of view to the minimum.

Location of mother trees (Pariyaram village)

Pariyaram village 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 the Chalakudi Railway Station, Thrissur District.

Climate and soil conditions of the area

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

The soil of the area where the mother trees are located is sandy alluvium with pH 5.5 -5.8 and belonging to the order of Entisol. The soil is low in available N and P_2O_5 and high in available K_2O.

Once fruit collection and observations 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 experiences a warm humid tropical monsoon climate. It is situated at 12° 32'N latitude and at 74° 20'E longitude at an altitude of 22.5 m above mean sea level.

Soil type is a typical sandy clay loam with pH 5.4, EC 1.25 dsm^{-1}, and belonging to the order Ultisols.

Mother plant characters

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

1. Trees having an age of less than 25 years;
2. Trees having an age of 25-50 years;
3. Trees having an age of 51-75 years;
4. Trees having an age of more than 75 years.

Within each age group, ten fruits per tree were collected from five mother plants randomly, so that each age group had a total of fifty fruits. Care was taken to see that the mother plants under selection fell near the mid value of each age group and so that the five plants in a group were more or less uniform in growth characters (height and spread). Fruits were labeled individually and seeds were extracted from the fruits. The seeds were sown separately in black polythene bags (45x30 cm) filled with potting mixture made up 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 the four age groups (Table 1) were recorded separately as presented below.

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- or more seeded fruits, number of seedlings produced per fruit and seed specific gravity were recorded.

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 seeds producing one seedling, number of seeds producing two or more than two seedlings (Table 2), number of days taken to germination, and germination rate were recorded based on ISTA guidelines (ISTA, 2003).

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, and total leaf area were limited to a twelve-month stage.

Shoot and root characters

Shoot and root 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. Based on the fruit index, seed index and seedling index the selection indices were determined.

Biochemical analysis

The following biochemical characters were estimated in seeds and leaves of the mother plants and seedlings of the four age groups. However biochemical analyses were restricted to the treatments showing the growth of best, in-

Table 1 - Latent vectors and variance of the principal component analysis performed for generating fruit, seed and seedling indices separately in mangosteen (*Garcinia mangostana* L.)

Sl. No.	Characters	Principle component 1	Principle component 2
	Fruit characters		
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	0.16
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	0.0 1
11	Number of three and multi seeded fruits	0.00	0.01
12	Number of seedlings/Fruit	0.00	0.04
	Cumulative variance	**96.27**	**98.68**
	Seed characters		
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	0.1 I
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
	Cumulative variance	**97.63**	**99.50**
	Seedling characters		
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 twelth 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	0.1 8
15	Total number of roots	0.20	0.94
	Cumulative variance	**70.05**	**95.77**

Table 2 - Average fruit index, seed index and seedling index values of four age groups in mangosteen (*Garcinia mangostana* L.)

Age groups (Years)	Fruit index	Seed index	Seedling 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

termediate and least categories, in the experiments of activation of seedling growth using growth regulators and *A M* 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. Abscisic acid - seeds and leaves

Selection index

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

Fruit characters

Individual fruits were labeled immediately after harvest. Fruit weight was then recorded using an electronic balance (Contech precision balance) and the average expressed in grams. Girth of the fruit was measured using a thread and its length measured using a metre scale and the average expressed in centimeters. Fruit volume was measured by water displacement method and the average volume expressed in milliliters. The fruit hull was carefully removed and the weight of the white-segmented pulp (aril) of each fruit with seeds was measured using an electronic balance. Seeds were extracted and their weight recorded and the average expressed in grams. Pulp weight of each individual fruit alone was calculated using the formula:

Pulp weight alone (g) = Pulp weight with seed (g) - seed weight alone (g)

The rind weight of each individual fruit was calculated using the following formula and the average expressed in grams:

Rind weight (g) = Total fruit weight (g) - Pulp weight with seed (g)

Numbers of white juicy segments were counted immediately after the fruits were opened and the average

expressed as a number. Numbers of seeds per fruit were counted and categorized as one, two, three and more in three-seeded and seedless fruits and the average expressed as a number.

Total number of seedlings obtained from individual fruits was counted irrespective of the number of seeds per fruit and the average was expressed numerically.

The specific gravity fruits was calculated using the following formula and the average expressed as grams/milliliter:

Fruit specific gravity = (Fruit weight / Fruit volume)

Seed character

The seeds were extracted from the pulp and the weight of individual seeds in fruits was measured using an electronic balance; the average seed weight was expressed in grams. Seed length and thickness at the centre were also measured, with the aid of a meter scale, and averages expressed in centimeters. Seed volume was measured by water displacement method and the average expressed in milliliters. Seed specific gravity was calculated using the formula

Seed specific gravity = (seed weight / Seed volume)

and the average expressed as grams/milliliter.

Total number of seeds present in individual fruits, total number of seedlings produced by individual seeds and total number of ungerminated seeds were counted and averages expressed as a number. The number of seedlings produced by an individual age group was calculated and the average expressed as a number. The number of seedlings produced by individual seeds was counted and categorized as seeds producing one, two and more than two seedlings and the average expressed as a number.

The number of days from date of sowing to seed germination was counted and the average expressed as number of days. Germination rate was calculated for each individual age group and the average expressed as a percentage.

Germination % = (Total number of seeds germinated / Total number of seeds sown) x 100

Seedling characters

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

Seedling girth was measured at the collar using a thread; thread length was measured using a meter scale and averages expressed in centimeters. Total number of leaves produced by an individual seedling was counted and the average expressed as a number.

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

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

Leaf area was calculated by multiplying the length, the breadth and the factor (0.6727) and the average expressed as cm^2. The factor was pre-standardized, for this purpose, by measuring the length and breadth of 100 leaves: 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:

Factor = (Leaf area / Length x breadth)

Survival rate was determined from the number of established plants as a percentage of the total number of seedlings observed after germination.

Survival % = (Total number of seedings observed at each interval / Total number of seedlings observed immediately after germination) x 100

Shoot and root characters

Seedlings were uprooted one year after germination. The plants were immediately cut and separated into shoots and roots. Fresh shoot and root weights were recorded separately using an electronic balance and the average expressed in grams.

The samples collected for the fresh weight were dried in an oven at 60°C till the weight of the samples remained constant. Dry weights were recorded separately and averages expressed in grams.

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

Dry weight ratio = (Root dry weight / Shoot dry weight)

Length of the longest root (taproot) was measured from the collar region to the growing tip of the taproot using a meter scale and expressed in centimeters. 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 averages expressed as the number of roots.

Biochemical studies

Leaf samples from seedlings were collected one year after germination; 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 to estimate the content of N, P, K and Na.

The total nitrogen content of leaf samples was determined by microkjeldhal method (Jackson, 1973) and the average expressed as percentage. The phosphorus content of the samples were determined using the di-acid extract method (Jackson, 1973). A spectrophotometer was used to determine colour intensity developed by Vanado-molybdo phosphoric yellow colour method and readings were taken at 420nm wavelength. Phosphorous content was cal-

culated using a standard graph and the average expressed as a percentage. The potassium and sodium contents of samples were determined with di-acid extract (Jackson, 1973) and read in an EEL flame photometer, at 548 nm and 598 nm respectively, and averages expressed as a percentage. Nitrogen content was estimated by microkjeldhal method (Jackson, 1973) and the value of nitrogen content was multiplied with the factor 6.25 to get the crude protein content and the average expressed as a percentage.

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

Total sugars were estimated using standard procedure (A.O.A.C., 1980), total carbohydrates were estimated using Anthrone method (Dubois *et al*., 1951), and averages expressed in milligrams; total phenol content was estimated using the Folin-Ciocalteau method (Sadasivam and Manickam, 1996) and expressed in milligrams.

Procedure adopted for quantification of abscisic acid

The procedure adopted for 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 standardized and bands were obtained corresponding to the standard abscisic acid. Further quantification was done using a U-V spectrophotometer and standards of known concentration from which a standard graph was obtained.

Generation of new varieties as index

Variability in morphology characters (38 characters) were recorded. 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 (A.O.A.C., 1980) making it possible to identify the best age group of mother plants. The first principal component which accounted for maximum possible variance was selected. This is supported by the work of Manzano *et al*. (2001).

Estimation of correlation

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

Principal component analysis

The observations of 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 reducing dimensionality of the problem and which finds new variables that make the data easier to understand (Chatfield and Collins, 1980).

Principal component analysis (PCA) was used to determine the relationship among the fruit characters, seed characters, seedling characters and four age groups (Meilgard *et al*., 1991) and was 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:

Factor scores= each attribute factor loading x the original attribute mean score

Although the characteristic 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 character (Dever *et al*., 1996).

Step-wise regression

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

Cluster analysis

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

$$Drs : \{\sum^{P} (X_{ri} - X_{si})^2\} \text{ to } ½$$

- and the variable were the Principal component co-ordinates.

where Drs - Distance from individual r to individual s, X_{rj} - Value of individual r X_{sj} - Value of individuals.

Selection index

Selection index or total index values were worked out using 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 method described above. Regression analysis was performed for each age group separately to find 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

$$Y=a_1F1 + a_2S1 + a_3SDLI + C$$

where a_1, a_2, a_3 were regression coefficient or weightage of F1, S1 and SDLI, which are fruit index, seed index and seedling C the Intercept constant (Manoj, 1992).

3. Results

The results of the study have been divided into broad aspects for presentation.

Fruit, seed and seedling indices

The numbers of independent variables were large in the present study. Hence, to reduce the number of descriptors, principal component analysis was performed using the deviation squares and products matrix of the 12 fruit, 11 seed, and 15 seedling characters independently in order to establish a list of minimum descriptors (i.e. fruit index, seed index and seedling index), thereby enabling identification of the best age group of mother plants, as well as 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% respectively, are given in Table 1. The computed average fruit, seed and seedling index values of each age group are presented in Table 2 and figure 1.

Fruit index

The highest fruit index value was in the age group of 51-75 years of mother plants, followed by the age group of more than 75 Years.

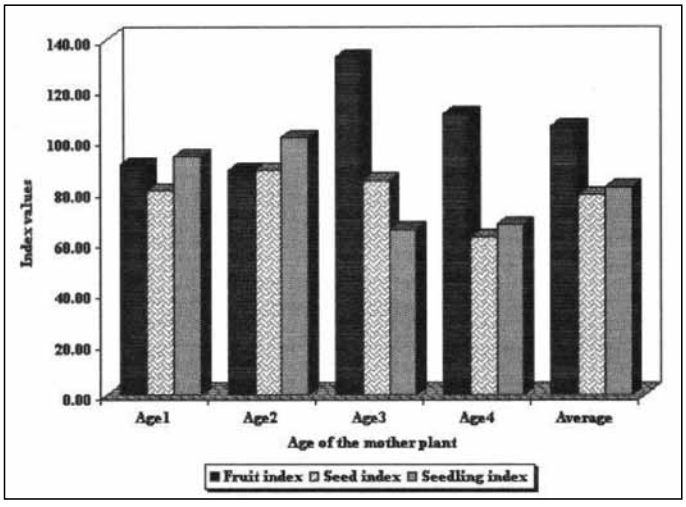

Fig. 1 - Fruit, seed and seedling index of four age groups in mangosteen (*Garcinia mangostana* L.).

Seed index

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

Seedling index

The highest seedling index was observed in the age group 25-50 years, followed by the age group of less than 25 years. An important observation was made: 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 the same for the seed and seedling characters. However, equal importance was given to each of the three index values and to the age group for finally determining the best age group of mother plant.

Principal component analysis

Principal component analysis was performed using the deviation squared and product matrix of the 14 fruit characters, 13 seed characters, 20 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 characters, were found to be 88.78, 92.94 and 92.49% respectively. The cumulative variance, factor scores and contribution of variation of each character are presented in Table 3 and the same for each age group in Table 4. The fruit index among the fruit characters, seed index among the seed characters 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

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

Where Y_1 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_1 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_1, 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 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 3). 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 characters of age group three (51-75 years) were dominant. On the other hand, the number of seeds per fruit was observed as the dominant characters in the

Table 3 - Eigen vectors, factors loadings and contribution of variations by each character in fruit, seed and seedling characters in mangosteen (*Garcinia mangostana* L.)

Characters	Eigenvectors		Factor loadings		Contributions of variation (%)	
	F1	F2	F1	F2	F1	F2
Fruit characters						
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	-4.22	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**				
Seed characters						
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**				
Seedling characters						
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	0.2l	-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**				

less two age groups (i.e. <25 and 25-50 years age groups). Interestingly, in age group four (>75 years), the most dominant character was observed to be seedlessness (Fig. 2).

Table 4 - Factor 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
Fruit characters				
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
Seed characters				
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
Seedling characters				
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. l5	-0.01	0.03	0.00

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 found for 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 second age group (25-50 years). In age group one (<25 years) the number of days taken to germination and seed specific gravity were noted to be the dominant characters. In age group three, seed weight, seed volume and seed length were the dominant characters, whereas in age group four, the dominant character was the number of ungerminated seeds (Fig. 3).

In the case of seedling characters, negative scores were observed only for the root to shoot dry weight ratio in factor I; in factor II negative scores were found for girth, survival rate, shoot dry weight, root length and 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 age group two. In the case of age group one characters such as the root fresh

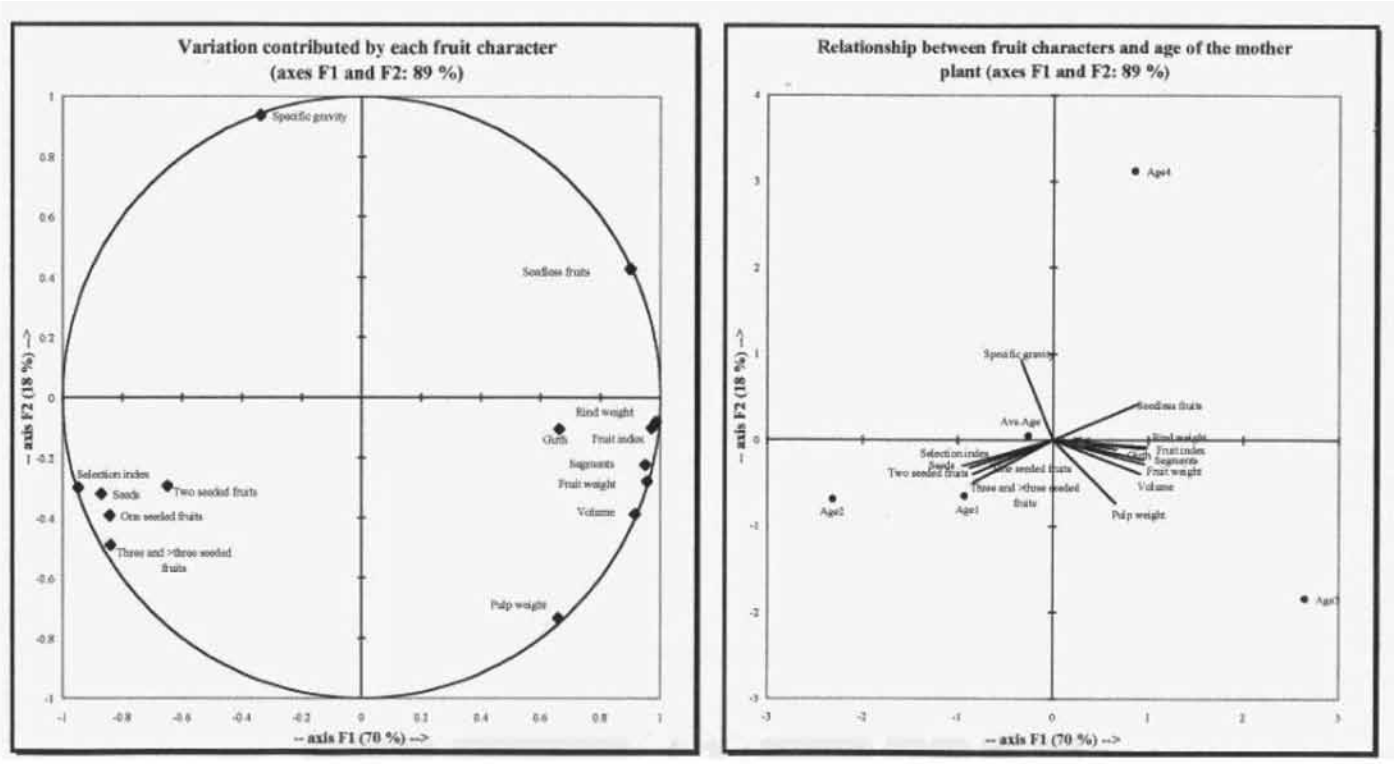

Fig. 2 - Plot showing the percentage of variation contributed by each fruit character and the relationship between age of the mother plant and fruit characters in mangosteen (*Garcinia mangostana* L.).

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. 4).

Principal component analysis reduces only the dimensionality, but not the number of variables involved. Hence, to reduce the number of variables and to identify the major

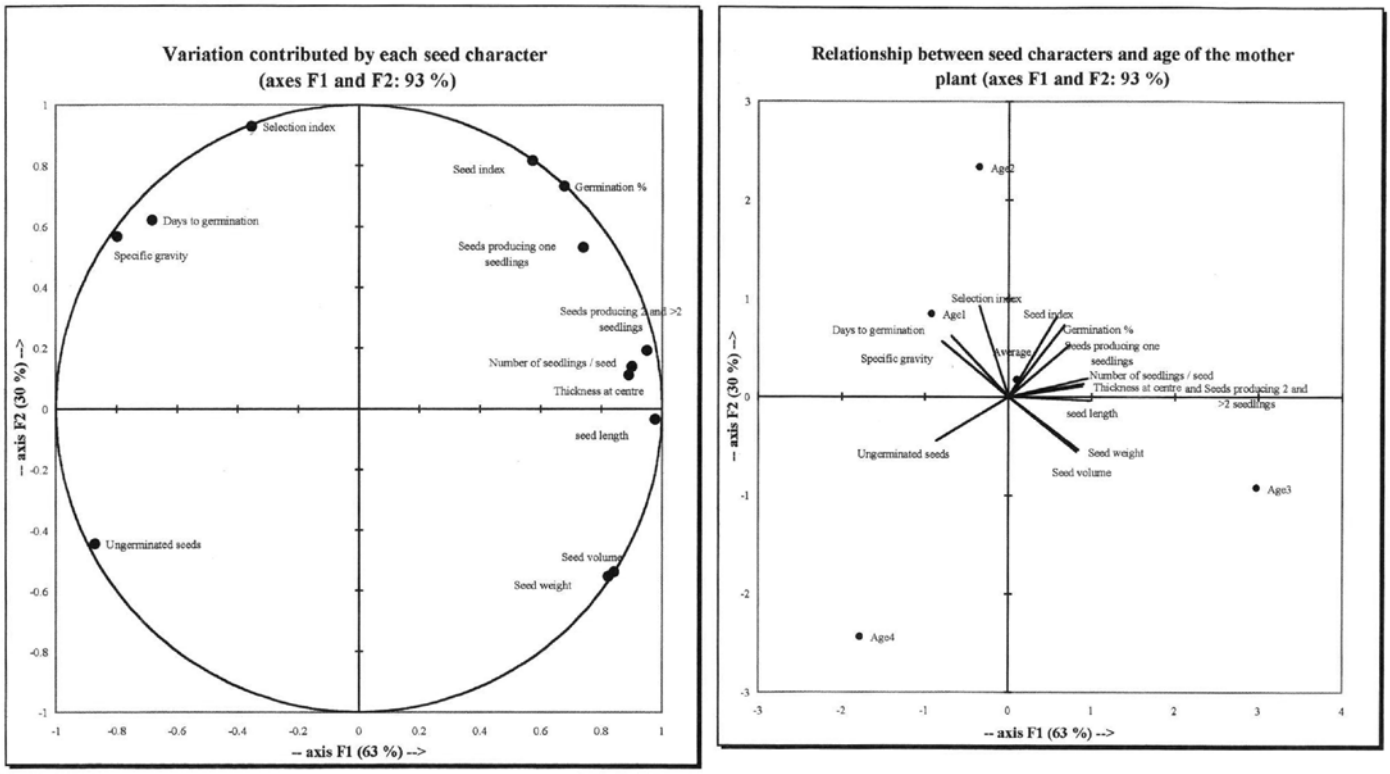

Fig. 3 - Plot showing the percentage of variation contributed by each seed character and the relationship between age of the mother plant and seed characters in mangosteen (*Garcinia mangostana* L.).

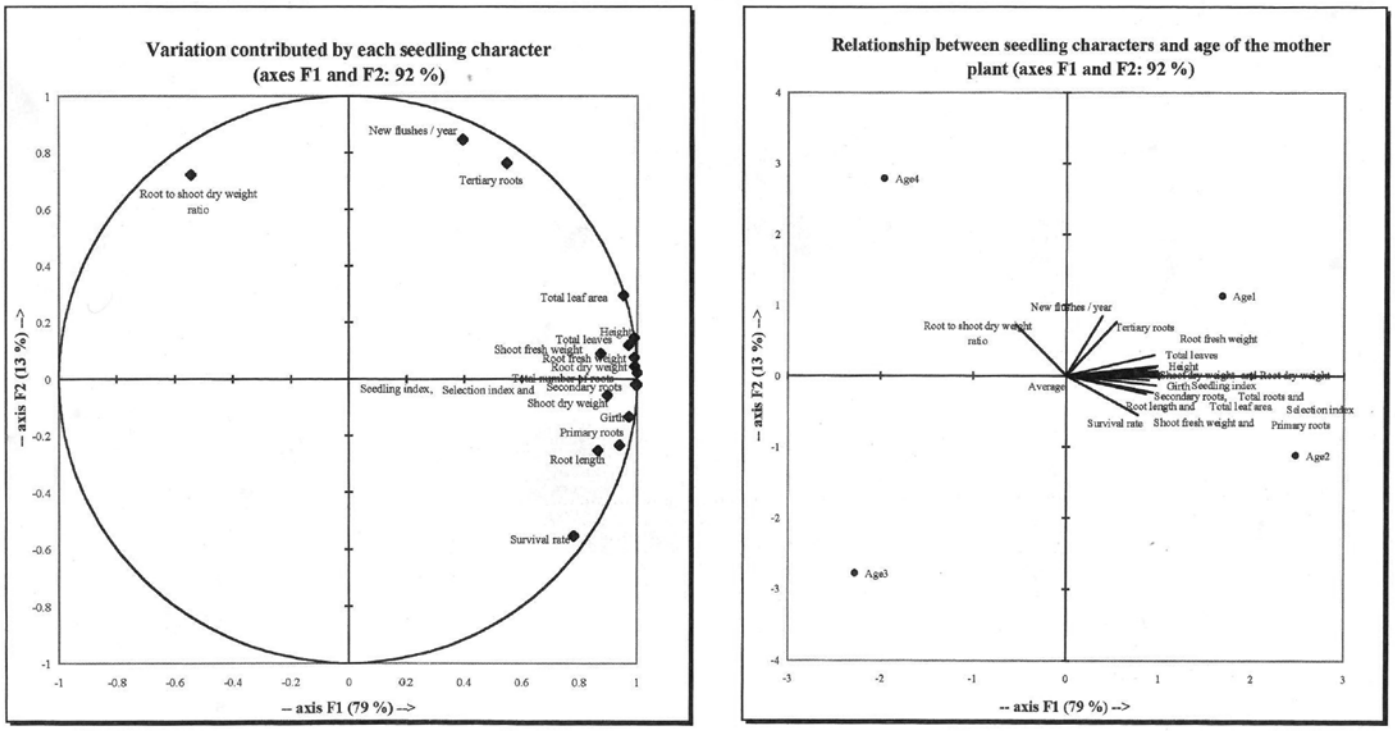

Fig. 4 - Plot showing the percentage of variation contributed by each seedling character and the relationship between age of the mother plant and seedling characters in mangosteen (*Garcinia mangostana* L.).

variables that contribute greater variation to the fruit, seed and seedling index, a step-wise regression was performed.

Step-wise regression

Step-down regression of the 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 characters collectively, and seedling index on 13 fruit characters, 12 seed characters, 19 seed characters including age separately and also collectively (all the 42 fruit, seed, seedling characters and age) was carried out and the following regression equations with major variable, to each, indices on each group of characters, were observed.

Fruit index on fruit characters alone

$Y = 1.295\ x_7 + 1.7\ l5x_8 + 1.3\ 19\ x_{14} - 4.17$ with an R^2 at 0.993

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

Seed index on fruit characters alone

Y = -a.282 x2 + 0.427 x3 + 14.416 x5 + 22.368 x10+ 126.73 with an R2 at 0.203.

Where Y – seed index, x2 – age of the mother plant, x_3 - fruit weight, x_5 - fruit girth, x_{10} - number of seedless fruits.

Seed index on seed characters alone

Y= 0.007 x15 - 0.004 x16 - 0.012 x17 + 0.009 x18- 0-008 x19 + 0.002 x20 +0.004 x21 + 0.015 x22 + 0.002 x24 + x25 + 0'01 with an R2 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.

Seed index on fruit and seed index collectively

$Y = -0.002\ x_{11} - 0.006\ x_{15} - 0.006\ x_{17} + 0.006\ x_{18} - 0.007\ x_{19} + 0.005\ x_{21} + 0.015\ x_{22} - 0.002\ x_{23} + x_{25+}\ 0.01$ with an R^2 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_{13} - 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.

Seedling index on fruit characters including age

Y =-0.481 x2 + 107.15 with an R2 of 0.0388

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

Seedling index on seed characters

Y =136.67 x17 - 1083 with an R2 of 0.1087

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

Seedling index on seedling characters

Y= 0.979 x30 + 0.037 x31 + 0.042 x32+ 0.027 x33 + 0.031 x39+ 0.202 x40 + 0 .36 with an R2 of 1.00

where, Y - seedling index, x_{30} - total leaf area per seedling, x_{3l} - survival rate at l2-months stage, x_{32} – shoot fresh weight, x_{33} - root fresh weight, x_{39} - foot length, x_{40} - total number of roots.

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

Y= 0.026 x26 + 0.030 x28+ 0.977 x30 + 0.037 x31 + 0.0034 x32- 0.029 x33+ 0.017 x35 + 0.009 x36 + 0.031 x_{39} + 0.031 x_{39} + 0.201 x_{40} with an R^2 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, - root dry weight, x_{36} - root dry weight, x_{39} - root length, x_{40} - total number of roots.

Cluster analysis

Cluster analysis was performed to highlight 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 Table 5. Figure 5 illustrates the dendrogram showing the clusters (or similarities) based on the fruit, seed and seedling characters among the four age groups.

Considering fruit characters, closest distance was observed between age groups of more than 25 years and 25-50 years, followed by the age group of 25-50 years and more than 75 years; in all the remaining combinations greater distances were observed, indicating that the age group of more than 25 years and 25-50 years have more similar fruit characters.

With regard to seed characters, closest distance was again observed between age groups of more than 25 years and 25-50 years, followed instead by the age group of more than 25 years and more than 75 years. With regard to all the remaining combinations greater distances were observed, indicating that the age group of more than 25 years and 25-50 years have more similar seed characters.

For seedling characters, closest distance followed the same trend (i.e. age group of more than 25 years and 25-50 years). All the remaining combinations were observed at greater distances, indicating that also for seedling charac-

Table 5 - 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
Fruit				
1	0.00	14.41	39.25	20.57
2	14.41	0.00	3 1.60	15.6
3	39.25	31.60	0.00	22.57
4	24.57	15.60	22.57	0.00
Seed				
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
Seedling				
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
All characters				
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

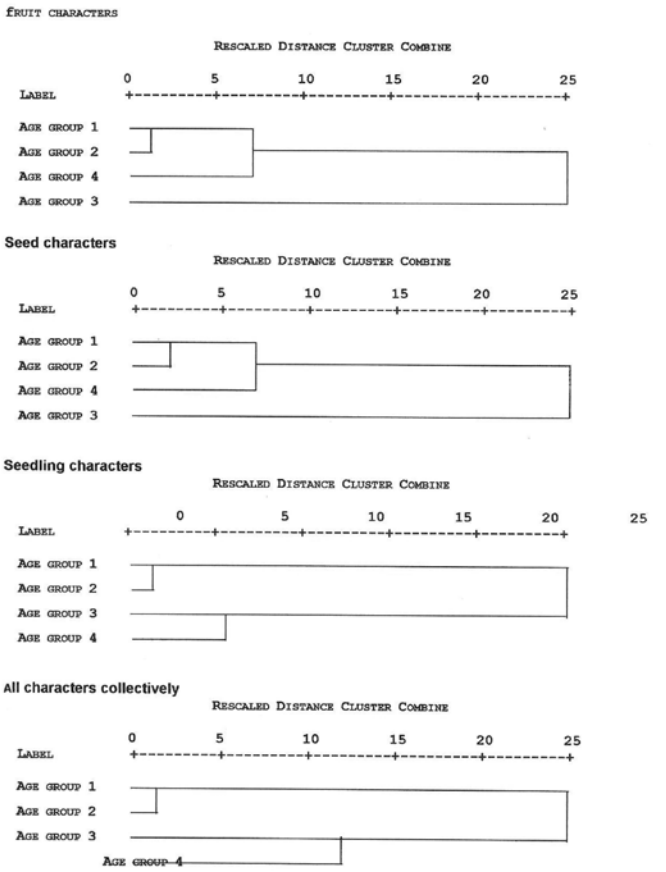

Fig. 5 - Dendrogram showing the similarity and proximity of the four age groups based on the fruit, seed and seedling characters individually and collectively in mangosteen (*Garcinia mangostana* L.).

ters the age group of more than 25 years and 25-50 years are more similar.

When the fruit, seed and seedling characters were taken collectively, the closest distance was observed between age group of more than 25 years and 25-50 years, followed by the age group of more than 25 years and more than 75 years; in all the remaining combinations greater distances were observed. Finally it may be confirmed that, based on all four dendrograms, maximum similarity for all the characters was between the age group of less than 25 years and 25-50 years.

Discriminant function analysis

Fruit index, seed index and seedling index of the 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
$Z = 0.0004\ FI - 0.0547\ SI - 0.0004\ SDLI$ with $D^2 = 0.4313$

For groups 1 and 3
$Z = -0.0483\ FI - 0.0313\ SI + 0.0075\ SDLI$ with $D^2 = 2.381$

For groups 1 and 4
$Z = -0.0183\ FI - 0.0680\ SI + 0.0047\ SDLI$ with $D^2 = 1.739$

For groups 2 and 3
$Z = -0.0406\ FI + 0.1264\ SI + 0.0137\ SDLI$ with $D^2 = 2.782$

For groups 2 and 4
$Z = -0.0265\ FI + 0.3508\ SI + 0.0150\ SDLI$ with $D^2 = 10.29$

For groups 3 and 4
$Z = 0.0024\ FI + 0.2152\ SI + 0.0004\ SDLI$ 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 coefficients in each age group is given in Table 6. In this maximum number of positive directions were observed in the age group of 25-50 years, when discriminated with other three

Table 6 - 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	+	+	-

age groups (Table 7). The corresponding discriminant values of each age group (criteria) and the mid values of each pair of discriminant values were taken to draw the conclusion 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 8.

Selection index

Principal component analysis was performed on all the fruit, seed and seedling characters collectively and first principal component was taken as the index value for selection (Fig. 6). The selection index was predicted using the multiple regression equation constant for each age group independently and also the average of all age groups. The predictor equation was found to be

For the less than 25 years group

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

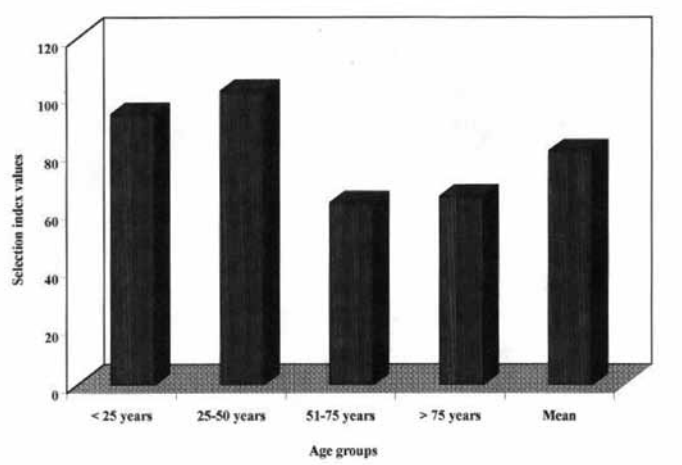

Fig. 6 - Selection index or total index values of all the four age groups in mangosteen (*Garcinia mangostana* L.).

Table 7 - 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
Age group 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 8 - Criteria and criterion for discrimination of age groups in mangosteen (*Garcinia mangostana* L.)

Sl. 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 it 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 it falls in Group I, if not Group II
3	<25 and >75	4.26	2.52	3.39	If the value is > 3.39 it falls in Group I, if not Group II
4	25-50 and 5 1-75	8.96	6.17	7.57	If the value is > 7.57 it falls in Group I, if not Group II
5	25-50 and >7 5	30.17	19.87	25.02	If the value is >25 .02 it 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 it falls in Group I, if not Group II

For group 25-50 years

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

For the 51-75 years group

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

For the more than 75 years group

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

For the average of all age groups

$Y = -0.0527\ FI + 0.0446\ SI + 0.9978\ SDLI + 1.056$ (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 averages of all the age groups were recorded and are given in Table 9.

Table 9 - 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

Index values

The highest index value was found in the 25-50 years age group of mother plant, which was concluded to be the best age group for selection of the mother plants. This was followed by the age group of less than 25 years. The mean values of the important characters in the best age group (25-50 years) were fixed on the basis of the corresponding character for selection. Classification was made as above average if positively correlated and below average, if negatively correlated.

4. Discussion and Conclusions

Presentation of the results of the studies are broadly discussed and organized under subheadings to make them more accessible to the reader.

Association of morphological characters of fruit, seed and seedling

The fruit index was positively correlated with most of the fruit and seed characters, except fruit specific gravity, number of one-seeded fruits, seed thickness at centre, seed specific gravity, number of seedlings per fruit, and germination rate; all the seedling characters were negatively correlated. An analysis of the age group variations revealed that the maximum values of all the morphological characters of fruit and seed were recorded in the 51-75 years group and the lowest values were recorded in the 25-50 years group. As fruit index is a function, which is derived from all the morphological characters of fruit, the characters ought to be naturally correlated. However 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.

Seed index was observed to be negatively correlated with all the fruit characters. Although the pattern of gradation observed in the values of seed characters in the various age groups was the same as that observed for fruit characters in the same age group, a corresponding size or weight of the seed was not observed. The relative differences observed at 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 to fruit weight is computed. The second age group registered the highest ratio values, which again reveals that 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 showed a very high ratio in spite of the fact that for both of the above characters the first age group had the highest values individually.

The positive correlations of seed index with all seedling characters once again confirms that the seedling characters are more governed by both the individual as well as collective characters of the seed. While in the standard methodology that was adopted, equal importance (weightage) was given to seed, fruit, and seedling characters and age of the mother plant, the results confirm that it is the seed characters which play a more determining role for better seedling characters. Even though identical reports are not available in mangosteen, the studies of Reddy (1997) revealed that the size of the seeds was highly variable, the difference in seed weight brought about the variation in germination and that the ability to germinate and grow successfully is related to the amount of food stored in the seed. Another author suggested that it is better to establish new plantings only from the larger seeds weighing 1 g and above in Florida (Campbell, 1966).

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 because the seed characters

were positively correlated with seedling characters and the age groups that recorded the highest values for 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 seedlings produced per seed was negated by the character of comparatively slower growth. Another positive aspect in this case is that normally seedlings with exposed food storage or haustorial cotyledons are very vulnerable, and this attractive food source is prone to attack by rodents when it is present above ground. However in the Garcinia type, the food reserve is stored in the hypocotyl, which is protected by the envelopments and situated at, or below, soil level making it less vulnerable (Vogel, 1980).

In general, most of the fruit characters are positively correlated with seed characters and negatively correlated with seedling characters; most seed characters are positively correlated with seedling characters. Generally this is because the values of fruit characters increase with mother plant age group, but this increase is not matched by a corresponding increase in seed characters. In the case of seedlings, the age groups with increased fruit characters produce only weaker seedlings, as revealed by the lower seedling index. The increase generally observed in the seed characters leads to increased seedling growth and, hence, over emphasizes the absolute command of seed characters in determining the quality attributes of seedlings.

Principal component analysis. Fruit characters and index

A figurative plot of the principal components of the fruit characters is presented in figure 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 and describing actually the high positive correlation that exist between them. The principal component analysis of fruit characters and age of the mother plant showed that factor I and factor II account for 88.76% of the cumulative variance. A critical analysis of the plot reveals that for all major characters of the fruit, age group three showed narrow angles, underlining that most of the improved fruit morphological characters are observed in this group. On the other hand, seedlessness showed narrow angles to age groups 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 and more than three-seeded) are in opposite directions, illustrating that they are negatively correlated. A similar positioning is observed in the case of specific gravity and pulp weight, which reconfirms the negative correlation.

Seed characters and index

Principal component analysis of the seed characters and age of the mother plant showed that factors I and II account for 92-94% of the cumulative variance. A critical perusal of the plot (Fig. 3) of the seed characters revealed that maximum seed characters (seed index, selection index, germination percentage, seed producing one seedling, number of seedlings 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 this age group. The number of ungerminated seeds was in close proximity to age group four and positioned opposite germination percentage, showing the negative correlation. Similarly, seed weight and volume are positioned at opposite ends with respect to the days to germination and specific gravity, confirming the highly significant negative correlation observed in the study.

Seedling characters and index

Principal component analysis of the fruit characters and age of the mother plant showed that factors I and II account for 92.49% of the cumulative variance. The most important or major characters of the seedling and selection index are in close proximity to age group two (Fig. 4), which clearly establishes that seedlings of this age group are superior in all characters. The narrow angles between the various characters and this age group also establish 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, more notably, the importance of roots which are critical in the case of mangosteen.

Step-wise regression

Step-wise regression was carried out to identify the variables contributing maximum variations and to reduce the number of variables. There was reduction in the number of variables influencing the fruit characters. With regard to 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 found to be maximum in the best age group. For 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. As for seedlings, root characters were logically found to be important as the root system in mangosteen is magnolioid but cannot be recommended as an index 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 the plant.

Similarities between age groups based on fruit, seed and seedling characters

A critical analysis of the various age groups points to a very important conclusion: for most of the fruit characters, age groups one and two gave comparatively lesser values, whereas the older groups gave maximum values and have higher fruit index. Likewise in the case of seeds, the older groups had better size but the younger age groups gave more seeded fruits and gave better germination and more

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, a comparative study reveals more similarity and also when all fruit, seed and seedling characters were collectively 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 (less than 25 years and 25 - 50 years) and the close proximity in the dendrogram (Fig. 5).

Discriminant function

Further extrapolation of the coefficients (Table 7) used in discrimination of various groups were critically analysed and are presented in Table 8. The directions of coefficients were used to prepare the dendrogram presented in figure 7, showing both the positive and negative direction of the coefficients 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 the case of age group two when two specific pairs of age groups were discriminated as envisaged in this study. This was actually a reflection of the higher seed and seedling characters in age group two, compared to the other age groups, which reconfirms that this group is the best age group for selection as mother plants.

Selection index

Based upon the equation, the elaborated selection index revealed that the 25-50 years age group 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 higher index values. Although the fruit characters were better in the older 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. Furthermore, any attempt to lift the bare seedlings normally results in death of the plants, as they are highly sensitive. As the root characters are positively correlated with shoot characters, selection based on the shoot characters reflects 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 so that destructive procedures could be avoided. Considering the complex of results obtained in the study, the following characters and mid values were selected as indices for selection.

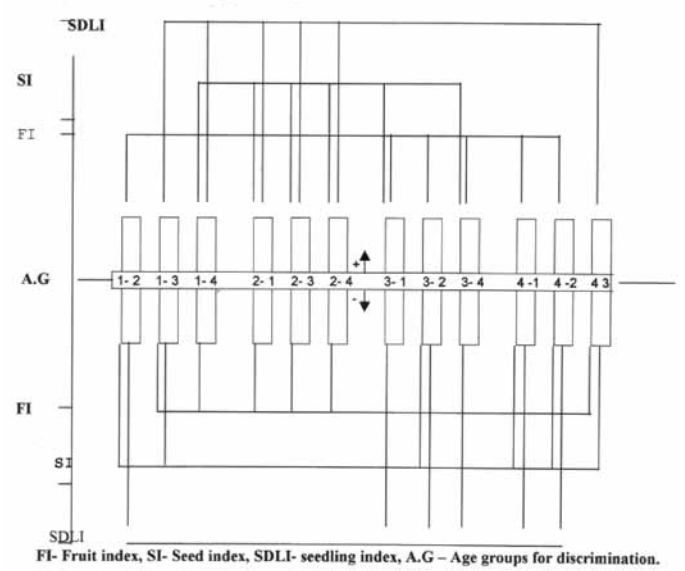

Fig. 7 - Dendrogram showing the directions of discriminant coefficients of fruit, seed and seedling indices of each age group when compared to the remaining three age groups in mangosteen (*Garcinia mangostana* L.).

The selection should be such that the fruits from mother plants of the age group of 25-50 years should have fruit weight of not less than 58 g, fruit girth of not less than 5 cm, fruit volume of not less than 51 ml, pulp weight of not less than 16 g, rind weight of not less than 41 g, and number of segments less than 5.

Seeds obtained from the fruits with the above characters should have a seed weight of not less than 0.66 g, seed length of not less than 1.61 cm, seed thickness at centre of not less than 0.66 cm, seed volume of not less than 0.44 ml, seed specific gravity of not less than 1.50, days to germination not less than 21, germination percentage not less than 87% and preferably have more than one seed per fruit.

Furthermore, seedlings at the one-year stage from this age group with the identified fruit and seed characters should have a height of not less than 10 cm, seedling girth at collar region of not less than 2 cm, total number of leaves per seedling not less than 9, number of new flushes per year more than one, total leaf area per seedling not less than 72 cm^2 and survival rate not less than 85%.

In conclusion, it can be said that the present study has generated results of immense practical relevance which will directly aid in selection or act as a powerful tool for the selection of mother plants, fruit, seed and seedling characters for improved seedling growth.

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