STUDIES ON THE VARIABILITY OF THE SPECIES *GMELINA ARBOREA* LINN.

THESIS
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by

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CERTIFICATE

This is to certify that the thesis entitled **Studies on the variability of the species, *Gmelina arborea* Linn.** is a record of *bonafide* research carried out by Mrs.Indira,E.P., under my guidance and supervision. No part of this work has been presented elsewhere for any degree, diploma, fellowship or other similar titles.

Peechi,

March 1999.

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DECLARATION

I hereby declare that the thesis **'Studies on the variability of the species, *Gmelina arborea* Linn.'** submitted by me in partial fulfilment for the Ph. D. degree of the University of Calicut, incorporates the results of the work done by me. This thesis has not been submitted by me to any other University for the award of any other degree, diploma or any other titles and it represents the original work done by me.

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Chapter 1.

INTRODUCTION

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1. INTRODUCTION

Gmelina arborea Linn., a member of the family Verbenaceae, is a fast growing tree species of South East Asia. The species occurs naturally almost through out India, Nepal, Sikkim, Bangladesh, Sri Lanka, Myanmar, Thailand, Laos, Cambodia, Vietnam and southern provinces of China. It has been planted extensively in Malaysia and has been established successfully along the West coast of Africa, Brazil, Malawi and other tropical countries. Altogether it has been introduced to at least 35 countries, eight of which have planted it on a large scale (Greaves,1981).

The tree yields excellent timber, well appreciated for its durability, lack of shrinkage and distortion, smooth finish and for the ease with which it can be worked. It has a wide variety of uses in general construction, and in making furniture, plywood and veneer. Moreover, it is a potentially important source of wood pulp (Doat,1976). It gives high yield of paper, superior to that obtainable from most tropical hard woods (Hughes and Esan, 1969). It is also used to make musical instruments, artificial limbs, printing blocks and boat decking. The leaves, roots, drupes, flowers and bark are widely used in indigenous medicines.

This species can be easily established as plantations. Its marked ability to suppress weeds and the rapid growth in favourable sites leading to high Mean Annual Increment in short rotations attracted planters of many other countries. Lamb (1968) opines that few other species are found that can rival *G. arborea* with respect to high early economic returns. Because of all these qualities, this species received international support for its genetic improvement programmes.

Identification of genetically potential seed sources is the first step in any genetic improvement programme, for which collection of seed sources from different geographic areas and their testing through provenance trials become inevitable. Provenance is a synonym for natural seed origin. Through these trials intraspecific variations can be studied since environmental variations at different geographic areas influence the genetic constitution developed through years after natural and artificial selection. Natural selection has tended to produce natural populations that are well adapted to the conditions in which they evolved. These trials help to separate the genetical and environmental components of the phenotypic expression and through exploiting these variations, the most suitable, well adapted and productive populations can be selected for immediate planting and also for utilising in future breeding programmes. Many tree breeders consider the use of proper seed source as the most important step since this leads to the largest, cheapest and fastest gains in most tree improvement programmes, no matter how sophisticated are the other breeding methods (Zobel and Talbert, 1984). Earlier work in temperate trees also show that genetic differences associated with place of origin have often been several times as great as those among individual trees in the same stand (Wright, 1976).

Provenance trials are established to find out the best population for commercial planting as well as for studying the extent and pattern of variation within the species for a variety of characters. Theoretically the vast distribution range of *G. arborea* in India alone, from 8^0 to 27^0 N and 72^0 to 96^0 E should have given rise to a rich genetic diversity (Lauridsen, 1977).

Taking into consideration of the above facts, this study was undertaken with the following major objectives during the years 1994 to 1998.

1. to determine the provenance variation pattern.

2. to study the extent of genetic variation in various traits within and between Indian provenances.

3. to choose the most appropriate provenance for raising plantations.

International provenance trials of *G. arborea* had been conducted by many countries to select the best seed sources for the region and the experiments were co-ordinated through the DANIDA Seed Centre, Denmark as a part of the action programme formulated by the FAO Panel of Experts on Forest Gene Resources (Keiding *et al.*, 1984). In connection with this programme, seeds were collected from various states of India in collaboration with Forest Research Institute, Dehradun and the State Forest Departments. From these seed lots, Kerala Forest Research Institute obtained seeds of Indian provenances for establishing a trial. Silviculture Division of KFRI established the provenance trials at Chempankolly and Kariyamuriam areas of Kariyamuriam Forest Section, Nilambur Range, Kerala. The field observations for the present study were taken from these plots.

Growth performance and tree form are the main factors considered for any tree improvement programme. Wood density determines the strength of wood , its resistance to breakage and its elasticity and durability (Ogbonnaya, 1993). Wood density and fibre length are also important characters when the tree is a pulp wood species. If wood density is low, then its economical yield of pulp will also be low. Hence, height, girth, clear bole percentage and tapering were measured, as these characters influence productivity. Clear bole percentage, tapering, straightness, persistence of axis, mode of branching and branch size are taken into consideration since these characters affect tree form. Wood density and fibre length were also estimated since these characters, as mentioned above, greatly influence pulp yield and quality. In addition, other morphological characters like leaf size, petiole length, fruit size, stone size and seed size were also measured for studying the intra and interprovenance variation. Earlier reports show that there are significant differences between geographic sources with regard to fruit stones, seeds and seedling characters but well-defined geographic trends could not be seen (Arimah, 1979). Number of seeds per fruit was also counted to find out the variation if any, as this character influences the reproductive capacity of the provenances.

Height and girth were measured yearly during seedling stages and also at 15^{th} year. All other characters were observed at the age of 15 years. The growth measurements taken during seedling stages (years 1979 to 1984) in connection with one of our projects were also considered for studying the variability to get a clear picture of the genetic control over these characters. The characters observed were subjected to analysis of variance to find out the significance of variance. In addition, the percentage of heritability, the extent of phenotypic and genotypic coefficients of variation and genetic advance were also estimated to study the extent of genetic variation, adaptability of seed sources to the new environment and to find out the influence of environment on these characters. The provenances were clustered into best, moderate and poor performers taking into consideration the characters for which provenances significantly differ.

The interrelationship between these characters and also with geoclimatic parameters were also studied through correlation coefficients. The genetic distance was also estimated to study the genetic diversity and the provenances were grouped into different clusters.

REVIEW OF LITERATURE

Chapter 2.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Reliable information on the extent of variability and pattern of inheritance of the characters of economic importance are the basis for a sound breeding strategy. Through provenance trials intraspecific variations can be studied in detail.

Classic provenance experiments started during early 1800, like NC-99 experiment at USA on Scotch pine with 170 seed sources from Europe and Asia. Another example is that of Loblolly pine provenance trials at Mississippi with 115 seed sources. Provenance tests have been conducted in many tree species, especially temperate trees. Trials were established for at least 50 temperate tree species and many other interesting tree species like *Gmelina*, *Tectona*, *Eucalyptus* and *Acacia*.

Wright (1976) identified three major factors influencing the amount of geographic variability, even though there are some still unidentified influencing factors. First and most important factor is the size of the species' range. Species like Scotch pine with very large natural ranges in most parts of Europe and Northern Asia and Ponderosa pine with large natural distribution in Western half of US, and parts of Canada and Mexico have much more genetic diversity than the species with very limited range like Monterey pine or Japanese larch. The second influencing factor is the amount of environmental diversity occurring within the species natural range. The third one is the extent of range discontinuities because continuous range allows abundant gene exchange through pollen or seed dispersal. But in some cases these rules are not applicable as some unknown factors influence the extent of variability (Wright, 1976).

2.1. STUDIES ON VARIABILITY AND DIVERSITY

Genetic improvement programmes mainly depend on the extent of the genetic variability present in the species. To chalk out the programmes scientifically it is essential to estimate the phenotypic and genotypic coefficients of variations for different characters of economic importance and to observe how these characters are inherited and correlated. Earlier reports on the variability, correlation and heritability are briefly reviewed with regard to *Gmelina arborea* and other important tree crops.

G. arborea is reported to be extremely site sensitive (Greaves, 1981; Sandiford, 1989), yet it is capable of surviving as a stunted bushy tree in adverse conditions. Rapid early growth occurs on moist sites within the moist tropical lowlands but the growth rate soon diminishes on all sites except the best soils (Greaves,1981). The diameter at breast height of this species reaches about 42 cm in 15 years and 48 cm in 20 years at better sites with a good rain fall around 3000 mm (Fox,1967).

Experiments in *G. arborea* at site Subri of Ghana recorded 19.6 m height and 23 cm diameter at breast height in 7th year (Nwoboshi, 1994). Results from the international provenance trials with a total of 36 provenances at 27 sites (with 11 provenances at each site) in many tropical countries at the age of 2 to 6 years showed that provenance performance in terms of production was fairly consistent irrespective of the trial location, whereas difference in survival between provenances changed with trial location (Lauridsen *et al.*,1987). During the second evaluation, at the age of 11-15 years with 25 provenances in 11 trials, Lauridsen *et al.* reported that the performance of provenances from Central-North and Central-West India were consistently below average in terms of survival, health and volume production. Provenances from North-east India were found to be good performers. They also noted that fastest growing provenances would in general have lowest wood density and the average loss in wood density is around 2 to 3 per cent. Akachuku (1984) found that there were considerable differences between trees in wood density, fibre length, fibre proportion and tree size of the same age, at the same spacing and environment. Some individuals combined comparatively high density, fibre length and fibre proportion with fast growth rate and uniform wood.

The provenance trials conducted at two sites in Thailand with 8 provenances of *G. arborea* from Thailand, India and Sri Lanka showed that at the age of one year, there was pronounced provenance X environment interaction in terms of height growth indicating that the provenances are possibly well adapted only to narrow ranges of environmental conditions (Kingmuangkow *et al* ., 1974).

There are widespread criticisms on the tree form which is usually with forking, bending and basal sweep, although the early growth rate of *G. arborea* is quite impressive on good sites (Leggate, 1966; FAO, 1976; Greaves, 1974; Tillman, 1975). Greaves (1974) was of the opinion that in the third or later growing seasons a number of apical shoots lose vigour and then the lateral buds start growing resulting in a major bend or forking in the stem.

Laboratory and green house experiments at Oxford with 16 provenances of *G. arborea* from natural and exotic stands show that there are significant differences between provenances with regard to fruit stones, seeds and seedling characters (Arimah,1979) but there are no well-defined geographic trends. Principal component analysis of all characters indicated that the most distinguishing characters are leaf size and petiole length.

Significant variation between trees within sites for wood density was noted in *G. arborea* by Akachuku (1976; 1984) but the variation between sites was insignificant. Tang and Ong (1982) found significant differences in wood density between sites, but not between trees of different form and vigour. On evaluation of international provenance trials assessed at the age of 3 to 6 years, Keiding *et al.* (1984) noted significant differences between provenances on all sites for several characters, particularly wood density. Lauridsen *et al.* (1983) reported that there was clear separation of provenances into significantly different density groups on analysis of provenance trials in India. Akaoun *et al.* (1985) during their studies on wood density found considerable variation within provenances. Ogbonnaya (1993) reported that the specific gravity of *Gmelina* wood was markedly improved by the supply of all nitrogen sources. He also found that application of different sources of nitrogen affected the fibre dimensions in quite different way as NO_3-N supplied as Potassium nitrate increased the fibre length while NH_4-N supplied as Ammonium sulphate decreased the fibre length. Supply of Urea produced narrow fibre cells while Ammonia produced wide fibres with thick walls. Studies conducted with seven year old trees distributed at 5 sites showed that there are significant between tree variations with regard to fibre length, proportion of fibres, vessels and parenchyma but, site effect was significant only for fibre length in *G. arborea* (Akachuku, 1978; 1984).

Similar studies were conducted in several other tree species extensively planted in India like Teak, *Acacia* and *Eucalyptus.*

Huang (1989) studied provenance variation in *Acacia auriculiformis* planted in China and observed significant variations for height, diameter and fruit weight. In Thailand, Luang Viriyaseng *et al.* (1991) studied provenance variation in *A. auriculiformis* and reported significant differences for growth and survival.

Harwood and Williams (1991) analysed the international provenance trials of *A. mangium* and reported that there were highly significant differences in growth performance between experimental sites, between provenance regions and among local provenances within regions.

Pinyopusarerk *et al.* (1991) studied the provenance variation in *A. auriculiformis* and noted that pinnule and phyllode variations are highly significant between seed origins.

Studies with 35 provenances of *A. nilotica* in India by Bagchi and Dobriyal (1992) showed that there were significant variations between seed sources in number of nodes at clear bole length.

Moran *et al.* (1992) studied the pattern of genetic diversity in populations of *Acacia* species and found that there was high level of allozyme variation which are within populations rather than between populations.

Vakshasya *et al.* (1992) reported the existence of significant genetic variation among ten seed sources of *Dalbergia sissoo* from different states of India with respect to seed and seedling traits.

Eucalyptus is one of the most intensively studied genera among forest trees. Pryor (1956) initiated the variation studies in *Eucalyptus pauciflora* and found that there were genotypic variations between populations. He also found linear correlation between a number of characters and elevations. Variations in height with altitude of the seed source was reported by Eldridge (1966) based on his studies on *E. regnans*.

Rudman (1970) looked into the influence of genotype and environment on wood properties of juvenile *E. camaldulensis* and reported marked genetic variations in fibre length.

Burley *et al.* (1971) studied leaf characters in 25 provenances of *E. camaldulensis* planted in Zambia. Significant variations within and between provenances for most of the characters were reported by them. Chaturvedi *et al.* (1989) made a critical assessment of 32 *E. camaldulensis* and 14 *E. tereticornis* provenances planted at various locations. Significant variations were seen among provenances for height and girth. Krishnamoorthy (1989) also evaluated the performance of Australian provenances of *E. camaldulensis.* Luis (1991) analysed the performance of *E. saligna* provenances obtained from Australia, Cuba and Columbia. On analysis of growth and tree form in *E. camaldulensis* provenances planted in Nigeria, Otegbeye and Samarawira (1990) noted a large amount of genetic variability in characters like height, dbh, forking, stem form, branch characters and taper. Otegbeye (1991) also found that stem diameter of *E. tereticornis* was under genetic control and the degree of genetic control increased with age. He noted that adaptive growth differences existed among provenances, the intensity of which increased with age.

Infante and Prado (1991) reported significant differences between provenances of *E. globulus* planted in Chile with respect to height and diameter at 20 months age. But they could not find any clear pattern of geographical variation.

Otegbeye and Samarawira (1992a) estimated the genetic parameters for growth and quality traits of *E. camaldulensis* provenances planted at 2 sites in Nigeria.

While reviewing the performance of 20 year old species-provenance trials of 10 *Eucalyptus* species established at Madagascar, Lebot and Ranaivoson (1994) observed that performance of provenances and progenies are quite irregular and unpredictable on the basis of site. Large provenance x site interactions were noted. King *et al.* (1994) studied the provenance variation in *E. delegatensis* planted in New Zealand with respect to growth rate and tree form. Wang *et al.* (1994) studied the provenance variations in growth rate and wood properties in *E. grandis* planted in China. Out of the 15 provenances, North Queensland grew better. Considerable tree - to - tree variation was seen for wood density though there was no variation between provenance.

Patterns of genetic variations in the length and shape of juvenile leaves of *E. globulus* collected from 44 localities in Australia were studied by Potts and Jordan (1994). They could find significant additive genetic variation within populations for all traits. Significant genetic differences were also present between populations in both leaf length and shape with the strongest differentiation occurring in leaf length.

Romero (1995) studied the performance of *E. saligna* and *E. grandis* provenances planted at various localities in Columbia. He found that growth variables showed high genetic variation between provenances and were significantly affected by environmental variables. Low genetic variations were reported within provenances for height, diameter and volume. Environment greatly influences height and diameter growth. Alvear and Gutierrez (1995) studied the early growth and survival of 196 families of 23 *E. camaldulensis* provenances from Australia planted at 4 sites in Central Chile. Significant variations within and between provenances were observed and progenies from Victoria were recommended for Chile.

On an investigation to study the pattern of genetic variation and correlation between economically important characters like height, diameter, basal area and clear bole height in 17 Australian provenances of *E. grandis* planted in Tamil Nadu, India at the ages of 7 and 9 years, Subramanian *et al.* (1995) observed large variations between provenances. There were fair differences between phenotypic and genotypic coefficients of variation.

Pinyopusarerk *et al.* (1996) evaluated growth variation in 24 *E. camaldulensis* provenances from Australia planted at Thailand. Significant variations were noted in height, diameter and volume between regions and within and between provenances. Venkatesh and Vakshasya (1979) studied the floral variations in *E. camaldulensis*.

In *Santalum album*, Bagchi and Sharma (1989) reported significant variations among families for the characters length, breadth and weight of seeds.

Kedharnath and Matthews (1962) studied the variations present in different teak populations in India. Kedharnath *et al.* (1963) during their studies with replicated teak provenance trials observed that significant geographic and tree - to - tree variation with regard to fibre length. With increasing age the coefficient of variation for plant height and internodal length were reported to be decreased in teak (Lakshmikantham *et al.*,1974). They also observed high positive correlation between height and diameter.

On analysis of the international teak provenance trials at Ivory coast, Delaunay (1977a) reported that provenances from India, Thailand and Laos were significantly different in survival and flowering. Another trial at Ivory cost comprising provenances from India, Thailand, West Africa and Tanzania showed that there were no significant difference between provenances for vigour but had highly significant differences for quality of tree form as well as flowering at the age of six years (Delaunay, 1977b) . West African provenances were found to be precociously flowering which lead to high forking with 90 per cent of the trees forked.

On evaluation of the teak provenance trial in Andhra Pradesh, Muniswami and Parthasarathy (1977) observed that the variation between provenances for height was not significant at early ages of 1 and 2 years but became significant at third year.

During the studies on international provenance trials in Teak with provenances from India, Ghana, Indonesia, Ivory Coast, Thailand and Nigeria at six sites in Nigeria, Egenti (1977a) noted significant variations between provenances for height, girth and stem form at most of the sites. There were also significant differences in crown and branching habits between the provenances at some locations at 3½ years age. Egenti (1977b) also reported significant variation in vigour and form of various seed sources between sites and between and with in provenances.

Keiding (1977) while reviewing the 5 year old international provenance trial in Teak with 75 provenances over 50 sites in 16 countries reported that height growth showed some evidence of genotype-environment interaction. Indian provenances showed good tree form with finer branches compared to West African and Indonesian provenances.

Kjaer *et al.* (1996) conducted a multivariate study on genetic variation in different populations of teak from many countries. They examined 9 qualitative characters and found that large differences between populations. Regional patterns were revealed by multivariate analysis of data, but there were also substantial variation within eco-geographical defined regions. Kadambi (1972) reported geographic variations in morphological characters in teak.

Kuang *et al.* (1996) from China evaluated the teak provenances from India, Thailand and Nigeria for nine characters of growth and quality and reported significant to highly significant differences between provenances for all characters except survival rate. Studies on the provenance variation for wood density in teak revealed that between provenance variation was not significant (Indira and Bhat, 1997). It was also reported that the within provenance variation was much higher than the between provenance variation.

Corbasson and Souvannavong (1988) reported the results of a provenance trial established in 1969 in Cote d' Ivoire with 17 provenances of *Terminalia superba*. The results showed significant differences in characters such as vigour and growth rate.

2.2. STUDIES ON HERITABILITY AND GENETIC GAIN

Lauridsen *et al.* (1987) estimated heritability of 9 characters, namely, survival, health, diameter at breast height, basal area, axis dominance, forking height, number of branches, straightness and wood density while evaluating provenance trials in *Gmelina arborea* at 27 localities with a total of 36 provenances and found that heritability of each character differed widely from one experiment to another.

High provenance heritability ranging from 0.67 (for taper) to 0.95 (for height) were recorded by Otegbeye and Samarawira (1992a) in *Eucalyptus camaldulensis.*

On analysis of provenance trials of *E. camaldulensis* established at 3 climatically different localities in Mexico, Garcia *et al.* (1992) noted that heritability and genetic gain for height and diameter were different in each environment.

During an investigation on a reciprocal recurrent selection scheme involving *E. urophylla, E. grandis* and *E. pellita*, Bouvet and Vigneron (1995) studied the trends in variations and heritability with age, in order to find the growth phases which could indicate an optimal age for early selection. The results showed that variances and heritabilities were strongly influenced by the experimental processes like nursery, planting and environmental effects.

Subramanian *et al.* (1995) reported low heritability and genetic gain for height, diameter at breast height, basal area and clear bole height in *E. grandis* based on their experiments with 17 provenances.

2.3. STUDIES ON CORRELATION

The relative density and fibre length in *G. arborea* were highly significantly and positively correlated (Esan,1966; Hughes and Esan, 1969; Akachuku,1978). Correlation between diameter at breast height and wood density was poor and extremely variable (Tang and Ong,1982). Hughes and Esan (1969) also found no indication of any influence of rate of growth on wood density and they argued that fast growth was not adversely affecting the wood density and thereby not reducing the mechanical strength or pulp yield. But Lauridsen *et al.* (1995) observed that the fastest growing provenances in general had lowest wood density. But Tang and Ong (1982) reported that correlation between dbh and wood density was poor and extremely variable.

Phenotypic and genotypic correlation between height and girth was strong (>0.5) indicating that early selection for these traits would be effective (Lokmal, 1994). He also noted that single tree heritability for height and girth to be very low up to 6 years of age in *G. arborea.* Fresh leaf biomass and stem volume were reported to be highly correlated with basal girth, Gbh and height in 7 year old *G. arborea* plantation (Datta, 1997).

Experiments at Nigeria showed that total dry weight of seedlings of *G. arborea* raised from large-sized seeds were more than small seeds but the relative growth rate of seedlings from small seeds was more than that of large seeds (Agboola, 1996).

Dhillon *et al.* (1992) reported that tree height, crown spread, self pruning ability and age had positive correlations with diameter and breast height in *Dalbergia sissoo*.

Karschon (1974) observed that the yields of *E. camaldulensis* in Israel was directly related to latitude and longitude of the seed origin. The results indicated that straightness of the stem was inversely related to latitude of the seed origin and survival was directly related to longitude.

Kedharnath and Vakshasya (1977) reported significant positive correlation between height and diameter in second to fourth years in *E. tereticornis*. Lacaze (1977) while reviewing the performance of international provenance trials in *E. camaldulensis* with 32 trials in Mediterranean and tropical countries indicated a generally good juvenile - mature correlation between growth characters. Rathinam *et al.* (1981) made a biometrical assessment of *E. tereticornis* in Tamil Nadu, India. They reported high positive and significant correlation between weight of green billets and girth, height and weight. Surendran (1982) also studied the variability in the same species. He reported genetic correlation for height, number of branches, girth at base, leaf length, leaf breadth and internode length.

A multivariate study of geographical variation in *E. tereticornis* showed correlations between morphological variation and latitude, representing responses to environmental factors especially temperature and annual rainfall (Wang *et al.*, 1988).

Volker *et al.* (1990) reported that in *E. globulus*, volume and stem form were poorly correlated both genetically and phenotypically. Volume was adversely correlated both genetically and phenotypically with branch size. Stem form and branch size showed strong positive correlation.

Otegbeye and Samarawira (1992b) studied the correlations of growth and form characteristics in *E. camaldulensis* and could find that height and Gbh were positively correlated with all form characteristics except taper which had positive correlation with tree height but negative correlation with dbh. In *E. nitens,* Whiteman *et al.* (1992) found a strong positive correlation between diameter, height and stem straightness. Mazanec and Mason (1993) on analysis of genetic variations in *E. diversicolor* found that height, stem straightness and branching had positive genetic correlation.

In *E. globulus* phenotypic and genotypic correlations were analysed between length and shape of juvenile leaves, growth characters and populations (Potts and Jordan, 1994).

While analysing the growth performance and genetic variation in *E. grandis* planted in South Australia, Arnold *et al.* (1996) found that significant correlations existed between latitude of seed source and height growth, between altitude of seed source and height growth and between seed source distance from the sea and height growth.

Kedharnath *et al.* (1969) reported high positive genetic correlation between girth and number of internodes in teak. Studies on the wood aspects of teak revealed that fibre length and specific gravity were highly correlated (Purakaystha *et al.*, 1972).

Indira and Bhat (1997) reported that in teak the phenotypic correlation between girth and wood density was positive and weak while genotypic correlation was negative.

MATERIALS AND METHODS

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Thesis. Kerala Forest Research Institute Peechi , University of Calicut, 1999

Chapter 3.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study was conducted at the Kerala Forest Research institute, (KFRI) Peechi, Kerala. The field observations were taken from the *Gmelina arborea* provenance trial plots established during 1977-`78 by the Silviculture Division of KFRI at Nilambur, Kerala.

3.1. MATERIALS

Seeds of *Gmelina arborea* from different geographic areas in India designated as different provenances were obtained from the seed lots collected through Indo-Danish Seed Procurement project and they were from the semi-evergreen, moist deciduous, semi moist deciduous and dry deciduous forests of North eastern, Northern, Central and Southern parts of India.

According to the rules followed during seed collection, seeds were collected from at least 25 trees of each of the provenance. These trees were located at least 100m apart to avoid close relationship between individual trees. Approximately the same amount of seeds were collected from each tree and then mixed up.

The ripened fruits were depulped, cleaned and dried. The nursery was raised and the seedlings were field planted at Nilambur by the Silviculture Division of KFRI during 1977-'78. When the seedlings were six months old, they were field planted at Chempankolly area (Latitude 11° 22' N and Longitude 76° 17' E) with 8 provenances (Table 1) and at Kariyamuriam area (Lat. 11°23' N and Long. 76° 16' E) with 9 provenances (Table 2). Both areas fall in the Kariyamuriam section of the Nilambur Range, Nilambur Forest Division. The average rainfall in

Table 1. Provenances planted at Chempankolly, Nilambur

Provenance		State	Latitude	Longitude	Altitude (m)	Rainfall (mm)	Type of forest
No	Name						
1	Agarthala 1	Tripura	23° 50'N	91° 25'E	150	2400	Moist deciduous
2	Agarthala 2	Tripura	23°50'N	91° 25'E	140	2400	" "
3	Baramura	Tripura	23° 49'N	91° 33'E	130	2403	" "
4	Cachar	Assam	24° 00'N	92° 15'E	200	1675	" "
5	Ghottil	Maharashtra	17° 14'N	73° 57'E	1000	1000	Semi moist deciduous
6	Khasi Hills	Meghalaya	25° 46'N	91° 46'E	550	2509	Moist deciduous to semi-evergreen
7	Kundrukutu	Bihar	22° 30'N	85° 50'E	600	1400	Dry deciduous
8	Shikaribari	Tripura	23° 58'N	91° 54'E	300	2245	Moist deciduous

Table 2. Provenances planted at Kariamuriam, Nilambur

Provenance		State	Latitude	Longitude	Altitude (m)	Rainfall (mm)	Type of forest
No	Name						
1	Begur	Kerala	11° 55'N	76° 05'E	700	2500	Moist deciduous
2	Lambasingi	Andhra	17° 52'N	82° 30'E	900	505	Dry deciduous
3	Sankos	W. Bengal	26° 40'N	89° 50'E	50	4800	Moist deciduous
4	Baramura	Tripura	23° 49'N	91° 33'E	130	2403	" "
5	Sewanthiwadi	Maharashtra	15° 54'N	73° 46'E	100	3000	" "
6	Kundrukutu	Bihar	22° 30'N	85° 50'E	600	1400	Dry deciduous
7	Herrur	Karnataka	12° 27'N	75° 25'E	1000	1025	Semi moist deciduous
8	Sitabai valley	Maharashtra	18° 22'N	73° 49'E	1000	1000	Dry deciduous
9	Khasi Hills	Meghalaya	25° 46'N	91° 46'E	550	2509	Moist deciduous to semi-evergreen

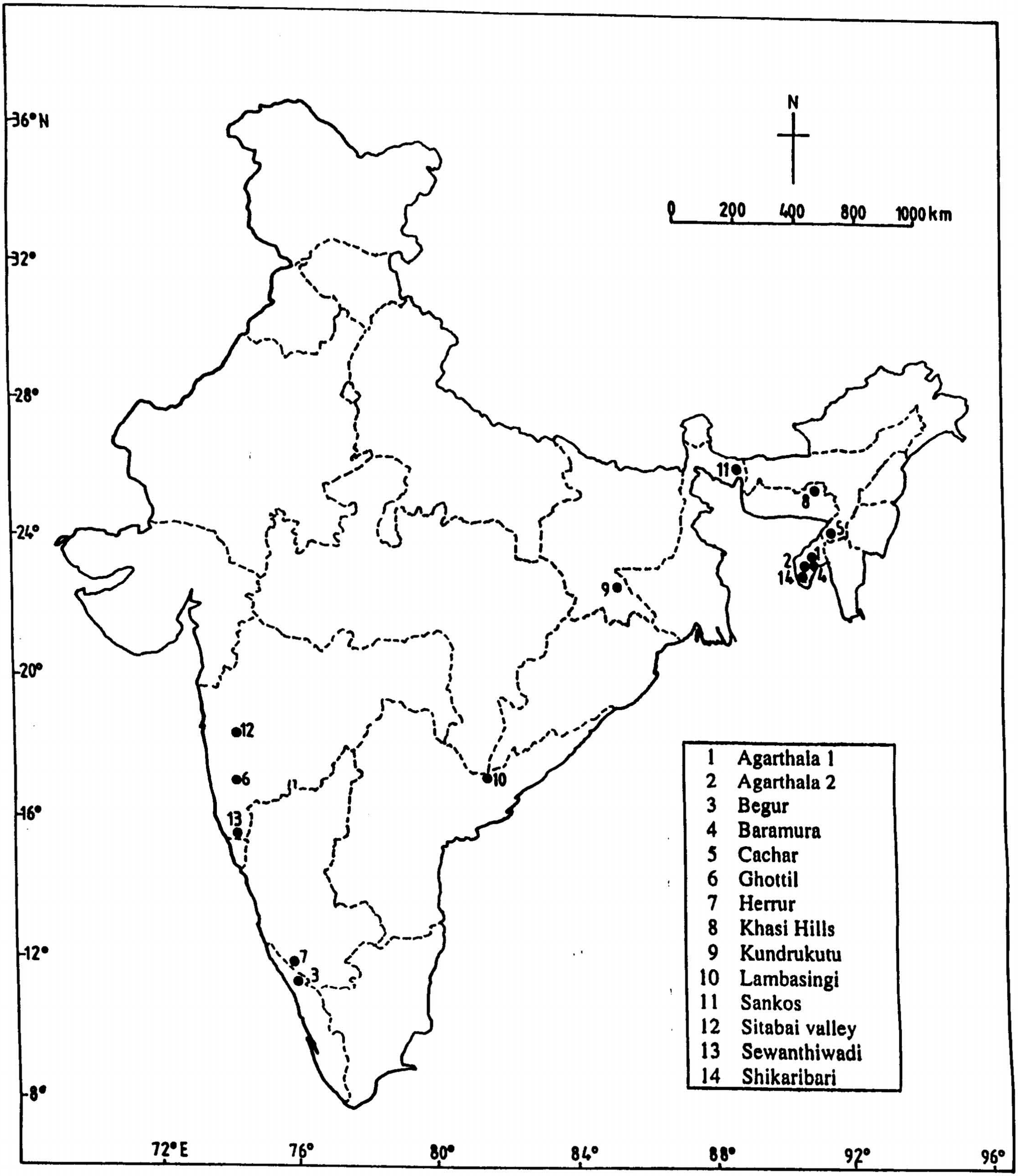
Nilambur is around 2600mm and temperature falls around 27^0 C (17 - 37^0 C). In Nilambur generally deep disintegrated gneiss soil is seen with good drainage. Three provenances were common to both areas. The provenance trial plots were established in an area of 1 ha at Chempankolly and in 0.5 ha at Kariyamuriam. The seedlings were planted in randomised block design with treatments replicated 3 times. In each block 72 plants (6 x 12) of each of the 8 provenances were planted at Chempankolly and 49 plants (7x7) of each of the 9 provenances were planted at Kariyamuriam with a 2 x 2 m spacing.

For studying the morphological characters all the provenances planted at both sites were considered as shown in Table 3. The localities from where these provenances were collected are given in Fig.1.

Table 3. Provenances used for studying the morphological characters

Provenance		
No	Name	State
1	Agarthala 1	Tripura
2	Agarthala 2	Tripura
3	Begur	Kerala
4	Baramura	Tripura
5	Cachar	Assam
6	Ghottil	Maharashtra
7	Herrur	Karnataka
8	Khasi Hills	Meghalaya
9	Kundrukutu	Bihar
10	Lambasingi	Andhra pradesh
11	Sankos	West Bengal
12	Sitabai valley	Maharashtra
13	Sewanthiwadi	Maharashtra
14	Shikaribari	Tripura

Fig. 1. Area of provenances



3.2. DATA COLLECTION

Observations for the present study were taken in two phases from the experimental plots mentioned above. The early growth measurements were taken during 1979-1984 in connection with one of our projects. Observations on older tree growth, tree form, wood characters and morphological characters were taken during 1994 -1997 and analyses were carried out.

Measurements were taken only on the experimental plants leaving the border plants to avoid border effect. Observations on height of seedlings were recorded from first to sixth year with one year interval. Girth at breast height (Gbh - girth at 1.37 cm height) was measured from fourth to sixth year. At the age of 15th year, height, Gbh, girth at 2.37m height (for estimating form factor which indicates the intensity of tapering) and clear bole height were measured. Characters like persistence of axis, straightness, branch size and mode of branching were scored following Lauridsen *et al.* (1987). Wood density and fibre length were also estimated using core samples. A few morphological characters were also subjected to study. The methods followed to measure each character are described in detail.

3.2.1. Growth characters

For early growth measurements all the experimental seedlings were measured leaving the border plants. For the final measurements at 15th year ten randomly selected trees per provenance per block were considered. Hence a total of 30 trees (10 x 3) were measured for each provenance.

Height:

Height was measured with a tape when the seedlings were very young and with a bamboo pole when they were grown up. Final measurements at 15th year were taken using a multimeter.

Girth:

Girth at breast height (Gbh) was measured only when the seedlings attained a height of 1.37 m. Girth at 2.37 m was also measured for estimating form factor which indicates the intensity of tapering.

3.2.2. Tree form characters

The following tree form characters were evaluated using the data taken on the same 10 trees randomly selected for growth measurements per provenance per block. So 30 (10 x 3) trees were considered for each provenance.

Clear bole percentage:

Clear bole length is that height where the main axis is forking. This height was measured using a multimeter. The percentage of clear bole length to the total height was then estimated.

Form factor:

It gives an indication of the intensity of tapering. It was estimated as

$$\text{Form factor} = \frac{\text{Girth at 2.37 m height}}{\text{Girth at 1.37 m height}}$$

Tree form characters like persistence of axis , straightness etc. were scored since they have no absolute value. These score values are meaningful for studying the variations in individual characters. But to compare the provenances, the percentage of good trees in each provenance also will be useful. Hence, proportion of trees with good axis persistence, straight trees and light branched trees were also estimated.

Persistence of axis:

Total height of the tree was divided in to 4 quarters and the following visual scoring system was followed to assess the persistence of axis.

Value 1 - Tree is multiple stemmed from the ground itself,

Value 2 - When the main stem branched out in the lowest quarter,

Value 3 - Main stem branched out in lower second quarter,

Value 4 - Main stem forked in the third quarter,

Value 5 - Main stem forked in the fourth quarter,

Value 6 - Complete persistence of axis

(Values 4–6:) ***Trees with good axis persistence***

Then proportion of the last three categories representing trees with good axis persistence was estimated.

Straightness:

Five classes were given for scoring straightness.

Value 1 - Trees with crooked and more than three serious bends,

Value 2 - Trees crooked and with 1 to 2 serious bends,

Value 3 - Trees slightly crooked with many bends,

Value 4 - Trees slightly crooked and few bends, } ***Straight trees***

Value 5 - Straight trees

Categories with 4 and 5 marks were pooled to find out the proportion of straight trees.

***Branch size*:**

Here also 5 classes were identified as follows.

Value 1 - Trees with very heavy branches of more than half the size of the main stem,

Value 2 - Trees with heavy branches of half the size of the main stem,

Value 3 - Trees with medium branches with one fourth to half the size,

Value 4 - Light branched with one fourth size of the main stem, } ***Light branched trees***

Value 5 - Light branched trees with very light branches with less than one - fourth size of the main stem

Trees with light branches with a score value of 4 and 5 are pooled together to estimate the proportion of light branched trees.

Mode of branching:

Five classes were allotted for scoring the mode of branching as given below.

Value 1 - Trees with double limbs,

Value 2 - Trees with scattered but pronounced branching,

Value 3 - Trees with light forking,

Value 4 - Trees with scattered but light branching,

Value 5 - Trees with very light branching.

3.2.3. Wood characters

Wood Density:

Five trees were randomly selected per provenance from each of the 3 blocks. Hence 15 (5 x 3) tress were sampled for each provenance. Selected trees were of moderate growth and also of more or less same Gbh. Cardinal direction was reported to have no significant effect on the wood density values (Akachuku, 1978), however, in the present study core samples were taken from only one direction. Wood discs and core samples were reported to give similar results for wood density in this species (Tang and Ong, 1982). Studies conducted by Mensah (1992) had indicated that samples at breast height were enough to characterise the weighted whole tree specific gravity and fibre dimensions. Hence, core samples of 12mm size from the outer most part of the wood, just below the bark, were collected from the trees at breast height. The wood samples were covered in polythene bags as soon as they were collected. The relative density was estimated from the saturated volume and oven dry weight. Wood samples were soaked in water for 2 days and green volume determined by the displacement method. The blocks were then oven dried at 120^0 C to constant weight. Then relative density was estimated as

$$\text{Relative density} = \frac{\text{Oven dry weight}}{\text{Green volume}}$$

Fibre length:

Wood samples were collected from the out side portion of stem sample (inside the bark) since this portion contains extra xylary fibres which are longer and/or more uniform in size than the xylary fibres found towards the pith (Fahn,1981). Small slivers of the samples were then kept in the macerating fluid of acetic acid, hydrogen peroxide and distilled water in the ratio of 2:2:1 at 60^0 C. After maceration, the materials were washed in water and small pieces of macerated materials were placed on a clean slide and gently teased out. Observations were made under a light microscope (Leitz LABORLUX S). A minimum of 25 fibres were measured from each sample for estimation of fibre length which was done on a projection microscope. For quantification a video image analyser (Leica-Quantimet 500+) was used. It provided quick and accurate data. The computer quantimet 500+ provided fibre length measurements with mean and range.

All the values including score values measured or estimated for the growth, tree form and wood characters have been arranged in such a way that a high value would correspond to a positive characteristic.

3.2.4. Morphological characters

Mature leaves and fruits were randomly collected from 5 trees per provenance from each block. Ten leaves and fruits from each tree were used for measurements. Hence, altogether 150 leaves and fruits (10 leaves/fruits x 5 trees x 3 blocks) were measured for each provenance. The maximum leaf length excluding petiole , maximum width and petiole length were measured using a scale.

Fruit samples were used to measure maximum fruit length, fruit girth, and the stone girth and stone length after depulping the fruits. Stones were then broken, and the number of seeds per stone and the seed length and width were measured.

3.3. STATISTICAL ANALYSIS:

Statistical analysis were done using the computer software packages SPSS/PC+ advanced statistics V 2.0 and Spar 1.

3.3.1. Analysis of variance

The data on growth, tree form, wood and other morphological characters were analysed statistically. Variability, heritability and genetic advance were estimated using the following ANOVA table.

The data were subjected to analysis of variance as follows.

Source	D.F.	Mean Sum of Squares	E (M.S.)
Provenance	(t-1)	$M.S._{prov}$	$\sigma_e^2 + r\,\sigma_g^2$
Replication	(r-1)	$M.S._{repl}$	
Error	(r-1) (t-1)	$M.S._{er}$	σ_e^2

r = number of replications t = number of provenances.

σ_e^2 = error variance σ_g^2 = genotypic variance

To analyse the growth over periods from one to six years, growth data over periods were combined and the age effect, provenance effect and interaction between age and provenance were estimated using split-plot analysis. The different provenances were considered as the levels of main plot factor and different time periods as different levels of sub-plot factor. The analysis was done using the software package SPSS/PC + advanced statistics V2.0 through Multivariate analysis of variance (MANOVA): Repeated measures procedure described in Norusis (1988).

3.3.2. Variability, heritability and genetic Advance

Phenotypic and Genotypic coefficient of variation (Pcv and Gcv):

Phenotypic and Genotypic coefficient of variation (Pcv and Gcv) were computed following Burton (1952) as follows.

$$\text{Genotypic variance } (\sigma_g^2) = \frac{MS_{prov} - MS_{er}}{r}$$

$$\text{Phenotypic variance } (\sigma_p^2) = \sigma_g^2 + \sigma_e^2$$

Genotypic coefficient of variation (Gcv) = $\frac{\sqrt{\sigma_g^2}}{\bar{x}}$ x 100

Phenotypic coefficient of variation (Pcv) = $\frac{\sqrt{\sigma_p^2}}{\bar{x}}$ x 100 where, $\bar{x}$ is the mean.

Heritability:

Broad sense heritability of different traits for the provenances planted at 2 localities were estimated following Lush (1940). Heritability was estimated as percentage.

Heritability (H^2) = $\frac{\sigma_g^2}{\sigma_p^2}$ x 100

Genetic Advance (Genetic Gain)

Genetic Advance was worked out according to Johnson *et al. (1955).*

$$\text{Genetic Advance (Genetic gain, G.A.)} = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}} \times K$$

where, K is 2.06, a constant of selection differential at 5 per cent selection intensity.

Genetic Advance as percentage of mean was also worked out as follows.

$$\text{G.A.(as \% of mean)} = \frac{\text{Genetic Advance}}{\text{Grand mean}} \times 100$$

The values of genetic parameters were classified into low, moderate and high as given below.

Genetic parameter	Low	Moderate	High
Gcv and Pcv	0 - 10 %	10 - 20 %	More than 20%
G.A. as % of mean	" "	" "	" "
Heritability	0 - 30 %	30 - 60 %	More than 60 %

3.3.3. Correlation and Regression :

Correlation:

Correlation coefficients between different parameters were estimated after Goulden (1952).

$$\text{Correlation between characters 1 and 2} = \frac{\text{Covariance between 1 and 2}}{\sqrt{\text{Variance of 1 x variance of 2}}}$$

Regression :

In cases where certain characters were highly correlated with geoclimatic parameters, the regression functions were fitted in order to study the pattern of changes in the characters with geoclimatic variations. This was done through computer software SPSS/PC+ advanced statistics V 2.0.

3.3.4. Genetic diversity and clustering:

Among the four broadly classified characters such as 1) Growth characters, 2) Tree form characters, 3) Wood characters and 4) Morphological characters, significant differences between provenances were noted in a number of traits in the category of morphological characters only. Hence genetic diversity based on D^2 statistic was done only for those characters.

Before taking up the study of genetic divergence, test of significance of difference with regard to the pooled effect of all the characters using Wilks' lambda criterion was carried out.

Wilks' criterion:

This was estimated using the formula given by Wilks (1932) and Rao (1952).

$$\text{Wilks' criterion} = \frac{|E|}{|E+V|}$$

Where,

E = Determinant of error sum of squares and sum of product matrix

E+V = Determinant of (Provenances + error) sum of squares and sum of product matrix

Then the value of `V' statistic was worked out using the Wilks' lambda criterion.

$$\text{`V' stat} = -m\ \Delta\ \log e$$

$$\text{Where, } m = n - \frac{(p+q+1)}{2}$$

p = number of characters

q = number of provenances -1

n = degrees of freedom for error + provenances at base of natural log i.e. 2.7183.

The value of `V' statistic was compared with the tabulated Chi-square value for pq degrees of freedom and thus significance was tested.

D^2 analysis:

Mahanalobis D^2 statistic was used for estimating the genetic divergence among the 14 provenances based on morphological characters.

The D^2 values were determined using the computer software Spar 1.

Determination of group constellation or clusters:

For determining the clusters, the method suggested by Rao (1952) was followed. The criterion of grouping was that any two populations belonging to the same cluster should at least on an average show smaller D^2 than those belonging to different clusters.

At first two closely associated provenances were selected and a third provenance which had the smallest D^2 from the first was added. Then, the fourth provenance was chosen to have the smallest average D^2 from the first three and the process was continued upto a stage where there was disruptive increase in the average D^2 by the addition of a particular provenance. This provenance was excluded from that cluster and the clustering was continued, omitting the provenances which had already been included in other groups. This process was continued until all the provenances were included in one or other cluster.

Based on the average distance between the clusters (D values) in the present

Category	D Value
Closely related	Below 3.00
Moderately divergent	Between 3.01 to 6.00
Highly divergent	Above 6.01

study, for the purpose of analysis of the results, the following grouping was adopted.

Euclidean clustering:

At early years only height and Gbh were measured and hence, the provenances were grouped using Euclidean clustering. At later stage (15 year old) when both growth and tree form characters were considered together, provenances significantly differed only for the characters, clear bole percentage and form factor and here also Euclidean clustering was done.

Where only one to very few characters were considered for clustering depending upon their significance, clustering was done using average linkage between groups algorithm. This corresponds to the "Group average method" reported by Everitt (1974). The distance measure used was Squared Euclidean Distance. The analysis was carried out using the statistical package SPSS/PC+ advanced statistics V2.0. The provenances were then clustered into three groups as best, moderate and poor performers.

RESULTS

Indira E.P. “Studies on the variability of the species gmelina arborea linn ”
Thesis. Kerala Forest Research Institute Peechi , University of Calicut, 1999

Chapter 4.

RESULTS

4. RESULTS

The general appearance of provenance trial plots at Chempankolly and Kariamuriam are shown in Pl. 1. Visual identification of provenances is difficult since there are no striking differences between provenances.

The results obtained are categorised into :

1. Growth characters (height and girth at breast height) at early growth period and at late stage,
2. Tree form (clear bole percentage, form factor showing tapering, axis persistence, straightness, branch size and mode of branching),
3. Wood characters (wood density and fibre length) and
4. Other morphological characters (leaf length, leaf width, petiole length, fruit length, fruit girth, stone length, stone girth, number of seeds, seed length and seed width) .

The analyses have been arranged into:

1. Mean performance and analysis of variance
2. Variability, heritability and genetic advance
3. Correlation and regression and
4. Genetic diversity and clustering.

The provenances established at two sites viz., Chempankolly and Kariamuriam were different (though three provenances were common) and hence, the results obtained are given separately for each site. But it is not a comparison of sites. However, the mean performance of the 3 provenances common to both the sites (Baramura, Khasi Hills and Kundrukutu) were compared to get an idea of the general effect of site on each character.

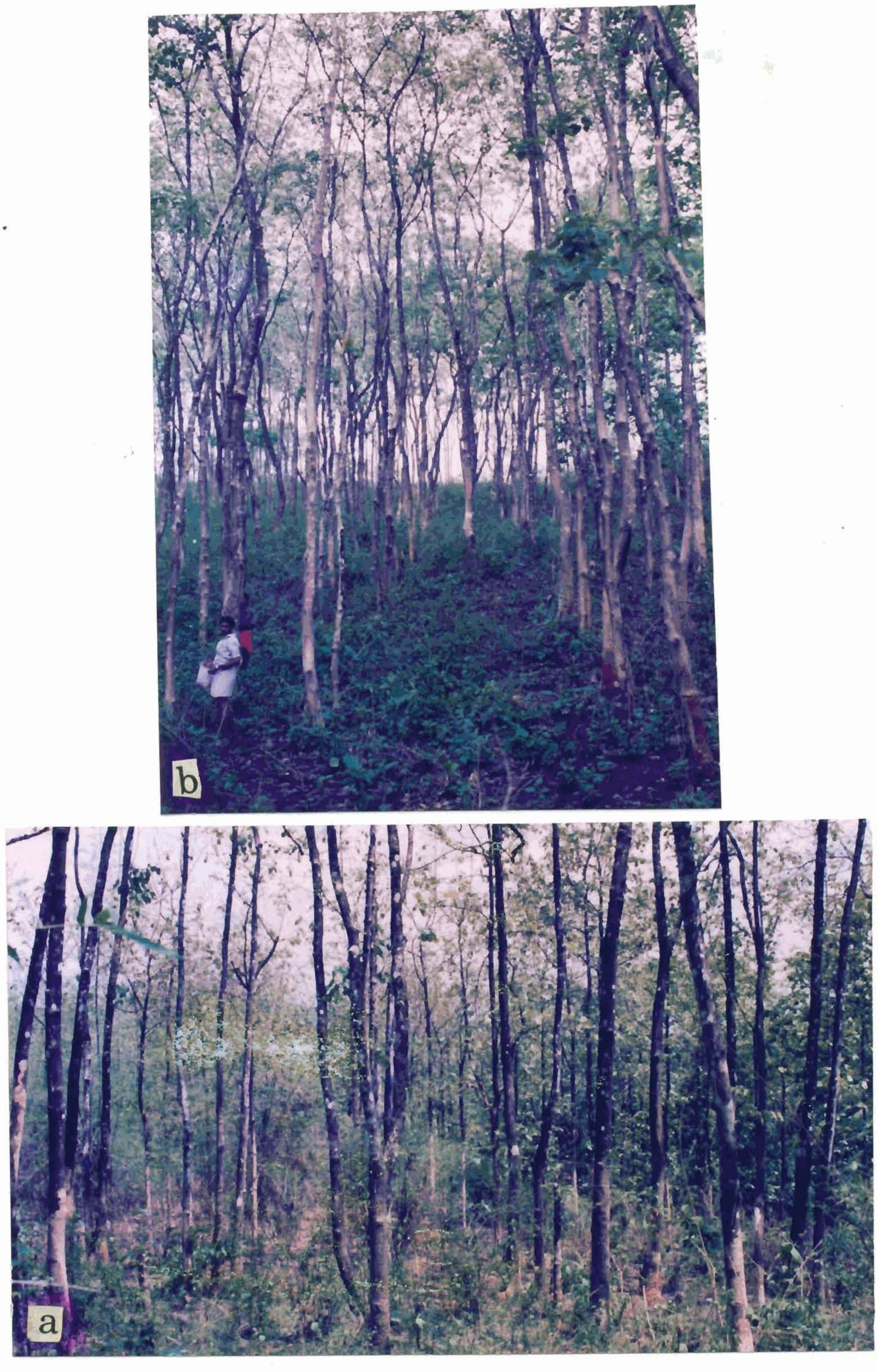


Plate 1. ***Gmelina arborea*** **provenance trial plots**
a) Chempankolly b) Kariamuriam

4.1. PERFORMANCE OF PROVENANCES AND ANALYSIS OF VARIANCE

The mean performance and analysis of variance of data on height and Gbh at early growth period upto 6 years age are presented in Tables 4 and 5 for Chempankolly area and in Tables 6 and 7 for Kariamuriam area. The mean performance and analysis of variance of provenances at 15th year are presented in Tables 8 and 9 for Chempankolly area and Tables 10 and 11 for Kariamuriam area. For other morphological characters mean performance and analysis of variance are given in Tables 12 and 13.

4.1.1. Seedling Stage

Seedlings at Chempankolly:

Height of 1 year old seedlings:

Mean value of 1 year height varied from 0.33 (in Provenances Agarthala 1 and Agarthala 2) to 0.55m (in provenance Cachar) with a grand mean of 0.40m and a coefficient of variation (c.v.) of 6.40 (Table 4). The analysis of variance showed that the between-provenance variation was highly significant (Table 5).

Height at the age of 2 years:

Mean value of 2 year height varied from 1.64m (in prov .Ghottil) to 2.17m (in prov. Cachar). The mean of all provenances was 1.87m with a c.v. of 9.07 (Table 4). There was significant difference between provenances (Table 5).

Height at the age of 3 years:

The average performance of 3 year seedlings varied much with 3.15m (in prov. Ghottil) to 5.61m (in prov. Cachar). Grand mean of all the provenances was 4.64m with a coefficient of variation of 13.76 (Table 4). Analysis of variance showed highly significant variation between provenances (Table 5).

Height at the age of 4 years:

Again the provenance Cachar grew fast with a mean height of 8.28m and provenance Ghottil was the most slow growing one with a mean height of 4.42m. The grand mean was 7.05m with a c.v. of 12.66 (Table 4). Analysis of variance again showed that the between provenance variation was highly significant (Table 5).

Height at the age of 5 years:

Provenance Cachar was again the fastest growing seed source with 9.19m height and provenance Ghottil had just half the height of Cachar with 4.88m. Mean performance of all the provenances was 7.78m with a c.v. of 12.87 (Table 4). Between-provenance variation was significant (Table 5).

Height at the age of 6 years:

At this stage provenance Baramura stood first in height growth with 10.62m and again the slow growing provenance was Ghottil with 5.59m. The grand mean was 9.1m and c.v. 11.48 (Table 4). There was highly significant variation between provenances (Table 5).

Table 4. Performance of provenances planted at Chempankolly

Provenance	Mean height in metres						Mean Gbh in centimeters		
	1 year	2 year	3 year	4 year	5 year	6 year	4 year	5 year	6 year
Agarthala 1	0.33 (24.2)	1.84 (12.0)	5.03 (9.0)	7.83 (8.8)	8.70 (10.3)	10.07 (8.4)	28.42 (20.1)	30.73 (19.5)	34.65 (21.0)
Agarthala 2	0.33 (30.3)	1.79 (18.3)	4.50 (26.6)	7.50 (43.9)	8.82 (24.3)	9.64 (18.7)	23.75 (24.7)	26.54 (28.1)	31.53 (27.2)
Baramura	0.44 (27.3)	2.05 (23.9)	5.41 (22.3)	8.15 (17.9)	8.97 (17.1)	10.62 (14.8)	26.42 (22.7)	28.38 (20.8)	32.51 (20.7)
Cachar	0.55 (31.5)	2.17 (21.0)	5.61 (17.4)	8.28 (16.4)	9.19 (14.7)	10.27 (13.7)	26.81 (15.9)	28.63 (17.8)	31.92 (19.5)
Ghottil	0.35 (34.3)	1.64 (14.6)	3.15 (17.1)	4.42 (15.9)	4.88 (15.5)	5.59 (18.2)	18.38 (25.3)	19.91 (25.0)	22.12 (25.7)
KhasiHills	0.41 (29.3)	2.05 (17.2)	5.29 (17.7)	7.87 (16.3)	8.51 (17.4)	9.72 (19.4)	26.53 (21.8)	27.78 (22.4)	29.90 (29.1)
Kundrukutu	0.41 (36.6)	1.75 (21.1)	3.64 (28.7)	5.34 (22.5)	5.86 (20.5)	7.22 (17.8)	18.29 (27.2)	20.41 (26.3)	23.16 (23.7)
Shikaribari	0.39 (33.3)	1.66 (23.5)	4.51 (27.9)	7.02 (21.4)	7.90 (21.1)	9.64 (16.6)	24.50 (27.8)	26.75 (26.8)	30.79 (26.8)
G.mean	0.40	1.87	4.64	7.05	7.78	9.10	24.14	26.14	29.57
C.V.	6.40	9.07	13.76	12.66	12.87	11.48	12.35	12.00	10.73

Figures in parentheses are coefficients of variation with-in provenances

Girth at Breast Height at the age of 4 years:

Girth at breast height (Gbh) varied significantly (Table 5) with a mean range of 28.42cm (in prov. Agarthala 1) to 18.29cm (in prov. Kundrukutu). Mean of all provenances was 24.14cm with a c.v. of 12.35 (Table 4).

Table 5. Analysis of variance for height and Gbh of provenances planted at Chempankolly

Character	Mean Sum of Squares		
	Provenance (DF=7)	Replication (DF=2)	Error (DF=14)
1 yr height	0.0164**	0.0015	0.0007
2 yr height	0.1173*	0.1890	0.0289
3 yr height	2.2996**	4.1453**	0.4086
4 yr height	6.0121**	5.9606**	0.7971
5 yr height	7.3208**	6.3879**	1.0018
6 yr height	9.1890**	8.4863**	1.0907
4 yr Gbh	44.5760**	51.9770**	8.8913
5 yr Gbh	45.9453*	55.9160**	9.8396
6 yr Gbh	60.9220**	55.4900**	10.0700

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Girth at Breast Height at the age of 5 years:

At 5th year also prov. Agarthala 1 had the highest mean Gbh of 30.73cm and prov. Ghottil had the lowest value of 19.91cm. The grand mean was 26.14 cm and c.v. 12.0 (Table 4). The provenances showed significant variation for this character (Table 5).

Girth at Breast Height at the age of 6 years:

Variation between provenances was again highly significant (Table 5) with a very wide range of 34.65cm in prov. Agarthala 1 to 22.12cm in prov. Ghottil with a c.v. of 10.73 (Table 4). The general mean was 29.57 m.

On close observation it could be seen that provenance Ghottil was the most slow growing one both in height and Gbh. Provenances Agarthala 1 and 2, Cachar and Baramura were the fast growing ones. The growth of the fast growing seed sources was just double the growth of the slow growing ones. Moreover, in height growth and Gbh, there was highly significant variation at all ages.

Seedlings at Kariamuriam:

Height at the age of 1 year:

The mean height varied from 0.69 m in provenance Sitabai valley to 0.50 m in provenance Begur. The grand mean was 0.60m with a c.v. of 12.39 (Table 6). The variation between provenances was not significant (Table 7).

Height at the age of 2 years:

The mean performance ranged from 1.26m in provenance Khasi Hills to 0.86 m in prov. Herrur. The grand mean was 1.09 with a c.v. of 15.49 (Table 6). Between provenance variation was again not significant (Table 7).

Table 6. Performance of provenances planted at Kariamuriam

Provenance	Mean Height in metres						Mean Gbh in centimetres		
	1 year	2year	3year	4year	5year	6year	4year	5year	6year
Begur	0.50 (23.1)	1.00 (33.0)	1.82 (29.0)	4.59 (24.2)	6.31 (20.0)	8.53 (21.0)	15.93 (35.9)	22.10 (31.0)	26.95 (33.6)
Lumbasingi	0.61 (22.3)	1.11 (32.8)	2.00 (32.2)	4.62 (24.7)	6.21 (23.0)	7.97 (20.3)	18.21 (38.6)	23.75 (33.0)	28.60 (34.1)
Sankos	0.66 (26.4)	1.21 (26.5)	2.18 (12.2)	5.17 (12.0)	7.63 (10.0)	9.94 (10.3)	17.98 (27.2)	23.98 (28.7)	28.03 (32.0)
Baramura	0.51 (27.0)	1.13 (29.9)	2.23 (28.8)	5.48 (14.2)	7.85 (14.1)	9.98 (15.3)	20.12 (34.2)	25.96 (34.4)	30.19 (35.1)
Sewanthiwadi	0.61 (32.4)	0.91 (25.1)	1.48 (28.2)	3.39 (24.0)	5.21 (19.6)	8.08 (14.1)	12.15 (43.2)	19.72 (32.6)	25.81 (32.6)
Kundrukutu	0.61 (25.1)	1.13 (22.8)	1.83 (26.3)	4.02 (26.6)	6.02 (28.5)	8.17 (25.5)	15.39 (39.7)	22.28 (37.2)	26.71 (37.2)
Herrur	0.56 (27.3)	0.86 (36.4)	1.35 (37.8)	3.46 (22.3)	6.03 (17.3)	8.18 (18.1)	10.87 (40.9)	19.05 (38.7)	24.82 (46.1)
Sitabai	0.69 (21.2)	1.16 (33.3)	1.94 (27.0)	3.69 (24.6)	5.23 (26.7)	7.69 (25.1)	12.99 (43.6)	19.74 (44.0)	24.06 (49.6)
Khasi Hills	0.60 (26.6)	1.26 (29.5)	2.76 (22.2)	6.23 (10.0)	8.47 (9.9)	10.75 (11.6)	21.95 (26.3)	27.36 (31.2)	30.36 (35.0)
G.mean	0.60	1.09	1.95	4.52	6.55	8.81	16.18	22.66	27.28
C.V.	12.39	15.49	19.97	17.82	16.30	12.44	23.99	17.63	14.52

Figures in parentheses are coefficients of variation with-in provenances

Table 7. Analysis of variance for height and Gbh of provenances planted at Kariamuriam

Character	Mean Sum of Squares		
	Provenance(DF=8)	Replication(DF=2)	Error(DF=16)
1 yr height	0.0123	0.0036	0.0055
2 yr height	0.0541	0.0009	0.0285
3 yr height	0.5237*	0.0359	0.1526
4 yr height	2.8591**	0.2004	0.6482
5 yr height	4.0469*	0.2311	1.1402
6 yr height	3.6638*	0.0028	1.2018
4 yr Gbh	41.8017*	0.5273	15.0630
5 yr Gbh	25.0096	1.5938	15.9532
6 yr Gbh	14.7201	3.4111	15.6840

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Height at the age of 3 years:

The 3 year height varied from 2.76 in prov. Khasi Hills to 1.35m in prov. Herrur. The overall mean was 1.95m with a c.v. of 19.97 (Table 6). Between provenance variation was found to be significant (Table 7).

Height at the age of 4 years:

Highest mean value for height was shown by prov. Khasi Hills with a value of 6.23m and lowest value of 3.39m by prov. Sewanthiwadi. The grand mean was

4.52m and c.v. 17.82 (Table 6). There was highly significant variation between provenances (Table 7).

Height at the age of 5 years:

The mean height ranged from 8.47m in prov. Khasi Hills to 5.21m in prov. Sewanthiwadi. The general mean was 6.55m with a c.v. of 16.3 (Table 6). Significant variation between provenances was noted (Table 7).

Height at the age of 6 years:

The mean height varied from highest value of 10.75m again in Khasi Hills to lowest value in Sitabai valley. The grand mean was 8.81m with a c.v. of 12.44 (Table 6). Between provenance variation was significant (Table 7).

Girth at Breast Height at the age of 4 years:

Gbh varied from 21.95cm in Khasi Hills to 10.87cm in prov. Herrur. The grand mean was 16.18cm and c.v. was 23.99 (Table 6). Between provenance variation was again significant (Table 7).

Girth at Breast Height at the age of 5 years:

Gbh ranged from 27.36cm in prov. Khasi Hills to 19.05cm in prov.Herrur. Grand mean was 22.66cm with a c.v. of 17.63 (Table 6). The analysis of variance showed that there was no between provenance variation (Table 7).

Girth at Breast Height at the age of 6 years:

The highest mean Gbh was 30.36cm again in prov. Khasi Hills and lowest mean Gbh was 24.06cm in prov. Sitabai valley. The grand mean was 27.28cm with a c.v. of 14.52 (Table 6). Again there was no significant variation between provenances (Table 7).

From second year onwards prov. Khasi Hills was the fastest growing one and the second best was prov. Baramura. Provenances Herrur and Sitabai valley were the poor ones. With regard to height, there was significant variation between provenances from third year onwards while significant difference for girth was seen only at the age of 4 years.

4.1.2. Trees at the age of 15 years

Provenances at Chempankolly:

Growth Characters

Height:

The mean height for the tallest provenance was 21m for provenances Baramura and Kundrukutu and the shortest provenance was Agarthala 2 with 18m height followed by Ghottil. The general mean for height was 19.67m with a c.v. of 9.90 (Table 8). Analysis of variance showed that there was no significant difference between provenances for height (Table 9).

Girth at Breast Height:

The mean performance of Gbh varied from 74.21cm for prov. Agarthala 1 follwed by 66.83cm for prov.Khasi Hills to 55.50cm for Ghottil. The general mean was 64.71cm with a c.v. of 10.92 (Table 8). There was no significant difference between provenances (Table 9).

Tree form characters

Clear Bole percentage:

The mean clear bole percentage was highest for prov. Khasi Hills with 60.98 and lowest for prov. Kundrukutu with 43.03. The grand mean was 54.17 with a c.v. of 6.47 (Table 8). There was highly significant variation between provenances (Table 9).

Form factor:

The highest mean form factor was 0.67 in prov. Agarthala 2 followed by 0.66 in prov. Baramura and 0.65 in prov. Shikaribari. The lowest value of form factor was 0.50 in Ghottil. The overall mean was 0.61 with a c.v. of 4.94 (Table 8). There was highly significant variation between provenances (Table 9).

Axis persistence:

The mean score for axis persistence was highest with a value of 4.00 in provenances Agarthala 1, Cachar and Khasi Hills and the lowest value of 3.33 in provenances Ghottil, Kundrukutu and Shikaribari. The general mean was 3.67 where as the c.v. was 12.09 (Table 8). There was no significant variation between provenances for this character (Table 9).

Percentage of trees with good axis persistence:

The mean performance of trees with good axis persistence ranged from 76.67 in prov. Khasi Hills to 40.00 per cent in prov. Kundrukutu. The general mean was 57.92 per cent with a c.v. of 27.07 (Table 8). There was no significant variation between provenances for this character (Table 9).

Table 8. Performance of 15 year old provenances at Chempankolly

Provenance	Ht in metre	Gbh in cm	Clear bole %	Form factor	Axis persistence	% of trees with good axis persistence	Straightness	% of straight trees	Branch size	% of light branched trees	Mode of branching	Wood density (g/cm^3)	Fibre length (mm)
Agar 1	18.67 (17.2)	74.21 (47.8)	49.31 (34.7)	0.59 (9.1)	4.00 (29.7)	53.33	1.67 (50.3)	3.40	3.67 (25.2)	50.00	3.33 (45.2)	0.37 (16.2)	1.37 (5.14)
Agar 2	18.00 (15.5)	64.01 (31.5)	53.06 (25.7)	0.67 (9.9)	3.67 (31.9)	50.00	1.33 (51.0)	3.40	3.67 (24.1)	53.33	3.00 (47.1)	0.39 (9.9)	1.18 (7.1)
Bara	21.00 (15.9)	66.26 (42.1)	58.68 (32.1)	0.66 (9.7)	3.67 (27.2)	70.00	2.33 (51.4)	16.67	3.67 (26.2)	50.00	3.33 (45.1)	0.47 (19.8)	1.33 (9.9)
Cach	20.67 (19.6)	64.89 (44.0)	55.05 (28.8)	0.62 (10.0)	4.00 (23.76)	70.00	2.33 (50.0)	20.00	4.00 (16.5)	83.33	4.00 (33.0)	0.39 (6.9)	1.17 (5.7)
Ghot	18.33 (16.9)	55.50 (48.9)	53.18 (19.9)	0.50 (15.6)	3.33 (41.6)	50.00	1.67 (62.6)	13.37	4.00 (25.7)	60.00	3.00 (44.1)	0.38 (11.5)	1.24 (7.7)
Khasi	19.67 (24.1)	66.83 (51.0)	60.98 (20.6)	0.62 (12.3)	4.00 (21.5)	76.67	2.00 (57.4)	10.00	4.00 (24.4)	63.33	3.67 (38.1)	0.42 (16.0)	1.25 (13.7)
Kundr	21.00 (21.0)	62.33 (34.3)	48.03 (24.0)	0.61 (6.8)	3.33 (27.4)	40.00	2.00 (62.9)	16.67	4.00 (17.6)	70.00	3.00 (41.0)	0.40 (7.0)	1.18 (4.5)
Shik	20.00 (29.2)	63.69 (48.1)	55.06 (30.0)	0.65 (10.4)	3.33 (27.4)	53.33	2.00 (57.0)	13.37	3.67 (27.5)	50.00	3.00 (45.5)	0.39 (17.7)	1.21 (7.9)
G.mean	19.67	64.71	54.17	0.61	3.67	57.92	1.92	12.11	3.83	60.00	3.29	0.40	1.23
C.V.	9.90	10.92	6.47	4.94	12.09	27.07	25.14	79.11	8.05	22.71	9.66	7.96	8.44

Figures in parentheses are coefficients of variation with in provenances

Straightness:

Straightness varied from a highest value of 2.33 in provenances Baramura and Cachar to a lowest value of 1.33 in prov. Agarthala 2. The grand mean was 1.92 with a c.v. of 25.14 (Table 8). The variation between provenances for this character was insignificant (Table 9).

Table 9. Analysis of variance for different characters among 15 year old provenances at Chempankolly

Character	Mean Sum of Squares		
	Provenance (DF = 7)	Replication (DF = 2)	Error (DF = 14)
1. Height	4.3809	6.7915	3.7917
2. Gbh	81.0690	322.7600*	49.9590
3. Clear bole%	56.5037**	35.7109	12.2777
4. Form factor	0.0080**	0.0039*	0.0009
5. Axis persistence	0.2857	0.2917	0.1964
6. % of trees with good axis persistence	485.1200	379.1700	245.8300
7. Straightness	0.3571	0.0417	0.2321
8. % of straight trees	112.7600	53.6700	91.7600
9. Branch size	0.0952	0.6667**	0.0952
10. % of light branched trees	428.5900	1400.0000**	185.7100
11. Mode of branching	0.4226*	0.2917	0.1012
12. Wood density	0.0031	0.0014	0.0010
13. Fibre length	0.0110	0.0078	0.0108

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Percentage of straight trees:

The percentage of straight trees were very low. It was seen that the highest mean was 20 per cent in provenance Cachar and lowest mean was 3.40 in provenances Agarthala 1 and Agarthala 2. The general mean was 12.11 with a c.v. of 79.11 (Table 8). The variation between provenances was not significant (Table 9).

Branch size

The mean of the score of branch size ranged from 4.0 in provenances Cachar, Ghottil, Khasi Hills and Kundrukutu to 3.67 in all other provenances. The general mean was 3.83 and c.v. was 8.05 (Table 8). The result showed that the variation between provenances was insignificant (Table 9).

Percentage of light branched trees:

Proportion of light branched trees varied from 83.33 in prov. Cachar to 50 per cent in provenances Agarthala 1, Baramura and Shikaribari. The grand mean was 60 per cent with a c.v. of 22.71 (Table 8). There was no significant variation between provenances (Table 9).

Mode of branching:

The mode of branching did not vary much. The mean ranged from 4.0 in prov. Cachar to 3.0 in provenances Agarthala 2, Ghottil, Kundrukutu and Shikaribari. The mean was 3.29 and c.v. was 9.66 (Table 8). The analysis of variance showed that the mode of branching was significant at 5 per cent level (Table 9).

Wood characters

Wood density:

Wood density ranged from a mean of 0.47gm/cm^3 in prov. Baramura to 0.37 in Agarthala 1. The grand mean was 0.402gm/cm^3 and c.v. 7.96 (Table 8). Between provenance variation was not significant (Table 9).

Fibre length:

Fibre length varied from a mean of 1.37 mm in prov. Agarthala 1 to 1.17 in prov. Cachar. The general mean was 1.23 mm with a c.v. of 8.44 (Table 8). There was no significant variation between provenances (Table 9).

Provenances at Kariamuriam:

Growth Characters

Height:

Height of 15 year old trees ranged from a mean of 20.67m in provenance Sitabai valley to 17.67 in prov. Khasi Hills. The grand mean was 19.19m with a c.v. of 6.99 (Table 10). Analysis of variance showed that there was no significant variation between provenances (Table 11).

Girth at Breast Height:

The Gbh varied from 65.35 cm in prov. Sankos to 52.83cm in prov. Kundrukutu. The grand mean was 56.26 cm and c.v. was 8.68 (Table 10). The analysis of

Table 10. Performance of 15 year old provenances at Kariamuriam

Provenance	Ht in metrè	Gbh in cm.	Clear bole %	Form factor	Axis persistence	% of trees with good axis persistence	Straight ness	% of straight trees	Branch size	% of light branched trees	Mode of branching	Wood density (gm/cm^3)	Fibre length (mm)
Begur	20.33 (21.7)	54.01 (41.3)	60.63	0.59	4.00 (18.2)	73.33	2.33 (51.5)	26.67	3.67 (28.9)	56.67	3.33 (30.3)	0.42 (15.4)	1.19 5.6)
Lumb	19.67 (22.0)	54.01 (53.1)	48.70	0.52	3.67 (25.1)	43.33	2.00 (37.4)	0.10	3.33 (22.3)	46.67	3.00 (37.1)	0.39 (10.5)	1.06 (6.5)
Sankos	18.67 (25.2)	65.35 (26.7)	53.80	0.65	4.00 (27.4)	63.33	2.00 (52.2)	16.67	3.00 (31.2)	36.67	3.00 (45.3)	0.49 (18.4)	1.23 (2.6)
Baram	18.33 (23.4)	53.87 (46.2)	50.90	0.64	3.33 (25.9)	43.33	2.00 (55.8)	10.03	3.67 (29.5)	46.67	3.00 (38.3)	0.39 (17.1)	1.17 (4.9)
Sewan	18.33 (19.5)	56.63 (48.5)	51.10	0.58	3.67 (24.1)	50.00	2.33 (43.8)	13.33	3.67 (23.2)	46.67	3.33 (33.9)	0.37 (10.9)	1.24 (5.6)
Kundr	18.67 (18.6)	52.83 (23.4)	54.40	0.61	4.00 (25.1)	63.33	2.67 (51.6)	20.00	4.00 (25.1)	53.33	3.00 (48.3)	0.38 (15.7)	1.31 (5.6)
Herrur	20.00 (21.1)	56.82 (41.9)	51.97	0.63	3.33 (25.1)	50.00	2.00 (51.6)	13.33	4.00 (25.1)	56.17	2.67 (48.3)	0.37 (2.7)	1.31 (3.8)
Sitabai	20.67 (28.7)	54.81 (21.7)	59.60	0.64	3.67 (22.4)	66.67	2.67 (55.8)	26.67	3.33 (28.8)	43.33	3.67 (33.7)	0.39 (6.1)	1.23 (8.8)
Khasi	17.67 (30.7)	55.28 (45.5)	58.97	0.62	4.00 (22.7)	63.33	3.00 (34.7)	26.67	3.33 (29.4)	53.33	3.67 (27.4)	0.39 (12.5)	1.17 (8.6)
G.mean	19.19	56.26	54.45	0.61	3.74	57.41	2.33	17.05	3.56	48.89	3.19	0.40	1.21
C.V.	6.99	8.68	5.66	6.63	9.27	19.44	16.75	56.81	13.67	25.96	18.00	6.54	5.87

Figures in parentheses are coefficients of variation with in provenances variance showed that there was no significant variation between provenances (Table 11).

Tree form characters

Clear Bole percentage:

The percentage of clear bole out of total height ranged from 60.63 in provenance Begur to 48.70 in prov. Lumbasingi. The c.v. was 5.66 and grand mean was 54.45 (Table 10). The between provenance variation with regard to this character was highly significant (Table 11).

Form factor:

The mean form factor indicating the intensity of tapering ranged from 0.65 in prov. Sankos to 0.52 in prov. Lumbasingi. The grand mean was 0.61 with a c.v. of 6.63 (Table 10). The variation between provenances was significant at 5 per cent level as shown by the analysis of variance (Table 11).

Axis persistence:

The highest mean score for axis persistence was 4.0 in four provenances while the lowest score of 3.33 was observed in two provenances. The grand mean was 3.74 and c.v. 9.27 (Table 10). Variation between provenances was not significant (Table 11).

Percentage of trees with good axis persistence:

Mean proportion varied from the highest value of 73.33 per cent in prov. Begur to 43.33 per cent in Lumbasingi and Baramura provenances. The grand mean of good trees was 57.41 with a c.v. of 19.44 (Table 10). There was significant variation between provenances (Table 11).

Table 11. Analysis of variance for different characters among 15 year old provenances at Kariamuraiam

Character	Mean Sum of Squares		
	Provenance (DF = 8)	Replication (DF = 2)	Error (DF = 16)
1.Height	3.092	6.2590**	1.8010
2.Gbh	40.587	75.1990	23.8280
3.Clear bole%	55.738**	1.7500	9.5020
4.Form factor	0.005*	0.0030	0.0020
5.Axis persistence	0.231	0.7040*	0.1200
6. % of trees with good axis persistence	356.480*	137.0400	124.5400
7. Straightness	0.417*	0.1110	0.1530
8. % of straight trees	243.920*	48.3330	93.8330
9. Branch size	0.333	0.1110	0.2360
10. % of light branched trees	133.333	11.1110	161.1110
11. Mode of branching	0.343	0.0370	0.3290
12. Wood density	0.004**	0.0007	0.0007
13. Fibre length	0.015	0.0070	0.0050

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Straightness:

The mean score for straightness varied from a maximum of 3.0 in prov. Khasi Hills to a minimum of 2 in four of the total provenances. The grand mean was 2.33 with a c.v. of 16.75 (Table 10). Analysis of variance showed that there was significant variation between provenances for this character (Table 11).

Percentage of straight trees:

The highest value of percentage of straight trees was 26.67 in 3 of the provenances and the lowest value was 0.10 in prov. Lumbasingi. The general mean was 17.05 and c.v. was 56.81 (Table 10). Analysis of variance showed that there was significant variation between provenances at 5 percent level (Table 11).

Branch size:

The highest mean score for branch size was 4.00 for Kundrukutu and Herrur provenances while lowest value was 3.0 for prov.Sankos. The general mean was 3.56 and c.v. was 13.67 (Table 10). Between provenance variation was insignificant (Table 11).

Percentage of light branched trees:

The mean of the percentage of light branched trees varied from a highest value of 56.67 per cent in Begur provenance to a lowest value of 36.67 in prov. Sankos. The grand mean was 48.89 with a c.v. of 25.96 (Table 10). Analysis of variance showed that there was no significant variation between provenances (Table 11).

Mode of branching:

The mean score for this character ranged from 3.67 in two of the provenances Sitabai valley and Khasi Hills to 2.67 in Herrur provenance. The grand mean was 3.19 with a c.v. of 18.00 (Table 10). There was no significant variation between provenances (Table 11).

Wood characters

Wood density:

Wood density varied from 0.49 in prov. Sankos to 0.37 in provenances Sewanthiwadi and Herrur. The grand mean was 0.40 and c.v. 6.54 (Table 10). There was highly significant variation between provenances (Table 11).

Fibre length:

Fibre length varied from 1.31 in prov. Kundrukutu and Herrur to 1.06 in prov. Lumbasingi. The grand mean was 1.21 with a c.v. of 5.87 (Table 10). There was no significant variation between provenances (Table 11).

4.1.3 Morphological characters:

The mean and coefficient of variation for the ten morphological characters studied are presented in Table 12 and the analysis of variance in Table 13.

Leaf length:

The mean leaf length varied from 16.33 cm in provenance Agarthala1 to a lowest value of 8.43cm in prov. Shikaribari. The grand mean was 11.56cm with a c.v. of 9.12 (Table 12). Between provenance variation was highly significant (Table 13).

Leaf width:

The mean leaf width ranged from the highest value of 15.90cm in prov. Agarthala 1 to 7.23cm in prov. Ghottil. The grand mean was 9.81cm and c.v. was 11.70 (Table 12). There was a highly significant variation between provenances (Table 13).

Petiole length:

The highest mean petiole length was 9.37cm in prov. Kundrukutu and lowest length was 3.53cm in provenance Agarthala 2. The overall mean was 5.98cm with a c.v.of 16.97 (Table 12). There was highly significant variation between provenances (Table 13).

Fruit length:

Fruit length varied between highest value of 4.23cm in prov. Sitabai valley and lowest value of 2.57cm in prov. Herrur. The grand mean was 3.77cm and c.v. was 11.24 (Table 12). Here also between provenance variation was highly significant (Table 13).

Fruit girth:

Fruit girth ranged from 7.80cm in prov. Agarthala 2 to 4.57cm in prov. Herrur. The grand mean was 6.72cm and c.v. was 7.36 (Table 12). There was highly significant variation between provenances at 1 per cent level (Table 13).

Stone length:

Highest mean stone length was 2.80cm in provenance Agarthala 1 and lowest stone length of 1.73cm in prov. Shikaribari. The grand mean was 2.25cm and c.v. was 8.14 (Table 12). The stone length variation was highly significant between provenances (Table 13).

Stone girth:

Mean stone girth ranged from 4.42cm in prov. Agarthala 2 to 2.67cm in prov. Herrur. The grand mean for stone girth was 3.73cm with a c.v. of 7.30 (Table 12). Between provenance variation was highly significant (Table 13).

Number of seeds:

Number of seeds varied from 3.0 in prov. Herrur to 1.0 in prov. Cachar. The grand mean was 2.20 seeds and c.v. was very high with a value of 31.38 (Table 12). Variation in number of seeds was not significant between provenances (Table 13).

Seed length:

Seed length ranged from 1.03 cm in prov. Baramura to 0.70 cm in prov. Lambasingi and Khasi Hills. The grand mean was 0.85cm and c.v. was 12.49 (Table 12). Between provenance variation was significant at 5 per cent level (Table 13).

Table 12.Mean values (in cm) of morphological characters in 14 *G.arborea* provenances

Provenances	Leaf length	Leaf width	Petiole length	Fruit length	Fruit girth	Stone length	Stone girth	No.of seeds	Seed length	Seed width
Agarthala 1	16.33 (3.02)	15.90 (4.13)	8.70 (21.84)	3.97 (5.47)	6.47 (2.01)	2.80 (8.38)	4.36 (9.01)	2.42 (21.51)	0.87 (17.65)	0.40 (25.00)
Agarthala 2	11.43 (0.66)	9.60 (2.76)	3.53 (11.78)	4.05 (5.34)	7.80 (5.13)	2.74 (7.42)	4.42 (5.59)	1.67 (34.61)	0.90 (11.11)	0.43 (13.39)
Begur	10.23 (7.34)	9.37 (10.70)	3.97 (2.90)	3.79 (7.39)	6.68 (11.40)	1.81 (9.30)	3.27 (4.68)	2.67 (57.29)	0.90 (11.11)	0.47 (12.42)
Baramura	12.20 (10.72)	9.07 (3.54)	7.10 (25.82)	4.17 (13.65)	7.22 (3.52)	2.57 (5.52)	4.27 (7.17)	2.00 (50.00)	1.03 (14.81)	0.57 (10.23)
Cachar	11.07 (14.12)	8.13 (20.91)	4.23 (20.08)	3.65 (3.97)	7.04 (4.08)	2.31 (8.21)	3.98 (6.56)	1.00 (0.10)	0.83 (6.96)	0.40 (0.10)
Ghotil	9.27 (8.72)	7.23 (11.76)	3.70 (9.76)	4.02 (4.38)	6.27 (4.73)	2.59 (15.44)	4.22 (4.05)	1.67 (34.61)	0.80 (12.50)	0.40 (25.00)
Herrur	10.50 (4.15)	7.57 (5.34)	4.93 (24.53)	2.57 (5.96)	4.57 (5.52)	1.80 (0.10)	2.67 (5.74)	3.00 (0.10)	0.77 (19.95)	0.37 (15.80)
Khasi Hills	12.50 (4.00)	11.00 (13.64)	4.73 (26.41)	3.52 (10.09)	7.18 (7.58)	1.93 (10.64)	3.63 (11.11)	1.92 (45.80)	0.70 (14.29)	0.50 (20.00)
Kundrukutu	9.60 (4.17)	8.83 (7.28)	9.37 (3.43)	4.09 (10.83)	6.97 (6.67)	2.00 (8.65)	3.27 (1.78)	2.33 (24.73)	0.90 (11.11)	0.53 (21.58)
Lumbasingi	13.53 (17.99)	10.90 (26.32)	9.10 (10.48)	3.66 (4.10)	6.83 (5.14)	2.03 (2.85)	3.43 (12.37)	2.50 (20.00)	0.70 (14.29)	0.37 (15.80)
Sankos	13.77 (2.55)	10.80 (2.45)	6.47 (13.14)	3.83 (9.14)	6.92 (7.98)	2.01 (6.83)	3.51 (10.70)	2.42 (21.51)	0.87 (6.69)	0.40 25.00)
Sitabai valley	12.87 (1.19)	10.67 (3.90)	6.53 (7.70)	4.23 (21.17)	6.70 (12.75)	2.60 (3.85)	4.07 (7.52)	2.42 (21.51)	1.00 (20.00)	0.43 (13.39)
Sewanthiwadi	10.10 (18.18)	9.73 (7.57)	6.07 (10.07)	3.87 (19.61)	7.05 (8.16)	2.55 (5.88)	3.93 (1.55)	2.50 (20.00)	0.75 (6.67)	0.37 (15.80)
Shikaribari	8.43 (6.75)	8.50 (5.13)	5.23 (3.98)	3.31 (5.92)	6.37 (7.08)	1.73 (6.53)	3.16 (3.73)	2.33 (24.73)	0.87 (17.65)	0.40 (25.00)
G.mean	11.56	9.81	5.98	3.77	6.72	2.25	3.73	2.20	0.85	0.43
C.V.	9.12	11.70	16.97	11.24	7.36	8.14	7.30	31.38	12.49	18.12

Figures in parentheses are coefficients of variation within provenance

Table 13. Analysis of variance for morphological characters

Character	Mean Sum of Squares		
	Provenance (DF= 13)	Replication(DF = 2)	Error (DF= 26)
Leaf length	13.546**	1.542	1.111
Leaf width	13.698**	0.151	1.316
Petiole length	11.978**	0.072	1.029
Fruit length	0.557**	0.128	0.179
Fruit girth	1.612**	0.076	0.245
Stone length	0.443**	0.045	0.033
Stone girth	0.840**	0.090	0.074
No.of seeds	0.772	0.542	0.478
Seed length	0.030*	0.056*	0.011
Seed width	0.012	0.007	0.006

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Seed width:

Mean seed width varied from a highest value of 0.57cm in provenance Baramura to a lowest value of 0.37cm in provenances Herrur, Lumbasingi and Sewanthiwadi. The grand mean was 0.43cm with a c.v. of 18.12 (Table 12). The variation between provenances was not significant (Table 13).

4.2. VARIABILITY, HERITABILITY AND GENETIC ADVANCE

The results obtained are presented for seedling and later stages at both the localities separately in Tables 14 and 15. The results for all other morphological characters are given in Table 16.

Provenances at Chempankolly:

Seedling stage:

Phenotypic coefficients of variation (Pcv) for height during the first six years were moderate to high and varied from 12.92 to 22.67 while genotypic coefficients of variation (Gcv) ranged from 9.20 to 18.70 (Table 14). Coefficient of variation within provenances were found to be moderate to high except Agarthala 1, where the c.v. was comparatively low (Table 4).

Pcv for Gbh were also moderate during four to six years of age which varied from 17.58 to 18.89 where Gcv ranged from 13.27 to 14.29 (Table 14). For this character moderate to high c.v. within provenances were estimated (Table 4).

Heritability (H^2) for height at all stages were high with values above 60 per cent except second year. For Gbh heritability were moderate with a range of 55.0 to 62.7 during four to six years (Table 14).

Genetic advance (GA) as percentage of mean were high for height at all stages with values 27.37 to 35 except second year. GA for Gbh were moderate with values 20.28 to 22.73 per cent (Table 14).

Trees at the age of 15 years :

At 15 years of age, phenotypic and genotypic coefficients of variation for height were low with values of 10.15 and 2.25 respectively (Table 14). Within provenance variations were moderate in most of the provenances while in Shikaribari and Khasi Hills it was high (Table 8). Heritability and genetic advance were extremely low with values 4.90 and 1.02 per cent (Table 14).

For Gbh also values were not high with a Pcv of 12.0 and Gcv of 4.98 (Table 14). Very high within provenance variations were estimated for this character (Table 8). Low heritability of 17.20 and GA of 4.25 per cent were shown for Gbh (Table 14).

Variability for clear bole percentage were low with a Pcv of 9.60 and Gcv of 7.09 (Table 14). High within provenance c.v. were expressed for this character (Table 8). Form factor also had low Pcv of 9.33 and Gcv of 7.91 (Table 14). Within provenance variations were also low (Table 8). However, moderate heritability of 54.60 and genetic advance of 10.78 per cent were estimated for clear bole percentage. Form factor showed a high heritability of 72 per cent and moderate GA of 13.11 per cent (Table 14).

Persistence of axis showed a moderate phenotypic coefficient of variation of 12.97 and low Gcv of 4.71 (Table 14) (see Pl. 2). High within provenance variations were estimated for this trait (Table 8). Heritability also was very low with a value of 13.20 and GA of 3.54 per cent. Regarding the percentage of trees with good axis persistence it could be seen that a high Pcv of 31.16 and a moderate Gcv of 15.42 were expressed. Heritability was low with a value of 24.50 but GA was moderate with 15.73 per cent (Table 14).

Character straightness showed a high phenotypic coefficient of variation (27.30) (see Pl. 3) while Gcv was moderate (10.65) (Table 14). Very high within provenance variations with values 50.00 to 62.90 were shown for this character (Table 8). Heritability was low with a value of 15.20 and genetic advance was 8.33 per cent. Regarding percentage of straight trees, very high Pcv of 82.08 was estimated while Gcv was only 21.85. Heritability was very low with a value of 7.10 per cent and GA was 11.97 per cent (Table 14).

Branch size showed a low Pcv of 8.05 and negligible Gcv of 0.02. Hence, heritability was zero so as genetic advance (Table 14). But within provenance variations were high except in two of the provenances (Table 8). Percentage of light branched trees showed high Pcv with a value of 27.22 and Gcv of 15.00. Heritability was low with a value of 30.40 and GA of 17.02 per cent (Table 14).

Mode of branching gave a Pcv of 13.87 and Gcv of 9.94 (Table 14). For this trait also high within provenance variations were noted, the values were around 40 per cent (Table 8). Heritability was moderate with a value of 51.40 and genetic advance of 14.59 per cent.

Wood density in these provenances showed a Pcv of 10.34 and Gcv of 6.60. Values for within provenance variations were found to be low to moderate (Table 8). Moderate heritability of 40.70 was estimated for this character and GA was 7.50 per cent (Table 14).

Fibre length was also having a low Pcv of 8.46 and very low Gcv of 0.63. Within provenance variations were estimated to be low except prov. Khasi Hills where 13.7 per cent c.v. was noted (Table 8). Heritability was extremely low and GA was zero (Table 14).

Plate 2. Trees with and with out persistence of axis

Plate 3. Trees with straight and crooked bole

Table 14. Variability, heritability and genetic gain in provenances planted at Chempankolly

Character	Pcv	Gcv	H^2	GA	GA as % of mean
1yr Ht	19.17	18.07	88.80	0.14	35.00
2yr Ht	12.92	9.20	50.70	0.25	13.37
3yr Ht	21.95	17.10	60.70	1.27	27.37
4yr Ht	22.58	18.70	68.60	2.25	31.91
5yr Ht	22.67	18.66	67.80	2.46	31.62
6yr HT	21.42	18.06	71.20	2.86	31.43
15yr Ht	10.15	2.25	4.90	0.20	1.02
4yr Gbh	18.89	14.29	57.20	5.37	22.25
5yr Gbh	17.89	13.27	55.00	5.30	20.28
6yr Gbh	17.58	13.92	62.70	6.72	22.73
15yr Gbh	12.00	4.98	17.20	2.75	4.25
Clear bole %	9.60	7.09	54.60	5.84	10.78
Form factor	9.33	7.91	72.00	0.08	13.11
Axis persistence	12.97	4.71	13.20	0.13	3.54
% of trees with good axis persistence	31.16	15.42	24.50	9.11	15.73
Straightness	27.30	10.65	15.20	0.16	8.33
% of straight trees	82.08	21.85	7.10	1.45	11.97
Branch size	8.05	0.02	0.00	0.00	0.00
% of light branched trees	27.22	15.00	30.40	10.21	17.02
Mode of branching	13.87	9.94	51.40	0.48	14.59
Wood density	10.34	6.60	40.70	0.03	7.50
Fibre length	8.46	0.63	0.60	0.00	0.00

Provenances at Kariamuriam:

Seedling stage:

From 1 year height to 6 year height, the phenotypic coefficient of variation ranged from 14.75 to 26.89 and genotypic coefficient of variation from 8.01 to 19.00. Upto fourth year Pcv and Gcv increased and then started decreasing (Table 15). Within provenance variations were moderate to high in most of the provenances at different years (Table 6). Heritability also increased to 53.20 per cent at fourth year and then started diminishing. Genetic advance also increased from 8.26 to 28.54 and then decreased to 13.51 per cent at sixth year (Table 15).

On analysis girth at breast height showed a phenotypic coefficient of variation diminishing year by year from 30.27 to 14.52 and Gcv from 18.46 to 0.12 (Table 15). Within provenance variations were generally high (Table 6). Heritability was low and it decreased from 37.20 to zero from fourth to sixth year.

Trees at the age of 15 years :

Height at the age of 15 years showed a phenotypic coefficient of variation of low value of 7.79 and genotypic coefficient of variation of 3.42 (Table 15). Moderate to high within provenance variations were estimated for this trait (Table 10). For height heritability was low with 19.30 per cent and genetic advance was also low with 3.07 per cent of total mean. Girth at breast height also had a low Pcv of 9.64 and Gcv of 4.20. Gbh showed high within provenance variations except in three provenances where, moderate c.v. were

Table 15. Variability, heritability and genetic gain in provenances planted at Kariamuriam

Character	Pcv	Gcv	H^2	GA	GA as % of mean
1 yr Ht	14.75	8.01	29.50	0.05	8.33
2 yr Ht	17.67	8.49	23.10	0.09	8.26
3 yr Ht	26.89	17.99	44.80	0.48	24.62
4 yr Ht	26.05	19.00	53.20	1.29	28.54
5 yr Ht	22.17	15.02	45.90	1.37	20.92
6 yr Ht	16.14	10.28	40.60	1.19	13.51
15 yr Ht	7.79	3.42	19.30	0.59	3.07
4 yr Gbh	30.27	18.46	37.20	3.75	23.18
5 yr Gbh	19.22	7.67	15.90	1.43	6.31
6 yr Gbh	14.52	0.12	0.00	0.00	0.00
15 yr Gbh	9.64	4.20	19.00	2.12	3.77
Clear bole%	9.17	7.21	61.90	6.36	11.68
Form factor	8.50	5.32	39.20	0.04	6.56
Axis persistence	10.61	5.14	23.50	0.19	5.08
% of trees with good axis persistence	24.75	15.32	38.30	11.21	19.53
Straightness	21.03	12.71	36.50	0.37	15.88
% of straight trees	70.34	41.48	34.80	8.59	50.38
Branch size	14.57	5.06	12.10	0.13	3.65
% of light branched trees	25.96	0.06	0.00	0.00	0.00
Mode of branching	18.13	2.14	1.40	0.02	0.63
Wood density	10.84	8.65	63.60	0.06	15.07
Fibre length	7.53	4.72	39.30	0.07	5.80

estimated (Table 10). For Gbh, heritability and genetic advance were low with a value of 19 per cent and 3.77 per cent respectively (Table 15).

Clear bole percentage showed a low phenotypic and genotypic coefficients of variation with values 9.17 and 7.21 respectively. Heritability was high as 61.90 per cent and a genetic advance of 11.68 per cent could be expected (Table 15).

Form factor, a measure to show the intensity of tapering also showed low Pcv and Gcv of 8.50 and 5.32 respectively. Moderate heritability of 39.20 and GA of 6.56 per cent were estimated (Table 15).

Persistence of axis showed moderate Pcv and low Gcv with values 10.61 and 5.14 respectively. High within provenance variations were expressed for this character (Table 10). Heritability was low with a value of 23.50 and genetic gain of 5.08 per cent (Table 15).

With regard to percentage of trees with good axis persistence, high Pcv and moderate Gcv were shown with values of 24.75 and 15.32 respectively. Moderate heritability and genetic gain were estimated as 38.30 and 19.53 per cent (Table 15).

Straightness showed 21.03 Pcv and 12.71 Gcv. Very high within provenance variations were noted for this trait (Table 10). Moderate heritability of 36.50 and GA of 15.88 per cent were expressed. Percentage of straight trees had very high phenotypic coefficient of variation (70.34) and genotypic coefficient of variation (41.48). Even though only 34.80 per cent of heritability was estimated, very high genetic gain (50.38 %) was expected for this character (Table 15).

Moderate Pcv (14.57) and low Gcv (5.06) were recorded for branch size with very low heritability of 12.10 and GA of 3.65 per cent. Within provenance variations were high (Table 10). Though high Pcv of 25.96 was recorded for percentage of light branched trees, the genotypic coefficient of variation was extremely low (0.06). Hence, heritability and genetic gain were estimated as zero (Table 15).

Moderate Pcv of 18.13 was recorded for mode of branching, while Gcv was very low (2.14). But high within provenance variations were observed for this character (Table 10). Heritability was extremely low with a value of 1.40 and GA also was low with a value of 0.63 per cent (Table 15).

Wood density was estimated to be having low Pcv and Gcv with values of 10.84 and 8.65 respectively. Except for two provenances namely, Herrur (c.v. = 2.7) and Sitabai valley (c.v. =6.1) all other provenances showed moderate within provenance variation (Table 10). But high heritability of 63.60 and moderate GA of 15.07 per cent were shown for this character (Table 15).

On analysis it was seen that fibre length had a low Pcv and Gcv of 7.53 and 4.72 respectively. This trait expressed very low within provenance variations (Table 10). Moderate heritability was expressed with a value of 39.30 and very low genetic gain of 5.80 per cent is expected (Table 15).

Morphological characters:

Leaf length:

Leaf length showed moderate phenotypic and genotypic coefficients of variation with values of 19.83 and 17.61 respectively (Table 16). Within provenance variation was found to be much varying between provenances from low value of 0.66 to moderate value of 18.18 (Table 12). Heritability of this character was as high as 78.90 and genetic advance was estimated to be 32.18 per cent.

Leaf width:

Leaf width expressed high phenotypic and genotypic coefficients of variation with values of 23.79 and 20.72 per cent respectively. Within provenance variation was again varying much from 2.45 to 26.32 for this trait (Table 12). High heritability and GA were estimated for this character, the values being 75.80 and 37.10 per cent respectively (Table 16).

Petiole length:

Petiole length was found to be a highly variable character (see Pl. 4) with a Pcv of 36.19 and Gcv of 31.97 per cent respectively (Table 16). Within provenance variation ranged from 2.90 to 26.41 (Table 12). Heritability and GA were very high with values of 78 and 58.19 per cent respectively.

Fruit length:

Fruit length was found to be a moderately variable character (see Pl. 4) with 14.67 per cent Pcv and 9.42 Gcv (Table 16). Within provenance variations were having a wide range of 3.97 to 21.17 (Table 12). Heritability and GA were estimated to be moderate with values of 41.30 and 12.47 per cent respectively.

Fruit girth:

Girth of fruits also showed moderate phenotypic and genotypic coefficients of variation (see Pl. 5), the values being 12.46 and 10.05 respectively (Table 16). Variations within provenances were comparatively less with a range of 2.01 to 12.75 (Table 12). High heritability (65.10%) and moderate GA (16.67%) were estimated for this trait.

Stone length:

Length of fruit stones showed moderate Pcv and Gcv of 18.35 and 16.45 per cent respectively (Table 16). Within provenance variations were generally low with values from 0.10 to 15.44 (Table 12). Very high heritability of 80.30 per cent was exhibited by this character with a high genetic advance of 30.22 per cent.

Stone girth:

This character also was exhibiting moderate phenotypic and genotypic coefficients of variation with values of 15.40 and 13.56 per cent respectively (Table 16). Low within provenance variations were expressed by this character with values of 1.55 to 12.37 (Table 12). Here also heritability was as high as 77.60 per cent. Genetic advance was found to be 24.66 per cent which is moderate.

Number of seeds :

Number of seeds exhibited a high Pcv of 34.45 per cent but Gcv was moderate

Plate 4. Leaf and fruit variation

Plate 5 Variation in fruits and seed stones

(14.21 per cent) (Table 16). This character was having a within provenance variation highly varying from 0.10 to 57.29 (Table 12). Low heritability was shown by this character with a value of 17 per cent but GA was moderate (12.27 per cent).

Seed length:

Seed length exhibited moderate phenotypic coefficient of variation of 15.55 per cent while genotypic coefficient of variation was low with a value of 9.27 (Table 16). Within provenance variations were also low to moderate with a range of 6.67 to 20.0 (Table 12). It showed a moderate heritability of 35.50 and GA of 11.76 per cent.

Table 16. Variability, Heritability and Genetic Advance for morphological characters

Character	Pcv	Gcv	H^2	GA	GA as % of mean
Leaf length	19.83	17.61	78.90	3.72	32.18
Leaf width	23.79	20.72	75.80	3.64	37.10
Petiole length	36.19	31.97	78.00	3.48	58.19
Fruit length	14.67	9.42	41.30	0.47	12.47
Fruit girth	12.46	10.05	65.10	1.12	16.67
Stone length	18.35	16.45	80.30	0.68	30.22
Stone girth	15.40	13.56	77.60	0.92	24.66
No.of seeds	34.45	14.21	17.00	0.27	12.27
Seed length	15.55	9.27	35.50	0.10	11.76
Seed width	20.85	10.32	24.50	0.05	11.63

Seed width:

Seed width showed a moderate Pcv and Gcv with values of 20.85 and 10.32 respectively (Table 16). Within provenance variations were found to be mostly moderate with a range of 0.10 to 25.0 (Table 12). Low heritability of 24.50 and GA of 11.63 per cent were estimated for this character.

4.3. CORRELATION AND REGRESSION

Correlation coefficients among growth and tree form traits in provenances planted at both localities and the correlation coefficients among the morphological characters in the 14 provenances were computed. For those characters for which the provenances significantly differed, correlation coefficients were computed with geoclimatic parameters such as latitude, longitude, rainfall and altitude of the area from where the provenance seeds were collected.

4.3.1. Seedling stage:

Provenances at Chempankolly:

Correlation coefficients between height and girth at breast height (Gbh) at varying periods are presented in Table 17. It shows that one year height was positively correlated with second, third, fourth, fifth and sixth year heights and also with fourth, fifth and sixth year Gbh. But it had highly significant correlation only with second year height and 5 per cent significance in third, fourth and fifth year height.

Table 17. Correlation between growth characters at early stage and geoclimatic parameters in provenances planted at Chempankolly

Character	2 yr Ht	3 yr Ht	4 yr Ht	5 yr Ht	6 yr Ht	4 yr Gbh	5 yr Gbh	6 yr Gbh
1yr Ht	0.657**	0.503*	0.409*	0.438*	0.385	0.307	0.282	0.229
2 yr Ht		0.899**	0.809**	0.816**	0.743**	0.770**	0.732**	0.641**
3 yr Ht			0.968**	0.973**	0.938**	0.936**	0.931**	0.884**
4 yr Ht				0.982**	0.976**	0.933**	0.944**	0.938**
5 yr Ht					0.982**	0.952**	0.961**	0.936**
6 yr Ht						0.913**	0.939**	0.941**
4 yr Gbh							0.984**	0.944**
5 yr Gbh								0.978**
Latitude					0.711**			0.579**
Longitude					0.797**			0.718**
Altitude					-0.745**			-0.719**
Rain fall					.694**			0.663**

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Heights at second, third, fourth, fifth and sixth year and Gbh at fourth, fifth and sixth year were highly significantly correlated with each other.

Correlations were also computed between sixth year growth and geoclimatic data (Table 17) namely latitude, longitude, altitude and rain fall which showed that all the geoclimatic parameters were highly significantly correlated with both height and Gbh. Latitude, longitude and rain fall were positively correlated while altitude was negatively correlated with growth.

Regression functions were fitted for 6^{th} year height and Gbh with latitude, longitude, altitude and rainfall.

***Provenances at Kariamuriam*:**

Correlation coefficients were computed for one year to six year height and also for four year to six year Gbh (Table 18). It showed that except first year height, all other characters namely second, third, fourth, fifth and sixth year height and fourth, fifth and sixth year Gbh were highly significantly correlated with each other. First year height was positively correlated only with second and third years height.

Correlation coefficients were estimated between the various geoclimatic data namely, latitude, longitude, altitude and rain fall with sixth year height and Gbh (Table 18). All geoclimatic parameters were highly significantly correlated with height. Correlation of altitude with height was found to be negative while other geoclimatic parameters were positively correlated with height.

Table 18. Correlation between growth characters at early stage and geoclimatic parameters in provenances planted at Kariamuriam

Character	2 yr Ht	3 yr Ht	4 yr Ht	5 yr Ht	6 yr Ht	4 yr Gbh	5 yr Gbh	6 yr Gbh
I year Ht	0.305	0.114	-0.093	-0.116	-0.106	-0.034	-0.029	-0.129
2 yr Ht		0.894**	0.728**	0.658**	0.633**	0.799**	0.766**	0.618**
3 yr Ht			0.897**	0.813**	0.779**	0.887**	0.841**	0.682**
4 yr Ht				0.951**	0.891**	0.962**	0.913**	0.774**
5 yr Ht					0.961**	0.898**	0.902**	0.797**
6 yr Ht						0.894**	0.867**	0.791**
4 yr Gbh							0.958**	0.842**
5 yr Gbh								0.947**
Latitude					0.558**			0.351
Longitude					0.671**			.508**
Altitude					-0.430*			-0.255
Rain fall					0.475**			0.172

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Gbh was found to be highly correlated with longitude and negatively correlated with altitude. With latitude and rainfall, Gbh was positively correlated.

Regression functions were fitted for 6^{th} year height with latitude and longitude and for 6^{th} year Gbh with longitude.

4.3.2. Trees at the age of 15 years

Provences at Chempankolly:

The correlation coefficients were estimated for the growth characters and tree form (Table 19.). Height had weak positive correlation with other characters except straightness which had significant correlation at 5 per cent level. But percentage of trees with good axis persistence had weak negative correlation with height.

Girth at breast height was found to have a weak positive correlation with height (0.161), form factor (0.272), persistence of axis (0.191), straightness (0.119) and mode of branching (0.316). With all other characters, Gbh had weak negative correlation.

Clear bole percentage was negatively correlated with Gbh and percentage of light branched trees. It was highly significantly correlated with percentage of trees with good axis persistence.

Form factor showed positive, but nonsignificant correlation with other characters except percentage of light branched trees and also with percentage of straight trees.

Axis persistence had significant correlation with mode of branching and negative correlation with height and branch size. It showed positive correlation with Gbh and straightness. Percentage of trees with good axis persistence was positively correlated with characters other than height and Gbh. This character was highly correlated with clear bole percentage (0.525).

Straightness was significantly correlated with height and had no correlation with branch size. It had positive correlation with Gbh, mode of branching and persistence of axis. Percentage of straight trees was negatively but not significantly correlated with Gbh and form factor.

Branch size was positively correlated with height and mode of branching but the correlations were not significant. This character was negatively correlated with Gbh and persistence of axis. Percentage of light branched trees had negative correlation with Gbh, clear bole percentage and form factor and insignificant positive correlation with other traits.

Mode of branching showed positive correlation with height, Gbh, straightness and branch size and shown significant positive correlation with persistence of axis.

Wood density was found to be positively correlated with fibre length (0.303) but it was not significant.

Table 19. Correlation between different characters in 15 year old provenances planted at Chempankolly

Character	Gbh	Clear bole %	Form factor	Axis persistence	% of trees with good axis persistence	Straig-htness	% of straight trees	Branch size	% of light branched trees	Mode of branching
Height	0.161	0.064	0.084	-0.182	-0.055	0.427*	0.299	0.116	0.299	0.189
Gbh		-0.025	0.272	0.191	-0.007	0.119	-0.070	-0.378	-0.073	0.316
Clear bole %			0.310		0.525**		0.051		-0.029	
Form factor					0.240		-0.135		-0.018	
Axis persistence.						0.263		-0.162		0.411*
% trees with axis persistence							0.092		0.048	
Straightness								0.000		0.349
% of straight trees									0.219	
Branch size										0.169

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Provenances at Kariamuriam:

Correlation coefficients estimated for growth and tree form are given in Table 20. Height had weak positive correlation with clear bole percentage, axis persistence, percentage of trees with good axis persistence, percentage of straight trees, branch size and mode of branching. All other characters had shown weak negative correlation with height.

Girth at breast height had weak negative correlation with all characters except form factor, percentage of trees with good axis persistence.

Clear bole percentage showed highly significant positive correlation with percentage of trees with good axis persistence and percentage of straight trees. It had weak positive correlation with height, form factor and percentage of light branched trees. It showed weak negative correlation with Gbh.

Form factor showed weak positive correlation with Gbh, clear bole percentage, percentage of trees with good axis persistence and percentage of straight trees. It had weak negative correlation with height and percentage of light branched trees.

Persistence of axis had weak positive correlation with height, straightness, branch size and significant positive correlation with mode of branching. It had weak negative correlation with Gbh.

Table 20. Correlation between different characters in 15 year old provenances in provenances planted at Kariamuriam

Character	Gbh	Clear bole %	Form factor	Axis persistence	% of trees with good axis persistence	Straig-htness	% of straight trees	Branch size	% of light branched trees	Mode of branching
Height	-0.236	0.079	-0.106	0.008	0.149	-0.080	0.050	0.169	-0.048	0.016
Gbh		-0.020	0.238	-0.124	0.117	-0.259	-0.125	-0.177	-0.064	-0.091
Clear bole %			0.125		0.595**		0.791**		0.234	
Form factor					0.043		0.156		-0.188	
Axis persistence						0.143		0.068		0.424*
% trees with axis persistence							0.577**		0.370	
Straightness								-0.146		0.033
% of straight trees									0.176	
Branch size										0.031

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Percentage of trees with good axis persistence has shown highly significant positive correlation with clear bole percentage and percentage of straight trees. With other characters, it had weak positive correlations.

Straightness had weak positive correlation with persistence of axis and mode of branching and weak negative correlation with height, Gbh and branch size. Percentage of straight trees had highly significant positive correlation with clear bole percentage and percentage of trees with good axis persistence. With other characters except Gbh it had a weak positive correlation. Gbh was having a weak negative correlation.

Branch size was having weak positive correlations with height, persistence of axis and mode of branching and had a weak negative correlation with Gbh and straightness. Percentage of light branched trees showed weak positive correlations with clear bole percentage, percentage of trees with good axis persistence and percentage of straight trees and had weak negative correlations with height, Gbh and form factor.

Mode of branching showed significant positive correlation with persistence of axis and weak positive correlation with height, straightness and branch size. It had a weak negative correlation with girth at breast height.

Wood density was found to be having a weak negative correlation (-0.131) with fibre length.

4.3.3. Morphological characters

Correlation coefficients between all the ten morphological characters in 14 provenances planted at both localities were computed and presented in Table 21.

Leaf length showed positive correlation with all characters except seed width. Highest positive and highly significant correlations were exhibited with leaf width (0.820) followed by petiole length (0.447). Correlations with stone length and girth were also significant at 5 per cent level.

Leaf width showed a positive correlation with all characters. Leaf width also had a highly significant correlation with petiole length (0.510) besides leaf length as mentioned above.

Petiole length was positively correlated with all other characters except stone girth. But except leaf length and leaf width, all other positive correlations were weak. Stone girth had a weak negative correlation.

Fruit length was positively correlated with all other characters except number of seeds. It had highly significant positive correlation with fruit girth (0.756), stone length (0.506) and stone girth (0.615). Number of seeds showed a weak negative correlation with a value of - 0.085.

Fruit girth also had positive correlation with all characters except number of seeds. It had highly significant positive correlations with fruit length and stone girth (0.559). It was also significantly correlated with stone length and seed width. Here also number of seeds had a weak negative correlation with a value of -0.196.

Stone length showed positive correlations with all characters except with number of seeds. Highly significant positive correlations were seen with stone girth (0.885) and with fruit length (0.506). Leaf length and fruit girth were also significantly correlated.

Number of seeds was weakly and negatively correlated with stone length with a value of -0.190.

Stone girth was positively correlated with all characters except number of seeds and petiole length. It had highly significant positive correlation with stone length, fruit length and fruit girth. Leaf length was also significantly correlated with stone girth at 5 per cent level. Stone girth had significant negative correlation with number of seeds with a value of 0.314.

Number of seeds was negatively correlated with most of the characters like stone girth, stone length, fruit length and girth. With all other characters weak positive correlation was seen.

Seed length was positively correlated with all characters but highly significant correlation was seen only with seed width (0.512).

Seed width was positively correlated with all characters except leaf length. Highly significant positive correlation was seen with seed length and there was significant correlation at 5 per cent level with fruit girth.

Correlation coefficients were computed between various geoclimatic parameters and morphological characters (Table 21).

With regard to geoclimatic data, latitude and longitude were having highly significant positive correlation with fruit girth and significant correlation with leaf length. Latitude and longitude had significant negative correlation with number of seeds. Latitude also had significant positive correlation with seed girth.

Table 21. Correlation between geoclimatic parameters and morphological characters

Characters	LL	LW	PL	FL	FG	SL	SG	No. of Seeds	SL	SW
Latitude	0.310*	0.282	0.159	0.231	0.482**	0.156	0.340*	-0.347*	0.132	0.220
Longitude	.312*	0.301	0.081	0.092	0.447**	0.043	0.253	-0.322*	0.100	0.206
Altitude	-0.191	-0.272	-0.031	-0.193	-0.477**	-0.251	-0.352*	0.200	-0.146	-0.081
Rainfall	0.192	0.248	-0.104	0.110	0.310*	0.025	0.095	0.020	0.090	0.057
Leaf length		0.820**	0.447**	0.169	0.139	0.331*	0.340*	0.002	0.085	-0.043
Leaf width			0.510**	0.199	0.187	0.281	0.308	0.165	0.060	0.022
Petiole length				0.133	0.041	0.047	-0.012	0.242	0.158	0.139
Fruit length					0.756**	0.506**	0.615**	-0.085	0.279	0.285
Fruit girth						0.324*	0.557**	-0.196	0.179	0.323*
Stone length							0.885**	-0.190	0.244	0.035
Stone girth								-0.314*	0.182	0.138
No. of seeds									0.141	0.130
Seed length										0.512**

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Altitude showed negative correlation with all morphological characters except number of seeds. With fruit girth altitude had highly significant negative correlation while seed girth was negatively correlated with altitude at a significance level of 5 per cent.

Rain fall had no significant correlation with any of the morphological characters except fruit girth where it was positively and significantly correlated at 5 per cent level. Petiole length was the only character negatively correlated with rain fall but it was a weak relationship.

Regression functions were fitted for fruit girth with latitude and altitude.

4.4 GENETIC DIVERSITY AND CLUSTERING:

4.4.1 Growth characters

Effect of age and provenances were estimated, for the growth data over periods, of both localities, by using MANOVA : Repeated Measures procedure. It showed that at Chempankolly there was highly significant variations for height between provenances, between periods and also the interaction between provenance and periods (Table 22). With regard to girth at breast height there was significant difference between provenances and highly significant differences between periods and for the interaction between provenance and period. Hence, data on growth over periods for various provenances were subjected to Euclidean cluster analysis.

Cluster analysis showed 3 distinct clusters (Table 23) among 8 provenances, cluster I was the best with 6 provenances viz., Agarthala 1, Agarthala 2, Baramura, Cachar, Khasi Hills and Shikaribari. The cluster II consisted of only one provenance viz., Kundrukutu and the cluster III comprised of only one provenance viz., Ghottil which showed very poor growth.

Table 22. Manova for early growth characters over periods at Chempankolly

Source	Height		Gbh	
	DF	Mean Squares	DF	Mean Squares
Provenance	7	16.39**	7	148.05*
Error (a)	16	4.29	16	44.48
Period	5	285.37**	2	181.37**
Prov X period	35	1.70**	14	1.69**
Error (b)	80	0.38	32	0.57

** Significant at $p = 0.01$

* Significant at $p = 0.05$

Table 23. Clusters based on early growth in provenances at Chempankolly

Cluster	No.of provenances	Name of provenances
I	6	Agarthala 1, Agarthala 2, Baramura, Cachar, Khasi Hills and Shikaribari
II	1	Kundrukutu
III	1	Ghottil

MANOVA, done for height in provenances planted at Kariamuriam, showed highly significant difference between provenances, between periods and for interaction between provenance and periods (Table 24). Girth at breast height was also subjected to MANOVA which showed no significant difference between provenances and also for interaction between provenance and period. But there was highly significant difference between periods. Euclidean cluster analysis was done taking only height into consideration, since there was no significant difference between provenances with respect to Gbh. On cluster analysis 3 groups (Table 25) were obtained where cluster I comprised only one provenance viz., Khasi Hills which showed the best performance. Cluster II was having 2 provenances viz., Sankos and Baramura with good performance. Cluster III was having all other provenances viz., Begur,Lambasingi, Sewanthiwadi, Kundrukutu, Herrur and Sitabai valley which showed poor performance.

In 15 year old trees, there was no significant difference between provenances at both localities with regard to both height and girth and hence no attempt was made for clustering.

Table 24 . Manova for early growth characters over periods at Kariamuriam

Source	Height		Gbh	
	DF	Mean Squares	DF	Mean Squares
Provenance	8	6.59**	8	76.71
Error (a)	18	1.71	18	39.34
Period	5	292.21**	2	840.18**
Provenance X period	40	0.91**	16	2.41
Error (b)	90	0.23	36	1.39

** Significant at $p = 0.01$

Table 25. Clusters based on early growth in provenances at Kariamuriam

Cluster	No.of provenances	Name of provenances
I	1	Khasi Hills
II	2	Sankos and Baramura
III	6	Begur, Lumbasingi, Sewanthiwadi, Kundrukutu, Herrur and Sitabai valley

4.4.2 Tree form characters

Significant variations were seen between provenances for only clear bole percentage and form factor out of the various tree form characters. Hence,the provenances at both localities were again clustered through Euclidean clustering based on these two characters.

Clustering done for the data at Chempankolly showed that the cluster I comprised of the best provenances viz., Baramura and Khasi Hills, Cluster II included 4 moderate provenances viz., Agarthala 2, Cachar, Ghottil and Shikaribari. The third cluster constituted provenances with poor performance viz., Agarthala 1 and Kundrukutu (Table 26).

At Kariamuriam again three clusters (Table 27) were formed where cluster I was having 3 best provenances viz., Begur, Sitabai valley and Khasi Hills, the second cluster having 5 provenances viz., Sankos, Baramura, Sewanthiwadi, Kundrukutu and Herrur. The third cluster comprised of only one provenance viz., Lambasingi with poor characters.

Table 26. Clusters based on tree form in provenances at Chempankolly

Cluster	No.of provenances	Name of provenances
I	2	Baramura and Khasi Hills
II	4	Agarthala 2, Cachar, Ghottil and Shikaribari
III	2	Agarthala 1 and Kundrukutu

Table 27 . Clusters based on tree form in provenances at Kariamuriam

Cluster	No.of provenances	Name of provenances
I	3	Begur , Sitabai valley and Khasi Hills
II	5	Sankos, Baramura, Sewanthiwadi, Kundrukutu and Herrur
III	1	Lumbasingi

4.4.3. Morphological Characters

Significant variations were seen between the provenances for most of the morphological characters. Hence, Mahanalobis D^2 statistics was used to estimate the genetic divergence among the total 14 provenances available. The D^2 values were computed for all possible n (n-1)/2 pairs of provenances planted at two localities considering the morphological characters.

The generalised D^2 values ranged from 11.22 to 172.61 (Table 28). By the application of clustering technique, the provenances were grouped into different clusters. Altogether 5 clusters were formed based on the D^2 values. The provenances which are included in each of the 5 clusters is given in Table 29.

Table 28. D^2 values between provenances based on morphological characters

Prov1	Prov2	Prov3	Prov4	Prov5	Prov6	Prov7	Prov8	Prov9	Prov10	Prov11	Prov12	Prov13	Prov14
37.89 (12)	15.65 (5)	11.22 (14)	15.05 (12)	15.65 (2)	28.31 (5)	42.22 (11)	24.91 (11)	28.49 (10)	28.49 (9)	24.91 (8)	15.05 (4)	32.59 (12)	11.22 (3)
51.30 (13)	41.08 (13)	25.51 (11)	25.50 (11)	25.11 (8)	29.90 (12)	47.95 (3)	25.11 (5)	49.72 (4)	28.58 (11)	25.50 (4)	26.86 (11)	35.86 (5)	28.58 (5)
72.53 (11)	44.00 (6)	26.45 (8)	26.19 (5)	26.19 (4)	39.17 (13)	60.00 (14)	26.45 (3)	54.28 (11)	58.75 (4)	25.51 (3)	29.90 (6)	39.17 (6)	37.88 (8)
74.89 (4)	48.27 (8)	27.42 (5)	37.60 (3)	27.42 (3)	39.69 (14)	68.00 (10)	37.88 (14)	58.36 (13)	62.62 (8)	26.86 (12)	32.59 (13)	40.15 (14)	39.69 (6)
78.40 (10)	54.90 (4)	35.01 (12)	41.69 (8)	28.31 (6)	41.81 (4)	68.00 (12)	41.69 (4)	61.71 (12)	63.06 (12)	28.58 (10)	35.01 (3)	41.08 (2)	40.15 (13)
92.51 (8)	59.31 (12)	37.60 (4)	41.81 (6)	28.58 (14)	43.32 (3)	77.18 (4)	48.23 (13)	63.59 (14)	65.85 (13)	42.22 (7)	37.85 (5)	42.65 (4)	43.02 (11)
92.94 (6)	61.95 (3)	43.32 (6)	42.65 (13)	35.86 (13)	44.00 (2)	78.32 (9)	48.27 (2)	78.32 (7)	68.00 (7)	43.02 (14)	37.89 (1)	48.23 (8)	45.16 (12)
102.21 (5)	64.58 (14)	47.95 (7)	46.30 (14)	37.85 (12)	75.27 (8)	84.53 (8)	54.62 (12)	79.33 (3)	78.40 (1)	44.22 (5)	45.16 (14)	51.30 (1)	46.30 (4)
103.96 (2)	85.01 (11)	55.98 (13)	49.72 (9)	44.22 (11)	78.60 (11)	102.34 (5)	62.62 (10)	83.90 (8)	86.15 (3)	54.28 (9)	54.62 (8)	55.98 (3)	60.00 (7)
106.40 (9)	103.96 (1)	61.95 (2)	54.90 (2)	97.01 (9)	92.64 (1)	102.62 (6)	75.27 (6)	97.01 (5)	86.20 (14)	57.28 (13)	59.31 (2)	57.28 (11)	63.59 (9)
107.66 (3)	150.01 (9)	79.33 (9)	58.75 (10)	100.75 (10)	102.62 (7)	109.32 (13)	83.90 (9)	106.40 (1)	100.75 (5)	72.53 (1)	61.71 (9)	58.36 (9)	64.58 (2)
114.97 (14)	150.41 (10)	86.15 (10)	74.89 (1)	102.21 (1)	108.02 (9)	141.01 (1)	84.53 (7)	108.02 (6)	135.85 (6)	78.60 (6)	63.06 (10)	65.85 (10)	86.20 (10)
141.01 (7)	172.61 (7)	107.66 (1)	77.18 (7)	102.34 (7)	135.85 (10)	172.61 (2)	92.51 (1)	150.01 (2)	150.41 (2)	85.01 (2)	68.00 (7)	109.32 (7)	114.97 (1)

Figures in parentheses are provenance number

Among the clusters, Cluster I was the largest with 6 provenances followed by cluster II having 4 provenances. Cluster III had 2 provenances, cluster IV and V had only one provenance each.The intra and inter cluster distance (D^2 and D values) among the 5 clusters are presented in Table 30.

Table 29. Clusters based on morphological characters

Cluster	No.of provenances	Name of provenances
I	6	Begur, Baramura, Khasi Hills, Sankos, Sitabai valley and Shikaribari
II	4	Agarthala 2, Cachar,Ghottil and Sewanthiwadi
III	2	Kundrukutu and Lumbasingi
IV	1	Agarthala 1
V	1	Herrur

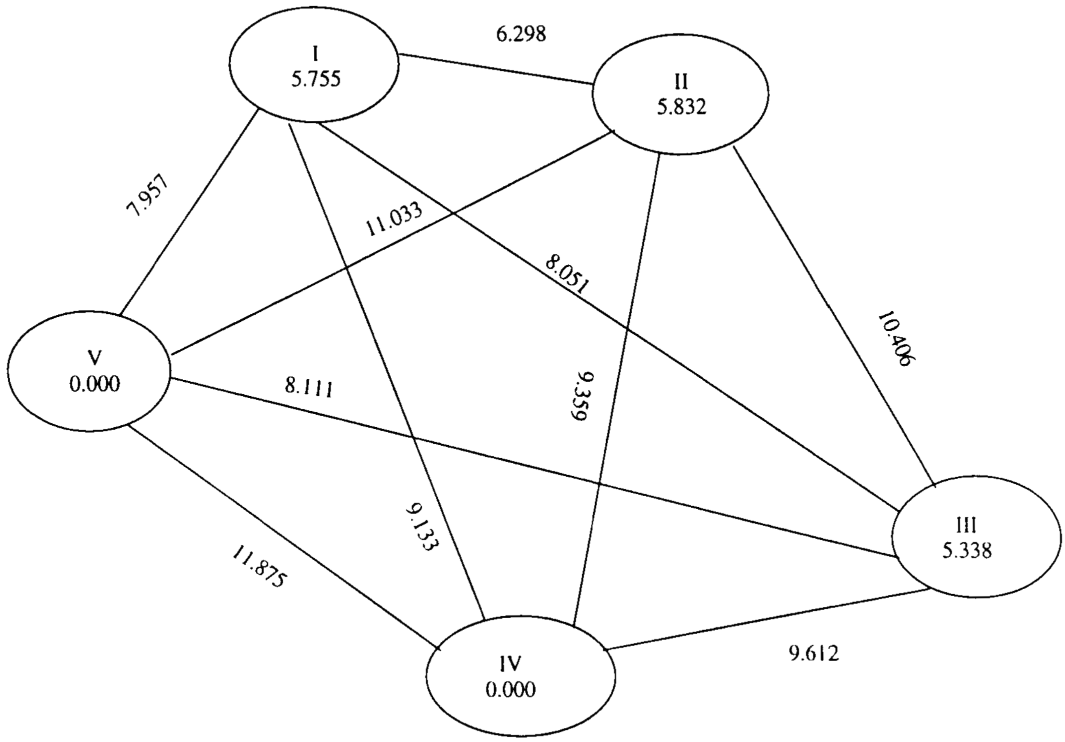
Table 30. Average intra and inter cluster D^2 and D values

Cluster	I	II	III	IV	V
I	33.12 (5.755)	39.67 (6.298)	64.82 (8.051)	83.41 (9.133)	63.31 (7.957)
II		34.01 (5.832)	108.28 (10.406)	87.60 (9.359)	121.72 (11.033)
III			28.49 (5.338)	92.40 (9.612)	65.79 (8.111)
IV				0.00 (0.000)	141.01 (11.875)
V					0.00 (0.000)

D values within parentheses

The relationship between different populations is shown in Fig. 2, where D values between and within clusters are given.

Fig.2. Intra and inter cluster distance (not to scale)



It could be seen that intra cluster distance was more or less same with values 5.755, 5.832 and 5.338 in clusters I,II,III. Cluster No.IV and V had no intra cluster distance. Inter cluster distance was highest between clusters IV and V with a value of 11.875 and lowest between clusters I and II with a value of 6.298.

Ranking of 10 characters and their contribution to divergence is presented in Table 31.

Table 31. Rank totals and percentage contribution of Characters

No.	Character	Rank total	Percentage contribution
1	Leaf length	441	8.81
2	Leaf width	580	11.59
3.	Petiole length	469	9.37
4.	Fruit length	624	12.46
5.	Fruit girth	439	8.77
6.	Stone length	433	8.65
7.	Stone girth	573	11.45
8.	No.of seeds	433	8.65
9.	Seed length	489	9.77
10.	Seed width	524	10.47

There was not much variations in the percentage of contribution of each character to divergence, which ranged from 8.65 to 12.46. Fruit length was the character which contributed the largest followed by leaf width and stone girth. Stone length and number of seeds were the least contributing factors.

DISCUSSION

Chapter 5.

DISCUSSION

5. DISCUSSION

Gmelina arborea is a fast growing multipurpose tree which received international attention. Planters, foresters and scientists are attracted by its rapid growth in favourable sites, ability to suppress weeds and high early economic returns. It also received support for its genetic improvement programmes.

The vast distribution range of *G. arborea* in India from a latitude of 8° to 27°N and longitude of 72° to 96°E should have given rise to a rich genetic diversity (Lauridsen, 1977). The variability present in different growth characters, tree form, wood characters and other morphological characters will definitely help planters and tree breeders in their venture.

The present study was conducted using 14 provenances from different parts of India. They were Begur provenance from Kerala, Herrur from Karnataka, Lambasingi from Andhra Pradesh, Sewanthiwadi, Ghottil and Sitabai valley from Maharashtra, Kundrukutu from Bihar, Sankos from West Bengal, Khasi Hills from Meghalaya, Cachar from Assam and Shikaribari, Baramura, Agarthala 1 and Agarthala 2 from Tripura. The study covered the growth characters at seedling stage of 1-6 years as well as at 15th year. Tree form, wood characters and other morphological characters were also studied in 15 year old trees. The general performance of different provenances, the within and between provenance variations, the phenotypic as well as genotypic coefficient of variations, the inheritance pattern, the correlation between different characters, the correlation between geoclimatic data and different characters and the genetic diversity and clustering of provenances were studied.

5.1. MEAN PERFORMANCE AND VARIANCE

There were highly significant variations between provenances planted at Chempankolly for seedling height and girth at breast height (Gbh). Significant differences between provenances were reported in other species also like *Eucalyptus camaldulensis* (Otegbeye and Samarawira, 1990; Pinyopusarerk, *et al.*, 1996). Provenances Agarthala 1, Baramura and Cachar were showing best performance followed by a few provenances while, provenance Ghottil was the worst one followed by Kundrukutu. Dominance of certain provenances and poor performance of others for growth in the early years were maintained till sixth year (Fig 3).

At Kariamuriam also there were significant variations between provenances in height from third to sixth year and in Gbh for fourth year. Provenance Khasi Hills showed the best growth performance followed by Baramura while, Sitabai valley showed poor growth. Here also early dominance of provenances was maintained till later seedling stage (Fig 4) to a certain extent. This type of dominance relations were reported in *Eucalyptus tereticornis* (Otegbeye, 1987), *Eucalyptus grandis* (Subramanian *et al.*, 1995) and in *Tectona grandis* (Kuang *et al.*, 1996).

In 15 year old trees there were no significant difference between provenances at both the localities. The differential growth behaviour between provenances, with a few showing faster growth rate in early phase can be exploited through high density short rotation forestry (HDSR), when this species is used for pulp. Studies conducted by Mensah (1992) at Ghana showed that *G.arborea* can be harvested on short rotation

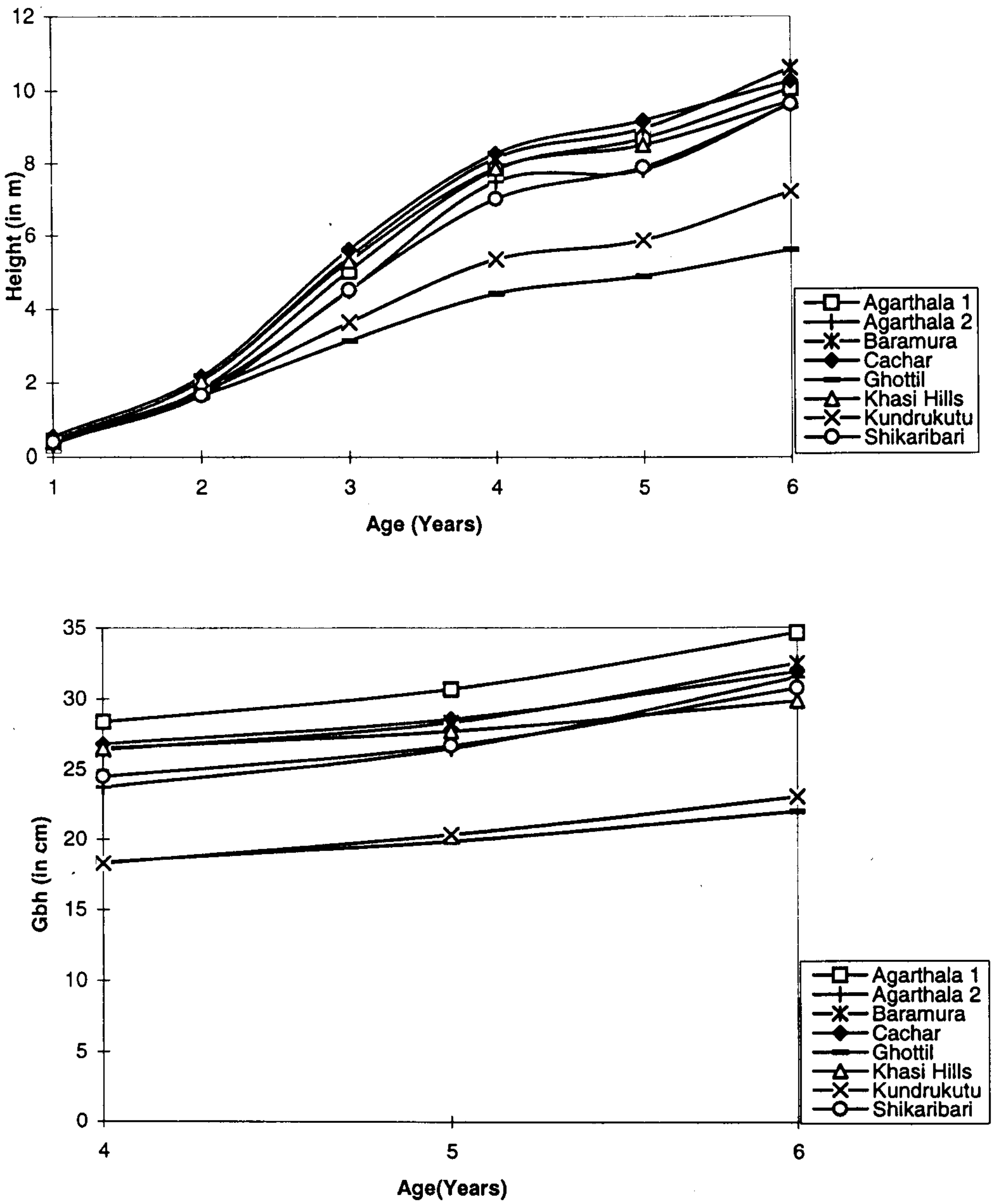


Fig. 3. Early growth in provenances at Chempankolly

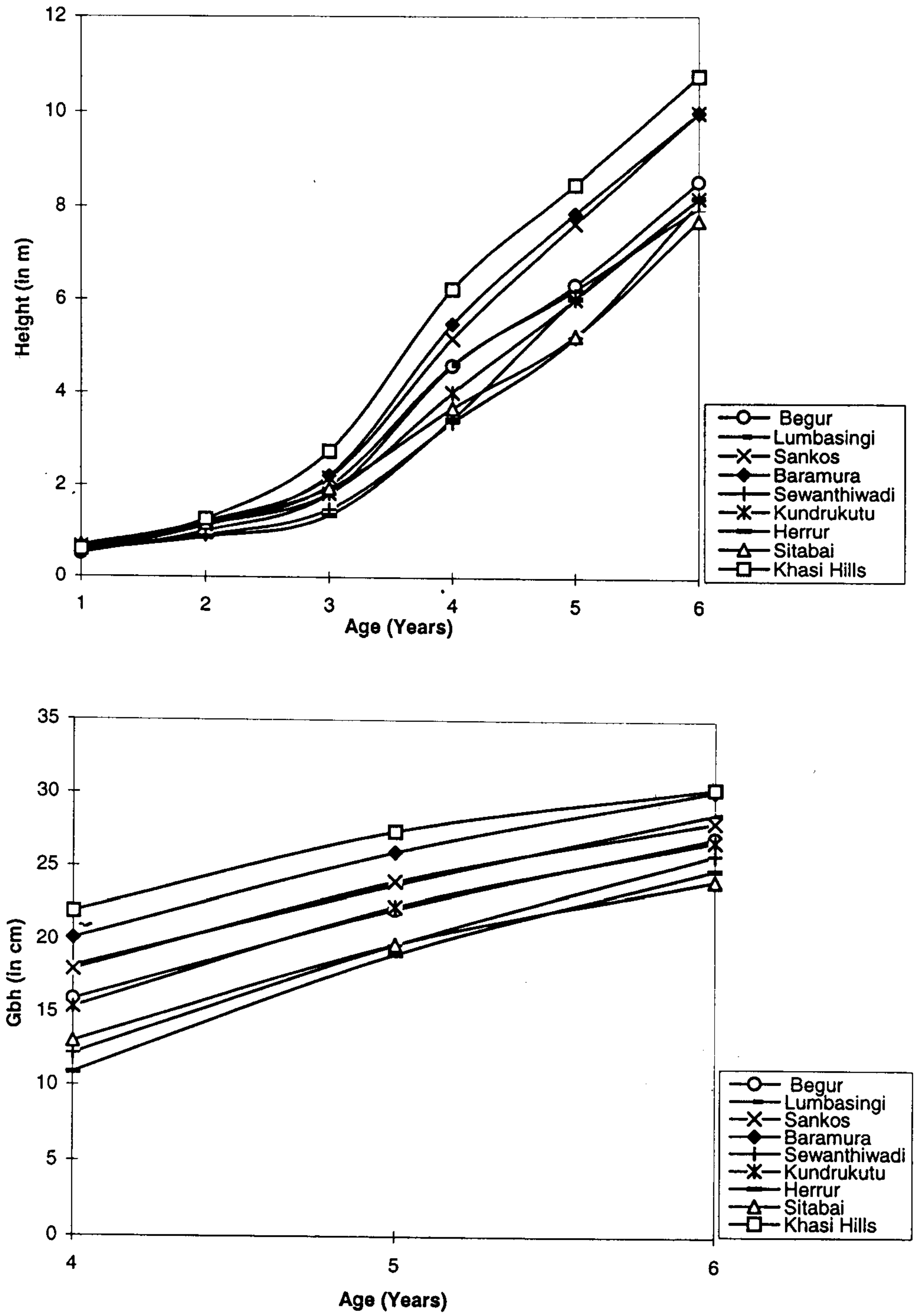


Fig.4. Early growth in provenances at Kariamuriam

of 8 years for pulp production. Vinay Rai and Srinivasan (1990) studied the benefits of HDSR plantations in *E. tereticornis* and *Casuarina equisetifolia*. The HDSR plantations or Silage harvesting was reported to be suitable for cutting down the waiting period for monetory returns (FAO,1979).

The components of variance as percentage of variance due to provenances, replications and error for growth were fluctuating over different years at both the localities . The fluctuations were more during the initial two to three years of growth and then got stabilized. This type of fluctuation and stabilization was reported in *Tecomella undulata* also by Jindal *et al.* (1992).

Analysis of the age effect and provenance effect on growth data combined over different periods have shown highly significant age effect and provenance effect in provenances grown at both localities. Highly significant age effect on height and diameter was reported by Otegbeye (1987) in *Eucalyptus tereticornis.*

When the growth characters of provenances up to sixth year were taken into consideration, it can be seen that the provenances from north-eastern regions were performing well. Cluster analysis had shown that at Chempankolly best performers were Agarthala 1, Agarthala 2, Baramura, Cachar, Khasi Hills and Shikaribari, all from the north-eastern part of India. The remaining provenances namely, Kundrukutu from Bihar and Ghottil from Maharashtra were poor growth performers. At Kariamuriam also Khasi Hills formed the best cluster followed by Sankos and Baramura in the second cluster, all exhibiting good growth. The remaining provenances which were poor in growth were Begur, Lambasingi, Sewanthiwadi, Kundrukutu, Herrur and Sitabai valley from the states of Kerala, Andhra pradesh, Maharashtra, Bihar and Karnataka. On evaluation of the international trials in *G.arborea* established in Solomon Islands, Sandiford (1990) also observed the best performance of provenances from North-east India.

In 15 year old trees there were no significant difference between provenances with regard to height and Gbh at both the localities. However, at Chempankolly, provenance Ghottil was again the poor performer.

There were highly significant variations between provenances with regard to the clear bole percentage and form factor. At Chempankolly, clear bole percentage was more in Khasi Hills followed by Baramura. Lowest value was shown by Kundrukutu followed by Agarthala 1. Highest form factor showing less tapering was seen in Agarthala 2 followed by Baramura and Shikaribari. Here also the provenance Ghottil had the lowest form factor indicating the high tapering nature.

At Kariamuriam, highest clear bole percentage was seen in Begur followed by Sitabai valley and Khasi Hills. The lowest value was shown by Lumbasingi. Highest form factor was shown by Sankos followed by Baramura and Sitabai valley and lowest form factor was seen again in Lumbasingi.

The provenances were again grouped into clusters taking the clear bole percentage and form factor into consideration. At Chempankolly, Baramura and Khasi Hills (cluster I) were showing the best performance. Agarthala 1 and Kundrukutu of cluster III were the poor performers and the remaining provenances in the third cluster showed moderate performance.

At Kariamuriam, provenances Begur, Sitabai valley and Khasi Hills were grouped into the best cluster and Lumbasingi in the cluster with poor performance. All the other provenances were in the remaining cluster with moderate performance.

Clear bole percentage and tapering are also factors which determine the final volume of wood. For these characters and for growth, at both the localities, Khasi Hills showed outstanding performance. At Chempankolly, Ghottil and Kundrukutu were the provenances with undesirable characters while at Kariamuriam, the most undesirable provenance was Lumbasingi.

With regard to axis persistence and percentage of trees with good axis persistence there were no significant difference between the provenances at Chempankolly. However, for axis persistence provenances Agarthala 1, Cachar and Khasi Hills showed good performance while Ghottil, Kundrukutu and Shikaribari were having poor axis persistence. Regarding the percentage of trees with good axis persistence again Khasi Hills stood first with 76.67 per cent followed by Baramura and Cachar. Kundrukutu was having the least number of trees with good axis persistence followed by Ghottil and Agarthala 2.

At Kariamuriam there were no significant difference between provenances for axis persistence. Begur, Sankos, Kundrukutu and Khasi Hills were the provenances showing good score values while Baramura and Herrur were having the lowest value. While Kundrukutu had good score value at Kariamuriam it had low value at Chempankolly. For percentage of trees with good axis persistence there was significant difference between provenances. Begur provenance stood first with 73.33

per cent of the trees with good axis persistence. Lumbasingi and Baramura were having the lowest percentage of trees with good axis persistence. At Chempankolly, Kundrukutu was having only 40 per cent whereas at Kariamuriam the same provenance was having 63.33 per cent of the total trees with good axis persistence. Like wise Baramura was having 70 per cent of their trees with good axis persistence at Chempankolly while it had only 43.33 per cent of their trees with good axis persistence at Kariamuriam. Hence, it could be inferred that this character is highly environmentally controlled.

In *G. arborea,* the general criticism is that the trees are having undesirable stem form with forking, bending and basal sweep. Our results also showed that more than 80 per cent of the trees were not straight. There were no significant difference between provenances for the character straightness as well as for percentage of straight trees at Chempankolly. Baramura and Cachar were having the highest score value for straightness while Agarthala 2 showed the lowest value. Cachar was having the highest percentage of straight trees with 20 per cent whereas, Agarthala 1 and 2 were having only 3.40 per cent straight trees. At Kariamuriam, provenances differed with significance for straightness and for percentage of straight trees. Provenance Khasi Hills was having the highest score value for straightness followed by Kundrukutu and Sitabai valley. Lowest score was shown by four provenances, Lumbasingi, Sankos, Baramura and Herrur. Regarding the percentage of straight trees, provenances Begur, Sitabai valley and Khasi Hills were having the highest percentage while, Lumbasingi was having practically no straight tree.

There were no significant differences between provenances for branch size as well as for percentage of light branched trees at both the localities. At Chempankolly, provenances Cachar, Ghottil, Khasi Hills and Kundrukutu were having the highest score value and all others were in the next score group. But Cachar was having the highest percentage of light branched trees and Agarthala 1, Baramura and Shikaribari were having the least number. At Kariamuriam, provenances Kundrukutu and Herrur showed the highest score value for branch size while Sankos was having the lowest value. Regarding the percentage of light branched trees at Kariamuriam, provenance Begur was having the highest percentage with 56.67 per cent followed by Herrur whereas Sankos had only 36.67 per cent of its trees light branched. Generally more light branched trees were seen at Chempankolly including the three provenances common to both localities. When the growth and tree form were considered together, provenance Khasi Hills outperformed others at both the localities. At Chempankolly, provenance Ghottil showed very poor performance by way of both growth and tree form. At Kariamuriam, provenance Lumbasingi was the most undesirable one.

At Chempankolly provenance Cachar showed good growth, moderate clear bole percentage and form factor, high percentage of trees with good axis persistence, highest percentage of straight trees and highest percentage of light branched trees.

Though Agarthala 1 and 2 showed better growth rate the lowest percentage of straight trees were seen in these provenances.

At Kariamuriam though provenance Begur was not preferred for its growth rate at early years, it was having best tree form like clear bole percentage, highest percentage of trees with good axis persistence, highest percentage of straight trees and light branched trees.

Hence, desirable characters from provenances having better tree form can be incorporated into the provenances with faster growth rate through inter provenance hybridization. It has been observed that combinational hybridization can be an important method of breeding for multiple characteristics (Nikles, 1970., Wright, 1976).

The performance of the three provenances common to both the localities is given in Table 32. The characters like 6 year height, 6 year Gbh, clear bole percentage, form factor and mode of branching did not vary much. These were the characters which showed significant difference between provenances. Percentage of trees with good axis persistence, percentage of straight trees and percentage of light branched trees showed wide variation between sites. Sandiford (1990) reported that the serious obstacle to make comparisons between populations was the marked sensitivity of *G.arborea* to site. Greaves (1981) also noted the extreme site sensitive nature of this species. Large provenance x site interactions were reported in other species also. Lebot and Ranaivoson (1994) noted this type of interaction in many species of *Eucalyptus*.

Significant difference in wood density between sites was reported in *G.arborea* by Tang and Ong(1982) while Akachuku (1976) noted no significant variation. The present study showed that wood density in provenance Baramura varied

Table 32. Mean performance of 3 provenances common to both sites

Provenance	6 yr Height in m	6 yr Gbh in cm	Clear bole %	Form factor	Axis persistence	% of tree with good axis persistence	Straig htness	% of straight trees	Branch size	% of light branched trees	Mode of branch	Wood density (g/cm^3)	Fibre length (mm)
Baramura													
i)	10.62	32.51	58.68	0.66	3.67	70.00	2.33	16.67	3.67	50.00	3.33	0.47	1.33
ii)	9.98	30.19	50.90	0.64	3.33	43.33	2.00	10.03	3.67	46.67	3.00	0.39	1.17
Khasi Hills													
i)	9.72	29.90	60.98	0.62	4.00	76.67	2.00	10.00	4.00	63.33	3.67	0.42	1.25
ii)	10.75	30.36	58.97	0.62	4.00	63.33	3.00	26.67	3.33	53.33	3.67	0.38	1.25
Kundrukutu													
i)	7.72	23.16	48.03	0.61	3.33	40.00	2.00	16.67	4.00	70.00	3.00	0.40	1.18
ii)	8.17	26.71	54.40	0.61	4.00	63.33	2.67	20.00	4.00	53.33	3.00	0.39	1.17

i) at Chempankolly ii) at Kariamuriam

highly between two sites compared to other two provenances. This type of variation, where some of the provenances or clones varied widely from others between sites were reported in few other species. In *Tectona grandis* it was observed that few clones showed more variations in wood density between sites compared to other clones (Indira and Bhat,1998). Fibre length in *G. arborea* was also reported to have significant site effect (Akachuku, 1978). Rudman (1970) noted genotype- environment interaction for fibre length in *E. camaldulensis.*

5.2. VARIABILITY, HERITABILITY AND GENETIC ADVANCE

Early stage:

The phenotypic coefficients of variation at Chempankolly and Kariamuriam for height during the first 6 years were moderate to high and genotypic coefficients of variation were moderate. At Chempankolly Pcv varied from 12.92 to 22.67 and Gcv varied from 9.2 to 18.7. Within provenance variations were generally moderate to high for 2 to 6 year height except in Agarthala 1 where low values were estimated. In provenances planted at Kariamuriam Pcv ranged from 14.75 to 26.89 and Gcv from 8.01 to 19.00. Coefficient of variation within provenances were generally moderate to high except in provenances Sankos and Khasi Hills.

For girth at breast height at 4 to 6 year in provenances planted at Chempankolly, coefficients of variations were moderate with Pcv between 17.58 and 18.89 and Gcv between 13.27 and 14.29. Within provenance variations were high except in provenance Cachar where moderate values were estimated. At Kariamuriam Pcv varied widely from 14.52 to 30.27 and Gcv from 0.12 to 18.46. Coefficients of variation within provenances were very high.

Experiments at Colombia showed that growth variables in six species of *Pinus* and *Eucalyptus saligna* and *E. grandis* had high genetic variation between provenances (Romero,1995). In the present study Pcv and Gcv for height and Gbh increased from third year upto fifth year at Chempankolly (Fig. 5a) while Pcv and Gcv increased from third to fourth year and then decreased (Fig. 5b) in provenances planted at Kariamuriam. In *Eucalyptus tereticornis* also this type of increase in the amount of variation with an increase in age was reported (Sidhu, 1994).

Regarding heritability for height, at Chempankolly, it was high in the first year and then decreased in the second year. From there onwards heritability increased from the moderate value to high value in the sixth year (Fig. 5a). At Kariamuriam, heritability for height decreased from first year to second year and then increased to moderate value (Fig. 5b). This type of decrease in the heritability value from the first year to second year and then an increase was reported for height growth in Black Walnut by Rink (1984) and the reason for heritability decrease in the first or second year is attributed to the effect of seed size or maternal inheritance during early years.

Heritability for Gbh was moderate at Chempankolly, while it reduced from moderate to zero at Kariamuriam.

Genetic gain as percentage of mean was around 30 from fourth to sixth year for height and around 20 to 25 for Gbh in provenances planted at Chempankolly. Moderate to high heritability and genetic gain suggest that these characters may

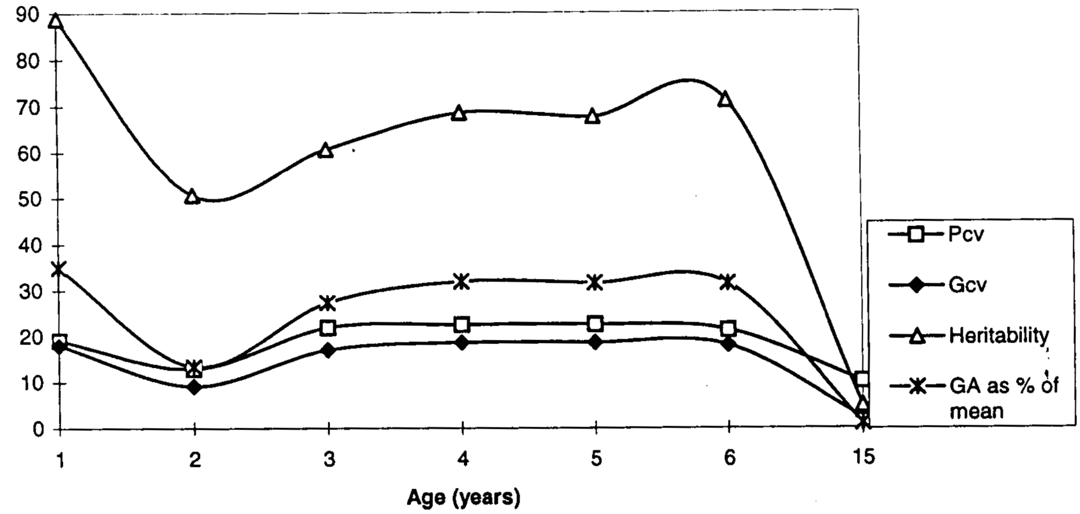


Fig. 5a. Provenances at Chempankolly

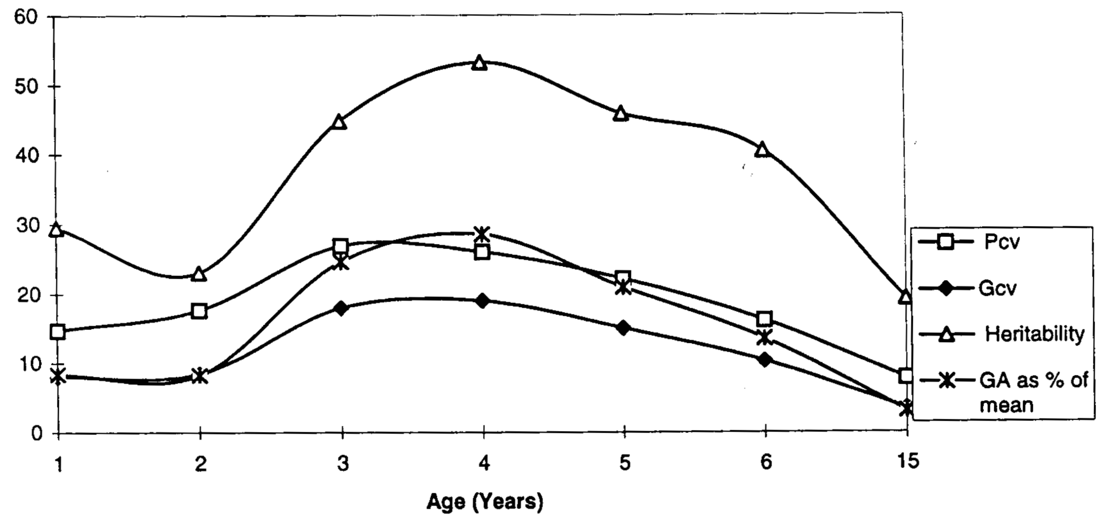


Fig. 5b Provenances at Kariamuriam

Fig. 5. Variation in genetic parameters (Height)

be improved through selection. Genetic gain increased from 8.26 to 28.54 for height and it reduced from 23.18 to zero for Gbh at Kariamuriam.

At Chempankolly and Kariamuriam the genetic sources used and the environmental conditions were different and hence, different trends in heritability and genetic gain were seen. International provenances trials in *Gmelina arborea* have shown that characters like survival, health, tree form, wood density and growth had different heritabilities from one experiment to another (Lauridsen, *et al.* 1987). This is in support of our observation. Moreover, the proportion of Gcv to Pcv was less in provenances planted at Kariamuriam. However, by utilising the genetic variations present in the provenances this species can be genetically improved substantially.

Trees at the age of 15^h year:

Growth, Tree form and Wood characters :

In 15 year old trees, at both the localities, there were no significant difference between provenances for height as well as girth at breast height. At Chempankolly height had a low Pcv of 10.15 and very low Gcv of 2.25. The proportion of Gcv to Pcv was low and heritability and genetic advance were extremely low with values 4.90 and 1.02 per cent respectively. The coefficient of variation, especially Gcv had decreased to a great extent from sixth year to fifteenth year. So also were the heritability and genetic advance.

At Kariamuriam also Pcv, Gcv, heritability and genetic advance for height showed a great fall from sixth year to fifteenth year.

At Chempankolly, Pcv, Gcv, heritability and genetic advance decreased from sixth year to fifteenth year. At Kariamuriam also Pcv and Gcv decreased compared to fourth and fifth years. Heritability and genetic advance were also low. The fluctuations in Pcv, Gcv and heritability, like a decrease in the second year and then an increase in the next year got, stabilized in the later seedling stage. Then these parameters decreased when the trees became older. This is in support of the observations made by Namkoong *et al.*, (1972) in Douglas fir and Namkoong and Conkle (1976) in Ponderosa pine.

If selections are made in the younger stages, more growth can be achieved in the shortest period. The best provenances from North-eastern India especially Khasi Hills, Cachar, Baramura and Sankos are best suited for high density short rotation forestry especially when the species is used in pulp industry.

Among the tree form and wood characters, provenances planted at Chempankolly, varied significantly for mode of branching (p=0.05) and in clear bole percentage (p=0.01), and form factor (p=0.01). Clear bole percentage, form factor, persistence of axis, branch size, mode of branching, wood density and fibre length showed their Pcv around ten. Among these, branch size and fibre length had lowest Gcv. Hence, these characters must be more environmentally controlled. Character straightness had a Pcv of 27.30 but Gcv was low with a value of 10.65. Heritability and genetic gain were also low. Hence, there is not much scope for selection without the recourse of progeny trial among the provenances for this character. Heritability was ~~highly~~ moderate for clear bole percentage and mode of branching. It was high for form factor and moderate for wood density. For all other characters low heritability was seen. Though high heritability was found for form factor, genetic gain was moderate. When clear bole percentage and form factor were considered together, provenances Baramura and Khasi Hills were grouped in the best cluster. Khasi Hills and Baramura were again considered best suited for both growth and tree form.

In provenances planted at Kariamuriam significant differences were seen between provenances for characters like straightness, percentage of straight trees, percentage of trees with good axis persistence, clear bole percentage, form factor and wood density. From among these, percentage of straight trees showed highest Pcv and Gcv with values 70.34 and 41.48 respectively followed by percentage of trees with good axis persistence with Pcv and Gcv of 24.75 and 15.32. Heritability was high for clear bole per cent (61.90) and wood density (63.60). Though clear bole percentage had high heritability, genetic gain was only moderate. At the same time, percentage of straight trees had moderate heritability and very high genetic gain.

The Pcv, Gcv, and heritability for each and every character under study were quite varying from one site to the other. The two possible reasons are i) the provenances planted at these two sites were different and ii) site factors were also different. This finding is in support of the observations made by Lauridsen *et al.* (1987) in *Gmelina arborea* and by Garcia *et al.* (1992) in *Eucalyptus camaldulensis* at Mexico. It indicated that values for heritability and genetic gain for height, diameter and volume varied depending on the localities of planting. Bouvet and Vigneron (1995) also had the same observation in many *Eucalyptus* species, where the variances and heritabilities were strongly influenced by the experimental processes like nursery, planting and environmental effects. Romero (1995) also found that growth variables in

E. saligna and *E. grandis* provenances were significantly affected by environmental variables.

Morphological characters:

Provenances were significantly different for all morphological characters except number of seeds and seed width. Agarthala 1 was the provenance with biggest leaf, by way of leaf length and leaf width and provenance Ghottil was with smallest leaf. Baramura was the provenance with biggest fruit while Herrur was having the smallest. Biggest stone size was exhibited by the provenance Agarthala 1 and smallest by Herrur. Number of seeds was more in provenance Herrur and less in Cachar. Largest seed was seen in provenance Baramura and smallest in Lambasingi.

Regarding the variations present in the provenances for morphological characters, petiole length showed the highest phenotypic and genotypic coefficients of variation. Number of seeds exhibited very high Pcv of 34.45 but its Gcv was only 14.21. Out of the total 10 morphological characters studied, 6 characters namely leaf length, leaf width, petiole length, fruit length, stone length and stone girth were having very high heritability, while number of seeds and seed width were having low heritability. Genetic gain as percentage of mean was highest for petiole length followed by leaf width, leaf length and stone length. Lowest genetic gain was estimated for seed length and seed width.

5.3. CORRELATION AND REGRESSION

Correlation studies at both the localities showed that at early years of growth, height and girth at breast height at various ages were highly correlated. Gbh at three to six years and height at different years were also correlated. This is in support of the report by Lokmal (1994) that strong correlation exists between height and Gbh in *Gmelina arborea.*

Hence, selection for height will naturally give an increase in Gbh and vice versa. Growth at two years to six years were found to be highly correlated. So, provenances or individual trees can be selected at an earlier age of 2 years. Hence, the second year performance can be used for the prediction of growth of the provenances at later seedling stages.

Correlation between early to later stages of growth were reported in many other species like *Prosopis cineraria* (Solanki *et al.*, 1984), *Eucalyptus tereticornis* (Kedharnath and Vakshasya,1977) and in *Bambusa bambos* (Indira, 1998).

It was also seen that geoclimatic parameters like latitude, longitude, altitude and rainfall were highly correlated with height and girth at early stage. Altitude was negatively correlated while other three parameters were positively correlated with growth. Since very good correlations were exhibited for height and Gbh with geoclimatic data, regression analyses were also done. Very good regression coefficients were obtained for height and girth with all the four geoclimatic parameters (Figs. 6,7 and 8).

The results showed that provenances from areas of higher latitude, longitude and rainfall are better for early growth. In *Azadirachta indica*, Kundu and Tigerstedt (1997) reported that provenances from low rainfall area showed comparatively low

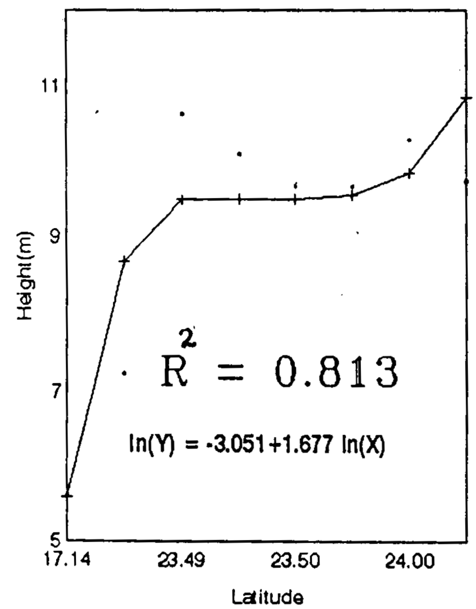


Fig.6a Relationship between height and latitude

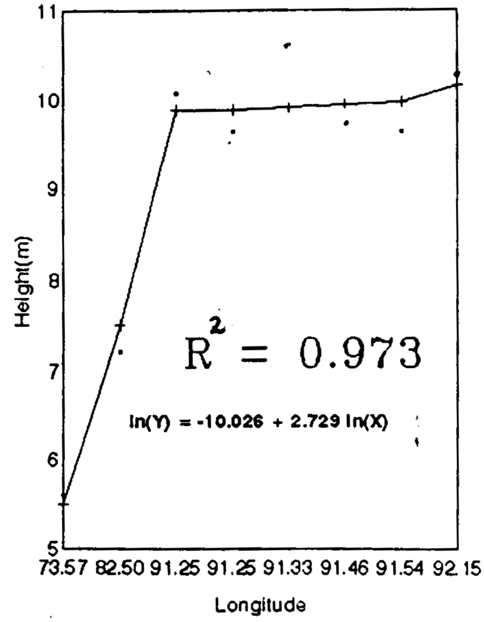


Fig.6b Relationship between longitude and height

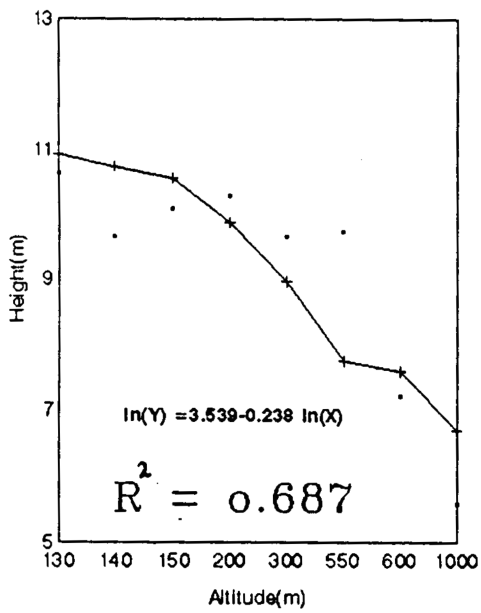


Fig.6c Relationship between altitude and height

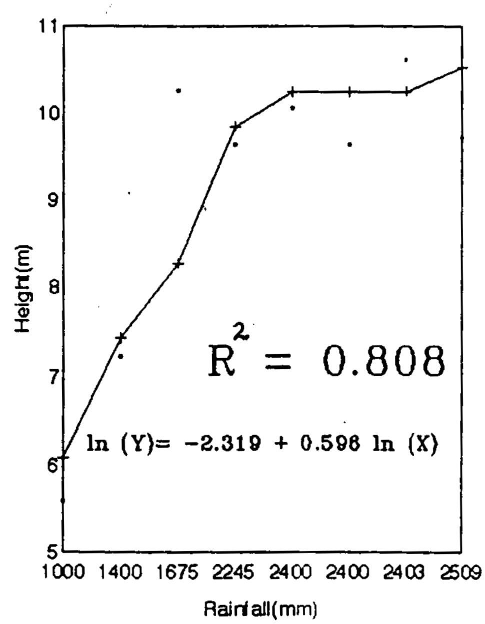


Fig.6d Relationship between height and rainfall

Fig. 6. Relationship between geoclimatic parameters and height in provenances at Chempankolly

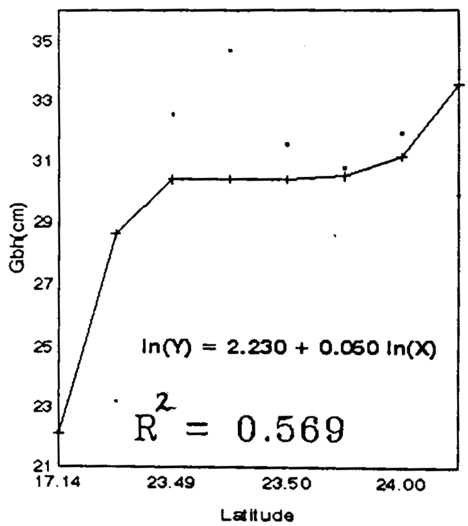


Fig. 7·a Relationship between gbh and latitude

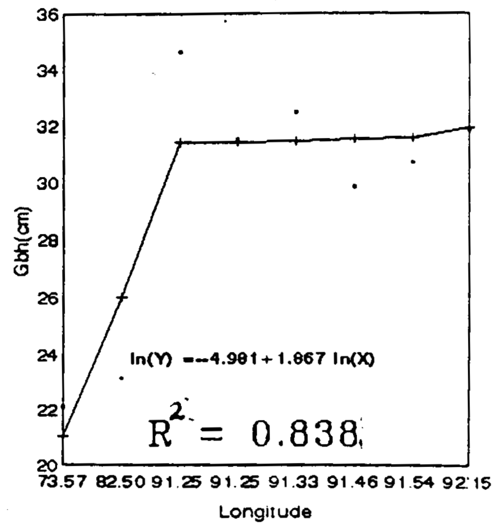


Fig. 7·b Relationship between longitude and gbh

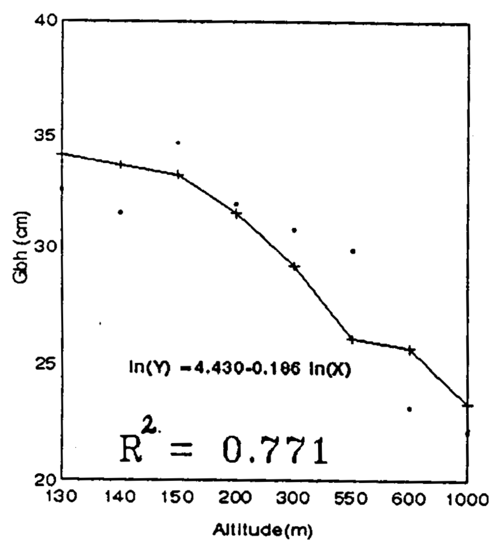


Fig. 7·c Relationship between altitude and gbh

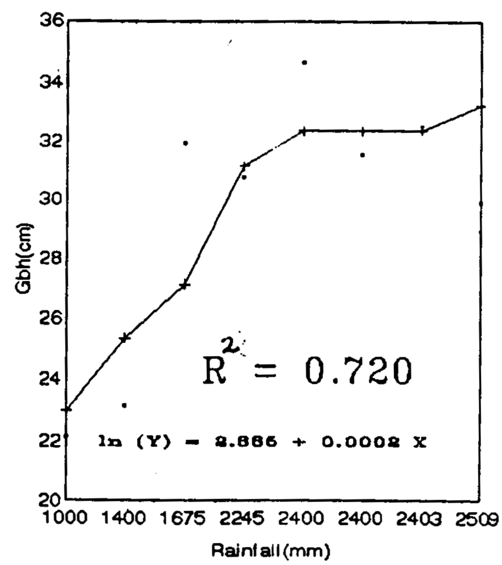


Fig. 7·d Relationship between gbh and rainfall

Fig. 7. Relationship between geoclimatic parameters and Gbh in provenances at Chempankolly

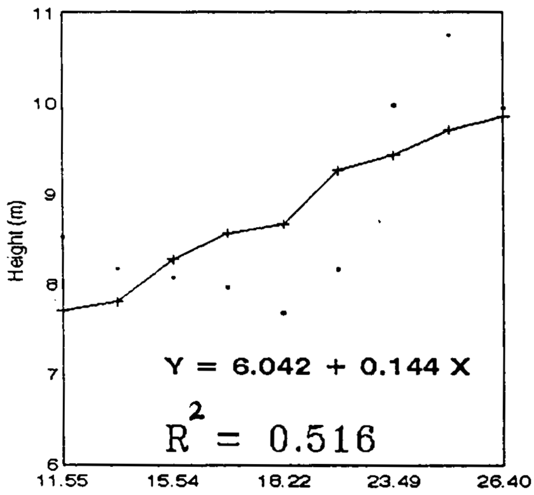


Fig. 8a Relationship between latitude and height

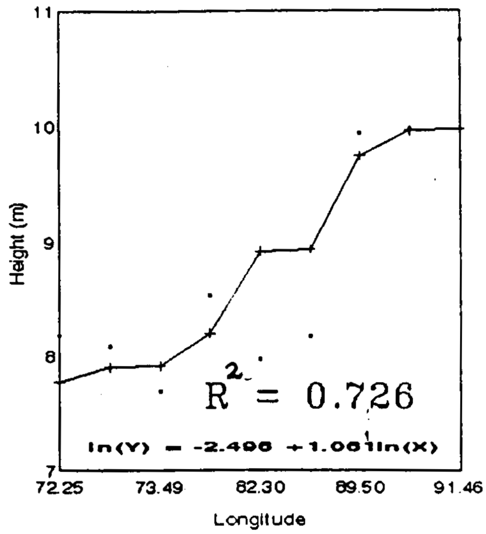


Fig. 8b Relationship between longitude and height

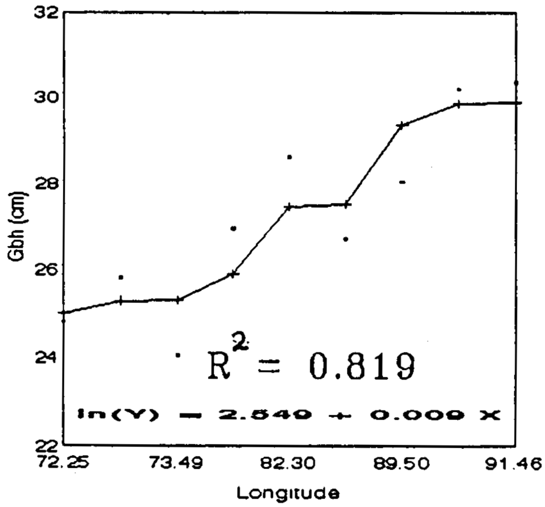


Fig. 8c Relationship between longitude and gbh

Fig. 8. Relationship between geoclimatic parameters and growth in provenances at Kariamuriam

height and Gbh. In the present study altitude has shown an inverse relationship with growth. Eldridge (1966) also reported relationship of altitude of seed source with height in *E. regnans*. In *E. grandis* Arnold *et al.* (1996) observed a significant correlation between latitude of seed source and height and also altitude of seed source and height. Karschon (1974) observed that the yield of *E. camaldulensis* in Israel was directly related to latitude and longitude of the seed origin. Arnold *et al.* (1966) also reported significant correlation between latitude of seed source and height growth in *E. grandis*

In 15 year old trees, clear bole per cent was found to be highly significantly correlated with percentage of trees with good axis persistence. It is a well known fact that trees with good axis persistence will have good clear bole percentage. Axis persistence was found to be significantly correlated with mode of branching. From this, it can be inferred that if forking is less in the main stem, it will be less in the branches also.

At Chempankolly, straightness was found to be having no correlation or a weak negative correlation with branch size. In *Eucalyptus camaldulensis*, Otegbeye and Samarawira (1992b) had found that trees with better stem straightness tended to develop large diameter branches.

With regard to morphological characters, leaf length, leaf width and petiole length were highly significantly correlated with each other. Leaf length also had shown high correlation with stone length and stone girth.

Fruit length, fruit girth, stone length and stone girth were highly significantly correlated with each other. But these characters had a significant negative correlation with number of seeds. Hence, fruit or stone size are not the determining factors of number of seeds. Latitude, longitude and rainfall showed positive significant correlation with fruit girth while altitude showed a significant negative correlation. Stone girth was also related to latitude. Longitude had significant relation with leaf length. Geoclimatic variation of seed source mainly affect fruit girth. Arimah (1979) reported significant difference between geographic sources with regard to fruit and stone size and seeds but without well defined geographic trends. He also noted leaf size and petiole length as the most distinguishing characters through principal component analysis. In the present study also no geographic trend could be seen with leaf size and petiole length. But a clear inverse relation of altitude of seed source with fruit size and a direct relation of latitude of seed source with fruit size could be seen (Fig. 9). Kundu and Tigerstedt (1997) also observed significant positive correlation between seed length and latitude of seed source area in *Azadirachta indica.* In *Eucalyptus tereticornis*, this type of correlation between morphological variations and latitude was reported by Wang *et al.* (1988) suggesting the influence of environmental factors.

Many early reports (Esan,1966; Hughes and Esan, 1969 and Akachuku, 1978) showed that the relative density and fibre length in *G. arborea* were highly significantly correlated in a positive direction. The present study showed that in provenances planted at Chempankolly there was insignificant positive correlation with a value of 0.303. But in provenances at Kariamuriam wood density was found to be having a weak negative correlation (-0.131) with fibre length. This difference may be due to the different provenances used in the two sites as well as the site effect on the wood

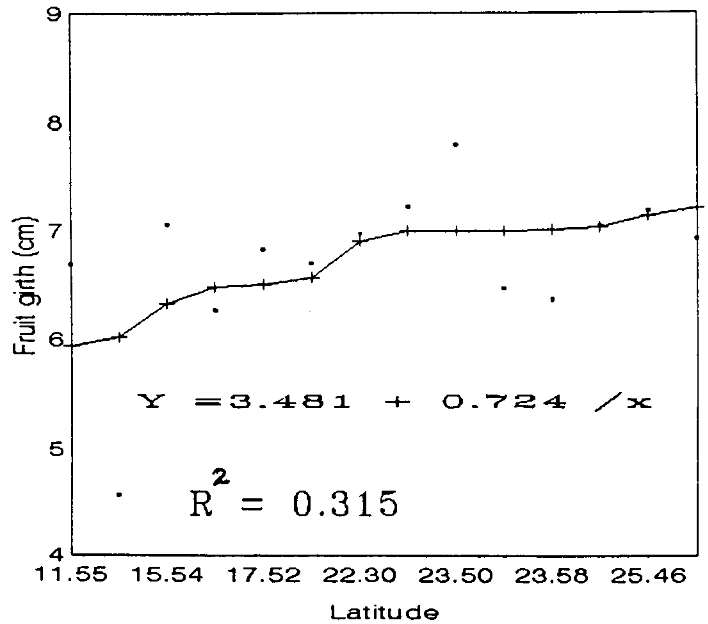


Fig. 9.a Relationship between latitude and fruit size

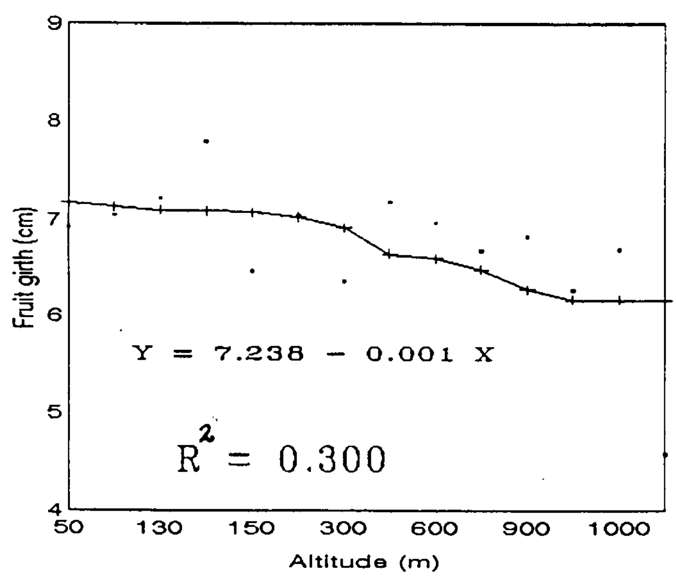


Fig. 9.b Relationship between altitude and fruit size

Fig. 9. Relationship between geoclimatic parameters and fruit size in provenances at Kariamuriam

characters. Studies conducted on the effect of supply of different sources of nitrogen on the wood characters of *G. arborea* (Ogbonnaya, 1993) have shown that supply of all nitrogen sources improved the wood density. But different types of nitrogen sources affected the fibre length in a positive or negative way depending upon the type of the nitrogen source. Hence, site may have a significant effect on the wood characters in *G. arborea*.

5.4. GENETIC DIVERSITY AND CLUSTERING

The genetic diversity among provenances was evaluated by the Mahanalobis D^2 statistic which is extensively employed as an efficient tool to find out genetic divergence among annual crop plants (Murthy and Pavate, 1962; Murthy, 1965; Murthy and Arunachalam, 1966 and Subramanian, 1979). In forest tree species Surendran and Chandrasekharan (1988) studied the genetic divergence of 35 half-sib progenies in *E. tereticornis* and Rajaram (1990) in provenances of *Gliricidia sepium*.

In the present study Euclidean clustering was done for growth and tree form at the early stage only, since in 15 year old trees there were no significant difference between provenances for most of the characters. For growth, 3 clusters were formed and the best clusters were provenances from North-eastern regions of India. Central and South Indian provenances were poor in performance. Geoclimatic parameters like latitude, longitude and rainfall of the seed source area were found to be directly correlated with growth. Altitude was found to be inversely related with growth. Kundu and Tigerstedt (1997) also observed such relation in *Azadirachta indica* and suggested the existence of selected environmental pressure through increasing aridity. For tree form, three groups were formed, but there was no geographic influence for these characters. From the above, it is understood that only certain characters and that also at certain ages are influenced by the geoclimatic parameters of the seed source.

Taking the 10 morphological characters into consideration, 5 groups were formed. But there was no relation between geoclimatic or geographic diversity and genetic diversity. From this it is understood that factors other than geographic diversity may be responsible for grouping of these sources into one. Though provenances Agarthala 1 and Agarthala 2 were from nearby areas, they were in different clusters both for tree form and morphological characters. Arimah (1979) also could not find any well defined geographic trend when he studied the fruits, stones, seeds and seedling characters in *G. arborea* provenances through principal component analysis. Lack of relationship between geographic diversity and genetic diversity was reported in many annual crops (Vairavan *et al.*,1973; Nagarajan and Prasad, 1980). Clusters I and II were the closely related among the total five clusters followed by I and V. Even then, they were highly divergent. Within cluster distances were also moderately divergent.

All the ten morphological characters contributed more or less same towards the divergence. However, fruit length was the character which contributed the largest followed by leaf width and stone girth. Arimah (1979) had noted leaf size and petiole length as the most distinguishing characters.

SUMMARY

Indira E.P. “Studies on the variability of the species gmelina arborea linn ”
Thesis. Kerala Forest Research Institute Peechi , University of Calicut, 1999

Chapter 6.

SUMMARY

6. SUMMARY

Studies were conducted at Kerala Forest Research Institute (KFRI) during the years 1994-1998 in 14 provenances of *Gmelina arborea* collected from main *Gmelina* growing areas in India to study the variability present in the species. Early growth measurements taken, in connection with one of our projects, during 1979 to 1984 were also analysed to get a clear picture of the variability and genetics of the species. These provenances were field planted by KFRI in Nilambur at two sites during 1977 and '78. Out of the total 14 provenances, 8 were planted at Chempankolly and nine at Kariamuriam with three provenances common to both the sites. The objectives of the study were to examine the provenance variation pattern, the extent of genetic variation in various traits and to choose the most appropriate provenance for raising plantations.

The characters studied were classified into five categories. They were :

1. Height and girth at breast height (Gbh) in the early years of growth upto sixth year,
2. Height and Gbh in 15 year old provenances,
3. Tree form (clear bole percentage, form factor indicating the intensity tapering, axis persistence, percentage of trees with good axis persistence, straightness, percentage of straight trees, branch size, percentage of light branched trees and mode of branching),
4. Wood characters (wood density and fibre length),
5. Morphological characters (leaf length, leaf width, petiole length, fruit length, fruit girth, stone length, stone girth, number of seeds, seed length and seed width).

The data collected were subjected to analysis of variance to test the significance of provenance variation. Variations within provenances were also estimated. In addition to this, the phenotypic and genotypic coefficient of variations, the heritability and genetic advance, correlation between characters and correlation of characters with the geographic and climatic parameters were also estimated. In cases where certain characters were highly correlated with geoclimatic parameters, the regression functions were fitted in order to study the pattern of changes in the characters with geoclimatic variations. The genetic diversity and clustering of provenances were also studied.

The study revealed that significant provenance variations were exhibited for growth parameters during early stages but these were found to be insignificant when the trees get older. Variations within provenances were also found to be moderate to high for growth at early years. At older stage, within provenance variations were very high for girth at breast height and moderate to high values for height.

Among tree form characters, only clear bole percentage and form factor were the traits for which the provenances varied significantly. Provenances at Kariamuriam significantly differed for straightness and those at Chempankolly for mode of branching. Variations within provenances were very high for straightness and high values for mode of branching.

For wood density, provenances were highly significantly different only at Kariamuriam. Variations within provenance were found to be low to moderate. Regarding fibre length, provenance variation was insignificant at Kariamuriam and Chempankolly. Variations within provenances were generally low for fibre length.

With regard to morphological characters, between provenance variations were highly significant for all the characters except number of seeds and seed width. Variations within provenances were varying much between very low value to moderate value for leaf length. Variations within provenancesfor leaf width, petiole length, fruit length and seed width also varied significantly between low value to high value. For fruit girth, stone length, stone girth and seed length also within provenance variations were low to moderate. Number of seeds was the highly varied character having their variations within provenances from low to very high value.

To get a clear picture of the phenotypic variations and how much these variations are affected by the environment and how much they are genetically controlled, the phenotypic and genotypic coefficients of variations were estimated. The phenotypic coefficient of variation (Pcv) for height decreased from moderate value at first year to second year and then increased gradually upto fourth to fifth year and then started decreasing. Genotypic coefficient of variation (Gcv) also showed the same trend. For Gbh both Pcv and Gcv decreased from fourth year.

Among tree form characters, clear bole percentage and form factor showed low Pcv and Gcv. Axis persistence showed moderate Pcv and low Gcv. Straightness showed high Pcv and moderate Gcv. Branch size exhibited low to moderate Pcv and very low Gcv. Mode of branching showed moderate Pcv and low Gcv. Wood density had almost low Pcv and low Gcv and fibre length also showed low Pcv and Gcv.

Regarding morphological characters, moderate Pcv were shown by leaf length, fruit length, fruit girth, stone length, stone girth and seed length and moderate Gcv were exhibited by all these characters except fruit length and seed length which were having low Gcv. Leaf width showed comparatively high Pcv and Gcv, petiole length showed high Pcv and Gcv and seed length exhibited high Pcv and moderate Gcv.

Characters with high heritability and genetic advance are generally easy to improve genetically. Heritability also indicates the quantity of parental influence on a character. The present study showed that height exhibited high heritability in the early years which diminished to very low value at older stage. For Gbh moderate heritability was seen in the early years which also decreased to low value at later stage.

Clear bole percentage and form factor showed moderate to high heritability depending upon the provenances and area of planting. Axis persistence was having low heritability and straightness was having low to moderate heritability. Branch size was found to be a very low heritable character. Mode of branching had shown moderate heritability at Chempankolly while heritability was extremely low at Kariamuriam.

Wood density had moderate to high value of heritability while fibre length showed very low to moderate heritability depending upon the provenances and site of planting.

Heritability was found to be high for leaf length, leaf width, petiole length, fruit girth, stone length and stone girth. Fruit length and seed length were having moderate heritability while number of seeds and seed width were the characters with low heritability.

Studies on correlation between characters and also between different ages will help in selection and improvement of the species. The present study showed that height at different ages in the early growth period were highly significantly correlated with each other. The same trend was followed for Gbh also. Hence provenances or individual trees can be selected at an earlier stage. Height and girth were also highly significantly correlated. Growth in the early years were also found to be significantly correlated with geoclimatic parameters like latitude, longitude, altitude and rainfall of the seed source area though altitude showed an inverse relationship. Very good regression coefficients were also estimated for the same. At older stage, height and Gbh were not significantly correlated.

In 15 year old trees, clear bole percentage was found to be highly significantly correlated with percentage of trees with good axis persistence. Axis persistence was found to be significantly correlated with mode of branching. Percentage of straight trees was highly significantly correlated with clear bole percentage and percentage of trees with good axis persistence at Kariamuriam. No other tree form character was found to be significantly correlated with others and also with growth. Wood density did not show any significant correlation with fibre length.

Among morphological characters, leaf length, leaf width and petiole length were highly significantly correlated with each other. Leaf length also showed highly significant correlation with stone length and stone girth. Fruit length, fruit girth, stone length and stone girth were found to be highly significantly correlated with each other but these characters had a significant negative correlation with number of seeds. Latitude, longitude and rainfall showed significant positive correlations with fruit girth while altitude exhibited significant negative correlation. Fruit girth also showed a significant regression coefficient with latitude and altitude.

Analysis of genetic diversity and clustering gave an idea on the relationship of different provenances when multiple characters were taken into consideration. Grouping of the provenances into different clusters was also done. From these studies it was found that the provenances from North-eastern region of India were the best, when tested for early growth performance. At older stage, there were no significant difference between provenances.

When the tree form characters were considered, the provenances significantly differed only for clear bole percentage and form factor. When these two characters were taken into consideration for clustering, Baramura and Khasi Hills were the best performers at Chempankolly and Begur, Sitabai valley and Khasi Hills were the best provenances at Kariamuriam. The provenances with poor tree form were Lambasingi at Kariamuriam and Agarthala 1 and Kundrukutu at Chempankolly. Taking into consideration both clear bole percentage and form factor, three clusters were formed but the influence of geographic parameters was not seen in this case.

Out of the ten morphological characters studied, for eight characters the provenances significantly varied. All the 14 provenances grouped into 5 clusters but no relation could be seen between geoclimatic or geographic diversity and genetic diversity. These five clusters were found to be highly divergent. Within cluster distances were also moderately divergent.

The variability estimated for different growth characters, tree form, wood characters and other morphological characters will help the planters and tree breeders in their venture.

The dominance of certain provenances and poor performance of others for growth in the early years maintained till sixth year and also the correlation between growth at different early years will help us to select the provenances/ individual trees in early stage of 2^{nd} or 3^{rd} year. The differential growth behaviour between provenances with a few showing faster growth rate in early phase can be exploited through high density short rotation forestry (HDSR) when species is used for pulp.

High inter provenance variations for early growth decreased to insignificant level when the trees grew older. Heritability also exhibited the same trend. The high heritability and genetic gain for early growth indicates the scope for selection to improve the species substantially. The information on the relationship of geoclimatic parameters of the area of provenances with early growth can be positively exploited for the genetic improvement of the species.

When the tree form characters are taken into consideration, it can be seen that only less than 20 per cent of the trees are straight. Hence, this character can be improved only through intensive selection. Axis persistence showed low heritability and branch size is also found to be more environmentally controlled. Hence, breeding programmes have to be opted accordingly. The study also showed that less forking in the main stem indicates less forking in branches also.

Provenance like Begur with poor growth in early years has shown best tree form which indicates the possibility of inter provenance hybridization for better growth and tree form.

When the growth and tree form characters were considered together, Khasi Hills was found to be the best provenance followed by some of the North-eastern provenances.

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