Genetic variability and plus tree selection in natural populations of *malaveppu* (*Melia dubia* Cav.)

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"GENETIC VARIABILITY AND PLUS TREE SELECTION IN NATURAL POPULATIONS OF *MALAVEPPU* (*MELIA DUBIA* CAV.)"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Certified that this thesis **"Genetic variability and plus tree selection in natural populations of *malaveppu* (*Melia dubia* Cav.)"** is a record of research work done independently by **Mr. Binu N. Kamalolbhavan (2016-27-002)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Dedicated to my beloved family

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Binu N. Kamalolbhavan

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Introduction

INTRODUCTION

An estimate of the supply of timbers in Kerala for the year 2014-15, showed that the 95 per cent of the total timber requirement of the state is met mainly from the homesteads and estates. The study further shows that the dependency on the state forest for meeting the timber demand of the state is minimal (Viswanath *et al*., 2019). This points to the fact that homesteads play a crucial role in meeting the wood demand of the state. It can be considered as one of the major ways to reduce the pressure of wood demand of the state. Till recently, exotic species were dominating in the farmlands. As there are many controversies regarding the cultivation of exotic trees, now preference is given to the fast growing indigenous species (Sharma *et al*., 2019). *Melia dubia* is one of suitable alternate species. It is an indigenous fast growing multipurpose tree species and is considered as a major wood in plywood and paper industries. The plant is also put into various medicinal uses, preferred for use in packing cases, cigar planks etc. It is highly suitable for agroforestry in India with adaptability to wide range of climatic condition (Kumar *et al*., 2017). In Kerala, there are instances where some farmers are planting melia as a plantation species replacing rubber due to its fast growth and thus giving higher economic returns. This created an increased demand for nursery-grown seedlings largely among farmers, which resulted in an urgent need to produce large stock of healthy and vigorous seedlings in short period of time.

Attempt has been done in different states of India to improve the genetic resources of this species. Some of the southern states has gone further and have released varieties of *Melia dubia*, whereas in Kerala, such an attempt has not been reported. It is well known that any attempt to genetically improve a species starts with an assessment of natural variation. In Kerala, no study has been done to ascertain the variation in the natural population of melia, hence this study has a large scope. After the assessment of the variation, the breeder uses this variation through selection and hybridization. Selection is regarded as a wise step to any

tree improvement programme (Ledig, 1974). There are many important characteristics of the tree to be considered for its selection of which, tree dominance in the stand is the prominent. As a rule of selection, trees that show superior growth should be compared with those trees having the same age growing under the same site conditions. Normally in uneven-aged forests and for the trees growing in isolation this is difficult. The most suitable method under this condition is the regression method.

The main hurdle in establishing forest plantation of this species is the poor germination percentage of seeds. For any large-scale afforestation programme to be successful the most important prerequisite is uniform germination of seeds with good vigour. Non availability of high quality planting stock from superior genotypes is a major issue in plantation establishment. For increasing wood productivity in any species, there is a need for efficient tree improvement strategy together with a clonal forestry programme (Tridasa *et al*., 2002). This could be achieved by screening genetically diverse and productive parents and multiplying them on commercial scales. There is no information on the genetic diversity of *M. dubia* in Kerala. The present study will help to catalogue the natural genetic diversity in the state, identify plus trees and develop a vegetative propagation method for raising quality planting stock.

With this background a study was done with the following objectives.

1. To study the genetic diversity in *Melia dubia* and select plus trees in natural populations of this species.
2. To analyse the clonal and seed progeny of plus trees for early growth and vigour.
3. To develop commercially viable clonal propagation protocol for the species.

Review of literature

REVIEW OF LITERATURE

The review of literature on the genetic variations, plus tree selection, evaluation of the progenies and clonal technology of *Melia dubia* Cav. are described in this chapter.

2.1. Growth and general description

Melia dubia Cav. synonym *Melia composita* generally known as Malabar Neem or Dreak or Gora Neems is a tree species indigenous to India and neighbouring countries like, Sri Lanka, Malaysia, Java, China and Australia (Kumar and Aiswarya, 2017). It is a huge deciduous fast growing species, of the family Meliaceae. In Kerala, it is distributed in semi evergreen and moist deciduous forests (Nair, 1991). The tree grows up to 25 m in height with a straight bole of about 5 to 12 m and nearly 1.5 m in girth at breast height (Rawat *et al*., 2018). The leaves are long, bipinnate and usually crowded. They are long stalked with a length; 30 to 90 cm. Shape of leaflets varies from ellipsoid to lanceolate and the length varies from 4 to 8 cm. The flowers are panicles. They are seen appearing in large numbers and are shorter than the leaves, usually seen on upper axils of the leaves. Colour varies from violet to white, fragrant, about 8 mm in length, with pubescent petals. The fruit is a drupe, ellipsoid, about 1.5 cm long, yellow when ripe. The seed varies from one to five and are pointed smooth and brown (Troup, 1921). The species is reported to be predominantly self fertilized (Johar *et al*., 2015). It coppices well and when the roots get injured enormous root suckers are produced. Pollarding ability is good and large number of new shoots emerge out from dormant buds (Kumar *et al*., 2013). It has tremendous adaptability to different climatic condition (Kumar *et al*., 2017). Though the tree grows well on variety of soils, it prefers deep fertile sandy soils.

Melia dubia has reasonably short rotation and the wood is of high demand for plywood and paper industries, as it is an important alternative species for supplying the raw material for these industries (Saravanan *et al*., 2013). It is preferred in the

paper industry because of increased pulp recovery, exceptional strength and anti-termite property (Suresh and Devakumar, 2017). Parthiban *et al*. (2009) recorded 50 per cent pulp recovery for this species, which was found to be better than other major pulp yielding species. It was also observed in this study that the Kappa number, which measures the bleachability of the pulp was less than 20, which is best in comparison to the other conventional raw material (Saini *et al*., 2007). The wood is utilized for match boxes, packing cases, agricultural implements, cigar boxes, ceiling planks, splints, pencils and kattamarans. It is also suitable for making musical instruments and tea boxes. The plant is put into various medicinal uses as it possesses anthelmentic, antiviral, carminative, antineoplastic properties (Vijayan *et al*., 2004; Susheela *et al*., 2008; Kiritkar *et al*., 1999). It is used for the preparation of traditional medicines for the treatment of leprosy, eczema, asthma, malaria, fevers and venereal disease (Govindachari, 1992), as well as cholelithiasis, acariasis and pain (Kokwaro, 1976). In Indian folk medicine, it is used to control insect pests (Koul *et al*., 2000). Leaves of *Melia dubia* are excellent fodder for ruminants as they are rich source of mineral elements, crude proteins and vitamins (Leela *et al*., 2016). Melia is also grown as shade tree in coffee and tea plantations. It has the potential to degrade commonly occurring pesticide in soil when grown along with *Trichoderma viridae* (Subasini *et al*., 2007). Studies has shown that germination in melia is lower with 14-34.4 per cent (Anand *et al*., 2012). It was reported that the fruits collected from superior trees after proper processing showed higher germination without any pretreatment (Kumar *et al*., 2018).

2.2. Variability in trees

The most important factor responsible for the creation of provenances, clines, races and ecotypes in nature is variations. Variation in the trees is an important source used to improve a tree species. Considerable variation exists in traits of trees as an undisturbed pool of high natural variability has developed over the years (Perry, 1978) and it is reported that variability in tree is double than that of other plants (Hamrick *et al*., 1979). Generally, forest trees maintain high level of genetic variation within population as trees being long-lived plants have high fecundity, an

out crossing mode of reproduction and wind pollination (Yeh and Arnot, 1986). The first step in the all selection and breeding work is the exploitation of the natural variability within a species. Therefore, foresters are fortunate to work on this as there exists a better scope for the selection of desirable genotypes (Vavilov, 1951). The breeder uses this variation through selection and hybridization. Wood qualities and tree form are the major sources of genetic variation. For improving the economically important traits in the trees the portion of the variation that is genetically controlled is made used. The natural variation existing in nature can be broadly divided into those variation from tree to tree in the same site, variation in certain characters of trees between localities and variations in trees due to geographical locations. The seed source variations are important, and the place of origin has great influence on it (Heydecker, 1972). The reasons attributed for the variations may be difference in environment, due to variation in temperature, rainfall, moisture, soil, latitude, altitude, and other external factors (Padmini and Banerjee, 1986; Holzer, 1965; Mathur *et al*., 1984;). The difference is also described for large number of tree species due to difference in seed source (Masilamani *et al*., 1999 and Vasudeva *et al*., 1999) which are further influenced by environmental and edaphic factors. But since most of the forest trees are wind pollinated and the seed dispersal mechanisms helps them to cover great distances, this can result in lower levels of genetic differentiation among populations. Thus, it is presumed that on an average 90 % of all genetic variations can be found within local populations, while very less variations distributed among populations across its ranges (Ingvarsson and Dahlberg, 2019).

In any given population, there are potentially different sources of phenotypic variation within it. The underlying cause of each of these sources may be different. To determine how a particular trait will respond to natural or artificial selection, knowledge about the source and kind of variation is necessary (Byer, 2008). It becomes necessary to determine the relative importance of both the genetic and the environmental factors that lead to a particular trait especially for the species with widespread natural distribution. In such populations, as they are growing under

different geographical conditions the variations are expected within species due to the genetic and environmental differences. The different subcategories of genetic sources of variation includes additive, dominance and epistatic variance. Once the total amount of genetic variation is determined for a trait, it can be used for determining the heritability of that trait. This knowledge will help in the improvement of highly heritable economic traits. It can be used to identify the best wild seed sources of a species and there is a scope to choose individuals among these seed sources and to improve varieties that are considerably better than the indigenous material. The genetic variation is important for the long-term adaptations of species (Falk and Holsinger, 1991). Low genetic diversity can lead to inbreeding depression affecting growth, survival and adaptation at individual tree level (Gradual *et al*., 1999). When this information is determined, the evolutionary dynamics of an entire population for a particular trait can also be predicted (Saastamoinen, 2008).

It was found that the size of the population does not limit the genetic diversity of that population. Studies showed that progenies from the parents of the small-sized natural population of *Scabiosa canescens* (with 25 individuals) did not differ in the level of additive genetic variance when compared to progenies of parents from large-sized population of similar species (Waldmann, 2001).

2.3. Selection in trees

Irrespective of the breeding techniques used, the largest, cheapest and fastest gains in most forestry improvement programme within species is assured with the appropriate use of suitable species and seed sources (Zobel and Talbert, 1984). Hence, selection of genetic resources amenable for varied edaphic climatic condition is essential to achieve a speedy gain of desired products (Zobel and Talbert, 1984). The basis of selection is the information on the magnitude of variability in a population. Selection of plus trees are done based on phenotypic variation. Studies has shown that even a small gain of one percent can pay for the tree improvement of a species if costs of phenotypic selection remain low. Selection

is regarded as a wise first step to any tree improvement programme (Ledig, 1974). When empirical values of the twenty four published research work was analyzed, it was observed that large genetic gains in the volume per unit area can be obtained through selection of plus-trees (Cornelius, 1994). In many of the early tree improvement programs, gain in volume (20 to 80 per cent) was obtained in the first stage of simple mass selection (Hardiyanto and Naiem, 2001). Selection helps to change the genetic properties of a population, one by choosing individuals to produce the next generation offsprings and second, by controlling the mating system (Falconer and Mackay, 1996). Selection does not create new allele but helps to identify and retain the individuals having a most favourable combination of alleles in an existing population (White *et al*., 2007).

A plethora of scientific evidence are available in deploying selection techniques for various species and stand types (Vidakovic, 1965; Morgenstern *et al*., 1975). The selection method depends on various factors which includes species attributes, evolutionary pattern, current status of the forest. It also considers whether pedigree information exists, variability and inheritance pattern of the significant characteristics together with the objective of tree improvement programme (Zobel and Talbert, 1984). The basic characteristics of the selection remains the same eventhough the selection principles for plus trees differ from species to species. Normally the age, height, diameter at breast height and form class of the trees are measured to determine the volume production in order to judge the growth rate of trees so, major quantitative characters that are usually considered for selection of trees are GBH and height as it is correlated to biomass productivity. Tree dominance in the stand is the important characteristic of the tree considered for its selection. This depends on the height and the diameter of the tree. The qualitative traits such as apical dominance, stem form and health status are also considered depending on the purpose of selection. For stem form assessment, the characters such as apical dominance, straightness, spiral bole, twists and cylindrical form of the exploitable stem freedom from growth defects like bole swelling, bends are desirable, whereas smaller size of branch, branch angle etc are preferred for the valuation of branching

characters. The choice of traits is important for the selection of trees. A maximum of three to five highly important traits and perhaps a few lesser important traits should be identified for selection depending on the purpose of selection. Those traits that are highly correlated with the breeding objectives and having higher economic importance and high heritability are considered to be important traits. However, the achievement of any phenotypic selection depends upon the amount of genetic variability available in the population for that economic characters and their interrelationship (Lone and Tewari, 2008). The great variation within the important traits of most forest trees and their reasonably strong inheritance pattern shall provide a good chance for gain by selecting desired phenotypes. There are different methods for selection of plus trees. The simplest method followed for the selection for biomass and fuel woods is the survey of the forest stand and visual selection of vigorous healthy trees without the measurement or rating of individual traits. The method followed in India for selection of plus trees is the comparison tree method, in which the candidate tree is compared with its nearest neighbours. In comparison tree method, trees superior in two or more traits are selected as plus trees. This procedure is efficient in plantations but less efficient than other methods if the neighbours are related (Ledig, 1974). Similar, growth characters were used for selection of candidate plus trees by many researchers. In South Gujarat twenty plus trees of *Melia dubia* were identified from natural forests and farmlands. Individual tree selection approach with independent culling method suggested by Surendran *et al.,* (2003) was used for selection of trees with superior phenotype (Chauhan, 2018). From *Melia dubia* growing areas in Tamil Nadu, twenty candidate plus trees were selected. The selections were done at an altitude ranged between 1550 ft and 3329 ft based on the phenotypic characters (Kumar *et al*., 2017). The growth and other phenotypic traits of the trees like clear bole height, bole form, branching pattern etc. were the important criteria for the selection of *Melia dubia* trees from the natural population (Chauhan and Kumar, 2014; Kumar *et al*., 2017; Chauhan, 2018). Selection of best phenotypes were done for *Terminalia chebula* and *T. bellirica* (Khobragade *et al*., 2013). Kumar *et al*., (2016) selected twenty trees of *Acacia mangium* based on the phenotypic characters. Similarly, twenty seven plus

trees of *Melia azedarach* were selected (Thakur and Thakur, 2015). Twenty one plus trees of *Ailanthus excelsa* Roxb. were selected through intensive survey from Haryana, Rajasthan and Gujarat based on the assessment of high priority characters that are having great economic values. (Daneva *et al*., 2018).

Wood properties like density, fibre length, chemical constituents and pulpability can be considered if trees are evaluated for specific purposes. Since melia is a suitable species for pulp and paper industry, determination of the wood density can be of a great practical value. Studies on the heritability of different wood properties for a large number of species, has shown that the basic density had a very high heritability (Settle *et al*., 2012). The conventional methods of measuring wood properties require destructive sampling, and this is difficult if the sampling has to be done for large number of trees. This is considered to be an important draw back for including wood density in the present tree improvement programme. In standing trees, pilodyn penetration depth is considered to be one of the indirect measurements and non-destructive method to estimate the wood density of outer wood (Raymond and MacDonald, 1998). Studies has shown that a good estimate of the wood density of whole tree or log can be made by this method particularly, if it is measured at the tree breast height (Cown *et al*., 1981). Based on this principle, *Eucalyptus* clones were ranked according to the basic density using Pilodyn (Greaves *et al*., 1996). Chauhan and Kumar (2014) in a study used this method for measuring the wood density in a nine-year-old plantations of *Melia dubia*. In this study a high correlation (r=0.77) between the Pilodyn penetration and wood basic density were observed.

In order to gain maximum from the genetic makeup of the trees, selection of the individuals should be made in population with minimum environmental differences, mainly from age, space, site, etc., Some traits are comparatively less affected by environment. Stem straightness, branching habit, wood density and disease resistance are some of the examples in this respect. The individuals growing even under variable environmental conditions (natural stands) show high heritability for these traits. So, selections for these traits would be quite effective

from natural stands also. However, in uneven aged stand, selection becomes difficult as the growth characteristics are highly affected by age.

There are several methods for selection in natural stands that contains trees of different ages (uneven-aged stands) which may also include the sprouts and inter-mixed species. As a general rule of selection, trees that show superior growth should be compared with those trees having the same age growing under the same site conditions. Normally in uneven-aged forests and for the trees growing in isolation this is difficult. Isolated trees that are having an inherent character suitable for selection but lack expression due to unfavourable environment should also be selected. Also, tree showing unusual characters such as disease resistance should be selected.

Mass selection (phenotypic selection) is the usual method of selection possible at the beginning of a tree improvement programme, if the base population is natural stand or plantation. But in natural forest the breeder cannot choose trees that are both taller and larger in diameter alone as there is a chance that the breeder may exclude genetically superior trees, but due to unfavourable environmental condition it has not achieved its true potential growth. The other way is also true the breeder can also include genetically inferior trees which are taller and larger, due to the favourable environmental condition in which it is growing. Comparison tree method is not possible for selection of melia population as the age of the tree in natural forest cannot be estimated and the trees are usually widely distributed. Trees for comparison may not be available in all the localities.

Individual tree selection is the selection method generally used to select trees in stands with unknown pedigrees, for characters with high narrow sense heritability. This method is inexpensive and used to make genetic gain quickly. This method is found to be the best for the natural stands where the age of the trees is similar or in the plantations (Zobel and Talbert, 1984). This method was used for *E. camaldulensis* where, Otegbeye (1985) reported a highly significant variation in height and girth growth. In *Gliricidia sepium*, selection of superior provenances

followed by selection of individual trees within the provenances showed significant variation for height and diameter between the provenances (Glover, 1987). Rajkumar (1999) reported a significant variation for growth parameters in the provenances of red sanders (*Pterocarpus santalinus* L.) by selecting the superior candidate plus tree by comparison check tree selection method. It is reported that *Bauhinia variegate*, improvement can be done even through simple individual tree selection of desirable types (Anand *et al.*, 2004).

The base value method and regression method are the methods commonly followed in uneven aged stands. In base value method base value (average value) for those traits having strong genetic control like bole straightness (Namkoong *et al*., 1969; Zobel and Talbert, 1984), wood density (Wilcox, 1977), characters such as branching habit and disease resistance (Namkoong *et al*., 1969) are prepared by recording observations by adopting suitable sampling (5-10 %) methods in base population. Superiority per cent of a candidate tree for each trait is worked out over the base value and trees are selected. This method was used for stem form selections in *Dalbergia sissoo* (Sidhu, 1995).

In the regression method, the observations on traits of economic interest are recorded from the sample plots marked in the base population. Then by plotting the observations against the age of the tree, regression lines are prepared for the population. The position of the trees on the regression line will determine the superiority of the tree. As the age determination in natural forest is difficult this is regarded as a cumbersome method (Zobel and Talbert, 1984; Sidhu, 1995). The difficulty of multiple trait breeding is its higher cost and time consumption, moreover trees in uneven aged stands differ in age and due to different age class, the traits of interest cannot be compared. Some researchers are of the view that while selecting for growth rate, selection should be directed towards finding, not the largest tree, but the tree that has utilized the growing space, light, and nutrients most efficiently. This requires finding the tree with the best growth in relation to its leaf surface area (Rudolf, 1956; Brown and Goddard 1961; Bedell, 1980). The technique which applies this concept is base line system. This kind of selection was

reported in many hard wood species such as *Picea abies*. In this method a regression of diameter at breast height (DBH) squared x height on crown width squared x crown length is determined. The trees falling above the regression lines reflect higher vigour and this can be selected. This is done seperately for each stand.

Lindgren *et al*. (1997) have studied about the appropriate number of initial selections and families needed to obtain short term gain. As many characters have low to moderate narrow sense heritability, usually selection among family provide a substantial part of the gain. It is always desirable to start with large number of initial selection and families to allow for intense family selection to ensure early gain.

2.4. Evaluation of genetic variations

The variability in the population can be assessed by using simple measures of variability which includes the range, arithmetic mean, variance, standard deviation, coefficient of variation, standard error etc. The second method is determining the components of total variance of a sample, by crossing several genotypes by one of the mating designs and evaluating the progeny thus obtained in replicated trials. But this procedure is costly, laborious and cumbersome. The third method is clustering techniques, which helps to determine the amount of diversification and the relative proportion of each component character to the total divergence. Some of the studies based on this are mentioned here.

High genetic divergence was reported for *Melia dubia* in a study done to estimate the genetic variations among half sib families of selected trees. Here the twenty genotypes of *Melia dubia* resolved into six clusters. Cluster I and cluster II were the largest having 10 and five members respectively (Kumar *et al*., 2013).

In a study done in Karnataka to develop high yielding varieties of *melia dubia*, a total of 230 phenotypically good trees were selected based on growth parameters like height, DBH, straightness. From these 121 trees were selected based on index value (>75) as per Cotterill and Dean (1986). The genetic worth of selected plus

trees was evaluated based on the progeny trials. Finally, cultivars named SHARAD and SHASHI were commercially released (Kumar *et al.,* 2017). In South Gujarat candidate plus tree selection of *Melia dubia* was done. Twenty five plus trees were selected from different regions based on the qualitative and quantitative characters like stem straightness, tree height, girth at breast height etc. The results showed that significant variation existed among the selected trees (Chauhan *et al*., 2018).

In *Tectona grandis* the clustering of eighty groups of teak was assembled into eight clusters, of which group 'A' formed the largest cluster consisting of 46 batches. In the study it was observed that the factors other than geographic distribution was responsible for the association of geographically differing provenances of teak in the same cluster (Subramanian *et al*., 1994).

The extent of genetic deviation among the progenies of eighty-eight plus trees of *Pinus wallichiana* selected from entire distributional range in Kashmir Himalaya was studied. The progenies resolved into ten clusters. The largest cluster contained 21 genotypes (Aslam *et al*., 2011). One of the clusters was the best in respect to the morphological characters measured. The result showed that diversity exists in the tree progenies and superior clusters can be made use for operational plantation purposes.

Clustering study done in *Acacia nilotica* also showed that twenty seven seed sources were grouped into clusters A, B, C, D and E and the cluster A consisted of twenty one seed sources, which was the largest group. Group B and C consisted of two seed sources each and Group D and E had only one seed source each (Bagchi, 1992), similar result was observed in *Prunus armeniaca* (Singh and Chaudhiri, 1992). It can be concluded that the pattern of deviation is not assigned to the geographical nearness of the genotypes but can be traced to the changes in the genetic constitution of the otherwise co-existing genotypes (Chauhan and Sehgal 2001). The *intra* and *inter* cluster analysis divergence were observed in the studies done for the species such as *Pinus gerardina* (Kant, 2006), *Pinus wallichiana* (Aslam *et al*., 2011), *Melia dubia* (Kumar, 2013). Such studies will help to identify

the most distant accessions and most closely placed ones for breeding experiments to obtain hybrid vigour.

In a provenance evaluation study of *Eucalyptus tereticornis* and *E. camaldulensis* it was reported that a significant variability for height, diameter and volume existed. Marked variability in leaf characters such as leaf length, breadth, shape, area and top leaf was observed in *Eucalyptus tereticornis* (Kapur and Dogra, 1987a) and in *E. camaldulensis* (Kapur and Dogra, 1987b).

Studies done in Taiwan for *Casuarina equisetifolia* shows that major differences exist between provenances for almost all the characters investigated. Tree height and DBH expressed significant differences at two sites investigated (Yang and Chen, 1996). Differences were observed between provenances for height in a similar study conducted in Sri Lanka (Gunasena and Fernando, 1996). Kumar and Gurumurthi (1998) reported a significant genetic variation in growth characters among the 55 clones of *Casuarina equisetifolia*.

Heritability is the measure of the degree to which parents transfer heritable characteristics to their offspring. Variations are the result of the differences in the degree of transfer of these characters in the genotypes of the offspring. The high valuations of heritability help the breeder in the selection programme. Johnson *et al*. (1955) proposed that heritability prediction together with genetic advance is important in predicting its resultant effect for selecting the best individuals. As high heritability (broad sense) is due to non-additive gene action (dominance and epistasis), it will be dependable only if accompanied with high genetic gain. This gives extensive opportunity for genetic improvement in the species because it offers an index of the relative role of heredity and the environment in the manifestation of various traits (Dorman, 1976).

In Tamil Nadu, a study done in *Eucalyptus tereticornis* for determining the heritability of different seedling characters that were raised from the seeds collected from thirty five selected plus trees, it was revealed that out of a large number of morphological characters of the seedlings studied, the heritability and genetic

advance were found to be high for number of branches. This information can be useful in the selection programme for producing seedlings having high biomass (Surendran and Chandrasekharan, 1984).

A significant difference existed among the provenances of *Eucalyptus microtheca* for all the character studied over different growth stages (Subramanian *et al.*, 1991), for *E. camaldulensis* for the traits such as height, trunk diameter and volume (Garcia Cuevas *et al*., 1992). Among the ten growth and quality characteristics studied in *E. camaldulensis*, tree height recorded the highest phenotypic variation while taper had the lowest values (Otegbeye and Samarawira, 1992). Contradictory results were obtained for *E. camaldulensis* and *E. tereticornis* in a study done by Chaturvedi *et al*. (1989) were absence of provenance variation was observed. Surendran and Chandrasekaran (1984) observed wide range of variation in growth traits of *E. tereticornis*.

In *Melia dubia*, differences in phenotypic coefficient of variation for the characters collar diameter and volume index were observed. The heritability was the highest for the number of leaves and lowest value were observed for the collar diameter. The highest genetic advance was recorded for volume index (Bharti, 2007). Heritability of the selected traits largely depends on the efficacy of selection. Kumar *et al*. (2013) have studied the genetic variation among the half sib families of melia and reported broad sense heritability of 0.51 and 0.30 for plant height and basal diameter respectively.

The genetic variation in growth and form of Mahogany (*Swietenia macrophylla*) progenies from 73 families of six plantation seed sources that were planted at two different sites were studied. At 50 months age, mean diameters and heights were different for the plants grown in the two sites (Abarquez, 2015). Two of the seed sources showed a consistently best ranking. The result showed that the additive genetic coefficients of variation for diameter and height were different for the sites. Narrow-sense heritability for diameter were the same for the two sites. This was different for height. Heritability of growth traits between the site was considerably

lower for both diameter and height due to genotype-by-environment interactions. These show that the diversity of the genotype is less in the plantations. In the Americas, it was recommended for infusion and testing of new germplasm from natural range mahogany to widen the base population for tree farms and agroforestry plantations in the country.

Thakur and Thakur, 2015 studied the progenies of *Melia azaderach* from selected mother trees one each at twenty seven locations. The study observed the extent and pattern of variation with respect to growth characters. The performance of the progenies for the measured traits was different. For the traits such as root length, collar diameter and root-shoot length ratio high heritability with high genetic gain was observed. Correlations between the genotypic and phenotypic observed, for majority of characters were highly significant and positive. Plant height showed positive genotypic and phenotypic correlation with the number of branches and collar diameter. A positive genotypic and phenotypic correlation was observed for collar diameter and the number of branches and leaves. This shows that selection would be effective for these traits.

In a breeding programme, the use of heterosis and success in getting advantageous segregates is mainly dependent on how much divergent a trait in that particular population is. It can be concluded that the more diverse is the parents the more is the chances of increased heterotic effects and high spectrum of variability in the coming generations. The genetically diverse parents should also possess consistency of genetic divergence under different environments (Paramathma and Surendran, 2000). In most of the studies, it was observed that the grouping of the members was independent to the geographic locations.

2.5. Evaluation of progenies of selected plus trees

Another important question in selection is whether it should be based on the phenotypic characteristics of the tree or based on the performance of the progenies. The ability of the parents to pass on to its progeny, the good characters for which the tree was originally selected and to evaluate the progenies themselves can be

well done, by the assessment of progenies of the plus trees. The information gathered from this type of study can be used for selecting the exceptionally good parents. The selected parents can be used for the establishment of seed orchard or can be used for hybridization programme many times in future.

Existence of variability in growth parameters due to different genotypes and their variations with the differences in soil and climatic conditions at nursery stage have been reported in studies done earlier (Schmutterer, 1995). In a study done to observe the genetic variations among the half-sib families of selected plus trees in *Melia dubia*, it was concluded that among the progenies of twenty trees studied, three families showed constant superiority for the growth characters such as height, basal diameter and volume index (Kumar *et al*., 2013). Such type of differences and superiority of a few seed sources among different half sib families and provenances was reported for *Lagerstromia spp.* (Jamaludheen *et al*., 1995). Similar results of superiority of provenances in *Acacia nilotica* (Ginwal *et al*., 1995) in *Acacia catechu* (Mohapatra, 1996) in *Prosopis cineraria* (Manga and Sen, 1998) in *Melia azaderach* (Jain and Dhar, 2008; Thakur and Thakur, 2015), in *Acacia catechu* (Gera and Gera, 2006), in *Ailanthus excelsa* (Daneva *et al*., 2018) were also reported.

The causes of variation could be assessed by partitioning the total variability into phenotypic and genotypic variability, which is heritable and can be exploited for future use. The above results indicate, there exists an environmental effect on these characters. It was reported earlier also in a similar study done in neem (Amit *et al*., 2018). In *Melia dubia*, volume index showed high PCV and GCV value, followed by height and collar diameter (Kumar *et al*., 2013). High GCV for the vigour index was earlier reported in teak (Prasad, 1996; Parthiban, 2001) and low GCV for height in *Eucalyptus tereticornis* (Sundararaju *et al*., 1995). In *Bambusa pallida* also it was reported that for the traits such as height and collar diameter the GCV and PCV were low (Singh and Beniwal, 1993).

For different growth parameters, high heritability together with moderate to high genetic advance have earlier been reported by Arun (1996) in *Tectona grandis*; Solanki *et al*., (1984) in *Prosopis cineraria*; Gera *et al*., (2001) in *Dalbergia sissoo* and Dhillon *et al*., (2003) in *Azadirachta indica*. In *Eucalyptus globulus* where the field study of the eight sub-races were done, low heritability for DBH was reported (Apiolaza *et al*., 2005). Similarly, in *Eucalyptus globulus* and *E. nitens* low to moderate heritability was observed for different genetic parameters (Raymond, 2002) and low to moderate heritability for height and tree volume was also observed in *E. grandis*. The study also concluded that the heritability changed with the age of the tree and also with the environment (Devagiri *et al*., 1997).

2.6. Physiological studies of progenies of plus trees

Photosynthesis is the fundamental processes that provide the organic blocks that contribute considerably to the growth of the plant (Rapparini and Penuelas, 2014). It largely influences the plant growth and yield (Yamori *et al*., 2016). Both the environmental factors and plant genetic characteristics influences the rate of photosynthesis. Thus, it can be concluded that photosynthetic activity is a complex process and interaction between plant genetic and environmental factors is involved in it.

Stomatal conductance measures the degree of stomatal opening, which and can be further used as a pointer to the water status in plants (Carmen *et al*., 2013). It is an important factor in energy, CO_2 and water cycling between plants and the atmosphere. It is also vital for both, prevention of desiccation and CO_2 acquisition (Medici *et al*., 2007). Studies has shown that plants respond to water deficit very early with closure of stomata, which leads to a limitation in carbon uptake by the leaves. This can in turn result in the reduction of photosynthetic rate of the plants. (Chaves, 1991 and Cornic, 2000). Studies have shown that the higher stomatal conductance of plants has been associated with higher leaf water content (Auge *et al*., 2015). The efficiency of net photosynthesis and stomatal conductance are often related to each other (Salisbury and Ross, 1992). Studies has also shown that the

net photosynthetic rates and opening of stomata are indirectly related to each other (Bunce, 1988). Hence, variations in stomatal conductance can result in the change in photosynthetic rates (Meng and Arp, 1992). It is also reported that the major determinants of plant productivity are changes in stomatal size and density and in net photosynthesis (Wang *et al*., 1995). Variations in the photosynthetic rate and stomatal conductance is usually seen between species and within species. In a study were a multispecies meta-analysis was done from the data sets of 17 published studies, the values for the net photosynthetic rate was observed to vary from 0.8 to 30.6 μmol m^{-2} s^{-1} and value of stomatal conductance, from 0.01 to 0.62 s cm^{-1} (Gago, *et al*., 2016).

Chlorophyll content in leaves is an important factor which help in evaluating plant photosynthetic efficiency and also helps to determine if the plant is undergoing any environmental stress (Zhu *et al*., 2012). Under such a situation, the stress can cause substantial damage to photosynthetic pigments and lead to the destruction of thylakoid membrane. Thus, it is likely that in seedlings exposed to the stress a reduction happens in photosynthetic capacity.

In addition to the study in the variation of morphological characters, the changes of photosynthetic parameters between clones and their relationship with growth characters though meagre, will be useful in tree improvement programme. The knowledge thus gained will help in developing highly productive and uniform clones, which can be used for large scale plantations. Based on this concept, a study done on *Populus nigra* from different regions, showed that the gas exchange and chlorophyll parameters were related with the growth of the species and it was observed that the species originating in Siberia, had high light use efficiency and thus can be used for future breeding purpose (Chu *et al*., 2010). Another study done in *Tectona grandis*, revealed that the photosynthetic parameters had high narrow sense heritability and are highly controlled by genetic factors. The study also revealed that photosynthetic parameters and growth traits in clones from different provenances showed great genetic variation. In this study a significant correlation was found between the net photosynthetic rate and growth parameters of the

seedlings. It was concluded that higher photosynthetic rate associated with some of the clones of teak can be used as a key resource for future breeding (Huang *et al*., 2019).

Significant variations in stomatal density, net photosynthesis, total guard cell length, stomatal conductance, leaf area and dry weight of the plant were observed in neem seedlings from the selected trees (Kundu and Tigerstedt, 1997). Similar reports have been observed by Mebrahtu and Hanover (1991) for blacklocust (*Robinia pseudoacacia* L.) and for black spruce (*Picea mariana* Mill.) by Johnsen and Major (1995). In a study done to investigate the dependence of the concentration of chlorophyll on stomatal conductance of 5 and 10 year old *Quercus serrata*, it was observed that a decrease in the chlorophyll content causes a decrease in stomatal conductance (Matsumoto *et al*., 2005).

For different clones of *Tectona grandis*, high heritability was observed for the photosynthetic rate, chlorophyll content and stomatal conductance. High heritability and genetic advance were observed for *Populus niagra* (Chu *et al*., 2010); in *Dalbergia sissoo* (Sharma and Bakshi, 2014); in *Populus trichocarpa* (Mckown *et al*., 2014). It was observed that net photosynthetic rate showed a significantly positive correlation with seedling height, individual volume, which was an interesting finding of this study. The results indicate that the seedlings of plus trees with high photosynthetic rate result in fast-growing plants. Studies done in different clones of *Tectona grandis*, were high heritability was observed for the photosynthetic rate, chlorophyll content and stomatal conductance. These traits were positively correlated with seedling height and volume of the clones (Huang *et al*., 2019). In *Populus nigra*, it was observed that species originating in Serbia had a high correlation with the growth, gas exchange and also with chlorophyll fluorescence parameters. Highly correlated germplasm which had high light-use efficiency was further used as a resource for the breeding (Chu *et al*., 2010). High heritability and genetic advance for the above-mentioned traits were observed for *Populus niagra* (Chu, 2010); in *Dalbergia sissoo* (Sharma and Bakshi, 2014); in *Populus trichocarpa* (Mckown *et al*., 2014).

Earlier the studies were mainly focused on ecophysiological aspects on photosynthesis in forest trees such as the effects of stress on photosynthetic physiology, and the photosynthetic responses to light intensity (Zhang *et al*., 2002) and CO_2 concentration (Su *et al*., 2003). Studies that focus on the measurement of the physiological parameters like photosynthetic gas exchange, the chlorophyll parameters, correlating these functions with growth of the plant is meagre. The review shows that no study has been done to observe the physiological characters of the seedlings of melia from different plus trees, variations in the physiological characters of the seedlings and with respect to the correlation of the growth and physiological characters.

2.7. Clonal propagation

2.7.1. Macro clonal propagation studies

Clonal propagation in tree breeding programmes is emerging as strong attraction to the traditional seed orchard breeding system. It has been widely used for the preservation of genotypes in clonal banks and for clonal seed orchard establishment (Zobel and Talbert, 1984; Surendran *et al*., 2000). It helps in the mass production of desired individuals for planting purposes, developing and maintaining a genetic base population for advanced generation. Clonal propagation is widely used for the development of selected plants collected for the breeding programmes or that obtained from natural populations (Hartman *et al*., 1990). This helps to produce plants which are identical in genotype with the source plant (ortet). Large genetic advances can be made in a single step by selecting unique superior trees from a population of seed producing trees and reproducing them by vegetative propagation. Vegetative propagation also helps in the removal of biological constraints associated with seed collection, viability, storages, germination and pest. To increase the productivity, planting disease resistant parent stock or by selecting parent stock showing wide range of adaptability can be used (Saini, 2001).

In many forest tree species techniques have been standardized which has helped for large-scale propagation with cost less than that for the seedling production. Clonal

techniques are also used for exploiting the considerable amount of genetic variability already existing in natural population of forest tree species that have been suitable to vegetative propagation. It is extensively used for the domestication and improvement of tropical tree species. This has helped in the yield improvement.

Several approaches such as stem cutting, hardwood cutting, sucker can be used. The causes of variation of the genetic component may be attributed to the lack of endogenous auxins or any of rooting co-factors, lack of enzymes for synthesis of auxin-phenol complexes, presence of inhibitors. Within clone variation, among plants is considered to be mainly due to the physiological condition of the stock plant, which in turn may be affected by the environment and season, position of the harvested shoots on the plants, age and size of the tree and the incidence of pathogens (Leakey, 1987).

The extraordinary capacity of plant cell to dedifferentiate and redifferentiate that in turn leads to the formation of new roots or shoots is dependent on the plants ability to reproduce vegetatively (Pacurar *et al*., 2014). Many studies have been conducted to understand the entire process of root formation. The studies show that adventitious root formation is quantitative genetic trait which is heritable, and it is controlled by many internal and external factor. The most important among them are auxin, mineral nutrients, light and temperature (da Costa *et al*., 2013). Two important types of adventitious root formation have been identified, which varies with the species a) in some species preformed AR's initials are already present, and under favourable conditions they become active which is seen in Salix, Populus and Jasminum. b) in other species, no preformed cells are present. The cells undergo dedifferentiation, during an induction phase first, to acquire the ability for cell division and organ formation (Pijut *et al*., 2011).

It was reported by Haissig and Davis, 1994 that for some of the important plant growth activities such as adventitious root formation, stem growth, etc. the role of auxin is inevitable. The study also proves that auxin is involved in the adventitious root formation on stems. It has been further observed that formation of the initial

cells of the roots are reliant upon auxins produced in the plants or on the auxins that are given externally to the plants if it is necessary (Gasper and Hofinger, 1988). External application of auxins has shown to induce roots. The results have found to be predictable and consistent, irrespective of the plant species. When compared to other auxins, IBA is generally used as rooting hormone as it found that it is able to induce roots efficiently. The important reason observed for this is that it is found to be more to light sensitive than IAA (Kurepin *et al*., 2011). There many studies to show how different rooting hormones can be used for the development of the cuttings from forest tree species (Baul *et al*., 2010). In different studies, it was observed that among the various rooting hormones applied, the performance of the cuttings treated with IBA was much better for many tropical forest tree species (Tchoundjeu *et al*., 2006; Husen and Pal, 2007). However, it is generally observed that the response of the tree species, clones varies with individual and mixed application of auxin at differing concentration, even though most of the other factors remain constant. hence usually studies are done based on this.

The literature review with respect to the different factors affecting the clonal propagation are discussed under the following subheadings.

2.7.1.1. Part and size of cuttings

The growth of different cuttings from soft, hardwood and semi-hard branch of 8 to 10 year old *Azadirachta indica* trees treated with IAA, IBA and 2, 4-D at 500, 1000 and 1000 mg l^{-1} were observed for rooting. It was observed that for hardwood cuttings, most of the auxin treatments increased growth over control, however highest increase in growth for the traits like main branch length and number of leaves was obtained for the cuttings treated in the 500 mg l^{-1} IBA and 1000 mg l^{-1} of hormones IBA and IAA respectively (Harish Chander *et al.*, 1996).

Palanisamy and Pramod Kumar, (1996) studied the variation in rooting of branch cuttings of neem collected from superior 25 year old trees, from proximal, middle and distal portions of the branch of different lengths (5, 15 and 25 cm). When this was treated with 1000 mg l^{-1} IBA, it was observed that the cuttings with a length

of 25 cm and 0.5 cm diameter from the distal end gave 100 per cent rooting. It was observed that the percentage of rooting has an inverse relation with the length of the cutting used, and roots were not initiated for 5 cm long cuttings. The two-year-old sapling cuttings of *A. catechu* gave good rooting performance (63.2%) in 100 mg l^{-1} IBA (Verma *et al.*1996).

Cladode cuttings of *Casuarina equisetifolia* rooted significantly, when treated with the hormone IBA at 2000 mg l^{-1} when compared to the cuttings kept as control (Gurumurthi and Bandari, 1988). Macropropagation was successful in *Eucalyptus tereticornis*, when the branch cuttings were treated with IBA at 2000 mg l^{-1} (Bulgannawar *et al.*, 1992). Several reports are available for clonal multiplication of *Eucalyptus tereticornis*. Successful clonal propagation techniques were developed using leaf cuttings on treatments with IBA as a powder form formulation when the concentration was 5000 mg l^{-1}. In soft stem cuttings of *Prosopis alba*, the rooting (43%) was observed in the IBA 3000 mg l^{-1} + Kinetin 1300 mg l^{-1} treatment (Karoshi *et al.*, 2000).

Taymour Rostami Shahraji *et al*, (2007) reported that the highest percentages of rooting were 21.1% for hardwood and for semi hard cuttings it was 71 % when the cuttings were treated with IBA 8000 mg l^{-1} with mixed media. The study also concluded that combination of IBA with mixed media is highly effective in increasing rooting capacity when compared to the perlite.

The medium sized cuttings of *Pterocarpus dalbergioides* when treated with IBA 100 mg l^{-1} exhibited maximum rooting per cent (62 %), root length (28.0 cm) and shoot length (38.3 cm) (Venkatesh and Pandey, 2006).

Reddy *et al.* (1992) reported that terminal cuttings when treated with IBA at 1000 mg l^{-1} was promising in *Prosopis juliflora*.

Successful vegetative propagation method has been developed for *P. juliflora* soft wood terminal cuttings on treatment with IBA when the concentration was 1000

mg l^{-1}. In *P. juliflora,* good rooting response of stem cuttings were shown when treated with IBA at 2000 mg l^{-1} (Goel *et al.*, 1997).

Parthiban *et al.* (1999) reported that double nodal stem cuttings of superior genotypes of *Ceiba pentandra* when treated with IBA at different concentrations (1000, 2000, 3000 and 4000 mg l^{-1}) on a quick dip basis showed high percentage of rooting in IBA at 2000 mg l^{-1} and 3000 mg l^{-1} .

Singh and Bhatt (2009) reported for the branch cutting of *D. sissoo* collected from the individuals among the populations seen in high ranges showed higher per cent of rooting, which was also transformed for other parameters. On average 25 % rooting was recorded.

Jagatram *et al*., (2003) reported that the maximum rooting per cent was found in IBA 2000 mg l^{-1} for hardwood cuttings (21.67%) while soft wood cuttings, 1000 mg l^{-1} IBA exhibited maximum rooting (21.67%) in *Madhuca latifolia* in nursery mixture medium.

2.7.1.2. Coppice shoots

Prasad and Kulkurani (1988) observed maximum rooting percentage (55.8%) in the coppiced shoot of Eucalyptus hybrid with 2000 mg l^{-1} IBA. Whereas, Meena Bakshi (1998) reported that the best treatment for maximum vegetative propagule production through coppice shoots of nodal cuttings is IBA 4000 mg l^{-1} powder.

2.7.1.3. Age of the planting material

Vallauri *et al.* (1995) reported that shoot terminal cuttings of *A. mangium* rooted well in 500 mg l^{-1} IBA. IBA was the most effective auxin, giving 40 % rooting (100, 200 or 500 mg l^{-1}) in branch cuttings of *Acacia nilotica* made in November (Gurumurthi *et al.*, 1994). Chuan *et al.* (1995) reported that cuttings from 3-year-old trees of *Eucalyptus grandis* treated with 5000 mg l^{-1} IBA gave 60 percent rooting.

Surendran *et al.* (1996) reported that rooting of branch cuttings of *Casuarina junghuahniana* (two year old tree) was good in 100 mg l^{-1} of IBA.

Bhupendra singh *et al*. (2011) reported that the use of IAA and IBA stimulated a greater number of cuttings to root, from the mother tree that was ten year old when compared to control in *Dalbergia sissoo*.

2.7.1.4. Different auxins

Gera *et al.,* (1998) studied the variation in rooting response in ten provenances of *A. indica* and observed that cuttings subjected with 1000 mg l^{-1} IBA increased rooting by 85.5 per cent; number of roots per cutting by 24.8 per cent; maximum root length by 68 per cent and root dry weight by 218.7 per cent over control.

Shamet and Kumar, 1988 reported that most effective treatments were IAA at 5000 and 10,000 mg l^{-1}, IBA at 5000 mg l^{-1} and NAA 200 mg l^{-1} in *D. sissoo* cuttings and all the treatments increased rooting to 40% compared with 5% for the controls.

The positive response of rooting in treatment with 2000 mg l^{-1} IBA in *Acacia albida* has been reported (Ahmed, 1988).

Puri (1990) concluded that IBA was most effective growth hormone than IAA and NAA for cutting propagation of *Casuarina equisetifolia*. Verma *et al.* (1996) studied the rooting of neem cuttings with 100, 500 and 1000 mg l^{-1} of NAA and IBA and reported that all IBA and NAA treatments increased the rooting and sprouting of cuttings, while no rooting or sprouting was observed for the control cuttings kept in the control.

In *Juniperus procera*, a threatened plant, the studies for the response of branch cutting showed that among the three hormones viz., IAA, IBA and NAA tried, the response for IBA was better when compared to other hormones (Berhe and Negash, 1998).

Aslam *et al.* (2007) observed that the among different auxins, IBA at 500 mg l^{-1} performed best of all the treatments of stem cutting regarding rooting behaviour *viz;* callusing percentage (11.3%), rooting percentage (76.66 %), number of roots (12.33) and length of roots (12.50 cm) per cutting.

In *Swietenia macrophylla* it was observed that the percentage of rooting and sprouting was considerably more for the cuttings dipped with 4000 mg l^{-1} IBA (Azad and Matin, 2015).

2.7.1.5. Auxin combination

Kulkarni and Jakawale (1999) observed the highest rooting (61.66%) in combination of 2500 mg l^{-1} IBA + 1250 mg l^{-1} kinetin, compared with a value of 28.33% in the control in *D. sissoo*. Karoshi *et al.,* (2000) reported that rooting was promoted in *Casuarina cunninghamiana* best using 3000 mg l^{-1} IBA + 1300 mg l^{-1} kinetin in mistless polytunnel (Hydropit).

2.7.16. Season of collection of propagules

Branch cuttings of *Melia azadirachta* treated with IAA and IBA triggered rooting and the best treatment was 50 mg l^{-1} IBA collected during February and treated with 50 mg l^{-1} IAA for the cuttings collected in May (Gupta *et al.*1989).

Badji *et al.* (1991) concluded that IBA (8%) promoted better rooting than 2% IBA, 0.2% NAA or 1% IAA in gum arabic (*Acacia Senegal*) cuttings during the rainy season.

Gurumurthi and Rawat (1992) found that July planted cladode cuttings of *Casuarina equisetifolia* treated with IBA or NAA at 4000 mg l^{-1} responded best (55-65% rooting) and also found that best rooting was in April and July cladodes, which reached 100%, after treatment with 200 mg l^{-1} IBA in the month of July and with 2000 mg l^{-1} NAA and 4000 mg l^{-1} IBA and NAA in April and July.

Palanisamy *et al.,* (1996) reported that the stem cuttings collected in February from neem tree showing complete leaf fall or at the bud break stage developed significant adventitious roots but the rooting percentage was poor in cuttings collected during the vegetative season and very poor in those collected in flowering and fruiting seasons. IBA at 1000 mg l^{-1} was the best hormonal treatment including 80 per cent rooting in February cuttings compared with 23 per cent rooting in untreated cuttings.

Palanisamy *et al.,* (1998) recorded increased rooting over that observed in controls, with IBA the best treatment in *Pongamia pinnata* cuttings. Rooting was best in March cuttings, followed by September cuttings and there was no rooting in July cuttings. IBA promoted 100 per cent rooting and the greatest number of roots, when the experiment was done during March. Palanisamy and Promod Kumar (1996) observed in *Pongamia pinnata* that 800 mg l^{-1} IBA induced 100 per cent rooting and more shoots during the month of March.

Palanisamy and Bisen (2001) reported that IAA 200 mg l^{-1} gave maximum rooting and root length in *Dendrocalamus* as per as compared to other treatments IBA and boric acid. The cuttings responded good rooting only in particular season i.e. March (53%), January (50%), February and April (35%) and in the remaining months the rooting was less than 20%. Palanisamy and Pramod Kumar (1996) reported branch cuttings of mature neem tree (*Azadirachta indica*) when dipped in IBA 1000 mg l^{-1} showed 81% rooting. The result also showed that root system grew extensively, and this was particularly seed in the month of February. In some of the studies it was also observed that the inter species variations were observed, when they were subjected to same treatment. Pal *et al.* (1994) observed 62 per cent rooting in the segments treated with 5000 mg l^{-1} IBA-talc for *Casuarina equisetifolia* while in *C. glauca* about 35% segments with 72% survivability was obtained when treated with 5000 mg l^{-1} IBA-talc. In *Dalbergia sissoo* and *D. latifolia* among different concentrations of IBA imposed, 5000 mg l^{-1} IBA has shown the best effect on all parameters of rooting behaviour. It was found that

D. sissoo showed comparatively more response than *D. latifolia* (Sharma and Pandey, 1999).

The literature indicates that clonal propagation using stem cutting has been successfully used in *Melia dubia*, where the response when dipped in 4000 mg l^{-1} and 5000 mg l^{-1} of IBA was observed to be 50 % for the rooting (Nair *et al*, 2005). In a different study, it was also observed that the cuttings from one year old branches from four year old trees, responded best, for the treatment IBA at 4000 mg l^{-1}. The rooting percentage was reported as 90 % (Ram *et al*., 2014). In a study done in six month old melia seedlings, stem cuttings obtained from the seedlings were rooted, without any hormone treatment and it was found that percentage of established seedlings were 76. It was demonstrated that a small number of plants produced by seed germination can be multiplied about sevenfold (Tilakaratna, 1996).

2.7.2. Mini clonal technology

For a majority of economically important forest tree species, the rooting of stem cuttings was not appropriate, the common method of rooted stem-cutting has major limitations to name a few problems, such as a rapid loss of rooting capability because of ontogenetic ageing, inferior root system and within clonal variation that results from topophysis. All this has a negative effect on the genetic expression of several clones. For many clones the complete genetic expression is prevented by the distortions mentioned above. The result is the reduction in the number of the selected trees when compared to the number of cuttings that can be made available for the use in plantation (Mustaq *et al*., 2017). This led to the development of other unconventional methods for the rooting of stem cuttings for cloning of tree species on a commercial basis and one such method is mini clonal technology. Mini clonal technology exhibits a great possibility as an alternate method of rooted stem-cuttings owing to its technical and economic advantages as well as the evidenced success of rooting in the auxillary sprouts. Success of this method is considerably dependent upon the rooting medium and optimal nutrient concentration.

Compared to stem cuttings, mini cuttings improve the rooting ability and its pace, increase the root system quality, in addition to the above it reduces the costs. This system also offers the chances for propagules to be homogenized physiologically and this significantly reduces the topophysis effects of the cuttings. Advancement of this highly intensive cloning system has emerged as a novel and effective method for mass clonal propagation in Eucalyptus and other tree species. In India, propagation by mini cutting represents the most modern concept of commercial cloning in Eucalyptus, Casuarina, *Melia dubia*, *Dalbergia sissoo* and *Neolamarckia cadamba.*

It is reported that plants have endogenous auxins. The production of these auxins reduces, as shoot apex of the stem is removed which in turn reduces the number of adventitious roots. So, the presence of hormones at lower concentration may be required to compensate the reduction in the endogenous auxins due to removal of shoot apex (Kurepin *et al*., 2011). At higher concentration, the hormones might have a deleterious effect on growth of the roots. Studies have shown that the high auxin application produces toxicity, further NAA is found to be more toxic than IBA (Zeng and Lu, 1988).

In a study done to standardize the rooting hormone in miniclonal technology in teak where different hormones (IBA, IAA and NAA) at various concentrations viz., 1000, 2000, 3000, 4000, 5000 and 6000 mg l^{-1} were applied to the mini cuttings. It was observed that the maximum rooting and sprouting percentage was for the treatment IBA at 6000 mg l^{-1} (Packialakshmi and Sudhagar, 2019). Superiority of IBA over other hormones has been reported earlier by many investigators in *Acacia albida* (Ahmed, 1988), *Woodfordia floribunda* (Shah *et al*., 1994), in *Parkia biglandulosa* (Reeves *et al*., 1996), *Azadirachta indica*, *Casuarina equisetifolia, Ceiba pentandra, Gmelina arborea and Thespesia populnea* (Parthiban *et al*., 1999), *Ceiba pentandra* (Rajendran *et al*., 2002) and *Pterocarpus dalbergioides* (Venkatesh and Pandey, 2006) and *Lannea coromendalica* (Prabhakaran, 2013).
The review shows that there exists variation in melia and no study has been done in the natural population of Kerala in this regard. The selection most suitable is the

base line system as it is found to be better for a natural population of the species where the trees are widely distributed and mostly isolated. Even though vegetative propagation has been standardized in other states of India, techniques suitable to our climatic condition is lacking especially for the mini clonal technology.

Materials and Methods

MATERIALS AND METHODS

3.1. Location

The natural populations of *Melia dubia* in the different forest of Kerala were selected. Locations were identified after referring relevant literature from district floras, herbaria and other leading publications. The field experience of the staff of the Kerala Forest Department was also made use to locate the melia population. Based on this, reconnaissance survey was carried out in all the forest divisions of Kerala having the natural population of the melia. In Wayanad four prominent locations were selected for the survey. They are Thirunelly in Begur Range, Tholpetty in Tholpetty Wildlife Sanctuary, Dasanakkara and Naykavala in Chedelathu Range. Five locations selected from Palakkad were Dhoni in Olavakkode Range, Poothundy and Thiruvazhiyad in Nenmara Range, Anakkaty in Agali, Mulli in Attappady Range, Walayar in Walayar Range, Parambikulam in Karimala and Sungam Range. In Idukki Chinnar was selected. In Thrissur two locations selected were Peechi in Peechi Wildlife Sanctuary and Pattikkad Range and Akamala in Machad and Wadkancherry Range. Two locations selected from Kollam are Arippa and Kulathpuzha in Palode and Kulathupuzha Range respectively. The fifteen locations of the identified natural populations of *Melia dubia* are provided in Fig. 1.

Twenty five plus trees were selected, and progeny evaluation of the selected plus trees was done by raising seedlings from the fruits collected from these trees. The nursery trials were conducted at the Tree nursery of the College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur district, Kerala located at 10º31'N latitude with an elevation of about 22.25 m above mean sea level. The study was conducted during 2016-19.

3.2. General description and climate of the study area

The locations selected for sampling were superimposed on the Agroecological units of Kerala map developed by ICAR (Figure 2). It was observed that the fifteen locations fell in seven AEU's.

3.2.1. Wayanad

The study area in Thirunelly spreads from the lower part of Brahmagiri to the other side of the Kaattikulam-Thirunelly road, where the vegetation mainly is Southern tropical moist deciduous forest. Some of the melia populations were also spread along both sides of the road, interspread between the plantations of Eucalyptus, from the Thirunelly to Thettu road. In Tholpetty the melia population was found interspread in teak plantations and some populations were also seen in the natural vegetation. These two regions fall in AEU 21- Wayanad Eastern Plateau as per the ICAR classification of different agroecological units of Kerala. The climate is tropical humid monsoon type. The area experiences a mean annual temperature of 22.6°C and rainfall 2700 mm. A dry period for three months is usually experienced.

The Dasankara and Neykaval locality in Wayannad come under the AEU 20-Wayanad Central Plateau. These regions are having a lower rainfall and longer dry spells compared to the AEU 21. The vegetation mainly is moist deciduous forest.

3.2.2. Palakkad

The area in Dhoni and Walayar comes under the AEU 22-Palakkad Central Plain. The population of melia is in the reserve forests in these regions. The vegetation generally is moist and dry deciduous forest. The region here experiences a mean annual temperature of 27.6°C and rainfall 1966 mm. The region experiences a dry period of about five months.

The study areas of Parambikulam and Thiruvazhiyadu comes under the AEU 14-Southern High Hills. The climate is tropical humid monsoon, but lower temperature than in coastal plain and midlands. The average annual temperature is 21.6°C, with

a rainfall of 3600 mm. In Parambikulam melia population is seen in the natural forest and also in the teak plantations, where as in Thiruvazhiyadu it is seen in natural forest.

The study area in Attappady comprises of Anakatty and Mulli area. These regions come under AEU 18- Attappady Hills and AEU 19- Attappady Dry Hills. The soils have a compact gravelly structure and are usually seen in sloppy areas. The soil has moderate to low drainage and low permeability. The study area in Attappady is considered to be one among the driest parts of the Kerala Western Ghats receiving a mean annual rainfall less than 900 mm and the dry period extending from 6 to 9 months. The mean annual temperature is 24.3°C. This area receives the bulk of rainfall from the north-east monsoon. The vegetation is mainly dry deciduous forest (Southern Tropical Dry Deciduous Forest 5A/C6) but presently the area has been thoroughly degraded and is dominated by pioneer euphorbiaceous scrub jungles.

3.2.3. Thrissur

The area in Akamala is classified as AEU 10- North Central Laterites. The climate is tropical humid monsoon type, with mean annual temperature 27.6°C and a rainfall of 3100 mm. The region usually has dry period of about two and a half months.

The area in Peechi is classified as AEU 14-Southern High Hills. The soil structure in this area has been badly damaged. The average annual rainfall is about 3160 mm, with a mean annual temperature 21.6°C. The main vegetation is moist deciduous forests.

3.2.4. Idukki

The study area in Chinnar comes under the AEU 17-Marayur Hills. The region experiences a mean annual temperature of 23.7 °C and a rainfall of about 2200 mm. The region represents the low rainfall region (rain-shadow) of the high hill zone.

The melia population is mainly seen along the sides of the river interspread with the species of riparine forests.

3.2.5. Kollam

The study area in Thenmala lies just on the northern side of the Shenduruney valley and is being drained by Aryankavu stream, a tributary of Kallada river. The soil mainly present throughout the stream and riverbanks is of an alluvial deposit. They are deep and considered to keep up good tree growth. It falls under AEU 14-Southern High Hills.

The experimental area in the nursery experiences a warm, humid tropical climate with distinct summer and rainy season. Total rainfall received during 2018 was < 3000 mm. The climatic data during the observation period are given below (Table 1). The data was collected from Agrometeorological observatory, COH, Vellanikkara.

Table 1. Weather parameters from January 2018 to May 2019.

Months	2018			
	Maximum Temperature (ºC)	Minimum Temperature (ºC)	Rainfall (mm)	Relative Humidity (%)
January	33.5	20.9	0	53
February	35.7	22.5	5.2	47
March	36.7	24	33.2	59
April	36.1	24.8	28.9	69
May	33.2	22.6	483.6	79
June	29.8	23.2	730	89
July	29.6	22.5	793.2	88
August	29.2	22.2	928	87
September	32.2	22.5	290	75
October	32.8	22.9	393	76
November	32.7	23.3	66.6	68
December	33	22.5	0	63

Months	2019			
	Maximum Temperature (ºC)	Minimum Temperature (ºC)	Rainfall (mm)	Relative Humidity (%)
January	32.9	20.4	0	55
February	35.3	23.4	0	59
March	36.7	24.8º	0	65
April	36.2	25.5	76.4	70
May	34.6	24.9	78.8	74

3.3 Estimation of genetic diversity and identification of plus trees.

From these locations' trees above the GBH of 1.3 m were selected. In total, 281 trees were evaluated for assessment of genetic diversity. In the present study, selection was made from available populations of *Melia dubia* growing in natural forests. Individual tree location, geographic information along with geo-coordinates were recorded using Global Positioning System. The following observations for all the trees were taken.

3.3.1. Quantitative traits

3.3.1.1. Total height (m).

The height of the standing tree (m) was measured using laser hypsometer. The height was taken from the base to the tip of the tree to the end topmost of the leading shoot.

3.3.1.2. Girth at breast height (m)

The girth at breast height (m) was measured using tape at 1.37 m. Measurements were taken at right angles to each other, and the mean values were taken as GBH.

3.3.1.3. Crown diameter (m)

The crown diameter was measured as the average of the two diameter measurements, i.e. the widest distance anywhere in the crown of the two live branches and the distance perpendicular to the widest measurement. It was averaged to arrive at the crown diameter (Schomaker *et al*., 2007).

3.3.1.4. Bole length (m)

Bole length measured as the distance from the base of the tree to the point of first branching.

3.3.2. Qualitative traits

3.3.2.1. Bole form - Length of clean bole straightness, cross-section, swellings etc were recorded. The branching habit of the trees based on height of first branch, apical dominance, forking, branch angle, branch thickness, self pruning ability etc also were recorded.

3.3.2.2. Health status – The foliar and stem damage of the trees were observed. The variations in the qualitative traits were determined using the scoring method developed by Jayaraj (1997). The format of the scoring is shown in appendix I.

3.4. Plus tree selection

From different locations selection of 25 plus trees was done using the base-line method (Rudolf, 1956; Bedell, 1980). For this, the regression of crown diameter squared x crown length and DBH squared x height was determined. The dependent variable and independent variable were taken as DBH squared x height and crown diameter squared x crown length respectively. Trees above the regression line reflect special vigour and were selected. If more trees were falling above the regression line, then the trees that are best for the scores for various qualitative parameters were selected. The scoring of the trees given as (Appendix III).

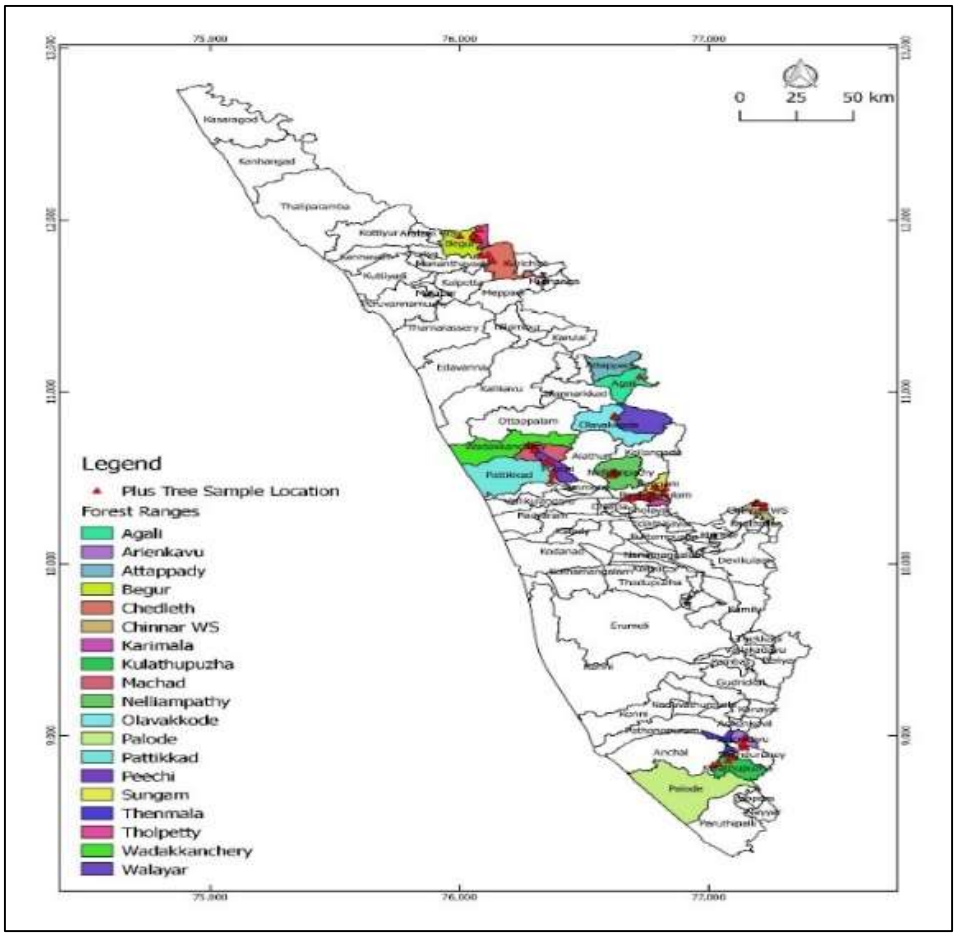


Fig. 1. Distribution of *Melia dubia* population in Kerala

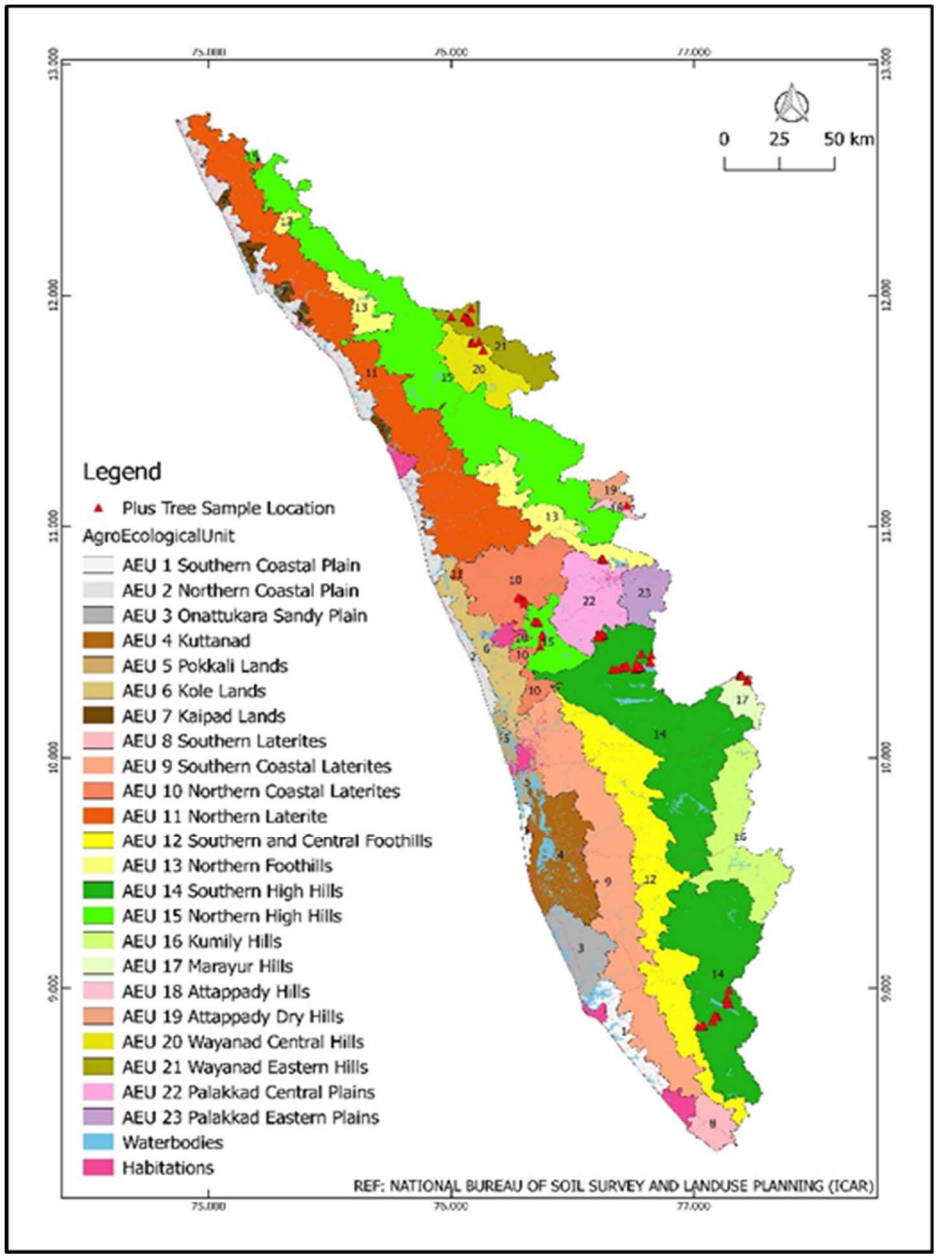


Fig. 2. Distribution of *Melia dubia* population in different Agroecological units.

3.6. Progeny evaluation

Fruits were collected from the twenty five selected plus trees from different localities. Yellow coloured ripened fruits were collected directly from the trees. Fallen fruits were also used if they were found fresh. They were immediately transported to the nursery in gunny bags. The fruits were soaked in acidic water for

few days for fermentation. For depulping, the fermented fruits were macerated manually by rubbing on a hard surface. Depulped seeds were dried in shade for two days.

3.6.1. Seed pre-treatments

The seeds were mixed with cow dung and dried for ten days in the sun in order to crack the hard coat of the fruits (a common practice by farmers). The seeds were then extracted from the fruits using a nutcracker, modified for this purpose (Plate 1). The extracted seeds were treated in 250 mg l^{-1} gibberellic acid.

3.6.2. Sowing of fruits and seeds

The seeds treated with gibberellic acid were sown in the tray filled with sand. The treated fruits from all the twenty five selected plus trees were also sown separately in the standard nursery beds during November 2016. Nursery sowing (Plate 2) was done to ensure germination if the seeds failed to germinate in the trays. Daily watering was done both for the trays and nursery bed. After germination, healthy seedlings from the tray (Plate 3) and nursery bed (Plate 4) were pricked out and transplanted to the polythene bags (15 cm x 25 cm and gauge 250 mm). The potting media used for the experiment was a combination of soil, sand and farmyard manure, which were mixed in the ratio of 2:1:1. The seedlings were then kept in the nursery under 25 per cent shade. The experiment was done in a completely randomised block design with three replications. In each replication, there were five seedlings. The seedlings were evaluated for the growth parameters in the nursery for five months. In total 375 seedlings were maintained in the nursery. Additional 75 seedlings were also maintained for replacing any casualties.

3.6.3. Biometric observations of progenies

3.6.3.1. Shoot height

Seedlings height was measured from collar to the tip of the terminal bud, using a meter scale.

Plate 1. Nutcracker designed for seed extraction

Plate 2. Seed germination in nursery bed

Plate 3. Seedlings in the tray for transplanting

Plate 4. Seedlings in the nursery for transplanting

3.6.3.2. Collar diameter

Seedlings collar diameter was measured along two diametrically opposite directions. This was done using vernier callipers (least count=0.02 mm) and this was expressed in millimetres.

3.6.3.3. Number of leaves

The total number of leaves retained, and which were functional were counted.

3.6.3.4. Biovolume index

Biovolume index is a rapid method to determine the above-ground portion of the seedlings. This was calculated using the formula

Biovolume index= Stem diameter (mm) x Plant height (cm) (Hatchell, 1985).

3.6.4. Physiological observations

3.6.4.1. Chlorophyll content

Chlorophyll meter (SPAD-502, Minolta) was used to estimate the chlorophyll content of the seedlings. For this, three matured leaves from the second whorl were taken for the measurement (Plate 5).

3.6.4.2. Photosynthetic rate

Seedlings photosynthetic rates were measured using Infra-red gas analyser (IRGA) (LI 6400m Portable photosynthesis system, LI-COR) model (Plate 6). The light intensity was fixed at 1000 lux and the amount of CO_2 expressed in μmol $m^{-2}s^{-1}$(McDermitt *et al*., 1989).

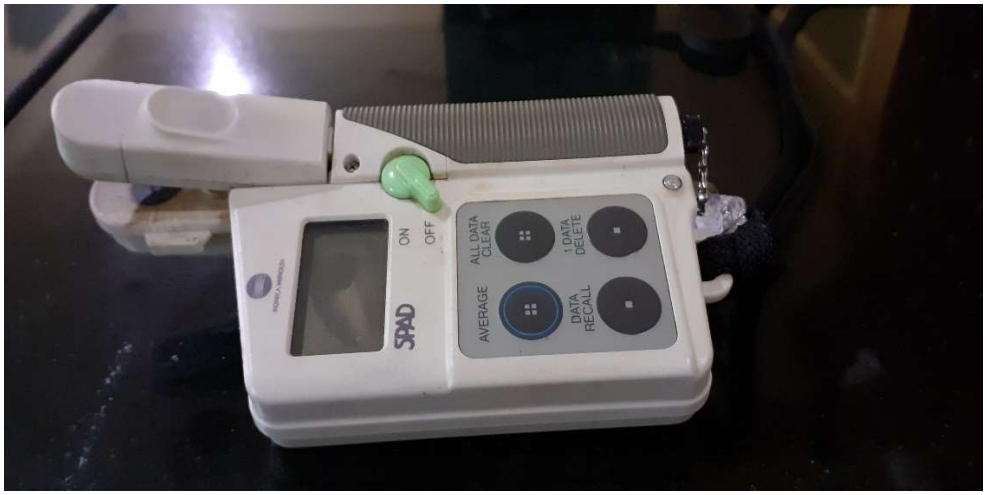


Plate 5. SPAD meter to measure the chlorophyll content of the leave

Plate 6. Infrared gas analyser used for measuring physiological attributes

3.6.4.3. Transpiration rate

The transpiration rates of seedlings were measured using Infra-red gas analyzer (IRGA) (LI 6400m Portable photosynthesis system, LI-COR) model. The light intensity was fixed at 1000 lux and the amount of H_2O expressed in $\mu molm^{-2}s^{-1}$(McDermitt *et al*., 1989).

3.6.4.4. Leaf temperature

The leaf temperature of the seedlings was recorded using IRGA and expressed in ^{o}C (McDermitt *et al*., 1989).

3.6.4.5. Stomatal conductance

The stomatal resistance of the leaves of seedlings was measured using Infra-red gas analyser (IRGA) (LI 6400m Portable photosynthesis system, LI-COR) model and expressed in s cm^{-1} (McDermitt *et al*., 1989).

3.6.4.6. Relative water content

In order to ascertain the relative water content, twenty small discs of leaf were cut, and fresh weight was taken. Immediately it was put in water for 4 hours. After removing from the distilled water, the leaf samples were dried for which a blotting paper was used and after ensuring that no moisture is there, turgid weight was measured. The samples were dried in hot air oven. The temperature was set to $70^{o}C$, this was done till the weight of the samples remained constant. The RWC was calculated based on the formula

$$\text{Relative water content} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}}$$

All the physiological data were taken for the period 60 DAT and 150 DAT.

3.6.5. Estimation of genetic parameters

3.6.5.1. Variability studies

These parameters were measured by the method developed by Johnson *et al*. (1955).

3.6.5.1.1. Genotypic Variance (G.V) (σ^2g) = (σ^2g - σ^2e)/r

Where,

σ^2g = Genotypic mean square

σ^2e = Error variance

r = Number of replications

3.6.5.1.2. Phenotypic Variance (P.V) (σ^2p) = σ^2g+ σ^2e

Where,

σ^2g = Genotypic variance

σ^2e = Error variance

3.6.5.1.3. Phenotypic (PCV) and genotypic (GCV) coefficients of variability were computed using the following equations suggested by Burton and De-Vane (1953).

Phenotypic Co-efficient of Variability

Phenotypic Co-efficient of Variability was calculated as given below

PCV (%) = $\sqrt{(\sigma^2p)} \times 100 \div \mu$

μ = Population mean for each trait

Genotypic Co-efficient of Variability

Genotypic Co-efficient of Variability was calculated as given below

$$GCV\ (\%) = \sqrt{(\sigma^2 g)} \times 100 \div \mu$$

3.6.5.1.4. Environmental coefficient of variation (ECV)

It is an estimate of the total environmental variation present for a character.

$$ECV\ (\%) = \sqrt{(\sigma^2 e)} \times 100 \div \mu$$

3.6.5.2. Heritability

3.6.5.2.1. Broad sense heritability (H^2)

Broad sense heritability (H^2), which is a measure of the amount of phenotypic variance contributed by genetic factor was estimated as per the formula developed by Lush (1940)

$$H^2 = \sigma^2 g / \sigma^2 p$$

$$\text{Heritability percentage} = H^2 \times 100$$

Genetic advance

Genetic advance is the increase in the magnitude of a specific character, which is expected when a selection pressure of chosen intensity is applied. The expected genetic advance at 5 per cent selection intensity was calculated as developed by Johnson *et al*., (1955). The genetic advance was calculated as:

$$\text{Genetic advance (GA)} = [(\sigma^2 g)/(\sigma^2 p)] \times k \times \sqrt{(\sigma^2 p)}$$

Where, Selection intensity (k) was presumed to be 2.06, the value is considered to be normal in case of 5 per cent selection in samples which are large and are from a normally distributed population (Allard, 1960).

Genetic advance as a percentage of mean was calculated using the formula given by Johnson *et al*., (1955).

$$GA \text{ as a percentage of mean} = GA/\text{Grand mean} \times 100$$

3.7. To standardize the clonal propagation

Stem cuttings from seedlings

The seedlings in the nursery (Plate 7) and the polybags (Plate 8) were used, for the standardization of clonal propagation. Stem cuttings were obtained from two-month-old seedlings when they reached a height of 25-30 cm. The shoot was cut from the base of the seedlings leaving a height of 5-8 cm from the base. This was left for the sprouting of new shoots. The excised shoots were then cut into 5 cm long (2-3) nodes and the base was treated with the three auxins at different concentrations (Table 2) to stimulate root formation. For this the base of the shoots was dipped in the solution containing auxins. Two to three cuttings were obtained from each seedling. Sands were used to plant the cuttings in trays (Plate 9). The cuttings started to sprout within one week. After taking the observations of the rooted cuttings, they were transferred to polybags of size 10 x 15. Soil, sand and FYM were mixed in the ratio of 2:1:1 which was used as the potting media for this purpose. The experiment was done in Completely Randomized Block design with three replications. Ten cuttings were planted per replication. Altogether 480 plants were maintained. The observations were taken after 30 days of transplanting. The rooted seedlings in the nursery (Plate 10) were then treated with nutrient solutions to enhance epicormic shoot production (Plate 11). After the emergence of the new shoots, again the shoots were excised and rooted, with the best concentrations of IBA, IAA and NAA which was standardized in course of the experiment was done.

Plate 7. Seedings maintained in the nursery for taking cuttings

Plate 8. Seedings maintained in the polgbags for taking cuttings

Plate 9. Cuttings maintained for sprouting ` and rooting

Plate10. Seedlings maintained for emergence of new flush

Plate 11. New flushes emerging after the removal of the shoot apex

Table 2. Treatment combinations for the rooting of stem cuttings from seedlings.

Treatment no.	**Growth regulator**	**Concentration (mg l^{-1})**
1.	IBA	1000
2.	IBA	2000
3.	IBA	3000
4.	IBA	4000
5.	IBA	5000
6.	IAA	1000
7.	IAA	2000
8.	IAA	3000
9.	IAA	4000
10.	IAA	5000
11.	NAA	1000
12.	NAA	2000
13.	NAA	3000
14.	NAA	4000
15.	NAA	5000
16.	Control	0

3.7.1. Collection of data on vegetative propagation

Different growth parameters on which observations recorded at the end of the study were as follows.

3.7.1.1. Sprouting per cent = Number of sprouted cuttings / Number of cuttings planted x 100

3.7.1.2. Rooting per cent = Number of rooted cuttings / Number of cuttings planted x 100

3.7.1.3. Collar diameter (mm): The diameter of cuttings at collar region was measured using digital calliper and expressed in millimeter.

3.7.1.4. Sprout length (cm): The length of the sprout was measured from the base of the sprout to the tip using scale and expressed in centimeter.

3.7.1.5. Stem length (cm): Total stem length was measured from collar region to tip of the sprout using scale and expressed in centimeter.

3.7.1.6. Root length (cm): The length of the longest root was measured from collar region to root tip by running a thread along with root and then measuring thread length using scale. Root length is expressed in centimeters.

3.7.1.7. Number of leaves: Total number of leaves in the cutting was counted.

3.7.1.8. Number of roots: Number of roots in the cutting was totalled.

Stem cuttings from matured trees using mini-clonal propagation techniques.

In order to standardize the stem cutting from matured trees, shoots were severed from the mother plants, wrapped with wet gunny bag material and transported to the laboratory. The shoots were then treated with a fungicide (2% Bavistin solution). Cuttings with 5-12 cm diameter and 1m length was used for planting. These were treated with 2% Bavistin (Carbendazim solution 50% WP) for 10 minutes and were subsequently washed with distilled water. The cuttings were planted in polybags containing the potting media soil, sand and FYM in the ratio of 2:1:1 (Plate 12). These polybags were placed in the mist chamber. After 20 – 30 days the new shoots started emerging and at two leaves stage, they were served from the mother plants and base of the shoots was treated with different concentrations of indole acetic acid (IAA), indole 3- butyric acid (IBA) and naphthaleneacetic acid (NAA). Concentrations of auxins ranged from 1000 to 9000 mg l^{-1}. In total, there were 28 treatments including control.

Table 3. Treatment combinations for the rooting of stem cuttings from mature trees are given as below.

Treatment no.	Growth regulator	Concentration (mg l^{-1})
1.	IBA	1000
2.	IBA	2000
3.	IBA	3000
4.	IBA	4000
5.	IBA	5000
6.	IBA	6000
7.	IBA	7000
8.	IBA	8000
9.	IBA	9000
10.	IAA	1000
11.	IAA	2000
12.	IAA	3000
13.	IAA	4000
14.	IAA	5000
15.	IAA	6000
16.	IAA	7000
17.	IAA	8000
18.	IAA	9000
19.	NAA	1000
20.	NAA	2000
21.	NAA	3000
22.	NAA	4000
23.	NAA	5000
24.	NAA	6000
25.	NAA	7000
26.	NAA	8000
27.	NAA	9000
28.	Control	0

3.7.2. Preparation of the growth regulators

The growth regulator was prepared as a liquid formulation. The different rooting hormones *viz*., IBA, IAA and NAA were used at 1000 mg l^{-1}, 2000 mg l^{-1}, 3000 mg l^{-1}, 4000 mg l^{-1}, 5000 mg l^{-1}, 6000 mg l^{-1}, 7000 mg l^{-1}, 8000 mg l^{-1} and 9000 mg l^{-1} concentrations. The stock solutions of these hormones were prepared by dissolving the weighed quantity of each hormone (i.e. 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0 and 9 g/l respectively) first in sodium hydroxide solution and making into

known volume with distilled water. The experiments were laid out in CRD with four replications, with each replication having five cuttings each.

3.7.3. Collection of data on vegetative propagation

3.7.3.1. Sprouting per cent = Number of sprouted cuttings / Number of cuttings planted x 100

3.7.3.2. Rooting per cent = Number of rooted cuttings / Number of cuttings planted x 100

3.8. Experiment on the clonal progeny evaluation

3.8.1. Collection of propagules

Propagules were collected from all the twenty five plus trees located in the natural forests at selected locations. Propagules used for the experiment were of two types viz. a) Semi-hardwood cuttings with 5-12 cm diameter with 1 m height (Plate 13). b) Root suckers from the injured roots. Semi-hardwood cuttings were collected from the plus trees from the leading branches of the tree. For initiation of the root suckers the roots thinner than 10 cm diameter were severed during the month of January (Plate 14). Suckers started arising from the injured part of the roots after one month of the root injury (Plate 15 a-d). These root suckers were used for the study. The coppice shoots were collected with the help of secateurs which were transported in iceboxes to the laboratory to avoid the desiccation.

3.8.2. Preparation of cuttings

The plants were produced from the semi-hardwood cuttings as mentioned above. The best auxin and the concentration for the production of the plants from the cuttings standardised during the experiment was IBA at 6000 mg l^{-1} which was used for this experiment.

The root suckers brought to the laboratory were cut into 10-15 cm length with a minimum of three nodes. Prepared cuttings were treated with two per cent Bavistin

Plate 12. Cuttings maintained for the emergence of new flush

Plate 13. Semi hard wood cuttings from the plus trees kept for the emergence of new flush

Plate 14.Roots severed for initiation of the suckers from the roots

Plate 15 (a). Initiation of suckers from the roots

Plate 15 (b). Root suckers at the time of the collection

Plate 15 (c). Root suckers from the plus tree FCV-MD-15 (Parambikulam) showing good growth.

Plate 15 (d). Initiation of shoot from the root suckers

solution (Carbendazim 50% WP, Systemic fungicide) for 5 minutes and were subsequently washed with distilled water. Then the cuttings were treated with the growth regulators IBA (1000 mg l^{-1}) (Plate 14), as standardized earlier before the start of this experiment. The suckers were immediately planted in the polybags of size 15 cm x 25 cm. The potting media used for this purpose was a combination of soil, sand and FYM mixed in the ratio of 2:1:1.

Statistical analysis

In order to study the genetic divergence in the population of melia, hierarchical cluster analysis was done for the data collected for different growth parameters. Clustering method of between groups linkages was applied which takes into consideration of squared Euclidian distance between groups. Dendrogram and a proximity matrix were also generated.

For the evaluation of progeny, final data of the experiment were subjected to one-way Analysis of Variance (ANOVA). Based on the result of ANOVA of all data, the means were separated using post-hoc analysis in the form of Duncan's Multiple Range test (Duncan, 1955) to separate the means. The data gathered from the nursery were analysed and tabulated. Mean, variance and standard error were estimated as per the procedure described by Panse and Sukhatme (1978).

Data on the clonal propagation using the cuttings from trees gave results only for the treatments of auxins for the concentrations 5000 mg l^{-1}, 6000 mg l^{-1} and 7000 mg l^{-1}. Hence the analysis was done as 3^2 factorial CRD with four replications. Factor 1 was taken as hormones and factor 2 as concentrations, both at 3 levels. The levels 1, 2 and 3 designated to hormone IAA, IBA and NAA and concentrations 5000 mg l^{-1}, 6000 mg l^{-1} and 7000 mg l^{-1}. The observed data was in percentage and as it exceeded the range (30-70%), the angular transformation was done to the data. All the analysis was done in SPSS.

Results

RESULTS

The results obtained in the present investigation titled "Genetic variability and plus tree selection in natural population of malaveppu (*Melia dubia* Cav.)" are presented in this chapter.

4.1. Variations observed in the located trees

4.1.1. Quantitative characters

The table showing observations on all quantitative characters of all the located trees is provided in appendix II. The frequency distribution of height (m) of all the trees enumerated, from all the localities is shown in Figure 3. It was observed that the highest number of trees (fifty eight) were in the range of 17.8 m to 20 m. Only fourteen number of the trees fell in the range of 30 to 35 m. Similarly, trees in the range of 12 to 15 m were 6 in numbers. Frequency distribution of the GBH (m) of all the trees (Figure 4) showed that the highest number of trees (sixty four) were in the range of 1.8 to 2.1m. This was followed by trees in the range 1.48 to 1.81 m and 2.14 to 2.47 m with total number of trees fifty five and forty seven respectively. Only 2 trees fell in the highest range 4.12 and 4.78 m GBH class. The trees in the lowest girth class 1.15 to 1.48 m were twenty nine. Also, no tree fell between the range of 3.8 to 4.15 m. The frequency distribution of the crown width (m) of all the trees (Figure 5) showed that highest number of the total trees (seventy one) were in the range of 15.0 to 16.5 m, followed by the trees in the crown width classes 16.5 to 18 m and 18 to 19.5 m with the total number of trees sixty five and forty five respectively. It was also observed that only 5 trees fell in the crown class 24 to 29 m. The frequency distribution of clean bole height (m) of melia trees (Figure 6) showed that the highest number of trees (eighty four) fell in the range 7 to 8 m. This was followed by the trees in the range 6 to 7 m and 8 to 9 m, with total number of trees fifty seven and forty three respectively. The trees having clean bole height above 12 m were only 6. Trees with clean bole height between 4 and 5 m class were twenty in number. The distribution of clean bole height: Tree height (m) of melia trees is shown in Figure 7. The highest number of trees (sixty) were in the range 0.38 to 0.44 m. The trees with highest ratio above 0.63 m were only 8 in numbers. The number of trees in the lowest class (0.15 to 0.21 m) were 9. The frequency distribution of the Pilodyn penetration depth (mm) of all the trees is shown in Figure 8. The highest number of trees with Pilodyn penetration depth (mm) in the range of

13.67 to 14.56 mm was 71. This was followed by trees in the range between 12.78 mm to 13.67 mm and 14.56 mm to 15.45 mm, with total number of trees sixty three and forty three respectively. Only six trees fell in the range of 17.23 mm to 18.12 mm. There was only one tree in the range of 18.12 to 19.01 mm. The total trees in the lowest range 11 mm to 12 mm were twenty.

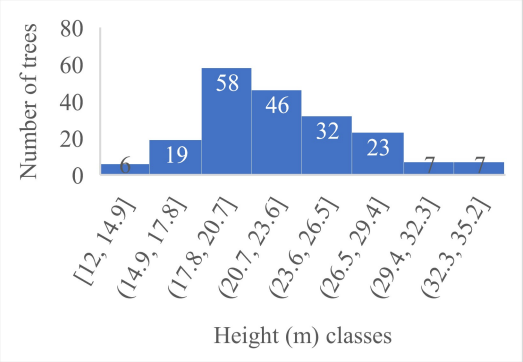


Fig. 3. Frequency distribution of the height (m) of *Melia dubia* trees.

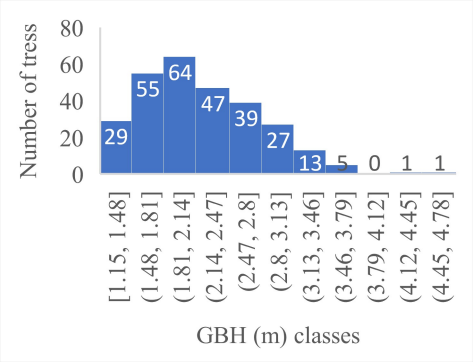


Fig. 4. Frequency distribution of the GBH (m) of *Melia dubia* trees.

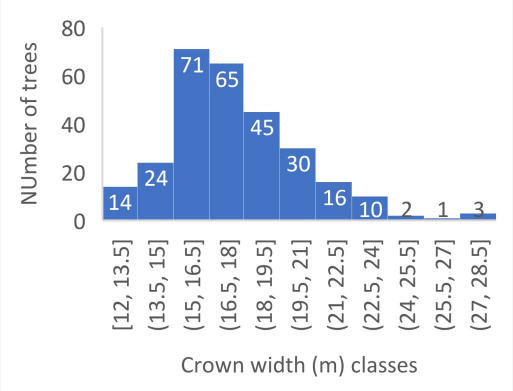


Fig. 5. Frequency distribution of crown width (m) of *Melia dubia* trees.

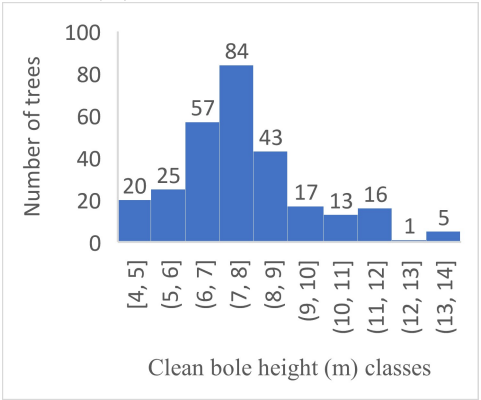


Fig. 6. Frequency Distribution of the CBH (m) of *Melia dubia* trees

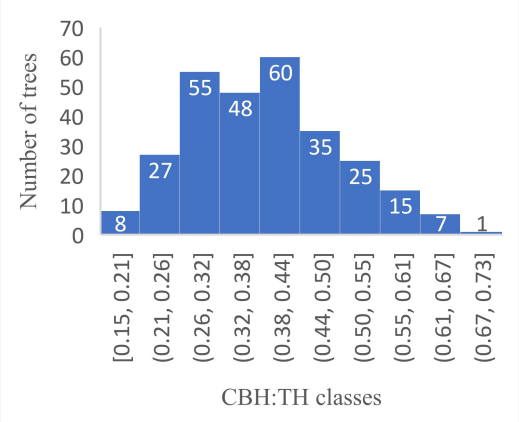


Fig. 7. Frequency distribution of the clean bole height:Tree height of *Melia dubia* trees

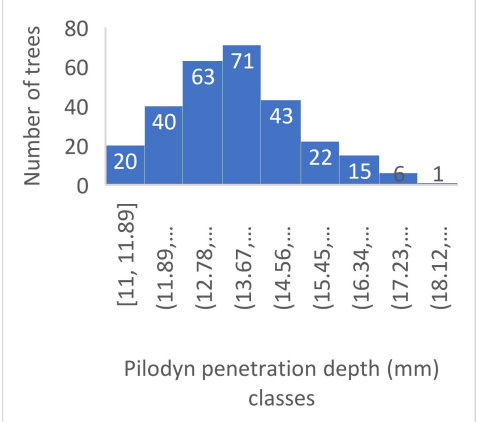


Fig. 8. Frequency distribution of the Pilodyn penetration depth (mm) of outer bark of *Melia dubia* trees

The variation in the height of the trees enumerated from all localities is shown in Figure 9. Each box plot shows five values with respect to the data. The lowest end shows the minimum value, the Q_1 (first quartile), lower end of the box separates the first 25 % of the data with the rest of the data. The line in the box Q_2 (second quartile) shows the median value, which separates 50 % of the data. The cross in the box shows the average value. The upper end of the box Q_3 (third quartile) separates the highest 25 % of the data. The last value shows the maximum value. In some of the box plots it was observed that some of the points were seen outside the box and whisker range which are the outliners. If the outliner is above the maximum value, then it indicates that the value is 1.5 times the maximum value and vice versa *i.e.* if seen below the minimum value it shows that the value is less than 1.5 times the minimum value.

It was observed that variation existed among the trees within the localities and between localities, as evident from the difference in the size of box plot and from the minimum, maximum and median values that were different for all the localities. The results also showed that a certain amount of similarity existed between localities Tholpetty and Dasanakkara and between Dhoni and Poothundy, as evident from the size of the boxplots. The box plot of the trees in Thirunelly showed that the maximum value for the tree height was 35 m. Similarly, the lowest value for the height was for Thirunelly (18 m) and the median value (26 m), which was observed to be the highest among all the localities. The lowest value for the tree height (16 m) was observed for trees in Chinnar and Aryankavu. The variation of the values for the trees in Thiruvazhiyad was less as the size of the box was small. The median values for the boxplots showed that except for trees in Neykavala, Walayar, Attappady and Chinnar the distribution of the height of tree was normal. The values were positively skewed for the localities Tholpetty, Dhoni, Thiruvazhiyad, Akamala and Aryankavu and negatively skewed for the localities, Thirunelly, Poothundy, Parambikulam, Peechi and Kulathupuzha. Two outliners were observed both for Parambikulam and Chinnar. The outliners were distributed each for minimum and maximum values for both the localities. The lower values of first quartile (Q_1) for the boxes Tholpetty

and Dasankkara were the same (19 m). The higher values for the third quartile (Q_3) for the boxes Dhoni and Poothundy were same (22 m).

The variation in the GBH (m) of the trees enumerated from all localities is shown in Figure 10. It was observed that variation existed in the GBH (m) among the trees within the localities and between localities, as evident from the difference in the size of a box plot and also from the minimum, maximum and median values that were different for all the trees in the localities. It was observed that the size of the boxplot of the trees in the Attappady locality was large, indicating a larger dispersion in the values. The minimum, maximum and median values observed were 1.2 m, 3.2 m and 2.3 m respectively. The first box plot of the trees in Thirunelly showed that the dispersion was minimum as evident from a smaller size of the box plot. The highest value for the GBH (4.4 m) was observed for the trees in Tholpetty and the lowest value (1.3 m) was observed for trees in Attappady. Normality for the distribution of GBH was not observed in any locality except for the trees in Attappady. It was observed that the values were positively skewed for the localities Dasanakkara, Thiruvazhiyad, Parambikulam, Akamala, Kulathupuzha and Aryankavu. Negatively skewed values were observed for Thirunelly, Tholpetty, Neykavala, Dhoni, Poothundy, Walayar and Chinnar. Three outliners were observed for the values one each for Thirunelly, Neykavala and Parambikulam. Some similarity with respect to the distribution was observed for trees in Dhoni and Poothundy.

The variation in the crown width (m) of the trees enumerated from all localities is shown in Figure 11. It was observed that variations existed in the crown width (m) among the trees within the localities and between localities, as evident from the difference in the size of the box plot. Variation was also observed for the minimum, maximum and median values for all the localities. It was observed that the size of the boxplot of the trees in the Thirunelly locality was large indicating a larger dispersion in the values. The minimum, maximum and median values observed were 13.65 m, 36.0 m and 21 m respectively. The box showed that 50 per cent of the values are in the range 16.5 to 28 m. The values more than 28 m and less than 16.35 m were 25 per cent. The box plot of the trees in Akamala showed that the

dispersion is minimum as evident from the smaller size of the box plot. The values were in between 16.5 m to 18 m. Three outliners for the crown width were observed, one each in Neykavala, Akamala and Aryankavu, their values were 23.5, 21.5 and 26.5 respectively. Normality for the distribution of values was observed for the localities Poothudy, Thiruvazhiyad and Attappady. Negatively skewed values were observed for Thirunelly, Dasanakkara, Neykavala, Thiruvazhiyad, Dhoni, Parambikulam, Chinnar, Walayar and Kulathupuzha. Positively skewed values were observed for the localities Tholpetty, Peechi and Aryankavu.

The variation in the clean bole height (m) of the trees enumerated from all the localities is shown in Figure 12. Variation existed in the clean bole height among the trees within the localities and between localities. This is evident from the difference in the size of the box plot. Tree with lowest clean bole height 4 m was observed in Thirunelly, whereas the highest clean bole height 13 m was observed for trees in Dasanakkara. The first quartile values for the trees in Dasanakkara, Neykavala, Dhoni, Poothundy, Thiruvazhiyad, Attappady, Parambikulam were the same (9 m). The dispersion of the value was more for the trees in Thirunelly and Dhoni locality. Least dispersion of the value was observed for the trees in Aryanavu locality. Outliners were observed for localities Neykavala, Walayar, Parambikulam, Peechi, Akamala, Kulathupuzha and Aryankavu.

The variation in the CBH:TH among the trees within the localities and between localities is shown in Fig. 13. The lowest value 0.15 was observed for the tree in the Thirunelly locality. The highest value for the CBH:TH was observed for the trees in Chinnar (0.68). The dispersion of the value was more for the trees in Dhoni, lowest dispersion of value was observed for trees in Peechi. Only one outliner was observed and that was for the locality Parambikulam.

The variation in the Pilodyn depth index (mm) of the trees in respective localities is shown in the Fig. 14. The variations within and between localities for the Pilodyn depth index (mm) for the trees existed as it is evident by the difference in the size of the box plots. It was also observed that the values for the minimum, maximum and median values were different for all the localities. The maximum dispersion for the value was observed of the trees in the Peechi WLS and Pattikkad Range of Thrissur.

Trees in Peechi WLS showed a minimum value (11 mm) maximum value (18 mm) and a median value (15 mm). The minimum (13 mm), maximum (19 mm) and median (15 mm) values were highest for the trees in Aryankavu forests. The result showed that these values were lowest value for the box plot. The values were normal for Dasanakkara, Neykavala and Peechi. The values were negatively skewed for the localities Thirunelly, Tholpetty, Dhoni, Walayar, Attappady, Parambikulam, Kulathupuzha and Aryankavu.

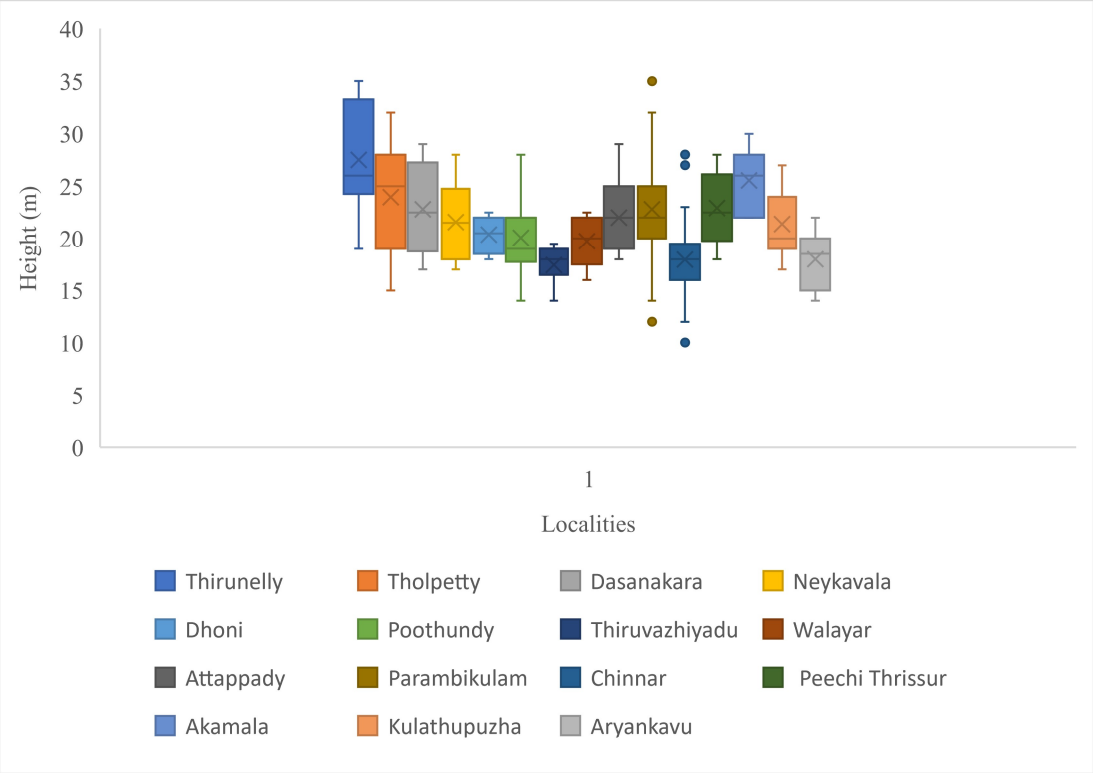


Fig. 9. Box and whisker plot showing the variations in the height (m) of *Melia dubia* trees.

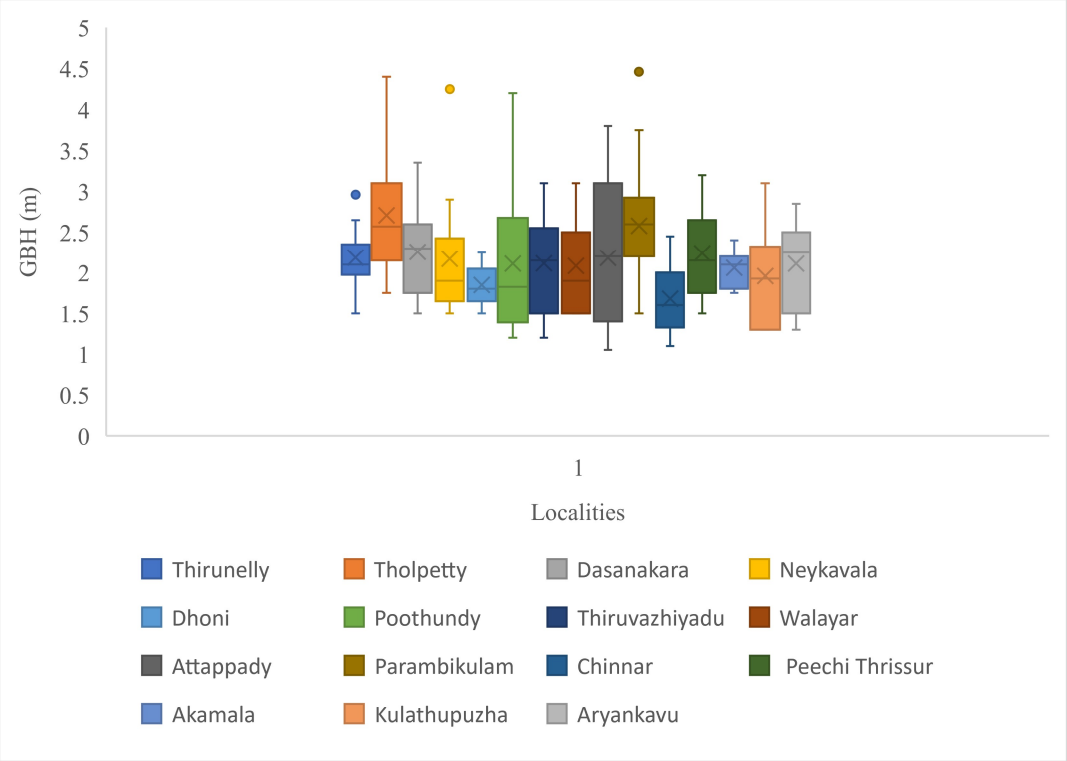


Fig. 10. Box and whisker plot showing the variations in the GBH (m) of *Melia dubia* trees.

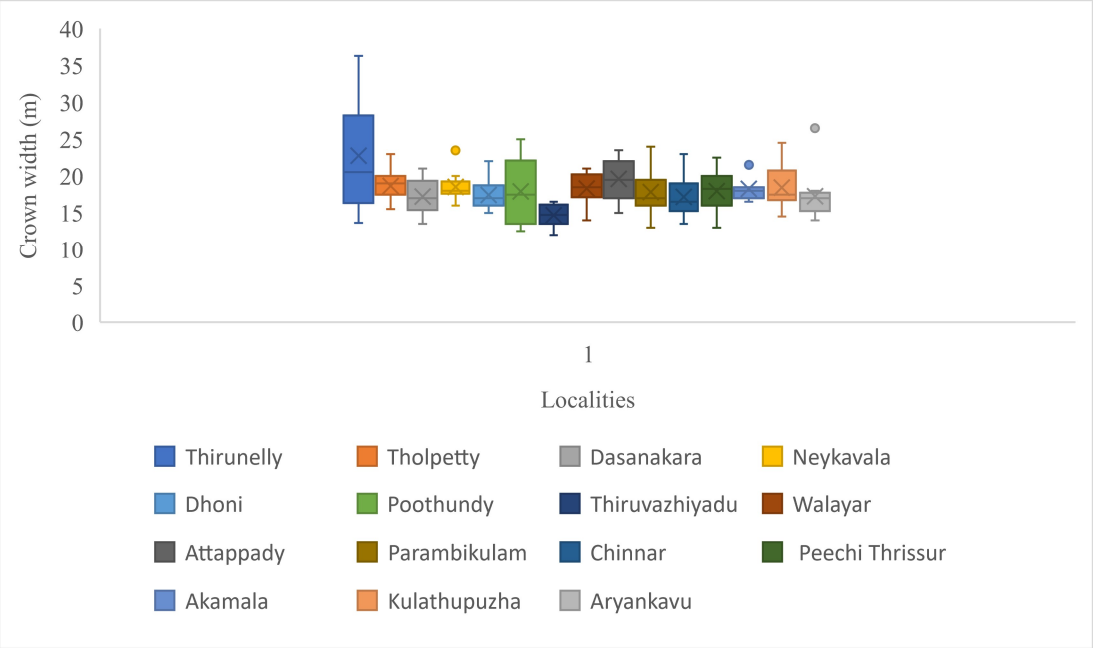


Fig. 11. Box and whisker plot showing the variations in the crown width (m) of *Melia dubia* trees.

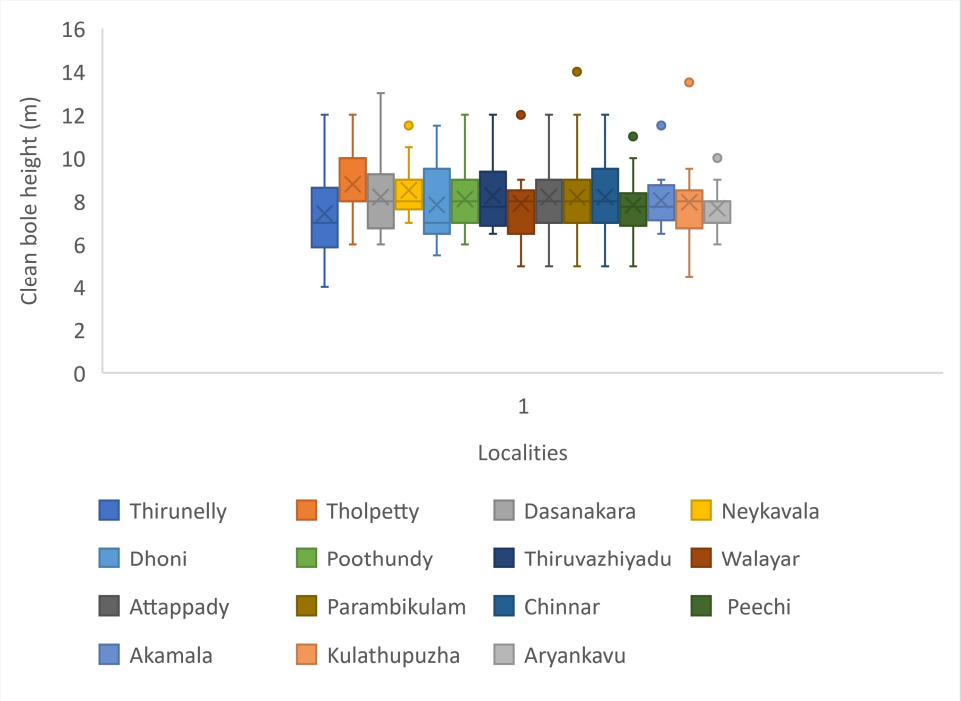


Fig. 12. Box and whisker plot showing the variations in the clean bole height (m) of *Melia dubia* trees.

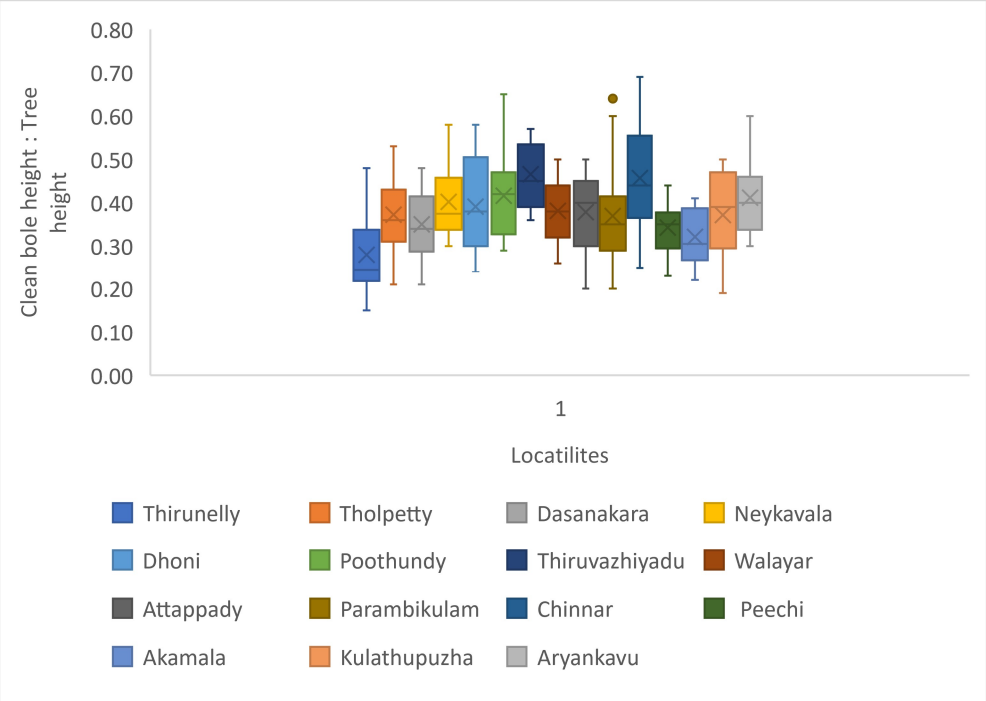


Fig. 13. Box and whisker plot showing the variations in the clean bole height:Tree height of *Melia dubia* trees.

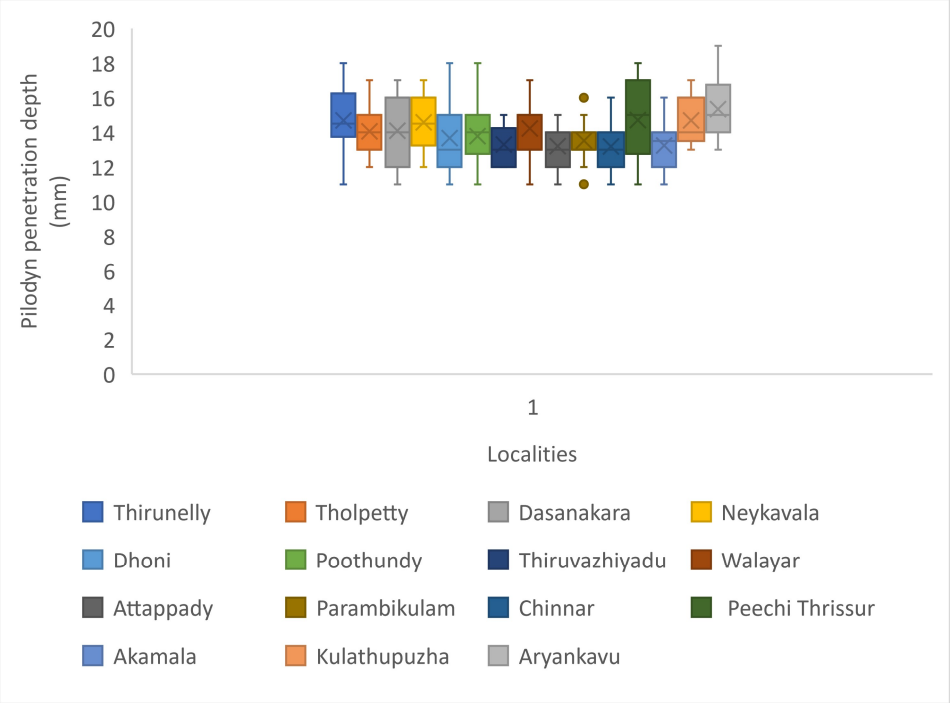


Fig. 14. Box and whisker plot showing the variations in the Pilodyn penetration depth (mm) of the outer bark of *Melia dubia* trees.

The mean of the quantitative characters for different localities is shown in Table 4. The mean height of trees in Thirunelly was observed to be the highest (27.5 m), followed by those in Kulathupuzha (25.5 m). The lowest height was observed for the trees in Attappady (17.5 m) followed by Thiruvazhiyad (17.6 m). For GBH, the highest mean value (2.7 m) was observed for trees in Tholpetty, followed by trees in Akamala (2.6 m). The lowest value of 1.7 m was observed for trees in Chinnar, followed by those in Dhoni (1.9 m). The mean crown width of the trees in Thirunelly (22.8 m) was the highest, the lowest (14.7 m) was observed for Attappady. It was observed that the mean crown width was almost similar for the trees in other localities. The clean bole height of the trees was highest for the trees in Tholpetty (8.8 m) and the lowest was for the trees in Thirunelly (7.4 m). The CBH:TH was highest for the trees in Attappady (0.47) and lowest for the trees from Thirunelly (0.28). Pilodyn penetration depth (mm), showed that not much variation existed between localities. The mean value ranged from 13 mm for Attappady, Chinnar and Akamala to 15 mm for Thirunelly, Neykavala, Peechi, Kualthupuzha

and Aryankavu. The coefficient of variation showed that the highest variation was for the character CBH:TH (50 %), followed for the trait height and GBH. The lowest CV % was observed for the traits, clean bole height and Pilodyn penetration depth.

Table 4. Mean of the quantitative characters of all located trees in different localities.

Sl. No.	Locality	Height (m)	GBH (m)	Crown width (m)	Clean bole length (m)	CBH:TH	Pilodyn penetration depth (mm)
1	Thirunelly	27.5	2.2	22.8	7.4	0.28	15
2	Tholpetty	23.9	2.7	18.7	8.8	0.37	14
3	Dasanakkara	22.8	2.3	17.2	8.2	0.35	14
4	Neykavala	21.6	2.2	18.5	8.5	0.40	15
5	Dhoni	20.4	1.9	17.4	7.8	0.39	14
6	Poothundy	20.1	2.1	17.9	8.1	0.42	14
7	Attappady	17.5	2.1	14.7	8.3	0.47	13
8	Thiruvazhiyad	17.6	2.1	18.3	7.9	0.38	14
9	Walayar	22.0	2.3	19.6	8.2	0.38	13
10	Parambikulam	18.0	2.1	17.3	8.2	0.37	14
11	Chinnar	17.9	1.7	17.2	8.2	0.46	13
12	Peechi	22.9	2.2	18.0	7.8	0.34	15
13	Akamala	22.8	2.6	17.8	8.0	0.32	13
14	Kulathupuzha	25.5	2.1	18.3	8.0	0.37	15
15	Aryankavu	21.0	2.2	17.8	7.7	0.40	15
Mean		**21.4**	**2.2**	**18.1**	**8.08**	**0.38**	**14.05**
CV %		**47**	**36**	**54**	**17**	**50**	**14**

4.1.2. Correlation between quantitative characters

The correlation between the quantitative characters of all the trees is shown in Table. 5. The result showed that the height of the tree was significantly correlated with GBH, crown width, clean bole height at 1 per cent probability level. Girth at breast height (GBH) was observed to be positively correlated with crown width, CBH and negatively correlated with CBH:TH at 1 per cent probability level. Crown width was observed to be negatively correlated with CBH:TH. Clean bole height was found to be positively correlated with CBH:TH.

Table 5. Correlations matrix of quantitative characters of all trees in different localities

	Height (m)	**GBH (m)**	**Crown width (m)**	**Clean bole height (m)**	**CBH:TH**	**Pilodyn penetration depth (mm)**
Height (m)	1					
GBH (m)	.537**	1				
Crown width (m)	.244**	.335**	1			
Clean bole height (m)	.179**	.200**	.038	1		
CBH:TH	-.593**	-.284**	-.161**	.652**	1	
Pilodyn penetration depth (mm)	.016	-.068	-.005	-.051	-.062	1

**. Significant at the 1 % probability level

4.1.3. Qualitative characters

The median scores for the qualitative characters of all the trees located in different localities is given in Table 6. For the characters such as verticality, straightness, forking, foliar damage, stem damage and cross section of the trees, branch angle and thickness and self pruning ability, it was observed that the variations were very less among the trees located. Maximum variations were shown for the character apical dominance, and bole swelling. Appendix IV showed that the highest score (52) was for the tree PBM-53 located in Parambikulam, but the tree was not selected as plus tree since it fell below the regression line due to its poor quantitative character. The tree PCI-05 had the lowest score (27). The values showed that not much variations existed for the qualitative character of the trees. The highest median value for the total score (38) was observed for the trees in Aryankavu. The lowest median value (32) was observed for the trees in Thirunelly.

Table 6. Median of the qualitative characters of all located trees in different localities

Sl. No.	Locality	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
1	Thirunelly	1	3	1	3	6	7	3	2	4	2	2	32
2	Tholpetty	1	3	1	3	6	7	3	2	4	1	2	35
3	Dasanakkara	1	3	1	3	6	7	3	2	4	1	2	35
4	Neykavala	1	3	1	3	6	7	3	2	4	1	1	36
5	Dhoni	1	3	1	3	6	7	3	2	4	1	1	36
6	Poothundy	1	3	1	3	6	7	3	2	4	1	2	36
7	Attappady	1	3	5	3	6	7	3	2	4	1	2	36
8	Thiruvazhiyad	1	3	5	3	6	7	3	2	4	1	2	36
9	Walayar	1	3	1	3	6	7	3	2	4	1	1	36
10	Parambikulam	1	3	5	3	6	7	3	2	4	1	2	37
11	Chinnar	1	3	5	3	6	7	3	2	4	1	2	37
12	Peechi	1	3	3	3	6	7	3	2	4	1	2	35
13	Akamala	1	2	1	3	6	7	3	2	4	1	2	34
14	Kulathupuzha	1	3	1	3	6	7	3	2	4	1	2	36
15	Aryankavu	1	3	1	4	6	7	3	2	4	1	1	38

4.2. Selection of plus trees

The result of the regression analysis (Figure 15) for the trees in Thirunelly, Begur Forest Range showed that the regression ($r=0.57$) is significant ($p<0.01$). It was observed that among the twenty two trees located, seven trees (TNI-03, TNI-04, TNI-09, TNI-10, TNI-11, TNI-13 and TNI-15) fell above the regression line. Two trees were selected as plus trees (TNI-03 and TNI-09), as the total score for the qualitative characters of the selected trees were 44 and 42 respectively (Appendix III). The trees TNI-04, TNI-10, TNI-11, TNI-13 and TNI-15 had scores 32, 31, 38, 29 and 34 respectively and thus were rejected. In Tholpetty forest, the regression analysis showed that the regression is significant ($r=0.53$, $p<.01$). The graph (Figure 16) showed that eight trees TPY-03, TPY-04, TPY-05, TPY-08, TPY-09, TPY-10 and TPY-15 were above the regression line. The total score for the qualitative characters of trees TPY-06 and TPY-09 had a value of 51 and 46 respectively and the trees were selected as plus trees. The trees numbered TPY-03, TPY-04, TPY-05, TPY-06, TPY-08, TPY-10 and TPY-15 had a lower value of 38, 30, 31, 44, 32, 33 respectively, hence were rejected. Similarly, the trees in Dasanakara forest area of the Chedaleth Forest Range showed significant variation, $r=0.53$, $p<.01$ and the four trees (Figure 17) fell above the regression line (DKA-01, DKA-06, DKA-07 and DKA-10). The tree DKA-10 had a score of 47 for the qualitative characters and was selected. As the score for the qualitative characters of the tree numbered DKA-01, DKA-06, DKA-07 were found to be lower 30, 29 and 31 respectively they were not selected. Regression was significant ($r=0.57$, $p<.01$) for the trees in the Neykavala forest of the Chedaleth Forest Range. The graph (Figure 18) showed that five trees were above the line, NKA-01, NKA-02, NKA-03, NKA-08 and NKA-11. Tree numbered NAK-01 was having higher score for qualitative characters (49) so it was selected as a plus tree. The trees NKA-02, NKA-03, NKA-08 and NKA-11 had a score of 37, 33, 29 and 39 respectively, so they were rejected. For the trees in Dhoni forest of the Olavakode Forest Range in Palakkad it was observed that regression was significant ($r= 0.054$, $p<0.01$) and the Figure 19 showed that three trees DHI-01, DHI-03 and DHI-08 were above the regression line. The score for the qualitative

characters for DHI-03 was the highest 44, so it was selected as plus tree. The scores for the trees DHI-01 and DHI-08 were 37 so both trees were rejected. Similarly, for the trees in the Poothundy forest area in the Nenmara Forest Range, among the eighteen trees enumerated, the r^2 value was 0.57, $p<.01$ and therefore significant. The graph (Figure 20) showed that five trees PDI-06, PDI-07, PDI-10, PDI-12 and PDI-13 were above the regression line. PDI-10 was selected as the plus tree as the qualitative score was higher 44 for this tree compared to the other trees. The scores for the trees PDI-06, PDI-07, PDI-12, PDI-13 were 30, 32, 37 and 31 respectively so they were rejected. The regression coefficient value was high ($r= 0.77$, $p<0.01$)), for the trees located in Attappady. The regression graph of the trees from different forest areas in Attappady showed (Figure 21) that four trees ATY-01, ATY-08, ATY-09 and ATY-10 fell above the regression line. The total score for the qualitative characters for the tree ATY-09 was 42 and hence, it was selected. The score for the trees ATY-01, ATY-08 and ATY-10 were 36, 36 and 37 respectively and were not selected. For the trees in Thiruvazhiyad forest of the Nenmara Forest Range regression was significant, $r=0.62$, $p<0.01$. Four trees TUD-01, TUD-04 and TUD-07 and TUD-08 were above the regression line (Figure 22). Trees TUD-04 and TUD-07 had a higher score of 45 and 41 respectively, whereas the scores for the qualitative characters of trees TUD-01, TUD-08 were 34 and 30 respectively so they were not selected. The regression was significant for trees located in the Walayar forest ($r=0.56$, $p<0.01$). The regression graph (Figure 23) showed that six trees (WLY-02, WLY-04, WLY-05, WLY-11, WLY-13 and WLY-14) fell above the regression line. Trees WLY-04 and WLY-14 were selected as the score for the qualitative characters were higher 43 and 44 respectively. The scores for the trees WLY-02, WLY-05, WLY-11 and WLY-13 were 29, 35, 31 and 38 respectively and hence were not selected. High regression coefficient value ($r=0.77$) was observed for the trees located in the forest areas of Parambikulam Wildlife Sanctuary and they were significant as well ($p<0.01$). Twenty six trees were found above the regression line as in Figure 24. Trees numbered PBM-12, PBM-26 and PBM-30 were selected based on the total score for the qualitative tree characteristics. The values were 49, 42 and 44 respectively. They also had higher values for trunk volume (dbh squared

x height) (Appendix II) so they were selected. The other trees PBM-04, PBM-05, PBM-06, PBM-07, PBM-08, PBM-09, PBM-10, PBM-11, PBM-13, PBM-16, PBM-17, PBM-19, PBM-23, PBM-31, PBM-34, PBM-35, PBM-40, PBM-42, PBM-43, PBM-46, PBM-47, PBM-48 and PBM-51 had values 35, 33, 32, 35, 36, 30, 31, 36, 34, 34, 38, 35, 30, 32, 31, 37, 35, 31, 37, 39, 38, 37 and 33 respectively. As the values for the qualitative characters were lower for these trees they were not selected as plus trees. For the trees in Chinnar Wildlife Sanctuary the regression coefficient was high, $r=0.6$, $p<0.01$. The graph (Figure 25) showed that twenty four trees fell above the regression line, but the trees numbered CNR-42, CNR-46 and CNR-48 were selected based on the score for the qualitative characters. They had values 45, 41 and 41 respectively. The other trees above the regression line, CNR-04, CNR-05, CNR-06, CNR-07, CNR-08, CNR-09, CNR-10, CNR-11, CNR-12, CNR-13, CNR-15, CNR-16, CNR-17, CNR-19, CNR-20, CNR-23, CNR-26, CNR-27, CNR-30, CNR-36, CNR-5 having the score for the qualitative characters 31, 37, 33, 38, 35, 35, 37, 33, 33, 39, 38, 36, 30, 37, 39, 33, 36, 35, 36, 38 and 33 respectively.

Similarly, for the trees in the Peechi forest of the Peechi-Vazhani Wildlife Sanctuary the regression, $r=0.52$, $p<0.01$ observed were significant. The graph (Figure 26) showed that among ten trees, PCI-07, PCI-08 and PCI-09 were observed to be above the regression line. Two trees were selected among these three trees, as the score for the qualitative characters for PCI-07 and PCI-08 were 46 and 41 respectively, while the score for PCI-09 was less than 32. The regression analysis ($r=0.56$, $p<0.01$) for the trees in the Akamala forest in Machad Forest Range showed that 7 trees AKA-02, AKA-03, AKA-04, AKA-05, AKA-06, AKA-07 and AKA-12 fell above the regression line out of the total twelve trees located (Figure 27). From this region, tree AKA-12 was selected as the plus tree as the score for the qualitative characters was more for this tree (46), when compared to the scores for other trees AKA-02, AKA-03, AKA-04, AKA-05, AKA-06 and AKA-07 which were 32, 35, 32, 25, 34, and 36 respectively. For the trees in Kulathupuzha and Arippa forests the regression analysis ($r=0.59$, $p<0.01$) showed that 7 trees KPA-04, KPA-05, KPA-07, KPA-09,

KPA-10, KPA-12 and KPA-13 fell above the regression line. The total score for the qualitative characters for KPA-04 was higher (49), when compared to trees KPA-05 (37), KPA-07 (38), KPA-09 (38), KPA-10 (26), KPA-12 (32) and KPA-13 (36), hence tree KPA-04 was selected as plus tree (Figure 28). Similarly, the regression analysis ($r=0.79$, $p<0.01$) showed high correlation of trees in the Aryankavu forest area. The graph (Figure 29) showed that the tree numbered AYU-02, AYU-03, AYU-04, AYU-06, AYU-11 and AYU-12 fell above the regression line. The score for the qualitative characters of the selected trees AYU-06 and AYU-12 were 45 and 42 respectively. They were found to be highest. The scores for the trees AYU-02, AYU-03, AYU-04, AYU-11 and AYU-12 were 33, 35, 37 and 33 respectively so they were not selected. From 15 localities 25 plus trees were selected (Plate 16). The details of the plus trees are given in Table 7.

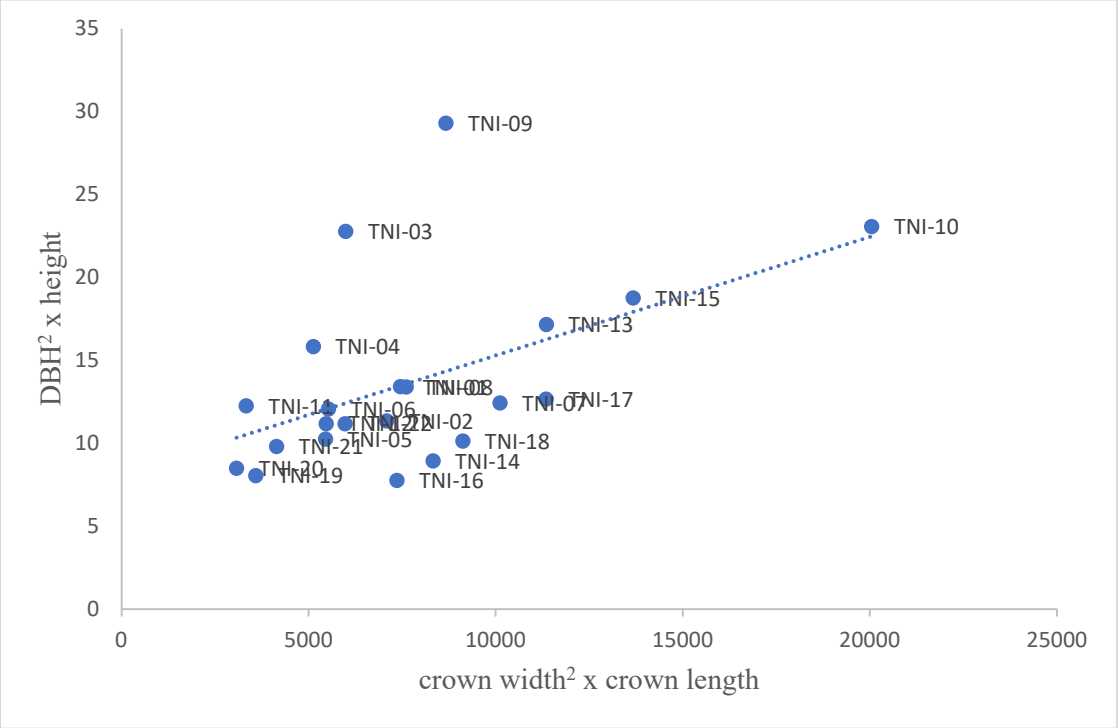


Fig 15. Regression graph of all the *Melia dubia* trees located at Thirunelly

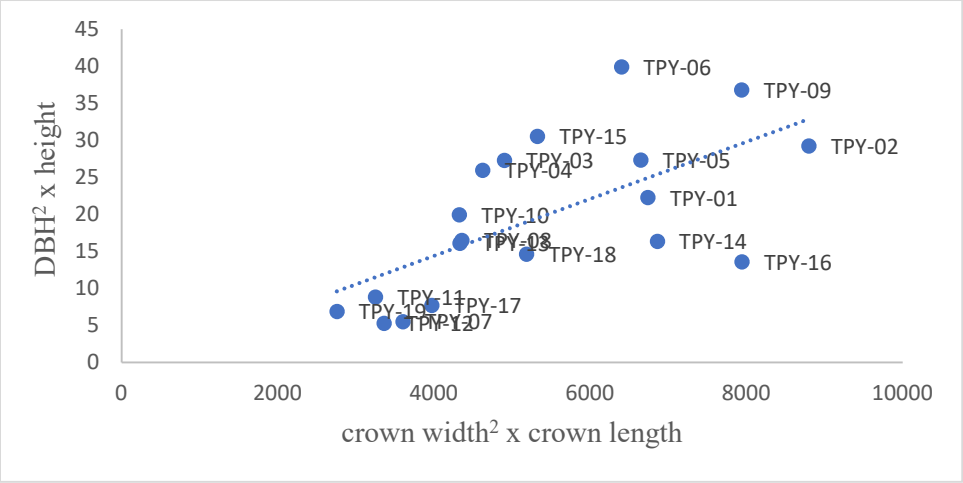


Fig 16. Regression graph of all the *Melia dubia* trees located at Tholpetty

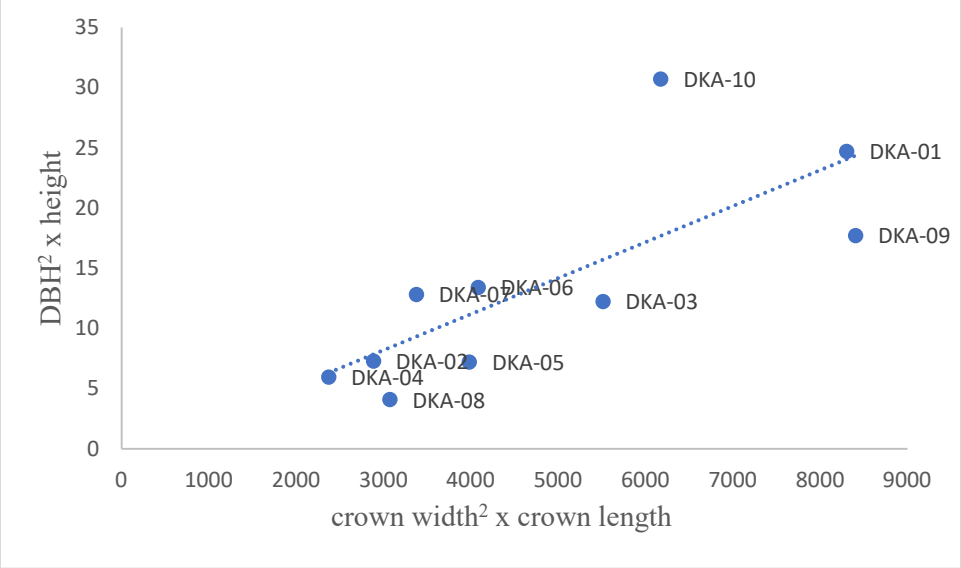


Fig 17. Regression graph of all the *Melia dubia* trees located at Dasanakara

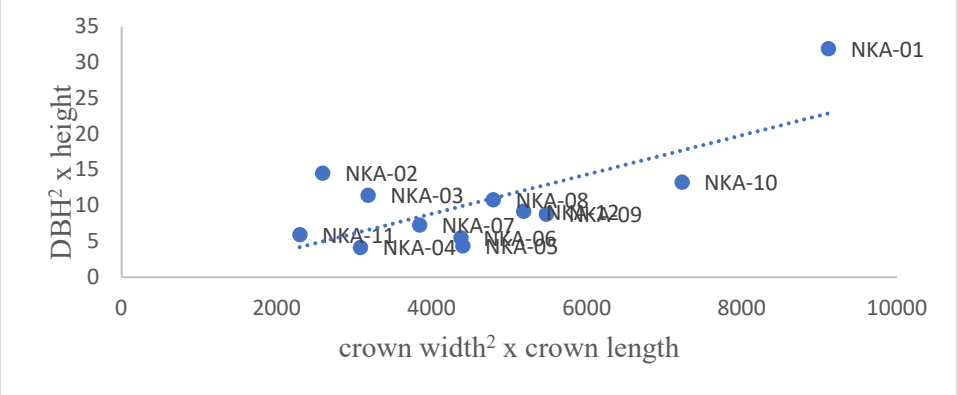


Fig 18. Regression graph of all the *Melia dubia* trees located at Neykavala

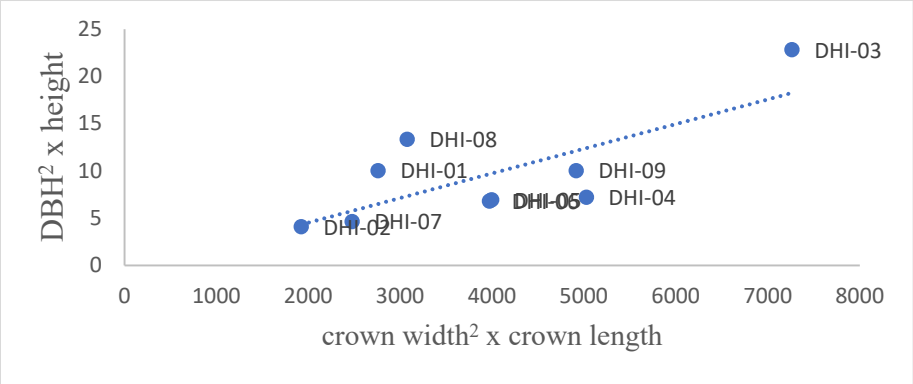


Fig 19. Regression graph of all the *Melia dubia* trees located at Dhoni

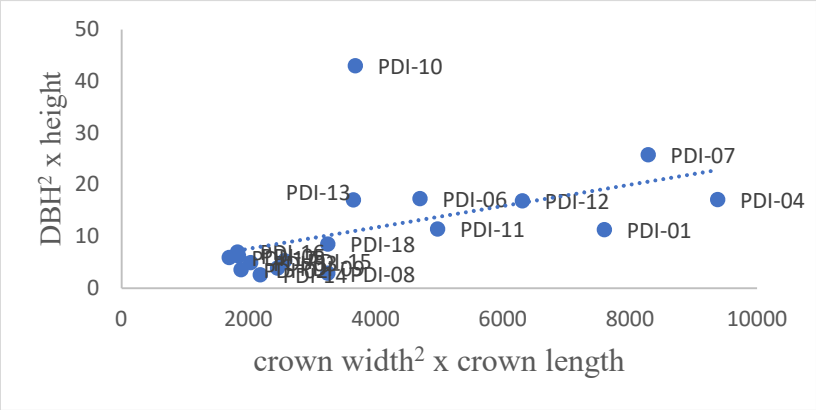


Fig 20. Regression graph of all the *Melia dubia* trees located at Poothundy

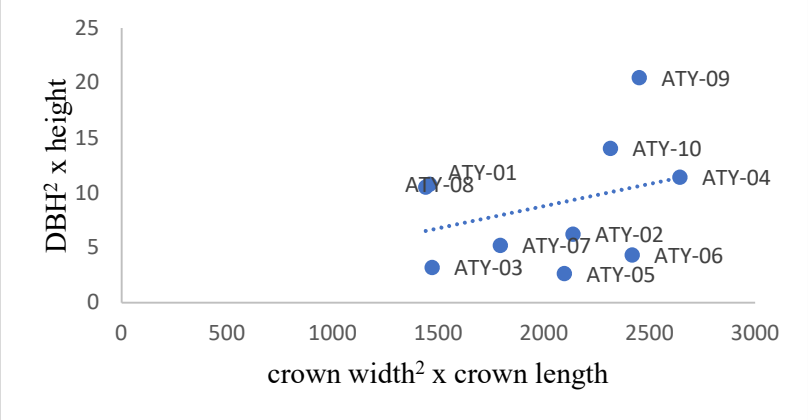


Fig 21. Regression graph of all the *Melia dubia* trees located at Attappady

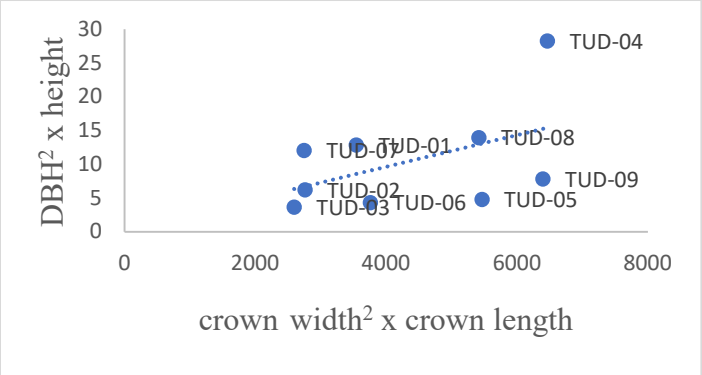


Fig 22. Regression graph of all the *Melia dubia* trees located at Thiruvazhiyad

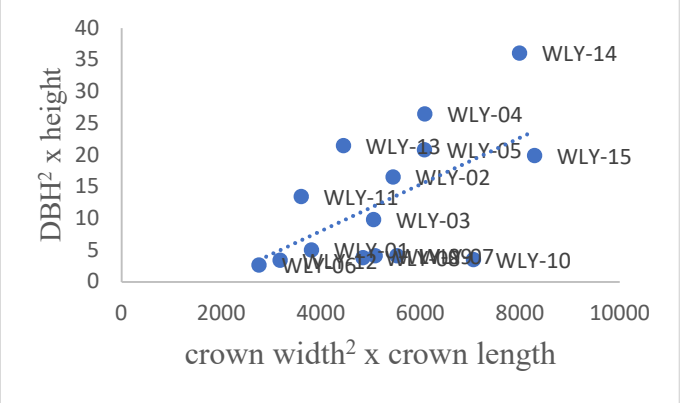


Fig 23. Regression graph of all the *Melia dubia* trees located at Walayar

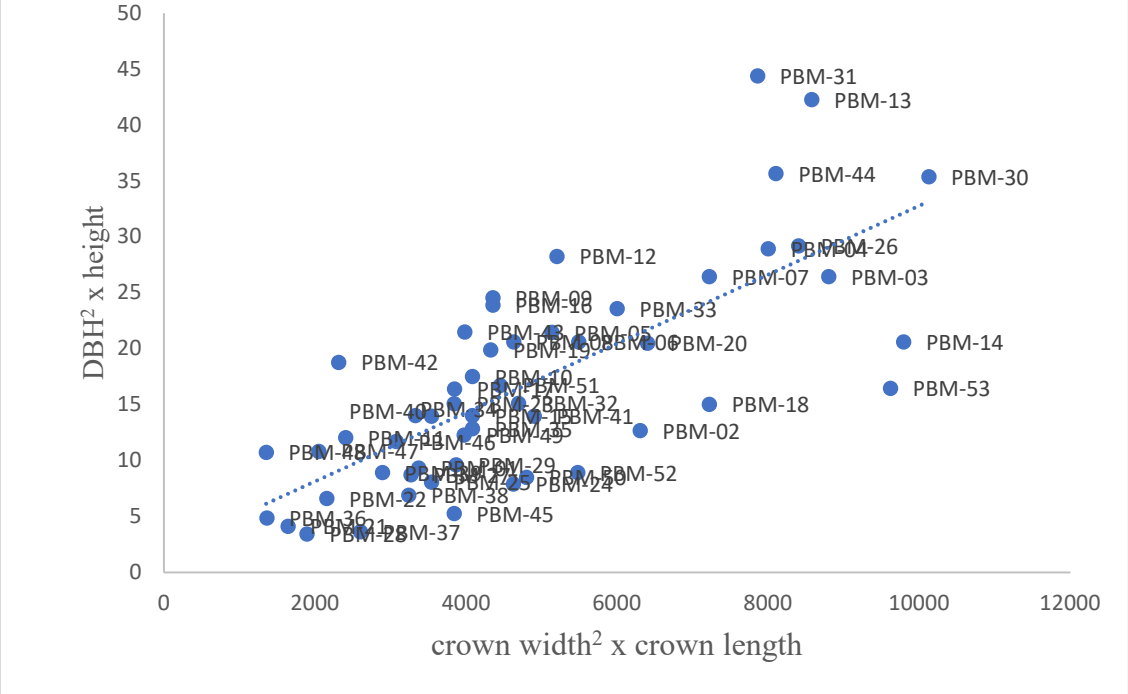


Fig 24. Regression graph of all the *Melia dubia* trees located at Parambikulam

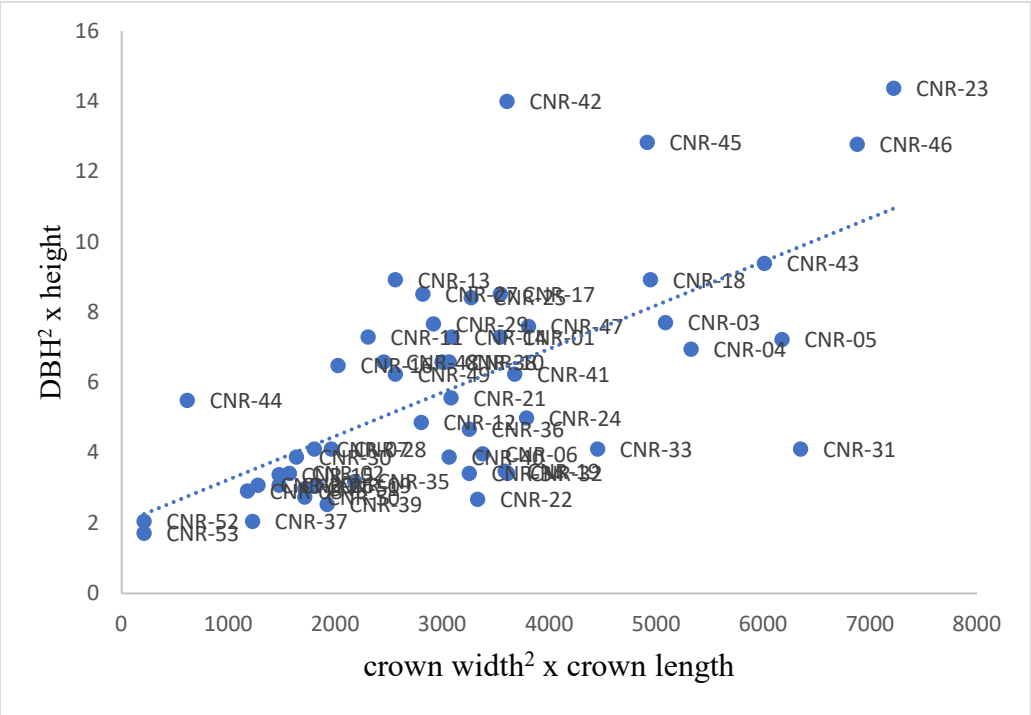


Fig 25. Regression graph of all the *Melia dubia* trees located at Chinnar

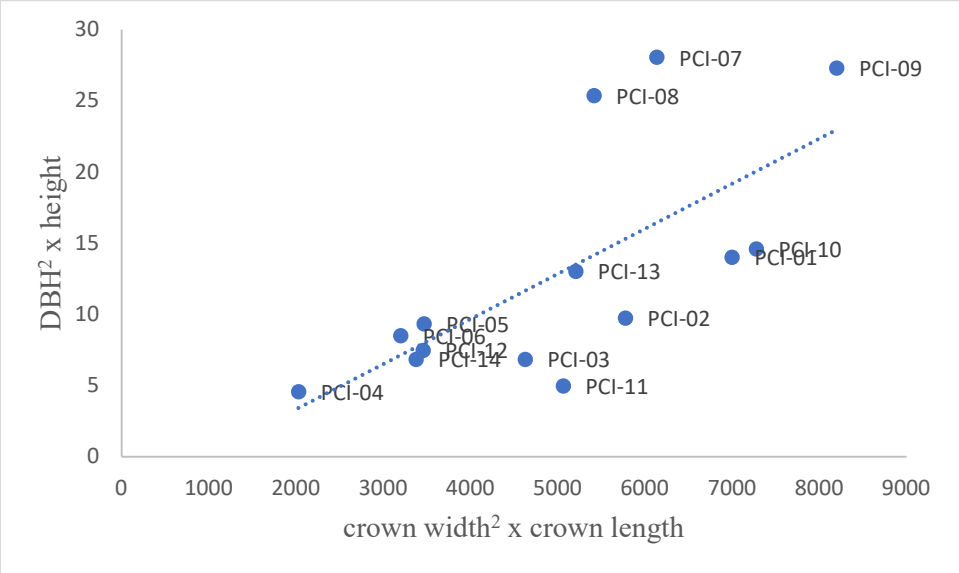


Fig 26. Regression graph of all the *Melia dubia* trees located at Peechi

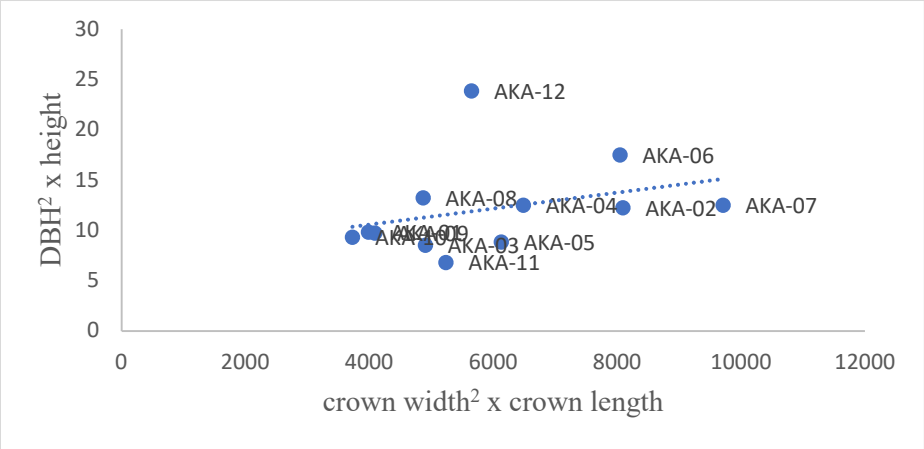


Fig 27. Regression graph of all the *Melia dubia* trees located at Akamala

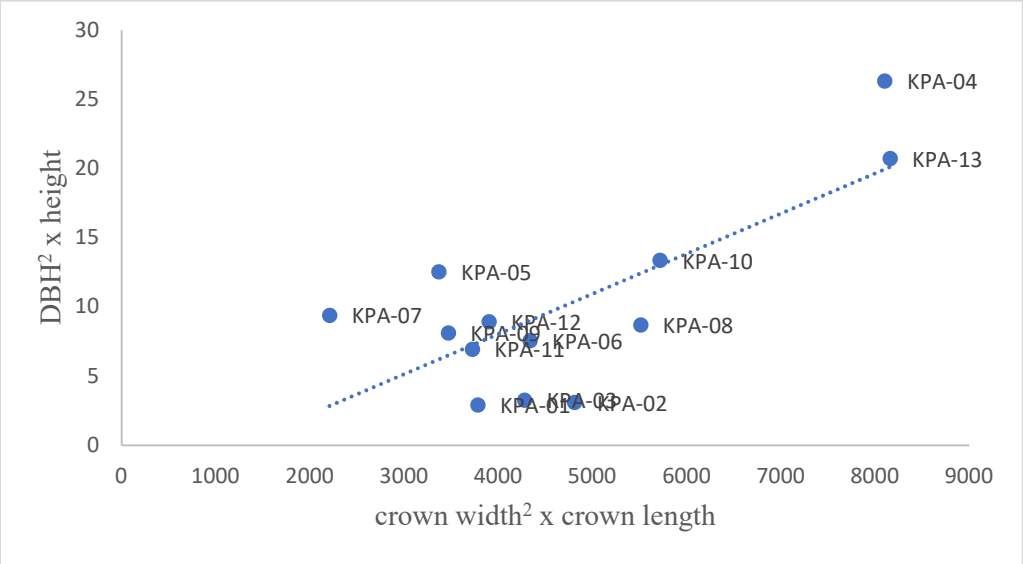


Fig 28. Regression graph of all the *Melia dubia* trees located at Kulathupuzha

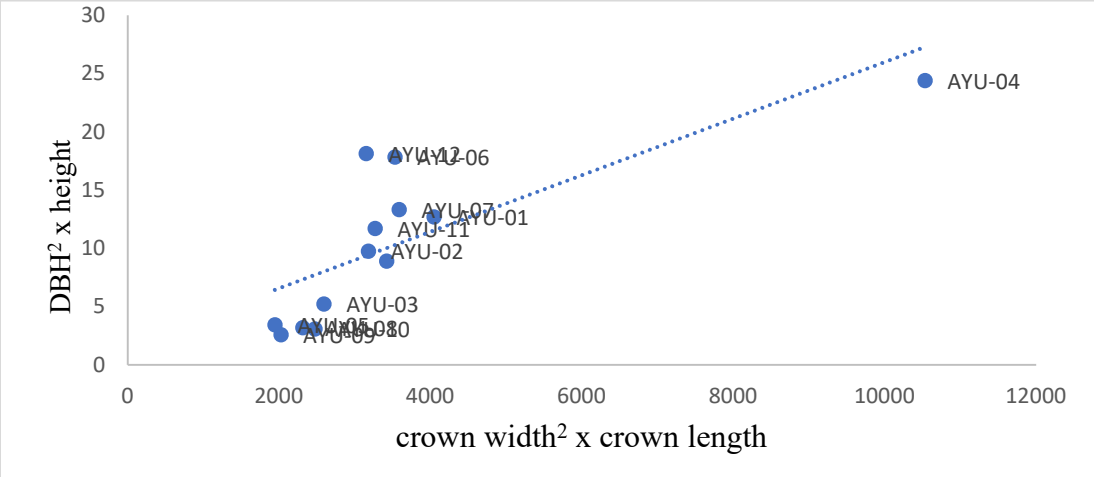


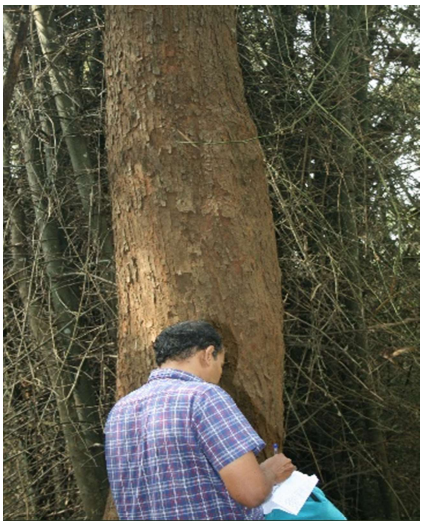
Fig 29. Regression graph of all the *Melia dubia* trees located at Aryankavu

Plate 16. Plus trees selected from different localities

FCV-MD-01-Thirunelly

FCV-MD-02-Thirunelly

FCV-MD-03-Tholpetty



FCV-MD-04-Tholpetty

FCV-MD-05-Dasanakara

FCV-MD-06-Neykavala

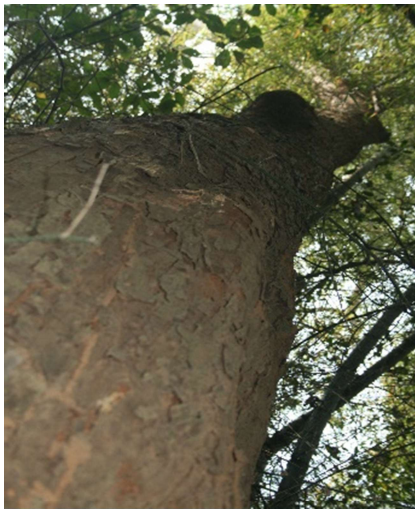
FCV-MD-07-Dhoni

FCV-MD-08-Poothundy

FCV-MD-09-Attappady

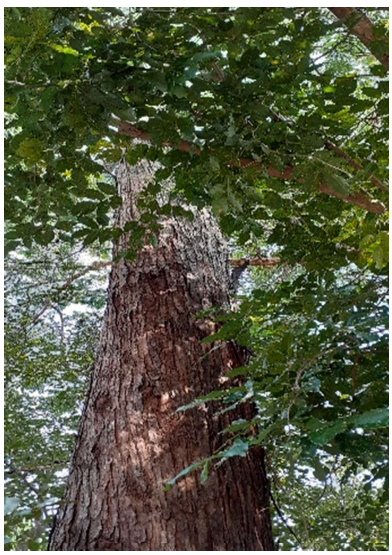


FCV-MD-10-Thiruvazhiyadu FCV-MD-11- Thiruvazhiyadu FCV-MD-12-Walayar


FCV-MD-13-Walayar FCV-MD-14-Parambikulam FCV-MD-15- Parambikulam





FCV-MD-16-Parambikulam FCV-MD-17-Chinnar FCV-MD-18-Chinnar

FCV-MD-19-Chinnar

FCV-MD-20-Peechi

FCV-MD-21-Peechi

FCV-MD-22-Akamala

Table 7. Details of the twenty five selected plus of *Melia dubia* trees from different localities.

Sl. No.	Locality	Range/WLS	Tree Id. No.	Accession No.	Location	Height (m)	GBH (m)
1	Thirunelly	Begur	TNI-03	FCV-MD-01	11°54'16.9" 75.59°'59.77"	32	2.65
2			TNI-09	FCV-MD-02	11°54'37.68" 76°00'02.40"	33	2.96
3	Tholpetty	Tholpetty WLS	TPY-06	FCV-MD-03	11°47'46.90" 76°05'04.10"	28	3.75
4			TPY-09	FCV-MD-04	11°53'13.20" 76°04'34.70"	28	3.60
5	Dasanakara	Chedelthu	DKA-10	FCV-MD-05	11°52'53.10" 76°04'39.20"	27	3.35
6	Neykavala	Chedelthu	NKA-01	FCV-MD-06	11°25'32.10" 76°06'02.30"	28	3.45
7	Dhoni	Olavakode	DHI-03	FCV-MD-07	10°27'02.10" 76°12'24.30"	22	3.20
8	Poothundy	Nelliampathy	PDI-10	FCV-MD-08	10°31'00.92" 76°37'00.28"	24	4.20
9	Attappady	Agali	ATY-09	FCV-MD-09	11°05'30.50" 76°43'23.50"	21	3.10
10	Thiruvazhiyadu	Nelliampathy	TUD-04	FCV-MD-10	10°31'15.20" 76°36'18.70"	29	3.50
11			TUD-07	FCV-MD-11	10°31'01.90" 76°36'30.40"	19	2.5
12	Walayar	Walayar	WLY-04	FCV-MD-12	10°51'35.90" 76°37'15.70"	28	3.05
13			WLY-14	FCV-MD-13	10°51'33.50" 76°37'27.10"	29	3.50
14	Parambikulam	Karimala Sungam	PBM-12	FCV-MD-14	10°22'56.90" 76°45'45.01"	32	2.95
15			PBM-26	FCV-MD-15	10°26'41.3" 76°49'35.90"	29	3.15
16			PBM-30	FCV-MD-16	10°24'40.40" 76°49'35.30"	32	3.30
17	Chinnar	Chinnar WLS	CNR-42	FCV-MD-17	10°21'16.20" 77°11'32.20"	23	2.45
18			CNR-46	FCV-MD-18	10°21'16.20" 77°11'29.60"	21	2.10
19			CNR-48	FCV-MD-19	10°21'13.50" 77°11'38.20"	21	2.45
20	Peechi Thrissur	Pattikkad Peechi Vazhani WLS	PCI-07	FCV-MD-20	10°31'56.20" 76°22'26.20"	27	3.20
21			PCI-08	FCV-MD-21	10°29'01.00" 76°22'00.01"	26	3.10
22	Akamala	Machad	AKA-12	FCV-MD-22	10°40'46.10" 76°18'10.30"	28	2.90
23	Kulathupuzha	Kulathupuzha	KPA-04	FCV-MD-23	08°50'36.80" 77°02'53.2"	27	3.10
24	Aryankavu	Aryankavu Thenmala	AYU-06	FCV-MD-24	08°51'22.3" 77°08'48.60"	26	2.60
25			AYU-12	FCV-MD-25	08°55'55.40" 77°08'38.70"	22	2.85

4.3. Diversity analysis of the plus trees

4.3.1. Cluster analysis

Hierarchical cluster analysis using the average linkage method was employed to classify the plus trees (Figure 30). All the quantitative characters of the tree, such as height, GBH, crown width, clean bole height, CBH:TH, pilodyn penetration depth, were considered for the classifications, while the qualitative characters considered were verticality, apical dominance, straightness, self pruning ability, forking, branch angle, branch thickness, cross section, foliar, stem damage, bole swelling. Based on these tree characters the dendrogram was formulated. Details of the eleven clusters are given in Table 8. Trees in the same cluster have similar morphological characters whereas the characters differed between two clusters. The result of the analysis showed that the twenty five genotypes of *Melia dubia* collected from different locations grouped into eleven clusters. Cluster I and II were the biggest cluster with seven members each. The seven members of cluster I were FCV-MD-01, FCV-MD-02, FCV-MD-04, FCV-MD-13, FCV-MD-15, FCV-MD-16 and FCV-MD-20, whereas the seven members of the cluster II were FCV-MD-03, FCV-MD-05, FCV-MD-06, FCV-MD-10, FCV-MD-12, FCV-MD-22 and FCV-MD-23. Two plus trees each from Thirunelly (FCV-MD-01, FCV-MD-02) and Parambikulam (FCV-MD-15, FCV-MD-16) clustered in cluster I. Cluster VIII and cluster IX had two members each. All the other clusters (III, IV, V, VI, X and XI) had only one plus tree in the groups. The average height, GBH, crown width, clean bole height, CBH:TH and pilodyn penetration depth of plus trees in cluster I, was 30 m, 3.19 m, 19.64 m, 9.57 m, 0.32, 13.39 mm respectively (Table 9). The average height of the trees observed in this cluster was the highest. The average height, GBH, crown width, clean bole height, CBH:TH and pilodyn penetration depth of the plus trees in cluster II was 27.86 m, 3.3 m, 20.93 m, 12.21 m, 0.44, 13.71 mm respectively. The lowest height was observed for the tree in cluster VI. The highest value for the GBH (4.2 m) was observed for the plus tree in cluster IV and the lowest average value for the GBH (2.3 m) was observed for the trees in the cluster IX. The highest average value for the crown width (22.3 m) was observed for the plus trees in the cluster IX, this was followed by the value (22 m) for the

tree in the cluster III. For bole height the tree in cluster VII showed highest value (14 m) and lowest (5 m) was observed for the tree in cluster VI. CBH:TH value was highest (0.57) for the tree in cluster V and lowest value (0.26) was observed for the tree in cluster VI. The highest value for the pilodyn penetration depth (19 mm) was observed for the tree in cluster XI. The lowest value (12 mm) was observed for the tree in cluster VII and X. The average value for height, GBH, crown width, clean bole height, CBH:TH and pilodyn penetration depth of the plus trees in all the clusters was 24.67 m, 3.01 m, 18.02 m, 9.71 m, 0.4 and 14.14 mm respectively. The coefficient of variation values showed that the variations were high for all the characters. The highest CV % value was observed for the character clean bole height (92 %). The CV % was comparatively low for the characters height and crown width.

The mean intra and inter cluster distances are given in Table 10. Intra cluster distance gives the mean distance between the elements within a cluster, whereas the distance between the two clusters gives the inter cluster distance. The diagonal elements show the intra cluster distances and the off-diagonal elements show the inter cluster distances. It is observed that intra cluster distances varied from 0.0 to 3.74. Highest intra cluster value was obtained for cluster I (3.74) followed by cluster II (3.09), cluster VIII (2.61) and cluster IX (1.45). No intra cluster distance was observed for clusters III, IV, V, VI, VII, X and XI as they contained only one family. From the inter cluster distance, it was observed that the cluster I and II (5.54) were similar while the dissimilarity was more between cluster VI and XI (17.42) followed by cluster VI and cluster VII (17.04) as the inter cluster distance was observed were more.

Figure 30. Dendrogram on the morphological characteristics of the twenty five plus trees of *Melia dubia*

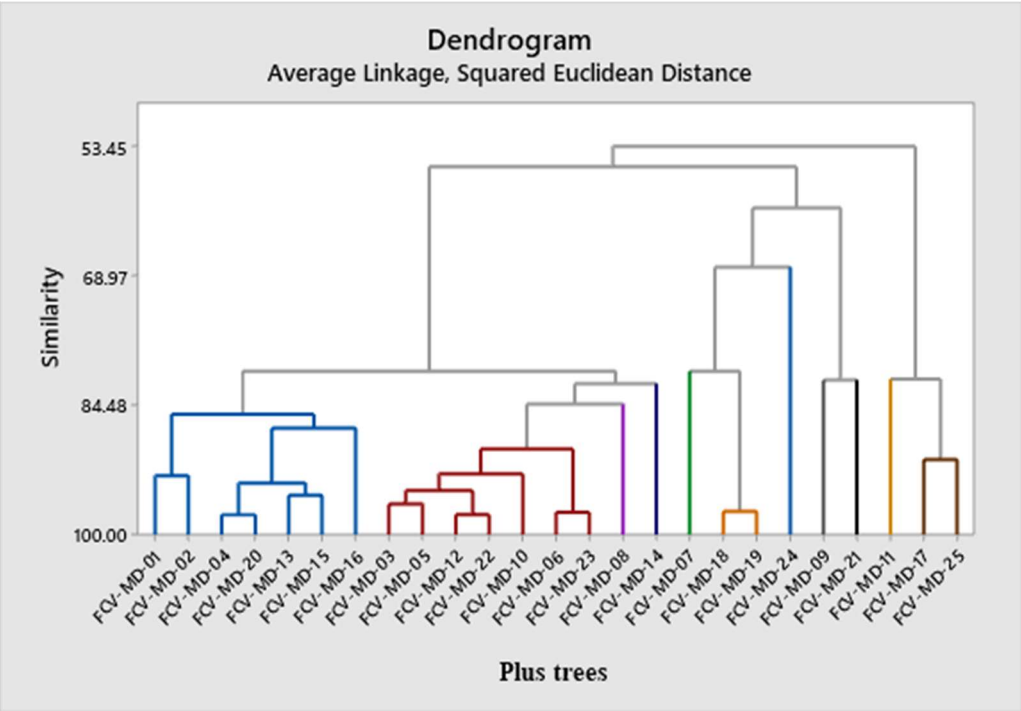


Table 8. Clusters formed by the twenty five plus trees based on their morphological characteristic using dendrogram.

Cluster 1	FCV-MD-01, FCV-MD-02, FCV-MD-04, FCV-MD-13, FCV-MD-15, FCV-MD-16, FCV-MD-20
Cluster 2	FCV-MD-03, FCV-MD-05, FCV-MD-06, FCV-MD-10, FCV-MD-12, FCV-MD-22, FCV-MD-23
Cluster 3	FCV-MD-07
Cluster 4	FCV-MD-08
Cluster 5	FCV-MD-09
Cluster 6	FCV-MD-11
Cluster 7	FCV-MD-14
Cluster 8	FCV-MD-17, FCV-MD-25
Cluster 9	FCV-MD-18, FCV-MD-19
Cluster 10	FCV-MD-21
Cluster 11	FCV-MD-24

Table 9. Mean of the quantitative characters of the plus trees in different clusters

	Height (m)	**GBH (m)**	**Crown width (m)**	**Clean bole length (m)**	**CBH:TH**	**Pilodyn penetration index (mm)**
Cluster 1	30.00	3.19	19.64	9.57	0.32	13.29
Cluster 2	27.86	3.3	20.93	12.21	0.44	13.71
Cluster 3	22.00	3.2	22.00	7.0	0.32	13.0
Cluster 4	24.00	4.2	17.5	12.0	0.5	14.0
Cluster 5	21.00	3.1	16.5	12.0	0.57	15.0
Cluster 6	19.00	2.5	14.0	5.0	0.26	15.0
Cluster 7	32.00	2.95	17.0	14.0	0.44	12.0
Cluster 8	22.5	2.7	15.3	8.0	0.4	15.0
Cluster 9	21.00	2.3	22.3	8.0	0.4	13.5
Cluster 10	26.00	3.1	19.0	11.0	0.42	12.0
Cluster 11	26.00	2.6	14.0	8.0	0.31	19.0
Mean	**24.67**	**3.01**	**18.02**	**9.71**	**0.40**	**14.14**
CV %	**45**	**63**	**46**	**92**	**65**	**50**

Table 10. Matrix showing inter and intra cluster distance

	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**	**Cluster 6**	**Cluster 7**	**Cluster 8**	**Cluster 9**	**Cluster 10**	**Cluster 11**
Cluster 1	3.74										
Cluster 2	5.54	3.09									
Cluster 3	8.98	9.09	0.00								
Cluster 4	8.34	6.12	8.79	0.00							
Cluster 5	13.83	10.88	12.26	8.26	0.00						
Cluster 6	13.55	14.20	9.30	10.83	12.03	0.00					
Cluster 7	7.13	6.36	14.00	9.32	13.61	17.04	0.00				
Cluster 8	8.56	9.80	9.01	8.04	11.26	7.06	11.77	2.61			
Cluster 9	11.73	11.62	7.58	10.29	10.88	11.69	16.14	11.75	1.45		
Cluster 10	8.96	7.41	10.35	8.09	7.50	13.32	9.44	10.52	9.42	0.00	
Cluster 11	12.43	10.73	11.80	11.88	12.77	17.42	15.57	14.85	8.62	10.45	0.00

4.3.2. Principal component analysis (PCA)

PCA analysis was done to emphasize the variations and to observe the strong relations in the data set of independent variables. Scree plot showed that four components had eigenvalue greater than one (Figure 31). The explanation was done with two components only (Table 11). These two components accounted for 42 per cent of the total variability. PC 1 accounted for 22 per cent of the total variability, which was mainly contributed by the quantitative characters such as clean bole height, GBH, height and qualitative characters such as apical dominance, forking, branch angle, straightness, branch thickness, cross section and verticality with the loading of 0.51, 0.357, 0.341, 0.342, 0.251, 0.189, 0.154, 0.141, 0.143 and 0.131 respectively. PC 2 accounted for 20 per cent of the total variability, which was mainly contributed positively by the CBH:TH (0.413), clean bole height (0.166), crown width (0.132), Pilodyn penetration depth (0.053), apical dominance (0.38) and the contribution was negative for the characters GBH (0.033), branch thickness (0.049), self pruning ability (0.068), height (0.322).

A PCA biplot that shows both PC scores of samples and loadings of variables is shown in Fig. 32. As the vectors move away from the PC origin, the more influence they have on that PC. Loading plots also shows as how variables correlate with one another, if the angle between the variables are less than 90º, it implies that they are positively correlated. If the angle made by the variables is 180 then they are negatively correlated. If the variables are making angles other than these it implies that they are not correlated. The component loading biplot given in Fig. 32 showed that the height of the tree and GBH are closely related. Branch angle and GBH were not related. Similarly, straightness and bole swelling had a strong relationship. The components GBH, branch thickness, forking, height, verticality, cross section, straightness, branch angle explained both the components. CBH:TH, apical dominance, crown width, clean bole height explained PC 1. Pilodyn penetration depth explained PC 2. Self pruning ability and bole swelling did not explain both the components. Based on first two components of PC analysis grouping pattern was prepared. Twenty five plus trees were classified into four groups (Figure 33), which graphically represented relative positions of various plus trees. It was

observed that group III had minimum number of plus all the other groups had equal number of trees.

Table 11. Variations in the morphological characters of selected plus trees of *Melia dubia* using Principal component analysis

Variable	**PC1**	**PC2**
Height (m)	0.341	-0.322
GBH (m)	0.357	-0.033
Crown width (m)	0.139	0.132
Clean bole height (m)	0.510	0.166
CBH:TH	0.332	0.413
Pilodyn penetration index (mm)	-0.200	0.053
Verticality	0.131	-0.268
Straightness	0.154	-0.355
Apical dominance	0.342	0.380
Forking	0.251	-0.176
Branch angle	0.189	-0.406
Branch thickness	0.141	-0.049
Self pruning ability	-0.154	-0.068
Cross section	0.143	-0.317
Bole swelling	-0.080	-0.179

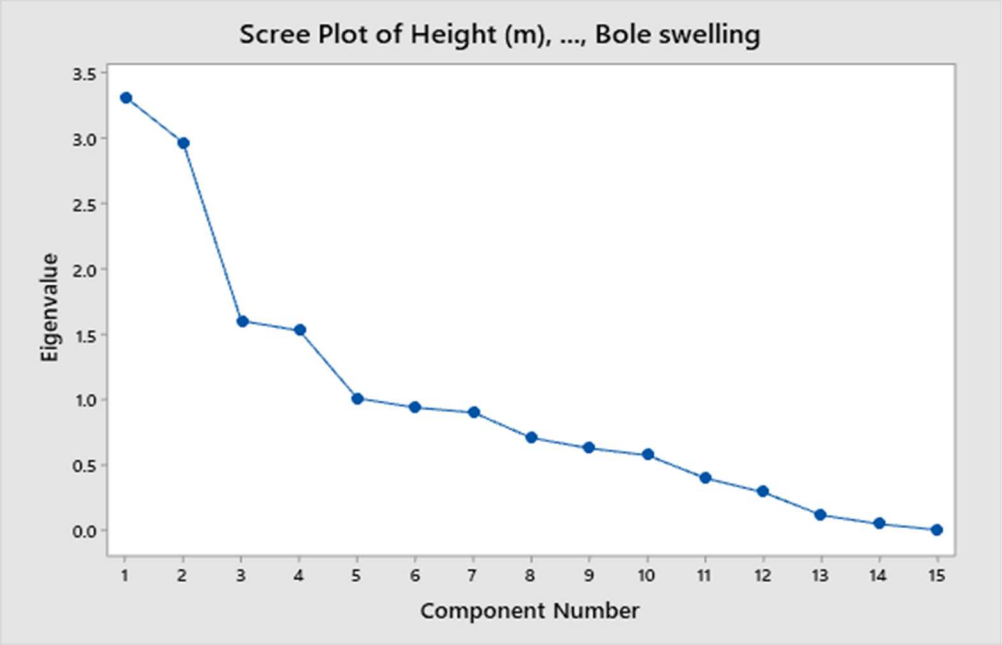


Figure 31. Scree plot of morphological characters of selected plus trees of *Melia dubia*

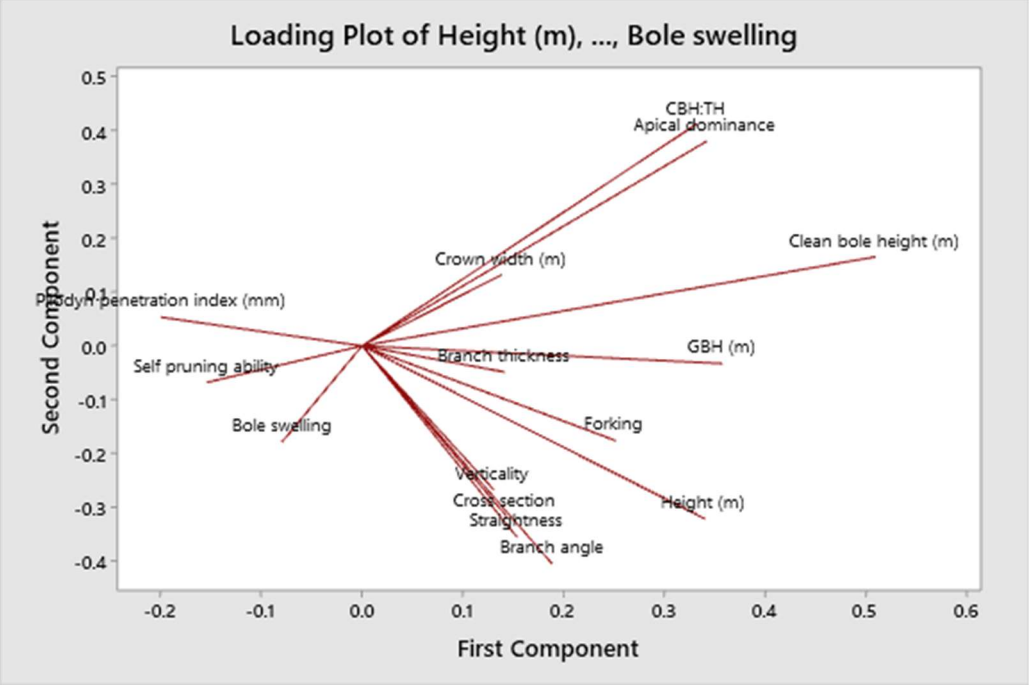


Figure 32. Loading plot of morphological characters of selected plus trees of *Melia dubia*

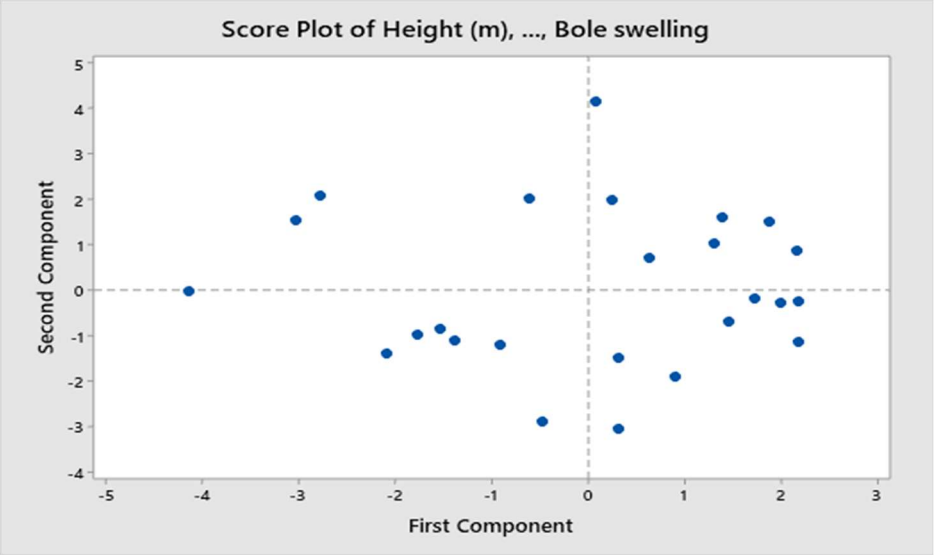


Figure 33. Grouping of 25 plus trees of *Melia dubia* based on morphological characters from first two components.

4.3.3. Selection index

The selection index value was worked out for the best plus trees based on the morphological characters of the trees using principal component analysis. The first principal component was taken as the index value for selection.

Best plus tree= 0.341 x height of the tree + 0.357 x GBH + 0.139 x crown width + 0.510 x clean bole height + 0.332 x CBH:TH - Pilodyn penetration depth x 0.2 + 0.131 x verticality + 0.154 x straightness + 0.342 x apical dominance + 0.251 x forking + 0.189 x branch angle + 0.141 x branch thickness – 0.154 x self pruning ability + 0.143 x cross section - 0.08 x bole swelling.

4.4. Progeny testing of seedlings

4.4.1. Morphological traits

4.4.1.1. Shoot height

Analysis of variance showed that the height of the seedling of the progenies from different plus trees showed significant variations over time, except for the period 60 DAT (Table 12). At 30 DAT it was observed that the progenies from all the plus tree were on par, except for the seedlings from the plus trees FCV-MD-10, FCV-

MD-17, FCV-MD-18 and FCV-MD-19. The highest value (17.4 cm) was observed for the seedlings of plus tree FCV-MD-04 from Tholpetty, FCV-MD-02 from Thirunelly (17 cm), FCV-MD-10 from Thiruvazhiyadu (17.3 cm), FCV-MD-22 from Akamala in Thrissur (17.1 cm), FCV-MD-23 from Kulathupuzha (17 cm) and FCV-MD-25 from Aryankavu (17 cm). The least height was observed for the progenies of all the plus trees collected from Chinnar (FCV-MD-17, FCV-MD-018, FCV-MD-19) and FCV-MD-10 from Thiruvazhiyadu. The values of the height of the seedlings were 13.6, 12.9, 13.7 and 13.7 cm respectively. At 60 DAT no significant difference in the height of the seedlings of plus trees selected from different region was observed. At 90 DAT the height of the seedlings was observed to be significant. The progenies of the following plus trees FCV-MD-02, FCV-MD-03, FCV-MD-04, FCV-MD-05, FCV-MD-07, FCV-MD-08, FCV-MD-11, FCV-MD-12, FCV-MD-14 and FCV-MD-22 were on par. It was observed that the seedlings of the plus trees FCV-MD-04 showed the highest value, 66.5 cm. The lowest height was observed for the progenies of plus trees FCV-MD-09 from Attappady (48.7 cm). At 120 DAT it was observed that the seedlings from the progenies of plus trees FCV-MD-03, FCV-MD-04, FCV-MD-05, FCV-MD-08, FCV-MD-11 and FCV-MD-12 were on par. The progenies of plus tree FCV-MD-04 showed the highest value (104.6 cm), followed by FCV-MD-03 (101.5 cm), both the plus trees were from Tholpetty. The lowest value (62 cm) was observed for the seedlings of plus tree FCV-MD-10 from Thiruvazhiyadu, followed by progenies from plus trees FCV-MD-17 (68.2 cm) from Chinnar. At the end of the experiment 150 DAT, it was observed that the seedlings of plus trees FCV-MD-03 and FCV-MD-04 performed well with values 199.0 cm and 198.7 cm respectively, followed with the seedlings of plus trees FCV-MD-12 (182.9 cm). The least was observed for the seedlings from plus tree FCV-MD-09 (112.2 cm), followed by seedlings from Thiruvazhiyadu, FCV-MD-10 (120.6 cm). The results showed that the progenies from the two plus trees (FCV-MD-03 and FCV-MD-04) selected from Tholpetty in Wayanad showed highest value consistently throughout the experiment. The lowest value was observed for plus tree (FCV-MD-09) from Attappady region.

Table 12. Seedling height (cm) of *Melia dubia* progenies from different plus trees at monthly intervals

Accession No.	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT
FCV-MD-01	15.8^{abcde}	27.1	56.8^{bcdefg}	87.7^{bcdef}	164.7^{bcd}
FCV-MD-02	17.0^{ab}	28.4	59.4^{abcde}	87.9^{bcdef}	164.1^{bcd}
FCV-MD-03	16.8^{abcd}	29.3	64.7^{ab}	101.5^{ab}	199.0^{a}
FCV-MD-04	17.4^{a}	30.8	66.5^{a}	104.6^{a}	198.7^{a}
FCV-MD-05	16.4^{abcd}	28.3	62.1^{abcd}	95.8^{abcd}	163.5^{bcd}
FCV-MD-06	15.8^{abcde}	28.0	57.8^{bcdef}	83.3^{defgh}	162.5^{bcd}
FCV-MD-07	15.9^{abcde}	28.0	58.5^{abcdef}	90.8^{bcdef}	165.1^{bcd}
FCV-MD-08	16.7^{abcd}	29.1	62.3^{abcd}	92.7^{abcde}	163.3^{bcd}
FCV-MD-09	14.0^{bcde}	25.2	48.7^{gh}	70.1^{ghi}	112.2^{g}
FCV-MD-10	13.7^{de}	22.9	46.9^{h}	62.0^{i}	120.6^{fg}
FCV-MD-11	17.3^{a}	28.7	62.9^{abc}	99.9^{abc}	182.9^{ab}
FCV-MD-12	16.6^{abcd}	28.4	60.8^{abcde}	96.8^{abcd}	181.3^{abc}
FCV-MD-13	16.3^{abcd}	26.6	57.9^{bcdef}	87.0^{bcdef}	160.6^{abc}
FCV-MD-14	16.0^{abcde}	26.4	60.2^{abcde}	88.7 ^{bcdef}	141.5^{def}
FCV-MD-15	15.1^{abcde}	26.0	57.7^{bcdef}	85.1^{cdefg}	141.3^{def}
FCV-MD-16	16.0^{abcde}	25.9	52.4^{efgh}	77.1^{efgh}	148.9^{de}
FCV-MD-17	13.6^{de}	22.2	50.4^{fgh}	68.2^{hi}	128.1^{efg}
FCV-MD-18	12.9^{d}	24.8	53.2^{de}	78.2^{efgh}	139.7^{def}
FCV-MD-19	13.7^{de}	23.9	54.3^{defgh}	77.2 ^{efgh}	140.3^{def}
FCV-MD-20	14.8^{abcde}	25.8	54.7^{cdefgh}	75.6^{fghi}	147.4^{def}
FCV-MD-21	16.0^{abcde}	27.5	56.1^{cdefg}	82.7^{defgh}	158.7^{bcd}
FCV-MD-22	17.1^{ab}	28.0	58.6^{abcdef}	86.7^{bcdef}	162.1^{bcd}
FCV-MD-23	17.0^{ab}	27.4	54.5^{defgh}	78.2^{efgh}	155.2^{bcde}
FCV-MD-24	15.3^{abcde}	27.1	56.7^{bcdefg}	85.5 ^{cdefg}	153.0^{cde}
FCV-MD-25	17.0^{abc}	29.1	60.5^{abcde}	85.0 ^{cdefg}	146.8^{def}
	S	NS	S	S	S

* Significant at 0.05 levels

Values with the same superscript in column at different month are homogenous

Plate 17. Progenies of the selected plus tree in the nursery at 30 DAT

Plate 18. Progenies of the selected plus tree in the nursery at 150 DAT

4.4.1.2. Collar diameter

Analysis of variance of the seedling collar diameter is presented in Table 13. The result showed that the collar diameter of the progenies from different plus trees varied significantly overtime throughout the experiment. At 30 DAT it was observed that the collar diameter of the seedlings except for the plus trees FCV-MD-11, FCV-MD-12 and FCV-MD-24, all were at par. The highest value (0.49 cm) was observed for the seedlings of plus tree FCV-MD-04, followed by the seedlings of PBM-30 (0.46 cm) from Parambikulam. The collar diameter of the seedlings of plus tree FCV-MD-11 and FCV-MD-12 showed the least value 0.31 cm. For the period 60 DAT, except for the seedlings of plus trees CNR-42, CNR-47 and FCV-MD-24 all were at par. The highest collar diameter (0.72 cm) was observed for seedlings from plus tree FCV-MD-04, followed by the value 0.71 and 0.7 for the seedlings of plus trees FCV-MD-01 and FCV-MD-03 respectively. The lowest value (0.57 cm) was observed for the seedlings of plus tree from Chinnar (FCV-MD-17 and FCV-MD-19) from Akamala, FCV-MD-24. At 90 DAT, the highest value was observed for the seedlings of plus tree FCV-MD-03 (0.95 cm) and FCV-MD-04 (0.96 cm). The lowest value was observed for the seedlings of plus trees FCV-MD-12 (0.63). At 120 DAT except for the highest value was observed for the seedlings from the plus tree FCV-MD-04 (1.32 cm), this was followed by plus tree FCV-MD-03 (1.21 cm). The lowest value was observed for the seedlings from plus tree FCV-MD-10 (0.77 cm) and FCV-MD-11 (0.72 cm). At 150 DAT the highest value was observed for the seedlings from plus tree FCV-MD-04 (1.61 cm), followed by the seedlings from plus tree FCV-MD-03 (1.54 cm). The lowest value was observed for the seedlings from the plus tree FCV-MD-11 (0.98 cm) and FCV-MD-12 (0.93 cm). It was observed that the values for the collar diameter were high for the seedlings from plus trees FCV-MD-04 and FCV-MD-03 consistently throughout the experiment period, while a lower value was observed for the seedlings of plus tree FCV-MD-11 and FCV-MD-12.

Table 13. Collar diameter (cm) of *Melia dubia* progenies from different plus trees at monthly intervals.

Accession No.	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT
FCV-MD-01	0.46^{ab}	0.71^{ab}	0.84^{ab}	1.02^{bcd}	1.26^{abcd}
FCV-MD-02	0.38^{abcd}	0.66^{abc}	0.83^{ab}	1.07^{bc}	1.37^{abc}
FCV-MD-03	0.44^{abcd}	0.70^{ab}	0.95^{a}	1.21^{ab}	1.54^{ab}
FCV-MD-04	0.49^{a}	0.72^{a}	0.96^{a}	1.32^{a}	1.61^{a}
FCV-MD-05	0.42^{abcd}	0.64^{abc}	0.75^{ab}	0.98^{bcd}	1.18^{bcd}
FCV-MD-06	0.42^{abcd}	0.64^{abc}	0.78^{ab}	1.01^{bcd}	1.29^{abcd}
FCV-MD-07	0.40^{abcd}	0.67^{abc}	0.85^{ab}	1.04^{bc}	1.31^{abcd}
FCV-MD-08	0.44^{abc}	0.68^{abc}	0.85^{ab}	0.94^{cd}	1.29^{abcd}
FCV-MD-09	0.39^{abcd}	0.60^{abc}	0.78^{ab}	0.98^{bcd}	1.20^{bcd}
FCV-MD-10	0.37^{abcd}	0.59^{abc}	0.65^{b}	0.82^{cd}	1.04^{cd}
FCV-MD-11	0.31^{d}	0.59^{abc}	0.69^{b}	0.77^{d}	0.98^{d}
FCV-MD-12	0.31^{d}	0.57^{abc}	0.63^{b}	0.72^{d}	0.93^{d}
FCV-MD-13	0.35^{abcd}	0.59^{abc}	0.67^{b}	0.88^{cd}	1.11^{cd}
FCV-MD-14	0.45^{abc}	0.67^{abc}	0.80^{ab}	0.96^{bcd}	1.10^{cd}
FCV-MD-15	0.34^{bcd}	0.65^{abc}	0.69^{b}	0.89^{cd}	1.11^{cd}
FCV-MD-16	0.46^{ab}	0.67^{abc}	0.76^{ab}	0.98^{bcd}	1.42^{abc}
FCV-MD-17	0.34^{bcd}	0.57^{c}	0.67^{b}	0.87^{cd}	1.08^{cd}
FCV-MD-18	0.39^{abcd}	0.59^{abc}	0.70^{b}	0.89^{cd}	1.12^{cd}
FCV-MD-19	0.35^{abcd}	0.56^{c}	0.75^{ab}	1.00^{bcd}	1.28^{abcd}
FCV-MD-20	0.36^{abcd}	0.58^{bc}	0.70^{b}	0.84^{cd}	1.08^{cd}
FCV-MD-21	0.40^{abcd}	0.59^{abc}	0.67^{b}	0.84^{cd}	1.06^{cd}
FCV-MD-22	0.32^{cd}	0.55^{c}	0.68^{b}	0.90^{cd}	1.20^{bcd}
FCV-MD-23	0.40^{abcd}	0.64^{abc}	0.78^{ab}	0.96^{bcd}	1.19^{bcd}
FCV-MD-24	0.38^{abcd}	0.61^{abc}	0.74^{ab}	0.86^{cd}	1.13^{cd}
FCV-MD-25	0.40^{abcd}	0.63^{abc}	0.72^{b}	0.85^{cd}	1.11^{cd}
	S	S	S	S	S

* Significant at 0.05 levels

Values with the same superscript in column at different month are homogenous

4.4.1.3. Number of leaves

Analysis of the number of leaves of seedlings of plus trees (Table 14) shows that the values were significantly different for all the months. At 30 DAT, the highest value was observed for the seedlings of plus tree FCV-MD-04 (13), followed by plus tree FCV-MD-16 (12) and FCV-MD-07 (12). The trees were from Tholpetty, Parambikulam and Dhoni respectively. The lowest value was observed for the seedlings of plus tree FCV-MD-09 (Attappady), FCV-MD-18 (Chinnar) and FCV-MD-23 (Kulathupuzha). The value observed was the same for all the seedlings (7). At 60 DAT, except for the seedlings of plus trees FCV-MD-09, FCV-MD-12, FCV-MD-18 and FCV-MD-23, the values for all the observations were at par. The highest value was observed for the seedlings of plus tree FCV-MD-04 (16), the lowest value was observed for the seedlings of plus tree FCV-MD-09, FCV-MD-18 and FCV-MD-23. The value observed was same (9). At 90 DAT, the highest value was observed for the seedlings of plus tree FCV-MD-04 (36). This was followed by the seedlings of plus tree FCV-MD-07 (34). The lowest value (22) was observed for the seedlings of plus tree FCV-MD-23, from Akamala. At 120 DAT, seedlings of plus trees FCV-MD-02, FCV-MD-04, FCV-MD-05, FCV-MD-06, FCV-MD-07 and FCV-MD-17, were at par. The highest value (33) was observed for the seedlings of plus tree FCV-MD-04, followed by the seedlings of plus tree FCV-MD-07 (30). The lowest value (17) was found for the seedlings of plus tree FCV-MD-23. The data for the 150 DAT, shows that the highest value (31) was observed for the seedlings of plus tree FCV-MD-04. This was followed by the seedlings of plus tree FCV-MD-07 (28). The lowest value (17) was observed for the seedlings of plus tree FCV-MD-23, followed by plus tree FCV-MD-12 and FCV-MD-24. The values observed was (19) for both. It was observed that the seedlings of plus tree FCV-MD-04 showed consistently good increase in collar diameter throughout the experiment. The seedlings of the plus tree FCV-MD-23 showed less value when compared to other plus trees. It was also observed that in values for the number of leaves for the seedlings at 150 DAT was less when compared to that for the period 120 DAT.

Table 14. Number of leaves of *Melia dubia* progenies from different plus trees at monthly intervals

Accession No.	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT
FCV-MD-01	10^{abcdef}	12^{bcde}	27^{bcde}	24^{bcde}	24^{bcde}
FCV-MD-02	8^{cdef}	10^{bcde}	32^{abcd}	27^{abcd}	26^{abcd}
FCV-MD-03	11^{abcd}	13^{abcd}	28^{abcde}	27^{bcde}	26^{abcd}
FCV-MD-04	13^{a}	16^{a}	36^{a}	33^{a}	31^{a}
FCV-MD-05	8^{cdef}	10^{bcde}	31^{abcd}	28^{abc}	26^{abcd}
FCV-MD-06	11^{abcde}	13^{abcd}	30^{abcde}	27^{abcd}	27^{abc}
FCV-MD-07	11^{abcd}	13^{abcd}	34^{ab}	30^{ab}	28^{ab}
FCV-MD-08	10^{abcdef}	12^{bcde}	27^{bcde}	25^{bcde}	22^{bcdef}
FCV-MD-09	7^{ef}	9^{de}	24^{de}	23^{cdef}	23^{bcdef}
FCV-MD-10	11^{abc}	13^{abcd}	28^{bcde}	22^{def}	20^{def}
FCV-MD-11	11^{abc}	13^{abcd}	30^{abcde}	22^{def}	21^{cdef}
FCV-MD-12	8^{def}	10^{de}	25^{cde}	21^{ef}	19^{ef}
FCV-MD-13	10^{abcdef}	12^{bcde}	30^{abcde}	25^{bcde}	22^{bcdef}
FCV-MD-14	10^{abcde}	12^{bcde}	29^{abcde}	26^{bcde}	23^{bcde}
FCV-MD-15	9^{bcdef}	11^{bcde}	26^{cde}	24^{bcde}	21^{cdef}
FCV-MD-16	12^{a}	14^{ab}	31^{abcd}	27^{de}	26^{abcd}
FCV-MD-17	12^{ab}	14^{abc}	32^{abc}	29^{abc}	26^{abcd}
FCV-MD-18	7^{f}	9^{e}	25^{cde}	23^{cdef}	23^{bcdef}
FCV-MD-19	9^{abcdef}	11^{bcde}	29^{abcde}	25^{bcde}	23^{bcdef}
FCV-MD-20	9^{abcdef}	12^{bcde}	24^{cde}	21^{ef}	21^{cdef}
FCV-MD-21	9^{abcdef}	12^{bcde}	27^{bcde}	23^{cdef}	22^{bcdef}
FCV-MD-22	8^{bcdef}	11^{bcde}	28^{abcde}	26^{bcde}	23^{bcdef}
FCV-MD-23	7^{ef}	9^{de}	22^{e}	17^{f}	17^{f}
FCV-MD-24	10^{abcdef}	12^{bcde}	27^{bcde}	24^{bcde}	19^{ef}
FCV-MD-25	11^{abcd}	13^{abcd}	29^{abcde}	26^{bcde}	24^{bcde}
	S	S	S	S	S

* Significant at 0.05 levels

Values with same superscript in column at different month are homogenous

4.4.1.4. Absolute Growth Rate (AGR)

Analysis of variance of the progenies of different plus trees for the character absolute growth rate is shown in Table 15. The absolute growth rate of the seedlings was significant for the period 120 DAT and 150 DAT, it was insignificant for 60 DAT and 90 DAT. At 120 DAT, it was observed that the highest value was observed for the seedlings of plus tree FCV-MD-03 (1.29 cm day^{-1}), FCV-MD-04 (1.27 cm day^{-1}), FCV-MD-05 (1.2 cm day^{-1}), FCV-MD-08 (1.27 cm day^{-1}) and FCV-MD-12 (1.2 cm day^{-1}). The least value was observed for the seedlings of plus

trees FCV-MD-17 (0.57 cm day^{-1}) followed by plus tree FCV-MD-09 (0.69 cm day^{-1}). At the end of the experiment, it was observed that the seedlings of the progenies of plus tree FCV-MD-03 was highest (3.23 cm day^{-1}), followed by the seedlings of plus tree FCV-MD-04 (3.1 cm day^{-1}). The least value (1.39 cm day^{-1}) was observed for the seedlings of plus tree FCV-MD-09. The performance of seedlings of plus trees FCV-MD-03 and FCV-MD-04, both from Tholpetty were better when compared to the seedlings from other plus trees. Least performance was observed for the seedlings of plus tree FCV-MD-09, from Attappady.

Table 15. Absolute Growth Rate (cm day^{-1}) of *Melia dubia* progenies from different plus trees at monthly intervals.

Accession No.	**60 DAT**	**90 DAT**	**120 DAT**	**150 DAT**
FCV-MD-01	0.38	0.99	1.04^{abcd}	2.51^{cde}
FCV-MD-02	0.40	1.03	0.95^{abcdef}	2.49^{cde}
FCV-MD-03	0.38	1.12	1.29^{a}	3.23^{a}
FCV-MD-04	0.45	1.19	1.27^{a}	3.10^{ab}
FCV-MD-05	0.40	1.15	1.20^{ab}	2.31^{cdefg}
FCV-MD-06	0.41	1.00	0.85^{cdef}	2.68^{bcd}
FCV-MD-07	0.40	1.02	1.08^{abc}	2.45^{cdef}
FCV-MD-08	0.33	1.12	1.27^{a}	2.51^{cde}
FCV-MD-09	0.37	0.79	0.71^{efg}	1.39^{h}
FCV-MD-10	0.33	1.06	0.93^{cdef}	2.20^{cdefg}
FCV-MD-11	0.39	0.93	0.95b^{cdef}	2.34^{cdef}
FCV-MD-12	0.39	1.08	1.20^{ab}	2.80^{abc}
FCV-MD-13	0.34	1.14	0.95^{bcdef}	1.75^{gh}
FCV-MD-14	0.34	1.09	0.97^{bcde}	1.87^{fgh}
FCV-MD-15	0.34	1.09	0.97^{bcde}	1.87^{fgh}
FCV-MD-16	0.31	0.91	0.86^{cdef}	2.36^{cdef}
FCV-MD-17	0.30	0.84	0.57g	1.94^{efgh}
FCV-MD-18	0.32	0.96	0.83^{cdef}	2.18^{defg}
FCV-MD-19	0.36	0.97	0.69^{fg}	2.39^{cdef}
FCV-MD-20	0.37	0.93	0.85^{cdef}	2.38^{cdef}
FCV-MD-21	0.37	0.93	0.85^{cdef}	2.38cdef
FCV-MD-22	0.33	1.02	0.91^{cdef}	2.46^{cdef}
FCV-MD-23	0.33	0.90	0.80^{defg}	2.46^{cdef}
FCV-MD-24	0.40	0.96	0.96^{bcde}	2.21^{cdefg}
FCV-MD-25	0.37	1.13	0.85^{cdef}	1.59^{h}
	NS	NS	S	S

* Significant at 0.05 levels

Values with same superscript in column at different month are homogenous

4.4.1.5. Biovolume

The analysis of variance of the seedling biovolume from different plus trees is presented in Table 16. The values were significant for all the period of the experiment. At 30 DAT, it was observed that the biovolume of the seedlings of all the plus tree FCV-MD-04 showed the highest value (82.02) and FCV-MD-08 (78.8). The least value was observed for the seedlings of plus tree FCV-MD-12 (44.3). For the period 60 DAT, except for the seedlings of plus trees FCV-MD-03 and FCV-MD-04 all were at par. The highest value (232.71) was obtained for the seedlings of plus tree FCV-MD-04, followed by the seedlings of plus tree FCV-MD-03 (195.7). The least value was observed for the seedlings of plus trees FCV-MD-17 and FCV-MD-18, the values are 132.98 and 132.22 respectively. Both the accessions were from Chinnar. At 90 DAT, it was observed that for the seedlings of plus trees FCV-MD-04 the value was highest (632.88), followed by the seedlings of plus tree FCV-MD-03 (592.42). Both the accessions were from Tholpetty. The lowest value (331.23) was observed for the seedlings of plus tree FCV-MD-17. This was followed by the seedlings of plus trees FCV-MD-10 (366.51), FCV-MD-11 (366.17), FCV-MD-18 (357.99) and FCV-MD-21 (360.31). At 120 DAT, it was observed that the highest value for the biovolume was observed for the seedlings of plus trees FCV-MD-04 and FCV-MD-03, the values were 1393.23 and 1234.78 respectively. This was followed by the seedlings of plus trees FCV-MD-05, FCV-MD-02, FCV-MD-07, FCV-MD-08. The values for the biovolume of the seedlings were 952.81, 945.89, 942.39 and 939.06 respectively. The lowest value (570.59) was observed for the seedlings of plus tree FCV-MD-17 from Chinnar. At 150 DAT the values of biovolume was at par for all the seedlings of plus trees except for FCV-MD-04 and FCV-MD-03. The highest value (3175.22) was observed for seedlings of plus tree FCV-MD-04, followed by seedlings of plus tree FCV-MD-03 (3048.57). The lowest value (1330.5) was observed for the seedlings of plus trees FCV-MD-17. It was observed that the value of biovolume for the plus trees FCV-MD-03 and FCV-MD-04 was higher consistently throughout the experiment period. The least value was observed for the plus tree FCV-MD-17.

Table 16. Biovolume of seedlings of *Melia dubia* progenies from different plus trees at monthly intervals.

Accession No.	30 DAT	60 DAT	90 DAT	120 DAT	150 DAT
FCV-MD-01	72.25^{abc}	176.95^{cd}	468.30^{bcde}	906.64^{bcd}	2062.68^{bcd}
FCV-MD-02	60.98^{abcde}	149.73^{cd}	485.15^{bcd}	945.89^{b}	2233.03^{b}
FCV-MD-03	72.54^{abc}	195.72^{ab}	592.42^{ab}	1234.78^{a}	3048.57^{a}
FCV-MD-04	82.02^{a}	232.71^{a}	632.88^{a}	1393.23^{a}	3175.22^{a}
FCV-MD-05	66.58^{abcde}	184.64^{cd}	468.62^{bcde}	952.81^{b}	1956.54^{bcde}
FCV-MD-06	66.05^{abcde}	177.28^{cd}	444.66^{cde}	832.15^{bcde}	2109.35^{bcd}
FCV-MD-07	63.72^{abcde}	183.57^{cd}	493.13^{bcd}	942.39^{bc}	2166.53^{bc}
FCV-MD-08	78.80^{ab}	186.69^{c}	513.44^{abc}	939.06^{bc}	2219.37^{bc}
FCV-MD-09	55.85^{cde}	150.74^{cd}	383.91^{cde}	687.40^{def}	1355.48^{e}
FCV-MD-10	59.46^{bcde}	154.15^{cd}	368.51^{de}	707.14^{cdef}	1599.09^{cde}
FCV-MD-11	45.46^{de}	153.85^{cd}	366.17^{de}	652.01^{ef}	1499.89^{de}
FCV-MD-12	44.30^{e}	160.54^{cd}	376.55^{cde}	689.88^{def}	1581.83^{cde}
FCV-MD-13	57.23^{bcde}	157.34^{cd}	408.92^{cde}	790.71^{bcdef}	1594.46^{cde}
FCV-MD-14	64.58^{abcde}	166.58^{cd}	448.49^{cde}	837.54^{bcde}	1591.94^{cde}
FCV-MD-15	52.63^{cde}	155.91^{cd}	391.49^{cde}	762.57^{bcdef}	1589.34^{cde}
FCV-MD-16	72.52^{abc}	169.97^{cd}	402.42^{cde}	762.43^{bcdef}	2145.34^{bc}
FCV-MD-17	50.50^{cde}	132.98^{d}	331.23^{e}	570.59^{f}	1330.50^{e}
FCV-MD-18	53.85^{cde}	132.22^{d}	357.99^{de}	677.59^{def}	1606.77^{bcde}
FCV-MD-19	54.26^{cde}	142.72^{cd}	416.15^{cde}	748.13^{bcdef}	1875.23^{bcde}
FCV-MD-20	53.52^{cde}	158.52^{cd}	377.05^{cde}	653.62^{ef}	1651.98^{bcde}
FCV-MD-21	59.55^{bcde}	152.26^{cd}	360.31^{de}	669.33^{def}	1581.13^{cde}
FCV-MD-22	54.45^{cde}	149.54^{cd}	398.17^{cde}	758.59^{bcdef}	1912.64^{bcde}
FCV-MD-23	67.93^{abcd}	168.92^{cd}	422.28^{cde}	735.10^{bcdef}	1773.99^{bcde}
FCV-MD-24	56.46^{bcde}	167.04^{cd}	413.74^{cde}	736.41^{bcdef}	1692.14^{bcde}
FCV-MD-25	64.62^{abcde}	171.05^{cd}	439.62^{cde}	758.68^{bcdef}	1500.83^{de}
	S	S	S	S	S

* Significant at 0.05 levels

Values with same superscript in column at different month are homogenous

4.4.2. Genetic parameters for morphological and growth traits

4.4.2.1. Shoot height

The genetic parameters for morphological and growth traits after 150 DAT (Table 17) shows that the broad-sense heritability for shoot height was 0.91. It was observed that the PCV, GCV and ECV were 12.62, 12.01 and 3.87 respectively. The genetic advance was 36.53 and genetic gain 23.55.

4.4.2.2. Collar diameter

For the collar diameter, the broad sense heritability was observed to be 0.53. The PCV, GCV and ECV values being 13.98, 10.18 and 9.58 respectively. Genetic advance for this trait was 0.18 and genetic gain was 15.26. The genetic advance for this character was observed to be highest when compared to the values for other traits.

4.4.2.3. Number of leaves

Broad sense heritability for the number of leaves was observed to be 0.65. The values for PCV, GCV and ECV were observed to be 13.45, 10.88 and 7.9 respectively. The genetic advance for number of leaves was 4.24 and genetic gain 18.15.

4.4.2.4. Absolute growth rate

The broad sense heritability for this trait was 0.83. The values for PCV, GCV and ECV were observed to be 18.28, 16.65 and 7.54 respectively. The value for genetic advance was 0.72 and genetic gain 31.25. The lowest value for the genetic advance was observed for this trait.

4.4.2.5. Biovolume

The broad sense heritability for this trait was 0.84. The value for the genetic advance was 792.58 and genetic gain 42.29. The highest values for the genetic gain and genetic advance were observed for this trait.

Table 17. Estimated genetic parameters of morphometrical traits of *Melia dubia* plus trees.

	H^2	PCV	GCV	ECV	Genetic advance	Genetic Gain
Height	0.91	12.62	12.01	3.87	36.53	23.55
Collar diameter	0.53	13.98	10.18	9.58	0.18	15.26
No of leaves	0.65	13.45	10.88	7.9	4.24	18.15
AGR	0.83	18.28	16.65	7.54	0.72	31.25
Biovolume	0.84	24.53	22.44	9.91	792.58	42.29

4.4.3. Physiological parameters

Significant differences in photosynthetic rate, transpiration rate, chlorophyll content, leaf temperature, stomatal conductance and relative water content were observed for the seedlings of the progenies from different plus trees at 60 and 150 DAT (Table 18). The table showed that the values for the relative water content, photosynthetic rate and chlorophyll content were more for the period 60 DAT when compared to 150 DAT. The leaf temperature for the period 60 DAT was less when compared the values for 150 DAT.

Analysis of variance revealed that the values for chlorophyll content (mg g^{-1}) of the progenies from plus tree FCV-MD-03, FCV-MD-04, FCV-MD-05, FCV-MD-08, FCV-MD-09, FCV-MD-14, PBM-30, CNR-42, CNR-47, PCI-07, PCI-08, AKA-12, were on par for the period 60 DAT. The highest values (57.93 mg g^{-1}) and (56.87 mg g^{-1}) were recorded for the progenies of plus trees FCV-MD-03 and FCV-MD-04 respectively. The least values (40.8 mg g^{-1}) and (40.13 mg g^{-1}) were recorded for the progenies of plus tree FCV-MD-13 and FCV-MD-11 respectively. The accessions were from Walayar and Thiruvazhiyadu. The table 12 showed that for the period 150 DAT the progenies from plus tree FCV-MD-06, FCV-MD-10, FCV-MD-11, FCV-MD-12, FCV-MD-13, FCV-MD-15, FCV-MD-18, FCV-MD-23, FCV-MD-24 and CNR-25 were on par. It was observed that the highest value for chlorophyll content (51.6 mg g^{-1}) was obtained for the seedlings of plus tree FCV-MD-03, followed by (49.4 mg g^{-1}) for the seedlings of plus tree FCV-MD-04. The lowest value (33.3 mg g^{-1}) for the seedlings of plus tree FCV-MD-11 and FCV-MD-13 (35.7 mg g^{-1}).

Photosynthesis rate was found to be at par for the seedlings of the plus trees FCV-MD-03, FCV-MD-04, CNR-43 for the period 60 DAT. The highest value (20.53 µmol m^{-2} s^{-1}) and (18.2 µmol m^{-2} s^{-1}) was observed for the seedlings of the plus tree FCV-MD-04. The lowest value (3.04 µmol m^{-2} s^{-1}) was observed for plus tree FCV-MD-17 (Chinnar). For the period 150 DAT, the photosynthetic rate of the seedlings of the plus trees FCV-MD-02, FCV-MD-03, FCV-MD-04, FCV-MD-14, PBM-26, KPA-04, AYU-04 were on par. The highest value (3.56 µmol m^{-2} s^{-1}) were observed

for the seedlings of the plus tree FCV-MD-04 and (2.8 µmol m^{-2} s^{-1}) for the plus tree FCV-MD-03. The lowest value (0.29 µmol m^{-2} s^{-1}) for plus tree FCV-MD-13.

The stomatal conductance of the leaves of the seedlings varied between the progenies from different plus trees. It was observed that for the period 60 DAT, the progenies from plus trees FCV-MD-03, FCV-MD-11, FCV-MD-12, FCV-MD-13, FCV-MD-14, FCV-MD-15, FCV-MD-16, FCV-MD-17, FCV-MD-20, FCV-MD-21, FCV-MD-23, FCV-MD-24 were on par. The highest stomatal conductance was observed for the progenies of the plus tree FCV-MD-23 and FCV-MD-14 (0.30 s cm^{-1}). The lowest value (0.04 s cm^{-1}) was observed for the progenies of the plus tree FCV-MD-19. The stomatal conductance of the leaves of the seedlings for the period 150 DAT showed that the progenies from plus trees FCV-MD-02, FCV-MD-03, FCV-MD-04, FCV-MD-14, FCV-MD-15, FCV-MD-23, FCV-MD-24 were on par. The highest stomatal conductance was observed for the progenies of the plus tree FCV-MD-03 (0.27 s cm^{-1}) and FCV-MD-04 (0.23 s cm^{-1}) and the lowest value (0.01 s cm^{-1} s cm^{-1}) was observed for the progenies of the plus trees FCV-MD-11 and FCV-MD-12, the accessions were from Thiruvazhiyadu and Walayar.

It was observed that the transpiration rate was on par except for the seedlings of plus trees FCV-MD-12, FCV-MD-14, FCV-MD-23 and FCV-MD-24 for the period 60 DAT. The value was highest for the seedlings from the plus tree FCV-MD-14 (6.44 µmol $m^{-2}s^{-1}$) followed by the plus tree FCV-MD-12 (5.16 µmol $m^{-2}s^{-1}$). The lowest value was observed for the seedlings of plus trees FCV-MD-18 (1.88 µmol $m^{-2}s^{-1}$) and FCV-MD-19 (2.14 µmol $m^{-2}s^{-1}$). The transpiration rate was on par except for the seedlings of plus trees FCV-MD-02, FCV-MD-03, FCV-MD-04, FCV-MD-05, FCV-MD-15, FCV-MD-20, FCV-MD-21, FCV-MD-22 for the period 150 DAT. The value was highest for the seedlings from the plus tree FCV-MD-03 (3.49 µmol $m^{-2}s^{-1}$) followed by the plus tree FCV-MD-04 (2.96 µmol $m^{-2}s^{-1}$). The lowest value (0.33 µmol $m^{-2}s^{-1}$) was observed for the seedlings of plus trees FCV-MD-10, FCV-MD-11, FCV-MD-12, FCV-MD-13.

Leaf temperature for the seedlings of plus trees FCV-MD-04, FCV-MD-05, FCV-MD-06, FCV-MD-07, FCV-MD-08, FCV-MD-09, FCV-MD-10, FCV-MD-11, FCV-MD-12, FCV-MD-13, FCV-MD-14 for the period 60 DAT was on par. The highest leaf temperature was observed for the seedlings of plus trees FCV-MD-22 (35.85 ºC) and the lowest value was observed for the seedlings of plus tree FCV-MD-16 (30.6 ºC). Leaf temperature for the seedlings of plus trees FCV-MD-09, FCV-MD-10, FCV-MD-11, FCV-MD-12, FCV-MD-13, was on par for the period 150 DAT. The highest leaf temperature was observed for the seedlings of plus trees FCV-MD-11 (37.1 ºC) and the lowest value was observed for the seedlings of plus tree FCV-MD-15 (31.15 ºC).

For the period 60 DAT, the relative water content of the leaves of the seedlings of plus trees FCV-MD-03, FCV-MD-04, FCV-MD-22 was on par. The highest relative water content was observed for the seedlings FCV-MD-04 (95) and FCV-MD-03 (94). The lowest value was obtained for the leaves of the seedlings from plus trees FCV-MD-08, FCV-MD-11, FCV-MD-13 (76). The relative water content of the leaves of the seedlings of plus trees FCV-MD-03, FCV-MD-04, FCV-MD-21 and FCV-MD-24 was on par. The highest relative water content was observed for the seedlings FCV-MD-03 (89) and FCV-MD-03 (88). The lowest value (73) was obtained for the leaves of the seedlings from plus trees FCV-MD-08, FCV-MD-09.

The chlorophyll content, photosynthetic rate and relative water content were found to be highest for the seedlings of plus trees FCV-MD-03 and FCV-MD-04, whereas the stomatal conductance, transpiration rate, leaf temperature was found to be more for the seedlings of plus trees FCV-MD-14 for the period 60 DAT. It was observed that for the period 150 DAT, the chlorophyll content, photosynthetic rate, stomatal conductance, transpiration rate and relative water content were found to be highest for the seedlings of plus trees FCV-MD-03 and FCV-MD-04, whereas the lowest value was observed for the seedlings from plus tree FCV-MD-11 and FCV-MD-14. Leaf temperature was found to be more for the seedlings of plus trees FCV-MD-11.

It was observed that except for the leaf temperature all the other physiological parameters showed a higher value for 60 DAT when compared to the values for 150 DAT. The decrease in the photosynthetic rate was more pertinent, when compared to other physiological parameters that were studied.

Table 18. Physiological parameters of *Melia dubia* progenies from different plus trees at 60 and 150 DAT.

	Chlorophyll content (mg g^{-1})		**Photosynthetic rate (µmol m^{-2} s^{-1})**		**Stomatal Conductance (s cm^{-1})**		**Transpiration rate (µmol m^{-2} s^{-1})**		**Leaf temperature (ºC)**		**Relative water content (%)**	
	60 DAT	**150 DAT**	**60 DAT**	**150 DAT**	**60 DAT**	**150 DAT**	**60 DAT**	**150 DAT**	**60 DAT**	**150 DAT**	**60 DAT**	**150 DAT**
FCV-MD-01	52.17^{abcde}	49.17^{abc}	14.87^{bc}	2.04^{bcdefg}	0.11^{bcd}	0.12^{cdefgh}	1.99^{d}	1.80^{bcde}	31.05^{gh}	32.67^{efgh}	87^{cdefgh}	82^{bcde}
FCV-MD-02	46.53^{cdefgh}	44.67^{abcdef}	13.47^{c}	2.64^{abc}	0.13^{bcd}	0.21^{abc}	2.49^{cd}	2.79^{abc}	31.54^{efgh}	31.70^{gh}	81^{ghij}	81^{cdef}
FCV-MD-03	57.93^{a}	51.6^{a}	18.20^{ab}	2.80^{ab}	0.14^{abcd}	0.27^{a}	2.43^{cd}	3.49^{a}	31.78^{defgh}	31.98^{fgh}	94^{ab}	89^{a}
FCV-MD-04	56.87^{ab}	49.40^{ab}	20.53^{a}	3.56^{a}	0.10^{bcd}	0.23^{ab}	2.25^{cd}	2.96^{ab}	32.81^{abcdefgh}	31.81^{gh}	95^{a}	88^{ab}
FCV-MD-05	49.17^{abcdefg}	48.00^{abcde}	16.53^{bc}	2.08^{bcdefg}	0.09^{bcd}	0.14^{bcde}	2.44^{cd}	2.25^{abcd}	31.83^{defgh}	33.00^{efgh}	84^{defg}	81^{cdef}
FCV-MD-06	48.77^{bcdefgh}	41.40^{bcdefgh}	12.79^{c}	0.78^{gh}	0.06^{d}	0.06^{efghi}	2.17^{d}	1.11^{defg}	33.74^{abcde}	34.29^{cde}	86^{cdefg}	81^{cdef}
FCV-MD-07	46.63^{cdefgh}	43.10^{abcdefgh}	4.27^{def}	0.71^{gh}	0.12^{bcd}	0.03^{ghi}	2.66^{cd}	0.82^{efg}	33.50^{abcde}	35.04^{bcd}	85^{cdefg}	84^{bcd}
FCV-MD-08	50.00^{abcdef}	46.37^{abcdef}	4.02^{def}	0.98^{efgh}	0.09^{bcd}	0.04^{fghi}	2.43^{cd}	0.89^{efg}	34.06^{abcd}	35.15^{bcd}	76^{j}	76^{fghi}
FCV-MD-09	50.00^{abcdef}	48.57^{abcd}	4.42^{def}	0.86^{efgh}	0.12^{bcd}	0.02^{hi}	2.68^{cd}	0.54^{fg}	33.56^{abcde}	35.60^{abc}	77^{hij}	73^{h}
FCV-MD-10	47.40^{cdefgh}	39.73^{bcdefgh}	4.06^{def}	0.79^{fgh}	0.08^{cd}	0.02^{i}	2.29^{cd}	0.42^{g}	34.15^{abcd}	36.77^{ab}	82^{efghi}	79^{defgh}
FCV-MD-11	40.13^{d}	33.30^{h}	5.64^{def}	0.81^{fgh}	0.16^{abcd}	0.01^{i}	3.83^{bcd}	0.33^{g}	34.34^{abc}	37.10^{a}	76^{ij}	74^{hi}
FCV-MD-12	45.23^{defgh}	40.87^{bcdefgh}	7.18^{de}	0.84^{fgh}	0.24^{abc}	0.01^{i}	5.16^{ab}	0.33^{g}	34.30^{abc}	37.03^{a}	89^{bcd}	83^{bcde}
FCV-MD-13	40.8^{fg}	35.70^{gh}	5.69^{def}	0.29^{h}	0.14^{abcd}	0.02^{i}	3.74^{bcd}	0.35^{g}	35.52^{a}	36.69^{ab}	76^{ij}	75^{ghi}
FCV-MD-14	54.67^{abc}	49.40^{ab}	8.05^{d}	2.58^{abc}	0.30^{a}	0.11^{defghi}	6.44^{a}	1.72^{bcdef}	35.13^{ab}	31.77^{gh}	85^{cdefg}	82^{cde}
FCV-MD-15	47.40^{cdefgh}	39.00^{defgh}	4.11^{def}	2.52^{abcd}	0.14^{abcd}	0.14^{bcdef}	2.68^{cd}	1.91^{bcde}	32.43^{cdefgh}	31.15^{h}	83^{defgh}	81^{cdef}
FCV-MD-16	53.67^{abcd}	49.83^{ab}	4.86^{def}	1.92^{bcdefg}	0.26^{ab}	0.14^{bcdef}	3.98^{bcd}	2.05^{bcde}	30.6^{h}	32.08^{fgh}	88^{bcdef}	82^{bcde}
FCV-MD-17	52.37^{abcde}	43.90^{abcdef}	3.04^{f}	1.09^{defgh}	0.14^{abcd}	0.11^{defghi}	2.71^{cd}	2.07^{bcde}	31.93^{cdefgh}	33.27^{efg}	88^{bcde}	80^{defg}
FCV-MD-18	43.70^{efgh}	41.00^{bcdefgh}	17.83^{ab}	1.70^{bcdefgh}	0.06^{d}	0.13^{cdefg}	1.88^{d}	1.81^{bcde}	32.65^{cdefgh}	32.14^{fgh}	82^{fghij}	78^{efghi}
FCV-MD-19	51.67^{abcde}	46.43^{abcdef}	13.20^{c}	1.19^{cdefgh}	0.04^{d}	0.09^{defghij}	2.14^{d}	1.59^{cdefg}	33.09^{bcdefg}	32.42^{fgh}	86^{cdefg}	80^{cdefg}
FCV-MD-20	50.67^{abcdef}	48.10^{abcde}	3.57^{de}	2.08^{bcdefg}	0.17^{abcd}	0.14^{bcdef}	3.08^{bcd}	2.26^{abcd}	31.82^{defgh}	31.87^{gh}	87^{cdefg}	82^{cde}
FCV-MD-21	53.47^{abcd}	48.60^{abcd}	4.31^{def}	1.46^{bcdefgh}	0.21^{abcd}	0.12^{cdefg}	3.37^{bcd}	2.24^{abcd}	31.21^{fgh}	32.44^{fgh}	89^{bcd}	84^{abcd}
FCV-MD-22	54.20^{abcd}	47.73^{abcde}	5.29^{def}	1.42^{bcdefgh}	0.12^{bcd}	0.13^{cdefg}	3.36^{bcd}	2.34^{abcd}	35.85^{a}	31.77^{gh}	91^{abc}	86^{abc}
FCV-MD-23	46.23^{cdefgh}	38.20^{efgh}	6.80^{def}	2.27^{abcdef}	0.30^{a}	0.18^{abcd}	4.58^{abc}	1.86^{bcde}	35.57^{a}	31.82^{gh}	85^{cdefg}	79^{defh}
FCV-MD-24	44.33^{efgh}	39.27^{cdefgh}	6.47^{def}	2.33^{abcde}	0.19^{abcd}	0.10^{defghi}	4.58^{abc}	2.11^{bcde}	35.07^{ab}	32.89^{efgh}	88^{bcdefg}	82^{cde}
FCV-MD-25	42.00^{efg}	37.60^{fgh}	5.00^{def}	1.98^{bcdefg}	0.15^{bcd}	0.10^{defghi}	3.30^{cd}	1.94^{bcde}	32.96^{bcdefgh}	33.82^{def}	86^{cdefg}	82^{cde}
	S	S	S	S	S	S	S	S	S	S	S	S

4.4.4. Genetic parameters for physiological traits

4.4.4.1. Chlorophyll content

The genetic parameters for the physiological traits of seedlings 150 DAT (Table 19) showed that the broad sense heritability for chlorophyll was 0.82. The genetic advance and genetic gain were observed to be 6.46 and 14.66 respectively. The value of genetic advance was the highest when compared with other values.

4.4.4.2. Photosynthetic rate

The value for the broad sense heritability was observed to be the lowest (0.72) for this character when compared with other traits. The genetic advance and genetic gain were observed to be 1.23 and 62.32 respectively.

4.4.4.3. Stomatal conductance

Broad-sense heritability value was observed to be (0.81) for this character. The genetic advance was estimated to be 0.12 and genetic gain was observed to be 105.94, which was found to be the highest among all the traits and for genetic advance it was observed to be the least.

4.4.4.4. Transpiration

The value for the broad sense heritability was observed to be (0.81) for this trait. The genetic advance and genetic gain were observed to be 1.45 and 86.26 respectively.

4.4.4.5. Leaf temperature

For the broad sense heritability, the highest value (0.92) was observed among all the traits. The genetic advance and genetic gain observed for these traits were 3.65 and 10.91 respectively.

4.4.4.6. Relative water content

The broad sense heritability (0.72) was found to be the least among all the characters studied. The genetic advance and genetic gain also showed the least value 1.23 and 1.52 respectively.

Table 19. Estimated genetic parameters of physiological traits of *Melia dubia*

	H^2	PCV	GCV	ECV	Genetic advance	Genetic Gain
Chlorophyll	0.82	8.71	7.87	3.73	6.46	14.66
Photosynthetic	0.72	41.74	35.53	21.90	1.23	62.32
Stomatal conductance	0.80	64.28	57.50	28.75	0.12	105.94
Transpiration	0.81	51.87	46.60	22.77	1.45	86.26
Leaf temperature	0.92	5.77	5.53	1.65	3.65	10.91
RWC	0.72	1.02	0.87	0.54	1.23	1.52

4.4.5. Correlation study of the morphological and physiological characters of seedlings

Correlation analysis of the morphological and physiological trait of progenies from the selected plus trees is given in Table 20. It was observed that the height had significant ($P<0.01$) positive relationships with all the growth traits of the seedling such as girth (0.608), absolute growth rate (0.741) and biovolume (0.9). The relation with the physiological parameters like photosynthesis (0.551), stomatal conductance (0.666), transpiration (0.633) and relative water content (0.608) of the seedlings were also positive ($P<0.01$). However, it was observed that height had a negative relationship with leaf temperature and positive relationship with the chlorophyll content, but the relation was not significant. Girth of the seedlings had positive significant ($P<0.01$) correlation with the biovolume (0.702) and stomatal conductance (0.428) of the leaves of seedlings. It was not related to absolute growth rate, chlorophyll content, photosynthesis, transpiration, relative water content. Absolute growth rate (AGR) was found to be positively ($P<0.01$) related to biovolume (0.516), transpiration (0.403) and relative water content (0.41). The relation with photosynthesis and stomatal conductance was not significant. Biovolume of the seedlings was significantly related with all the morphological and physiological parameters studied. It showed a positive relation with chlorophyll content (0.46), photosynthesis (0.608), stomatal conductance (0.704), transpiration (0.403) and relative water content (0.41). It showed a significant ($P<0.05$) negative relation with leaf temperature. The chlorophyll content of the leaves was significantly related with all the morphological and physiological parameters

studied. It was positively related to photosynthesis (0.455), stomatal conductance (0.704), transpiration (0.645) and relative water content (0.608). The chlorophyll content was negatively related ($P<0.01$) to the leaf temperature (0.506). The relation of photosynthesis with stomatal conductance (0.876), transpiration (0.833) and relative water content (0.608) was positive and significant at 0.01 per cent level, however a significantly ($P<0.01$) negative correlation was observed with leaf temperature (0.845). Highly positive correlation ($P<0.01$) was observed for stomatal conductance with transpiration (0.952) and relative water content (0.64), while it was negatively correlated with leaf temperature (0.845). Transpiration had significant positively correlation with the relative water content (0.704) and negative correlation with leaf temperature (0.873). Highly negative correlation ($p<0.01$) was observed with relative water content of the leaves (0.543). The leaf temperature had a significant negative correlation with all the growth and physiological traits of the seedlings.

Table 20. Correlation of various morphological and physiological characters of the seedlings of *Melia dubia*

	Height (m)	**Girth (cm)**	**Absolute Growth Rate (cm day^{-1})**	**Biovolume**	**Chlorophyll (mg/gm)**	**Photosynthesis (µmol m^{-2} s^{-1})**	**Stomatal conductance (s cm^{-1})**	**Transpiration (µmol CO_2 m^{-2} s^{-1})**	**Leaf temperature (º C)**	**RWC (%)**
Height (m)	1									
Girth (cm)	.608**	1								
Absolute Growth Rate (cm day^{-1})	.741**	.359	1							
Biovolume	.900**	.702**	.516**	1						
Chlorophyll (mg/gm)	.286	.344	-.014	.466*	1					
Photosynthesis (µmol m^{-2} s^{-1})	.551**	.261	.279	.608**	.455*	1				
Stomatal conductance (s cm^{-1})	.660**	.428*	.383	.704**	.478*	.876**	1			
Transpiration (µmol CO_2 m^{-2} s^{-1})	.633**	.390	.403*	.645**	.541**	.833**	.952**	1		
Leaf temperature (º C)	-.327	-.114	-.206	-.402*	-.506**	-.828**	-.845**	-.873**	1	
RWC (%)	.603**	.329	.410*	.600**	.494*	.608**	.640**	.704**	-.543**	1

** Significant at the 0.01 level.

* Significant at the 0.05 level.

4.5. Evaluation of clonal progenies of plus trees

The growth attributes of the clonal plants raised through mini clonal technology from selected plus trees, observed at 90 months after the treatment is shown in Table 21. Observation of plants of only four parent trees were taken for the studies as the other seedlings failed to establish in the course of the experiment. The evaluated plus trees were FCV-MD-20, FCV-MD-21, FCV-MD-23, FCV-MD-24. The result showed that height of the seedlings, collar diameter and number of leaves of the seedling had a significant difference with respect to the parameters observed. The height of plants (143.6 cm) obtained from the plus tree 20 was significantly different from the others. This was followed by plants from plus tree FCV-MD-21 (116.8 cm) and FCV-MD-23 (118.6 cm), which were at par. The least value (72.9 cm) was obtained for the plants from FCV-MD-24. In case of collar diameter, the value was at par for the plants raised from the plus trees FCV-MD-20, FCV-MD-21 and FCV-MD-23. Lowest value was observed for those plants obtained from the plus tree FCV-MD-24. The data pertaining to the number of leaves of the plants showed that the highest value (11) was observed for the plants from FCV-MD-24. All the other values were at par with each other.

Table 21. Growth attributes of clonal plants of *Melia dubia* at 90 days after treatment.

Accession No.	Seedling height (cm)	Collar diameter (mm)	No. of Leaves
FCV-MD-20	143.6^{a}	3.9^{a}	7^{b}
FCV-MD-21	116.8^{b}	3.4^{a}	9^{b}
FCV-MD-23	118.6^{b}	3.3^{a}	8^{b}
FCV-MD-24	72.9^{c}	2.4^{b}	11^{a}

4.6. Standardization of clonal propagation

4.6.1. Effect of different hormones and concentrations on the cuttings from the seedlings of the *Melia dubia*.

4.6.1.1. Sprouting percentage

The results of different hormones at different concentrations on the sprouting percentage are shown in Table 22. It was observed that the hormones at different

concentrations were significant. The sprouting percentage of the cuttings treated with IBA were highest (56 %), followed by IAA (45.77 %) and NAA (41.55 %). The concentration had a negative effect on the sprouting percentage, irrespective of the hormone. The highest sprouting percentage (68 %) was observed, when the concentration of the hormone was 1000 mg l^{-1} and the lowest for the concentration 5000 mg l^{-1}. The interaction between hormones and concentrations were significant (Fig. 34). The hormone and concentration interaction showed that the IBA at 1000 mg l^{-1} was found to be the best combination as the sprouting was 82 percentage and NAA at 5000 was the lowest performing combination (15 %).

4.6.1.2. Rooting percentage

It was observed that the hormones at different concentrations were significant (Table 23). The rooting percentage of the cuttings treated with IBA were highest (48.6 %), followed by NAA (43.93 %) and IAA (39.8 %). The different concentration levels had a negative effect on the sprouting percentage irrespective of the hormone. Highest rooting percentage (67.89) was observed for the concentration 1000 mg l^{-1} and least rooting percentage (12.61) was observed for the concentration 5000 mg l^{-1}. The interaction between hormones and concentrations were significant (Fig. 35). The hormone and concentration interaction showed that the IBA at 1000 mg l^{-1} was found to be the best combination (75.33 %) and 1AA at 5000 was the lowest performing combination (6.67 %).

4.6.1.3. Root length

The effect of hormones at different concentrations on the root length are shown in Table 24. It was observed that the hormones at different concentrations were significant. The root length for IBA (10.22 cm) and IAA (9.36 cm) were at par but were significantly higher when compared to NAA (7.61 cm) hormone treatment. Highest root length (14.39 cm) was observed for all the hormones at concentration 1000 mg l^{-1} and for concentrations 2000 mg l^{-1} and 3000 mg l^{-1} they were at par. Similarly, root length for the concentration 4000 mg l^{-1} and 5000 mg l^{-1} were at par. The highest root length was observed for the treatment IBA at 1000 mg l^{-1} (17.33 cm), while the lowest value (6.0 cm) was observed for the treatment IBA at 5000 mg l^{-1}. The interaction between hormones and concentrations were significant (Fig.

33). It was observed that the highest root length (17.33 cm) was observed for the cuttings subjected to the treatment T1 (IBA 1000 mg l^{-1}), this was followed by the treatment T6 (IAA 1000 mg l^{-1}), with root length (15.33 cm). The control performed better than some of the treatments particularly when the concentration of the hormone was higher.

4.6.1.4. Shoot length

The results of different hormones at different concentrations and their interactions are shown in Table 25. It was observed that the hormones at different concentrations were significant. The interaction between hormones and concentrations were insignificant. The shoot length of the cuttings treated with IBA were highest (6.97 cm), followed by IAA (5.93 cm) and NAA (5.2 cm). The concentration had a negative effect on the shoot length irrespective of the hormone. The highest shoot length (8.29 cm) was observed when the concentration of the hormone was 1000 mg l^{-1} and the lowest (4.5 cm) when the concentration was 5000 mg l^{-1}. The shoot length did not differ significantly for the concentrations 2000 mg l^{-1} and 3000 mg l^{-1}.

4.6.1.5. Collar diameter

The effect of hormones at different concentrations on the collar diameter (mm) is shown in Table 26. Collar diameter differed significantly with different hormones. There was no significant difference for the concentration and for the hormone and concentration interactions. The collar length for IBA (3.12 mm) was the highest. The collar diameter was at par for the cuttings treated with the hormones IAA and NAA.

4.6.1.6. Number of leaves

The effect of hormones at different concentrations on the number of leaves is shown in Table 27. Collar diameter differed significantly with different hormones and for different concentrations. The interactions between hormones and concentrations were insignificant. The number of leaves for IBA and IAA were on par. The highest number of leaves were observed for the concentration 1000 mg l^{-1}.

Table 22. Effect of different hormones for various concentrations on the sprouting percentage of stem cuttings from seedlings of *Melia dubia*

	Concentration (mg l^{-1})					
	1000	**2000**	**3000**	**4000**	**5000**	**Mean**
IBA	82.00 (1.13)^{a}	70.67 (1.00)^{b}	61.67 (0.90)^{c}	42.00 (0.70)^{d}	23.67 (0.51)^{e}	**56.00 (0.85)^{a}**
IAA	59.67 (0.88)^{a}	60.00 (0.89)^{a}	53.00 (0.82)^{b}	32.33 (0.60)^{c}	21.33 (0.48)^{d}	**45.27 (0.73)^{b}**
NAA	62.50 (0.91)^{a}	51.57 (0.80)^{b}	48.33 (0.77)^{b}	30.67 (0.59)^{c}	14.67 (0.39)^{d}	**41.55 (0.69)^{c}**
Mean	**68.06 (0.98)^{a}**	**60.74 (0.90)^{b}**	**54.33 (0.83)^{c}**	**35.00 (0.63)^{d}**	**19.89 (0.46)^{e}**	

Values in the parenthesis shows the logarithmic (Log x) values.

Table 23. Effect of different hormones and concentrations on the rooting percentage of stem cuttings from seedlings of *Melia dubia*

	Concentration (mg l^{-1})					
	1000	**2000**	**3000**	**4000**	**5000**	**Mean**
IBA	75.33 (1.05)^{a}	62.33 (0.91)^{b}	55.00 (0.84)^{b}	36.00 (0.64)^{c}	14.33 (0.39)^{d}	**48.60 (0.77)^{a}**
IAA	65.00 (0.94)^{a}	55.67 (0.84)^{b}	48.33 (0.77)^{b}	23.33 (0.50)^{c}	6.67 (0.26)^{d}	**39.80 (0.66)^{c}**
NAA	63.33 (0.92)^{a}	49.67 (0.78)^{b}	47.17 (0.76)^{b}	42.67 (0.71)^{b}	16.83 (0.42)^{c}	**43.93 (0.72)^{b}**
Mean	**67.89 (0.97)^{a}**	**55.89 (0.84)^{b}**	**50.17 (0.79)^{c}**	**34.00 (0.62)^{d}**	**12.61 (0.36)^{e}**	

Values in the parenthesis shows the logarithmic (Log x) values.

Table 24. Effect of different hormones and concentrations on the root length (cm) of the stem cuttings from seedlings of *Melia dubia*

	Concentration (mg l^{-1})					
	1000	**2000**	**3000**	**4000**	**5000**	**Mean**
IBA	17.33 (1.24)^{a}	11.17 (1.05)^{b}	9.17 (0.96)^{c}	7.43 (0.87)^{d}	6.00 (0.76)^{e}	**10.22 (0.98)^{a}**
IAA	15.33 (1.18)^{a}	8.67 (0.94)^{b}	8.50 (0.93)^{b}	6.93 (0.84)^{c}	7.37 (0.87)^{bc}	**9.36 (0.95)^{a}**
NAA	10.50 (1.02)^{a}	7.33 (0.86)^{bc}	7.50 (0.87)^{b}	6.07 (0.78)^{c}	6.67 (0.82)^{bc}	**7.61 (0.87)^{b}**
Mean	**14.39 (1.15)^{a}**	**9.06 (0.95)^{b}**	**8.39 (0.92)^{b}**	**6.81 (0.83)^{c}**	**6.68 (0.82)^{c}**	

Values in the parenthesis shows the logarithmic (Log x) values.

Table 25. Effect of different hormones and concentrations on the shoot length (cm) of the stem cuttings from seedlings of *Melia dubia*

	Concentration (mg l^{-1})					
	1000	**2000**	**3000**	**4000**	**5000**	**Mean**
IBA	10.17 (1.01)	6.97 (0.84)	6.80 (0.83)	5.73 (0.76)	5.17 (0.71)	**6.97 (0.83)^{a}**
IAA	7.30 (0.86)	5.67 (0.75)	6.33 (0.80)	5.67 (0.75)	4.67 (0.66)	**5.93 (0.76)^{b}**
NAA	7.40 (0.87)	5.43 (0.73)	5.50 (0.74)	4.00 (0.59)	3.67 (0.56)	**5.20 (0.70)^{c}**
Mean	**8.29 (0.91)^{a}**	**6.02 (0.78)^{b}**	**6.21 (0.79)^{b}**	**5.13 (0.70)^{c}**	**4.50 (0.64)^{d}**	

Values in the parenthesis shows the logarithmic (Log x) values.

Table 26. Effect of different hormones and concentrations on the collar diameter (cm) of the stem cuttings from seedlings of *Melia dubia*

	Concentration (mg l^{-1})					
	1000	**2000**	**3000**	**4000**	**5000**	**Mean**
IBA	3.08	2.90	3.40	3.05	3.16	**3.12^{a}**
IAA	2.83	2.47	3.03	3.18	2.75	**2.85^{b}**
NAA	2.75	2.93	2.70	2.80	2.59	**2.76^{b}**
Mean	**2.89^{a}**	**2.77^{a}**	**3.05^{a}**	**3.01^{a}**	**2.83^{a}**	

Values in the parenthesis shows the logarithmic (Log x) values.

Table 27. Effect of different hormones and concentrations on the no. of leaves of the stem cuttings from seedlings of *Melia dubia*

	Concentration (mg l^{-1})					
	1000	**2000**	**3000**	**4000**	**5000**	**Mean**
IBA	10.00 (0.99)	6.67 (0.82)	7.00 (0.84)	6.00 (0.77)	5.33 (0.73)	**7.00 (0.83)^{a}**
IAA	11.00 (1.04)	7.00 (0.84)	6.00 (0.77)	5.33 (0.73)	5.00 (0.69)	**6.87 (0.81)^{a}**
NAA	8.00 (0.90)	6.00 (0.77)	4.33 (0.63)	4.33 (0.63)	4.00 (0.59)	**5.33 (0.73)^{b}**
Mean	**9.67 (0.98)^{a}**	**6.56 (0.81)^{b}**	**5.78 (0.75)^{bc}**	**5.22 (0.71)^{cd}**	**4.78 (0.67)^{d}**	

Values in the parenthesis shows the logarithmic (Log x) value

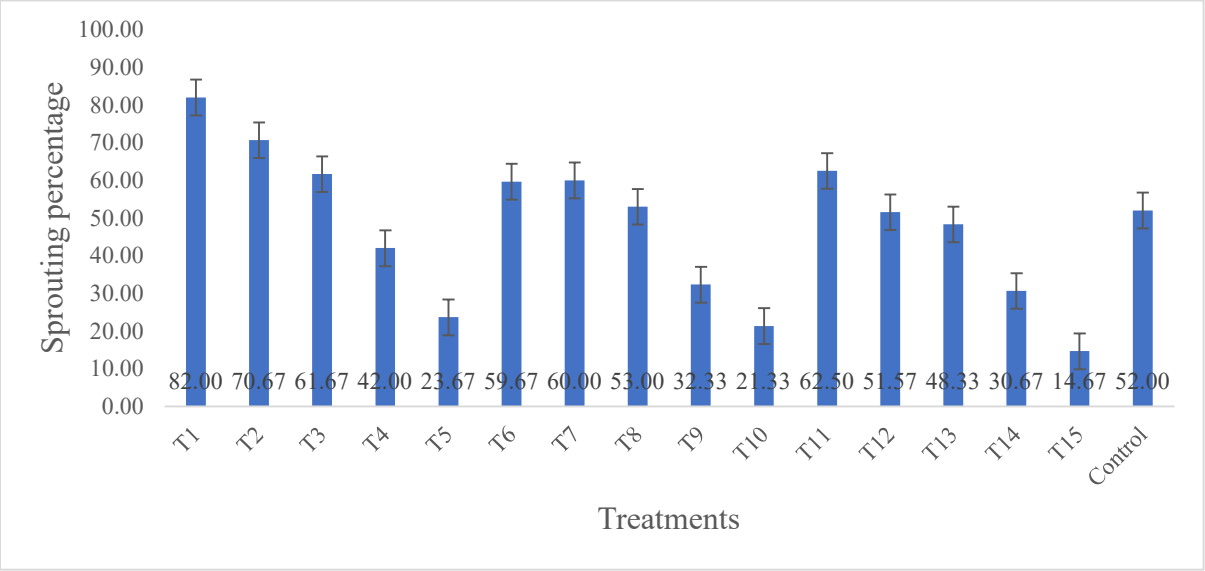


Fig. 34 Effect of different treatments on the sprouting percentage of the cuttings

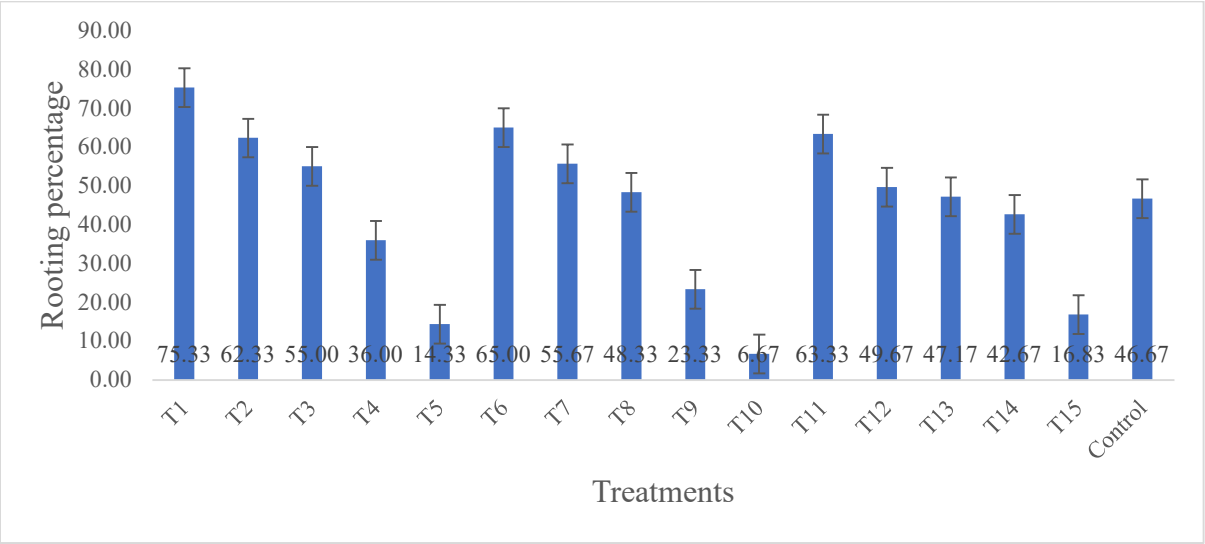


Fig. 35 Effect of different treatments on the rooting percentage of the stem cuttings from seedlings

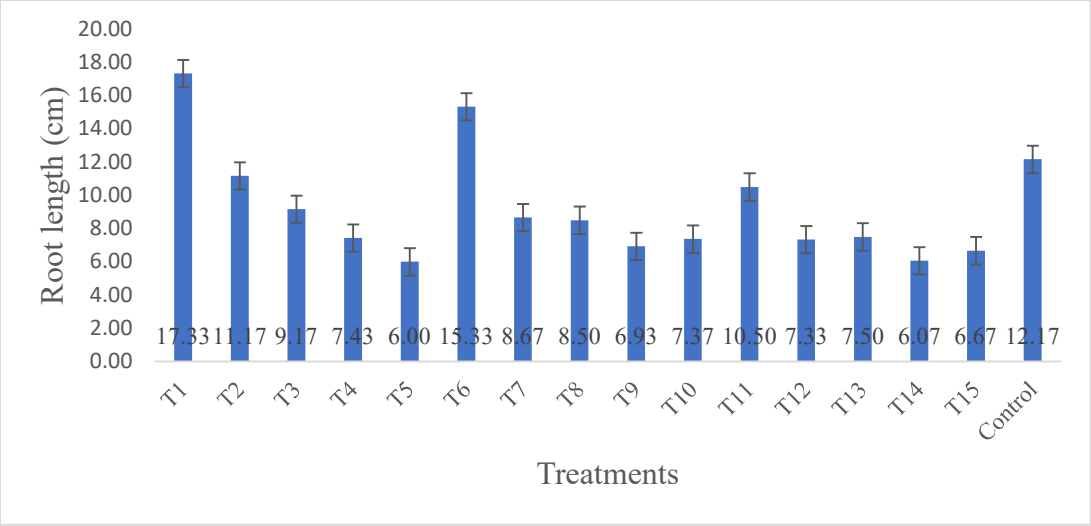


Fig. 36 Effect of different treatments on the root length (cm) of the stem cuttings from seedlings

4.6.2. Effect of different hormones and concentrations on the cuttings of mature trees of *Melia dubia*

The effect of hormones at different concentrations and the interactions between hormone and concentration on the cuttings collected from different plus trees of *Melia dubia* are shown in Table 28. The result showed that there was significant difference for the percentage of root initiation of the epicormic shoots from the cuttings. Root initiation was observed only for the concentration 5000 mg l^{-1}, 6000 mg l^{-1} and 7000 mg l^{-1}. For all the other concentrations the cuttings failed to root irrespective of the hormones. The result showed that of the three hormones experimented, effect of IBA was significant and the observed percentage of root initiation was 49.48. This was followed by IAA (32.49 %) and NAA (29.67 %). The maximum root initiation (57.23 %) was observed for the concentration 6000 mg l^{-1} for all the hormones. This was followed by 31. 28 and 23.13 for the concentrations 5000 mg l^{-1} 7000 mg l^{-1}. The best treatment combination was observed for T6 (IBA at 6000 mg l^{-1}) and the least performing combination was for the treatment T25 (NAA at 7000 mg l^{-1}). The values obtained were 78.1 % and 19.6 % respectively.

The result showed that different hormones at different concentrations had a significant variation with respect to the observed value of number of days taken to sprout, however the variations for the interaction was nonsignificant (Table 29). The value for the number of days taken to sprout (37.76 %) was less for the treatment where IBA was used, which was followed by the treatment with IAA (48.5 %) and for NAA (50.92 %). For the different concentration levels, the best treatment was observed the concentration 6000 mg l^{-1}, where the number of days taken to sprout was least (38.17 %), followed by 5000 mg l^{-1} concentration (46 %) and 7000 mg l^{-1} (52.92 %). It can be concluded that the hormone IBA at 6000 mg l^{-1} concentration was the best combination as far as the number of days to sprout and percentage of root initiation was considered.

Table 28. Mean table showing the effect of different hormones and concentrations on the sprouting percentage of root initiation of cuttings from mature trees of *Melia dubia*.

	Concentration (mg l^{-1})									**Mean**
	1000	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**	**9000**	
IBA	0	0	0	0	41.55 (0.70)^{b}	78.1 (1.09)^{a}	28.8 (0.57)^{c}	0	0	**49.48 (0.79)^{a}**
IAA	0	0	0	0	27.55 (0.55)^{b}	49.03 (0.78)^{a}	20.9 (0.48)^{c}	0	0	**32.49 (0.60)^{b}**
NAA	0	0	0	0	24.75 (0.53)^{b}	44.58 (0.74)^{a}	19.68 (0.46)^{c}	0	0	**29.67 (0.57)^{c}**
Mean	0	0	0	0	**31.28 (0.59)^{b}**	**57.23 (0.87)^{a}**	**23.13 (0.50)^{c}**	0	0	

Table 29. Mean table showing the effect of different hormones and concentrations on the percentage of root initiation of cuttings from mature trees of *Melia dubia*.

	Concentration (mg l^{-1})									**Mean**
	1000	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**	**9000**	
IBA	0	0	0	0	39.25	28.25	45.50	0	0	**37.67^{c}**
IAA	0	0	0	0	48.75	42.25	54.50	0	0	**48.50^{b}**
NAA	0	0	0	0	50.00	44.00	58.75	0	0	**50.92^{a}**
Mean	0	0	0	0	**46.00^{b}**	**38.17^{c}**	**52.92^{a}**	0	0	**48.50^{b}**

Discussion

Discussion

5.1. Variation in the natural population of melia

Foresters are exceptionally fortunate to usually work with an undisturbed pool of high natural variability that has developed over the years (Perry, 1978). The diversity maintained by the population ensures survivability, but the most difficult thing is the understanding of the origin and the mechanisms involved in the maintenance of such large amounts of diversity within forest stands. As the tree has long life span, during which it has to withstand broad climate patterns and microclimate changes, it becomes difficult to identify the causes which shape the variation within stand (Scotti *et al*., 2015). In any given population, there are multiple potential sources of phenotypic variation within it. The underlying cause of each of these sources may be different. The source of the phenotypic variation will determine if the trait responds to environmental changes or to natural or artificial selection. Thus, it is important to determine the relative importance of both the genetic and environmental factors that lead to a specific trait. The genetic causes of variation can themselves be divided into several subcategories. Once the total amount of genetic variation is determined for a trait, it can be used for determining the heritability of that trait. Hence, there is a broader scope for the improvement of high heritability traits such as stem form, wood quality and growth rate. The knowledge thus gained can be used to identify the seed sources from the wild which are best. This will help in the selection of individuals and to develop the selected varieties that are considerably better than the native material.

It was observed that variations existed among the trees within the localities and between localities, as evident from the difference in the size of box plot and from the minimum, maximum and median values that were different for all the localities. This was observed for all the characters (Figure 9-14). The box plot of the trees in Thirunelly showed that the maximum value for the tree height was 35 m. The lowest value of 16 m was observed for trees in Chinnar and Aryankavu. The variation of the values for the trees in Thiruvazhiyad was less as the size of the box was small.

It was observed that the size of the boxplot of the trees in Attappady locality was large, indicating a larger dispersion in the values. The box plot of the trees in Thirunelly showed that the dispersion was minimum as evident from a smaller size of the box plot. The highest value for the GBH (4.4 m) was observed for the trees in Tholpetty and the lowest value (1.3 m) was observed for trees in Attappady. Tree with lowest clean bole height (4 m) was observed in Thirunelly were as the highest clean bole height (13 m) was observed for trees in Dasanakkara. The variation within the localities were more compared to between localities. The breeder uses tree-to-tree variation in a locality for the breeding programme, as it is regarded that such variation is due to genetic factors, since the environmental variation is less in a locality (Zobel and Talbert, 1984).

The average height, GBH and crown width was observed to be more for the trees in Thirunelly whereas the lowest average value for the height, GBH and crown width was observed for the trees from the localities in Attappady, Chinnar and Thiruvazhiyad (Table 4). The CBH:TH for the trees in Thirunelly locality was found to be less, when compared to the other localities. It indicates that the natural pruning ability of the trees at Thirunelly in general is less and from commercial point of view the timber available for utilization is less. The result also shows that the coefficient of variation was highest (50%). When compared to other characters and from the breeding point of view, for the selection of the trees this can be made one of the major criteria. Similar variation in the CBH:TH was observed for the plus trees of *Melia dubia* in Gujarat (Chauhan *et al*., 2018). However, it was observed that the value for the CBH:TH was higher for the trees. This indicates that from commercial point of view more timber is available for utilization. The result also indicate that the natural pruning ability of tree is more and from the breeding point of view, there is further scope of improving these two group of trees.

In standing trees, pilodyn penetration depth is considered to be one of the indirect measurements and non-destructive method to estimate the wood density of outer wood (Raymond and MacDonald, 1998). Chauhan and Kumar (2014) in a study used this method for measuring the wood density in *Melia dubia*. This study also

showed that a high correlation (r=0.77) between the Pilodyn penetration and wood basic density existed. The results of our study for the Pilodyn penetration depth in the standing tree showed (box plot Fig. 14 and appendix II) that the variation for the trait was more within the trees in the locality. Trees in Peechi WLS had a minimum, maximum and median values of 11, 18 and 15 mm respectively. The highest values were observed for the trees in Aryankavu forests. The values for the minimum, maximum and median were 13, 19 and 15 mm respectively. This shows that within locality difference was more than between localities. In a similar study, Pilodyn penetration depth in the sampled trees from nine-year-old plantations ranged from 13 to 22 mm (Chauhan and Kumar, 2014). When both the results are compared, it can be observed that one of the reasons for the higher range for our values within localities may be due to the age of the trees. It is observed that the average variation of Pilodyn depth values for the trees among the localities (range of 13-15 mm) is very less as evident from the result (Table 4). Thus, it can be concluded that the individual tree variation is more when compared to the variations among populations. Our study shows that if the wood density of standing tree also has to be considered for selection, then Pilodyn penetration depth (mm) should be taken as a criterion as one of the quantitative characters. Even though it has disadvantages such as it is expensive and time consuming, the knowledge obtained will be valuable for the breeding programme.

For the characters such as forking, verticality, straightness, self pruning ability, branch angle and thickness, foliar and stem damage and cross section of the trees, it was observed that the variation was very less among the trees. This suggest that using these criteria for selection is of less importance and if measuring this is time consuming, from point of view excess cost avoiding these characters would not affect the selection of the melia trees. Similar results were observed for the studies done in melia, where the variation in qualitative characters was less when compared to the quantitative characters (Chauhan *et al*., 2018). In an experiment done to select superior trees from different plantations in *Acacia sp*., it was reported that the qualitative character especially branch angle and size, showed no significant

variation (Kumar *et al*., 2016). Maximum variation was shown for the characters apical dominance, and bole swelling, hence weightage must be given for these traits during selection. Based on the result of this study, a selection method that is more suitable for melia can be suggested. Availability of the variability in the population is the raw material in any breeding programme and our result shows that the variability is high and thus there is a better chance of selecting plus tree with individuals having desirable characteristics.

5.2. Plus tree selection

In order to make the selection efficient, Hazel and Lush (1942) emphasized on consideration of the extent of genetic variation present in the population, heritability of the traits and genetic and environmental correlation of each trait with the other. A successful phenotypic selection depends upon the amount of genetic variability available in the population for important economic characters and their interrelationship (Lone and Tewari, 2008). In any living organisms it is observed that a sizeable natural variability is present for various characteristics and this is considered as a characteristic feature of most of the populations. Thus, often there exists a better scope for the selection of desirable genotypes in natural variation (Thakur and Thakur, 2015). In species with widespread natural distribution, variations are expected between populations due to the genetic and environmental differences. In our study, variations were observed among the trees within the localities with respect to growth characteristics and most of the qualitative characters as discussed earlier.

The second important criteria while selecting the plus trees is the heritability of those selection traits. Stem straightness and roundness is known to have direct relationship with wood quality and even simple selection of tree form can improve the quality and quantity of product (Shelborne, 1969). In our study the qualitative and quantitative traits of the trees like clear bole height, bole form, branching pattern etc., were given importance for the selection of *Melia dubia* trees from the natural population. It was demonstrated earlier also that high heritability together

with high genetic advance existed for several growth characteristics like tree height, diameter (Dlamini *et al*., 2017), clear bole height (Jha, 2012) and bole straightness (Vargas- Reeve *et al*., 2013).

A plethora of scientific evidence are available in deploying selection techniques for various species and stand types (Morgenstern *et al*., 1975). The method of selection of plus trees followed in India is the comparison tree method. This procedure is efficient in plantations but less efficient than other methods if the neighbours are related (Ledig, 1974). Some researchers are of the view that while selecting for growth rate, selection should be directed towards finding, not the largest tree, but the tree that has utilized the growing space, light, and nutrients most efficiently. This requires finding the tree with the best growth in relation to its leaf surface area (Rudolf, 1956; Bedell, 1980). The technique which applies this concept is base line system that was adopted for the selection in this study. This kind of selection was reported in many hard wood species which thus endorses the selection programme in the current investigation. Moreover, *Melia dubia* is distributed naturally and sporadically across a large geographical region covering four districts and hence the best method possible was base line selection method. Similar, growth characters were used for selection of candidate plus trees by many scientists. In South Gujarat twenty plus trees were identified from natural forests and farmlands. Individual tree selection approach with independent culling method suggested by Surendran *et al.* (2003) was used for selection of trees with superior phenotype (Chauhan *et al.,* 2018). In Tamil Nadu from three dominant *Melia dubia* growing areas 20 candidate plus trees were selected from the natural population. In this study also the traits such as clear bole height, bole form, branching pattern etc. were taken into consideration (Kumar *et al*., 2017). Twenty one plus trees of *Ailanthus excelsa* Roxb. were selected through intensive survey from Haryana, Rajasthan and Gujarat based on the assessment of desirable characters of economic interest such as self-pruning ability, stem straightness, disease resistance, low branching habit, clear bole height, etc. (Daneva *et al*., 2018). The main advantage in the base line method when compared to the other mass selection method like

regression method is that, there is no need to determine the age of the tree. Determination or predicting age in tree is difficult, time consuming and expensive in natural forest. If for the species that are widely distributed in the natural forest especially if trees are found in isolation, then comparison method is difficult. The method we have adopted is having double check. Usually for selection of the trees based on base line method the qualitative characters are not taken into consideration. In our study, we have taken account of the qualitative characters of the tree also. In the first stage, trees having better quantitative characters were separated from the others. Then from those trees, the best trees were selected based on the score of the qualitative characters. Hence the selection will be more accurate. It is not necessary that the trees having higher values for the qualitative character gets selected as the Table 6, shows that the tree PBM-53, had the highest score for the qualitative character that any of the tree had obtained, but this was not selected as it was below the baseline.

The third criteria for selection was genetic and environmental correlation between selection traits. Stem girth at breast height and tree height are commonly recorded measures that give an idea about the tree growth (Chauhan *et al*., 2018). In our study (Table 5) it was observed the height of the tree was significantly correlated with GBH, crown width, clean bole height at 1 per cent probability level. Girth at breast height (GBH) was observed to be correlated in a positive manner with crown width. However, CBH was observed to be correlated negatively with CBH:TH at 1 per cent probability level. Similar observations were made by Tewari *et al*. (2012) in *Prosopis juliflora*, Gupta *et al*. (2012) in *Acacia catechu* and Chauhan *et al*. (2018) for the plus trees in *Melia dubia*. The present findings suggest that tree with larger height had larger girth at breast height so direct selection based on these characters may enhance the genetic gain in subsequent progeny. Crown width was observed to be negatively correlated with CBH:TH. Similar results were observed for melia and it was suggested that this might be due to natural pruning of a particular tree (Chauhan *et al*., 2018). Hence considering the natural pruning ability of the trees as a criterion for selection can be justified.

Against this backdrop, selections were made from the existing natural populations within the forest areas. In our study, twenty five plus trees have been selected from fifteen prominent *Melia dubia* growing areas of Kerala, covering six agroecological units. The selection aimed in the current experiment was from diverse regions thus attesting the essential needs of tree improvement programme This was also done so as to create maximum amount of diversity in the selected populations.

5.3. Cluster analysis

In a breeding programme, the use of heterosis and success in getting advantageous segregates is mainly dependent on how much divergent a trait in that particular population is, further the more diverse the parents the more are the chances of increased heterotic effects and high spectrum of variability in the segregating generations. The genetically diverse parents should also possess consistency of genetic divergence under different environments (Paramathma and Surendran, 2000). The cluster analysis done using hierarchical Eucledeian cluster analysis showed that eleven clusters were formed when the twenty five genotypes of *Melia dubia* genetic resources were resolved (Table 8). Cluster I and II were the biggest cluster with seven members each, cluster VIII and cluster IX had two members each. All the other clusters, cluster III, cluster IV, cluster V, cluster VI, cluster X and cluster XI had only one plus tree their respective groups. When we examine the clusters, it is evident that the grouping of the members was independent to the geographic locations. This clearly shows that the grouping of the diverse trees in a same cluster might be due to the factors other than geographic distribution. In a study done to estimate the genetic variation among half sib families of selected plus trees, high genetic divergence was reported for the selected plus trees of *Melia dubia*. Here, the twenty genotypes of *Melia dubia* resolved into six clusters. Among the six clusters, the cluster I and cluster II were the biggest with 10 and 5 members respectively (Kumar *et al*., 2013). In *Tectona grandis* the clustering of eighty batches of teak was grouped into eight clusters, of which group A formed the largest cluster containing 46 batches (Subramanian *et al*., 1994). In *Acacia nilotica* also clustering technique was used to group the 27 seed sources. The result showed that five clusters were

formed after the analysis, in which group A was the largest and it possessed 21 seed sources. Group B and C included two seed sources each and Group D and E included only one seed source each (Bagchi, 1992) and *Prunus armeniaca* (Singh and Chaudhiri, 1992) which supports to the results of our findings. Thus, the pattern of divergence is independent to the geographical nearness of the genotypes and further, such a grouping could be due to differences in the genetic constituent of the co-occurring genotypes (Bhaumik *et al*., 1971; Chauhan and Sehgal, 2001).

The *intra* and *inter* cluster analysis (Table 10), indicated that the highest intra cluster value was obtained for cluster I (3.74) followed by cluster II (3.09). By observing the clusters III, IV, V, VI, VII, VIII, IX and X it was clear that there was no intra cluster generalized distance because they consisted of only one family. From the inter cluster distance, it was inferred that the cluster I and II (5.54) were the closest while the maximum inter cluster distance was recorded between cluster VI and XI (17.42) followed by cluster VI and cluster VII (17.04). This showed that a wider genetic distance existed between *Melia dubia* plus trees. Such inter and intra cluster divergence were observed in the studies done for the species such as *Pinus gerardina* (Kant, 2006), *Pinus wallichiana* (Aslam *et al*., 2011), *Melia dubia* (Kumar, 2013). This study will help to identify the most distant accessions and most closely placed ones for breeding experiments to obtain hybrid vigour.

5.4. Evaluation of progenies of selected plus trees

In our study, significant differences among the progenies of the twenty five selected plus tree were observed for various morphological traits such as shoot height, collar diameter, number of leaves, absolute growth rate (AGR) and biovolume during five months of the nursery studies. It was observed that among the progenies studied, the performance of the progenies from the two plus trees FCV-MD-03 and FCV-MD-04 selected from the Tholpetty Forest showed highest growth consistently throughout the experiment. All the traits are economically important from the breeding point of view. Existence of variability in growth parameters due to different genotypes and their variations with the differences in soil and climatic

conditions at nursery stage have been reported in studies done earlier. All living organisms possess a sizeable quantity of natural variability that is present for various characters in most populations (Thakur and Thakur, 2015). Thus, there exists a better scope for the selection of desirable genotypes (Vavilov, 1951). In species with widespread natural distribution, variations are expected between populations due to the differences in the genetic and environmental. In our study the analysis of variance showed that significant differences existed among the progenies for different growth characters. Even though the seedlings from seeds of all the twenty five plus trees were raised under almost same environmental conditions, variations were observed between the progenies with respect to some of the traits related to the growth characteristics of progenies. Thus, it can be concluded that the differences observed in the growth traits are due to the difference in the genetic ability of individual progenies. The results of the assessment of progenies of the plus trees can be used to evaluate the progenies among themselves. It also gives fairly a good amount on the information about the ability of the parents to pass on the characters to its progeny, for which selection was originally done.

The information gathered from this study can be used for selecting the exceptionally good parents, which can be used over and over in future for the establishment of seed orchard or can be used for hybridization. In a study done to observe the genetic variations among the half-sib families of selected plus trees in *Melia dubia*, it was concluded that among the progenies of 20 trees studied three families exhibited superiority for different growth parameters when compared to other trees (Kumar *et al*., 2013). Similarly, this type of existence of differences and the ability of a few seed sources to excel, among different half sib families and provenances was reported for *Lagerstromia spp.* (Jamaludheen *et al*., 1995). Similar results of superiority of provenances was reported in *Acacia nilotica* (Ginwal *et al*., 1995) in *Acacia catechu* (Mohapatra, 1996) in *Prosopis cineraria* (Manga and Sen, 1998) in *Melia azaderach* (Jain and Dhar, 2008; Thakur and Thakur, 2015), in *Acacia catechu* (Gera and Gera, 2006), in *Ailanthus excelsa* (Daneva *et al*., 2018), thus supporting our current results.

5.4.1. Genetic analysis

5.4.1.1. Morphological traits

The causes of variation could be assessed by partitioning the total variability into phenotypic and genotypic variability. After partitioning the part of the variation that is heritable can be used for future programmes. In our study, the values of phenotypic coefficient of variation (Table 17) ranged from 12.62 per cent (height) to 24.53 per cent (biovolume), whereas the genotypic coefficient of variation ranged from 10.18 per cent (collar diameter) to 22.53 per cent (biovolume). The phenotypic and genotypic coefficient of variation in the current study indicated that biovolume registered the highest phenotypic and genotypic coefficient of variation compared to other parameters. This was followed by the absolute growth rate, the number of leaves, collar girth and height. Overall, the value of genotypic coefficient of variation was lower in magnitude when compared to that of the phenotypic coefficient of variation (Table 17). The above results indicate, there exists an environmental effect on these characters. It was reported earlier also in a similar study done in neem (Amit *et al*., 2018). In *Melia dubia*, volume index showed high PCV and GCV value, followed by height and collar diameter (Kumar *et al*., 2013). High GCV for the vigour index was earlier reported in teak (Prasad, 1996; Parthiban, 2001) and low GCV for height in *Eucalyptus tereticornis* (Sundararaju *et al*., 1995). In *Bambusa pallida*, low GCV and PCV was reported for height and collar diameter (Singh and Beniwal, 1993). In the current study also, height and collar diameter recorded lower GCV and PCV compared to other parameters (Table 17). The genotypic and phenotypic coefficient of variation recorded in this experiment, provides evidence that there exists adequate genotypic variation. For further improvement of the species these variabilities can be exploited. Similar results and conclusion were observed in *Melia dubia* (Kumar *et al*., 2010).

Heritability indicates the total amount to which a character is influenced by heredity when compared to the environment. The values of the heritability for different characters showed moderate to high heritability for height (0.91), collar diameter

(0.53), number of leaves (0.65), absolute growth rate (0.83) and biovolume (0.84). For all the traits it was observed that the heritability in the broad sense were higher than 50 per cent (Table 17). The high values of heritability help the breeder in the selection programme. Johnson *et al*., (1955) suggested that for selecting the best individuals from a given populations the heritability values and genetic advance are of great help, as from this the resultant effect can be predicted. Heritability (broad sense) is usually due to non additive gene action (dominance and epistasis), so this value to be more realistic has to be accompanied with high genetic gain. In our study, it was observed that the genetic advance (in per cent of the mean) was maximum for biovolume (792.58), followed by plant height (36.53) and the number of leaves (4.24) (Table 17). High heritability, coupled with moderate to high genetic advance (% mean) obtained for these characters indicated that the higher values are due to additive gene effects. This shows a broad scope for the genetic improvement in the species, as it gives an indication on the proportionate role of heredity and the environment at the time of expression of various traits (Dorman, 1976). Similar results were obtained in *Melia dubia*, were it was observed that the values of PCV were higher for volume index, followed by height and basal diameter (Kumar *et al*., 2013). High heritability together with moderate to high genetic advance for different growth traits have earlier been reported by Arun (1996) in *Tectona grandis*; Solanki *et al*., (1984) in *Prosopis cineraria*; Gera *et al*., (2001) in *Dalbergia sissoo* and Dhillon *et al*., (2003) in *Azadirachta indica*. In *Eucalyptus globulus* during the field study of the eight sub-races, it was observed that the heritability for DBH was low (Apiolaza *et al*., 2005). Similarly, in *Eucalyptus globulus* and *E. nitens*, it was observed that for different genetic parameters the heritability was low to moderate. It was observed again in *E. grandis* that the heritability for height and tree volume was low to moderate (Raymond, 2002). In another experiment, it was also observed that the heritability varied with changing environment and age (Devagiri *et al*., 1997).

5.4.1.1. Physiological variation of the progenies and correlation with the growth characters.

The physiological traits such as transpiration and photosynthetic rate, chlorophyll content, stomatal conductance, relative water and content leaf temperature of the seedlings were determined for two periods, 60 DAT and 150 DAT. It was observed that the mean values for all the traits for the period 150 DAT was lower than that observed for the period 60 DAT, except for the leaf temperature. The highest value for chlorophyll content, photosynthetic rate, relative water content was observed for the progenies from the plus trees FCV-MD-03 and FCV-MD-04 for both the period of observation DAT. The lowest value for the photosynthesis, stomatal conductance, transpiration, leaf temperature was observed for the seedlings of plus trees FCV-MD-14 for the period 60 DAT and for the seedlings from plus trees FCV-MD-11 and FCV-MD-17 for all the characters for the period 60 DAT and 150 DAT (Table 18 & 19).

The PCV for the physiological traits (Table 19) was found to be highest for the stomatal conductance (64.28) followed by transpiration rate (51.87), photosynthetic rate (41.74), chlorophyll content (8.71), leaf temperature (5.77) and relative water content (1.02). It was observed that the GCV for the traits varied from 57.5 (stomatal conductance) to 0.87 (RWC), further the values of PCV when compared to that of GCV for the similar characters were less. Similar results were observed for all the characters (Table 19). The values of heritability varied from 0.92 (leaf temperature), 0.82 (chlorophyll content), 0.81 (transpiration), 0.8 (stomatal conductance), 0.72 (photosynthesis and relative water content). The genetic gain was maximum for stomatal conductance (105.94), followed by transpiration (86.26), photosynthesis (62.32), chlorophyll content (14.66), leaf temperature (10.91) and the least for relative water content (1.52).

Photosynthesis is the fundamental processes that provide the organic blocks that contribute largely to the plant development and growth, among the various life processes that control plants growth (Rapparini and Penuelas, 2014).

Photosynthesis largely influences the plant growth and yield (Yamori *et al*., 2016). Both the environmental factors and plant genetic characteristics influences the rate of photosynthesis. Thus, it can be concluded that photosynthetic activity is a complex and interaction between plant genetic and environmental factors is involved in it.

Stomatal conductance measures the degree of stomatal opening, which can be further used as a pointer to the water status in plants (Carmen *et al*., 2013). It is an important factor in energy, CO_2 and water cycling between plants and the atmosphere. It is also vital for both prevention of desiccation and CO_2 acquisition (Medici *et al*., 2007). Studies have shown that plants respond to water deficit very early with closure of stomata, which leads to a limitation in carbon uptake by the leaves. This can in turn result in the reduction of photosynthetic rate of the plants. (Chaves, 1991 and Cornic, 2000). Studies shows that the higher stomatal conductance of plants has been associated with higher leaf water content (Auge *et al*., 2015). The efficiency of net photosynthesis and stomatal conductance are often related to each other (Salisbury and Ross, 1992). Studies has also shown that the net photosynthetic rates and opening of stomata are indirectly related to each other (Bunce, 1988). Hence, variations in stomatal conductance can result in the change in photosynthetic rates (Meng and Arp, 1992). Plants respond to water deficit, which is controlled by the stomata, which has been identified much earlier. The closure of the stomata leads to a limitation in carbon uptake by the leaves (Chaves, 1991). It is been observed that the higher stomatal conductance of plants has been associated with higher leaf water content (Auge *et al*., 2015). Hence, changes in stomatal conductance may cause changes in photosynthetic rates (Meng and Arp, 1992). It is also reported that there are many determinants of plant productivity. The most important among them is the changes that causes differences in net photosynthesis, stomatal density and size (Luukkanen and Kozlowski, 1972; Pallardy and Kozlowski, 1979; Blake and Bevilacqua, 1995; Wang *et al*., 1995).

Earlier the studies were mainly focused on ecophysiological aspects on photosynthesis in forest trees such as the effects of stress on photosynthetic

physiology, and the photosynthetic responses to light intensity (Zhang *et al*., 2002) and CO_2 concentration (Su *et al*., 2003). Our study focused on measuring the rate of photosynthesis and chlorophyll parameters, we also attempted at correlating the physiological characters of the seedlings with its growth. The results showed significant variation in net photosynthesis rate (3.04 to 20.53 µmol m^{-2} s^{-1}) and (0.29 to 3. µmol m^{-2} s^{-1}) for the period 60 DAT and 150 DAT respectively, for different progenies of the plus trees. Similarly, the values observed for the stomatal conductance varied from (0.06 to 0.3 s cm^{-1}) and (0.01 to 0.27 s cm^{-1}) for the period 60 DAT and 150 DAT respectively. Significant variations between the provenance for the physiological traits such as net photosynthesis, stomatal density, stomatal conductance, leaf area, whole-plant dry weight, total guard cell length was observed for neem seedlings (Kundu and Tigerstedt, 1997). Similar findings have been reported by Mebrahtu and Hanover (1991) for blacklocust (*Robinia pseudoacacia* L.) and for black spruce (*Picea mariana* Mill.) by Johnsen and Major (1995). In a study were a multispecies meta-analysis was done from the data sets of 17 published studies, the values for the net photosynthetic rate was observed to vary from 0.8 to 30.6 µmol m^{-2} s^{-1} and value of stomatal conductance, from 0.01 to 0.62 s cm^{-1} (Gago, *et al*., 2016).

In a study done in *Quercus serrata* to investigate the dependence of the concentration of chlorophyll on stomatal conductance on it was observed that as the chlorophyll concentration decreased a corresponding decrease in stomatal conductance was also observed (Matsumoto *et al*., 2005).

In this study, there was a general observation that the values for the relative water content, photosynthetic rate, stomatal conductance, chlorophyll content, was less for the period 150 DAP when compared to the observation done for these parameters for 60 DAT, the main reason may be due to nutrient deficiencies as no additional nutrients were provided to the plants in the polybags. These might have led to stress to all the plants in general. Chlorophyll content in leaves is an important value that evaluates how efficient is the plant as far as photosynthesis is concerned and it shows its response during environmental stress (Zhu *et al*., 2012). Usually a

decrease in chlorophyll content is associated with the plant stress. Under such a situation, the stress can cause substantial damage to photosynthetic pigments and lead to the destruction of thylakoid membrane. Thus, it is expected that the photosynthetic capacity in seedlings reduces as it is exposed to the stress.

The higher chlorophyll content and photosynthetic rate might have led to the accumulation of photosynthates in the progenies of plus tree FCV-MD-03 and FCV-MD-04, resulting in its above-average growth.

The values for the broad sense heritability were observed to be greater than 50 per cent for most of the traits (Table 19). The above results were generally inconsistent with the studies done in different clones of *Tectona grandis*, were high heritability was observed for the photosynthetic rate, chlorophyll content and stomatal conductance. High heritability and genetic advance were observed for *Populus niagra* (Chu, 2010); in *Dalbergia sissoo* (Sharma and Bakshi, 2014); in *Populus trichocarpa* (Mckown *et al*., 2014). In this study it was generally observed that the progenies of the selected plus trees had high variation and heritability (H^2) for most of the growth and physiological traits (Table 19). The photosynthetic rate was positively correlated to the relative water content, transpiration and stomatal conductance. In a study were a multispecies meta-analysis was done from the data sets of 17 published studies, it was observed that a significant positive correlation existed between the photosynthetic rate and stomatal conductance (Gago, *et al*., 2016). The results of our experiment showed that seedlings from different plus trees have different photosynthetic rate. The seedlings of plus trees FCV-MD-03 and FCV-MD-04 had high photosynthetic rates (Table 18). It was observed that net photosynthetic rate showed a significantly positive correlation with seedling height, individual volume, which was an interesting finding of this study (Table 20). The results indicate that the seedlings of plus trees with high photosynthetic rate result in fast-growing plants. The above result was generally inconsistent with the studies done in different clones of *Tectona grandis*, were high heritability was observed for the photosynthetic rate, chlorophyll content and stomatal conductance for some of the clones studied. These traits were positively correlated with seedling height and

volume of the clones. Their study further revealed that this parameter can be used as one of the major tools for the breeding and improvement programme of the tree species (Huang, 2019). In *Populus nigra*, it was observed that species originating in Serbia had a high correlation with the growth, the gas exchange and also with chlorophyll fluorescence parameters. The result showed that this germplasm can be used for future breeding programme as they were found to be highly correlated and having high photosynthetic efficiency (Chu *et al*., 2010). High heritability and genetic advance for the above-mentioned traits were observed for *Populus niagra* (Chu, 2010); in *Dalbergia sissoo* (Sharma and Bakshi, 2014); in *Populus trichocarpa* (Mckown *et al*., 2014).

Therefore, from our study and the results of other research, it can be concluded that the net photosynthetic rate showed variation between the genotypes. Thus, this can be used as a parameter for improving the efficiency of melia breeding. The results shall provide as a means of evaluation of melia germplasm and the knowledge can be used for the introduction, and improvement of melia resources in improvement programs. In our study it was observed that the photosynthetic rate, transpiration rate, chlorophyll content, stomatal conductance, leaf temperature and relative water content were significantly different among the seedlings from different plus trees. The results indicate that some of the germplasm are suitable for breeding of melia especially for the characters such as high photosynthetic efficiency. The above studies indicated the possibility of choosing the best plus tree for a breeding program based on morphophysiological characters of the seedlings.

5.5. Nursery evaluation of the clonal plants

The height of plants (143.6 cm) obtained from the plus tree 20 was significantly different from the others. This was followed by plants from plus tree FCV-MD-21 (116.8 cm) and FCV-MD-23 (118.6 cm), which were at par. The least value (72.9 cm) was obtained for the plants from FCV-MD-24. When we compare the data between the clonal progeny and seedlings it was observed that for the period 90

DAT, the growth for the clonal progenies were higher when compared to the seedlings.

5.6. Standardization of clonal propagation

5.6.1. Effect of different hormones on the cuttings from the melia seedlings

The results of different hormones IBA, IAA and NAA on the rooting and sprouting percentage of the cuttings from the seedlings showed that the hormone IBA gave the best results (Table 22-27). The study showed that the rooting and sprouting percentage of cuttings were 48.6 and 56 percentage respectively. The values for these observations were lower when cuttings were treated with the hormones IAA and NAA. It is a fact that a number of internal and external factors influences the process of adventitious root formation in the cuttings. The application of root promoting growth regulatory substances (auxins) is probably the single most effective external factor that enhances rooting in stem cuttings and thus helps to achieve successful propagation (Sevik and Guney, 2013). IBA is found to be more stable to light when compared to other auxins and this may be one of the reasons for using IBA, commonly as rooting hormone. However, there is lack in the knowledge of the roles of IBA, IAA and NAA particularly, how they differ in the formation of roots (Pacurar *et al*., 2014). It was observed that the increase in the concentration of the hormone level, irrespective of the hormones used, had a negative effect on the root initiation and rooting percentage of the cuttings (Table 20 and Table 21). It is reported that plants have endogenous auxins. As the shoot apex is removed a reduction in the production of these auxins follows which results in the reduction in the number of adventitious roots. So, the presence of hormones at lower concentration may be required to compensate the reduction in the endogenous auxins due to removal of shoot apex (Kurepin *et al*., 2011), but at higher concentration, the hormones might have a deleterious effect on growth of the roots. Studies have shown that the auxins at higher concentration produces toxicity and NAA is more toxic than IBA (Zeng and Lu, 1988). It was observed that the treatment control (T 28) performed better than most of all combination of the

hormones where the concentrations of the hormones were higher. Presence of a preformed adventitious roots initials, which are lying dormant is reported for some of the species of *Salix*, *Populus* and *Jasminum*. These adventitious root initials start growing when the stem is cut and placed in a condition favourable for the growth of roots (Geiss *et al*., 2009; Pijut *et al*., 2011). However, studies are meagre in these aspects and to confirm the result of our study, further study in this subject especially in melia cuttings is required. The effect of the hormones on the root length of the cuttings from the seedlings showed that the treatments T 1 (IBA + 1000 mg l^{-1}) and T 10 (NAA + 1000 mg l^{-1}) were on par. The values for the root length values were 17.33 and 15.33 cm respectively. The collar diameter, number of leaves and shoot length were highest for the treatment T 1.

5.6.2. Effect of growth promoting hormones and their concentrations on the percentage of root initiation and sprouting of the melia hard wood cuttings

It was reported by Haissig and Davis in 1994 that some of the important plant growth activities such as adventitious root formation, stem growth, etc. the role of auxin is inevitable. The study also proves that auxin is involved in the adventitious root formation on stems. It has been further observed that formation of the initial cells of the roots are reliant upon auxins produced in the plants or on the auxins that are given externally to the plants if it is necessary (Gasper and Hofinger, 1988). It has been widely studied that the use of different rooting hormones helps in the development of stem/branch cuttings. These has been widely studied in many forest tree species (Leakey *et al*., 1987; Husen and Pal, 2007; Baul *et al*., 2010). Different studies show that the hormone applied for cuttings that help in their rooting, particularly IBA, had a significant result in rooting of many forest tree species (Tchoundjeu *et al*., 2006; Husen and Pal, 2007). In *Juniperus procera*, a threatened plant, the studies for the response of branch cutting showed that among the three hormones viz., IAA, IBA and NAA tried, the response for IBA was better when compared to other hormones (Berhe and Negash, 1998). In *Swietenia macrophylla* it was observed that the of rooting and sprouting percentage was significantly

higher especially for the cuttings treated with 4000 mg l^{-1} IBA (Azad and Matin, 2015).

In a study done to standardize the rooting hormone in miniclonal technology in teak where different hormones (IBA, IAA and NAA) at various concentrations viz., 1000, 2000, 3000, 4000, 5000 and 6000 mg l^{-1} were applied to the mini cuttings. It was observed that the maximum rooting and sprouting percentage was obtained for the hormone IBA at 6000 mg l^{-1}. (Packialakshmi and Sudhagar, 2019). The result corroborates with our findings. Superiority of IBA over other hormones has been reported earlier by many investigators in *Acacia albida* (Ahmed, 1988), *Woodfordia floribunda* (Shah *et al*., 1994), in *Parkia biglandulosa* (Reeves *et al*., 1996), *Azadirachta indica*, *Casuarina equisetifolia, Ceiba pentandra, Gmelina arborea and Thespesia populnea* (Parthiban *et al*., 1999), *Ceiba pentandra* (Rajendran *et al*., 2002) and *Pterocarpus dalbergioides* (Venkatesh and Pandey, 2006) and *Lannea coromendalica* (Prabhakaran, 2013).

Summary

SUMMARY

An experiment was conducted to determine the genetic diversity of the trees and to select plus trees of *Melia dubia* from the forests of Kerala. Fifteen locations spread over eighteen localities where the species is common were identified from secondary data and reconnaissance survey. In total 281 trees were selected during the survey. Based on baseline selection system, total twenty five trees were selected from the enumerated trees. Seedling progenies from the selected twenty five plus trees were evaluated for its growth and physiological characters for five months in another experiment done at College of Forestry tree nursery. Another experiment was also done to standardize the vegetative propagation techniques in *Melia dubia*.

The salient findings of the study are given below.

1. The box plots for the various characters such as height, GBH, clean bole height, CBH:TH, Pilodyn penetration depth, showed that the minimum, maximum and median values of the trees were different for all the characters from different localities. The mean of the quantitative characters of the trees showed that variation between the localities was low. For the qualitative characters, except for apical dominance and bole swelling variation found between the trees were low.
2. The average height, GBH, and crown width were observed to be high for the trees in Thirunelly whereas the lowest average values for the height, GBH, crown width were observed for the trees from Attappady, Chinnar and Thiruvazhiyad. But, the CBH:TH for the trees in Thirunelly locality was found to be the lowest. It indicates that the natural pruning ability of the trees in general is less in these localities and from commercial point of view the timber available for utilization is less. However, it was observed that the value for the CBH:TH was higher for Attappady, Chinnar and Thiruvazhiyad. This indicates that more timber is available for utilization. The result indicates that the natural pruning ability of tree is more and from

the breeding point of view, there is further scope of improving these two group of trees.

3. The cluster analysis showed that the *Melia dubia* genetic resources resolved the twenty five genotypes into eleven clusters. When we examined the clusters, it was evident that the grouping of the members were independent to the geographic locations. This clearly shows that the factors other than geographic distribution might be responsible for the genetic similarity. The selection index value was also worked out for the best plus trees based on the morphological characters of the trees using principal component analysis.
4. Difference among progenies of the selected plus trees were observed for the morphological characters. It was observed that the progenies from the plus tree FCV-MD-03 and FCV-MD-04 selected from the Tholpetty Forest showed the highest growth consistently throughout the experiment for the characters shoot height, collar diameter, number of leaves, absolute growth rate (AGR) and biovolume. The lowest value for the shoot height and absolute growth rate (AGR) was observed for plus tree (FCV-MD-09) from Attappady region, while a lower value for the collar diameter was observed for the seedlings of plus tree FCV-MD-11 and FCV-MD-12. The number of leaves of seedlings of the plus tree FCV-MD-23, showed lowest value when compared to other plus trees. The least value for biovolume was observed for the progenies of plus tree FCV-MD-17 from Chinnar.
5. The values for the chlorophyll content, photosynthetic rate and relative water content were more for the period 60 DAT when compared to 150 DAT. The leaf temperature for the period 60 DAT was less when compared the values for 150 DAT. The decrease in the photosynthetic rate was more pertinent, when compared to other physiological parameters that were studied. The progenies from different plus trees also showed variation with respect to the chlorophyll content, photosynthetic rate, stomatal conductance, transpiration rate and of the relative water content (RWC) of

the leaves. The progenies from the plus tree FCV-MD-03 and FCV-MD-04 showed the highest values for the physiological characters.

6. Estimate of the heritability for the various morphological and physiological characters showed moderate to high heritability. The high values of heritability help the breeder in the selection programme. The heritability estimates together with genetic advance are usually more helpful in selecting the best individuals.
7. It was observed that net photosynthetic rate showed a significantly positive correlation with seedling height and individual volume, which was an interesting finding of this study. The result indicated that the seedlings of plus trees with high photosynthetic rate resulted in fast-growing plants. It can be concluded that the net photosynthetic rate as a parameter has high practical significance and can be effectively used for improving the efficiency of melia breeding. The results shall provide a means of rapid evaluation of melia germplasm, for introduction, utilization, and improvement of melia resources in future breeding programs.
8. The results of different hormones IBA, IAA and NAA on the rooting and sprouting percentage of the cuttings obtained from the two month old seedlings showed that the hormone IBA gave the best results. It was observed that the sprouting and rooting percentage of cuttings were 56 and 48.6 percentage respectively. The values for these observations were lower when cuttings were treated with the hormones IAA and NAA.
9. Effect of growth regulators and their concentrations on the percentage of root initiation and sprouting of the melia hard wood cuttings showed that the hormone IBA at 6000 mg l^{-1} concentration was the best combination as far as the number of days to sprout, and the percentage of root initiation was considered.

References

References

Abarquez, D., Bush, J. A., Tolentino, E. l. and Gilbero., D. 2015. Early growth and genetic variation of Mahogany (*Swietenia Macrophylla*) in progeny tests planted in Northern Mindanao, Philippines. *J. Trop. For. Sci*. 27(3): 314-324.

Ahmed, D. H. 1988. Preliminary report on macropropagation of *Acacia albida*. Technique of propagation of forest trees. Tissue culture Vs mist propagation. *Vanika Sandesh* 11:10-15.

Allard, R. W. 1960. *Principles of Plant Breeding*. John Wiley and Sons Inc., New York, 264p.

Anand, B., Devagiri, G. M., Maruti, G., Vasudev, H. S., and Khaple, A. K. 2012. Effects of pre-sowing seed treatments on germination and seedling growth performance of *Melia dubia* CAV: An Important Multipurpose Tree. *Int. J. Life Sci.* 1: 59-63.

Ansari, S. A., Kumar, P. and Mandal, A. K. 1995. Effect of position and age of cuttings and auxins on induction and growth of roots in *Dalbergia sissoo* Roxb. *Indian For*. 121(4): 201-206.

Apiolaza, L. A., Raymond, C. A. and Yeo, B. J.2005. Genetic variation of physical and chemical wood properties of *Eucalyptus globulus*. *Silvae genetica* 42(1): 9-15.

Arun, K. C. A. Variability studies in teak (*Tectona grandis* Linn. F.). M.Sc. Thesis, Tamil Nadu Agricultural University, Coimbatore.

Aslam, M., Arshad, S., Rather, S. M., Slathia, H. S. and Seth, C. M. 2007. Auxin induced rooting in *Taxus baccata* Linn. stem cuttings. *Indian J. For*. 30(2): 221-226.

Aslam, M., Reshi, Z. A. and Siddiqi, T. O. 2011. Genetic divergence in half-sib progenies of *Pinus wallichiana* plus trees in the Kashmir Himalaya, India. *Trop. Ecology* 52(2): 201-208.

Auge, R. M., Toler, H. D. and Saxton, A. M. 2015. Arbuscular mycorrhizal symbiosis alters stomatal conductance of host plants more under drought than under amply watered conditions: a meta-analysis . *Mycorrhiza* 25:13-24.

Badji, S., Ndiaye, I., Danthu P. and Colonna, J. P. 1991. Vegetative propagation studies of gum arabic trees *Acacia senegal* (L.) Wild using lignified cuttings of small diameter with eight nodes. *Agrofor. Syst.* 14(3): 183-191.

Bagchi, S. K. 1992. A preliminary study on the genetic divergence of *Acacia nilotica* through seed parameters. *Indian For.* 118: 416-424.

Bagchi, S. K. 2000. Genetic divergence in *Tectona grandis*. *Ann. For.* 8(1): 25-37.

Bakshi, M. 1998. Rooting response of coppice shoot nodal cuttings of *Eucalyptus* hybrid as influenced by season. 124 (12): 1032-1038.

Barnett, P. E. and Farmer, R. E. 1978. Altitudiual variation in germination characteristics of yellow poplar in the Southern Appalachians. *Silvae Genetica* 27(3-4): 101-104.

Becker, W. A. 1985. *Manual of quantitative genetics*. 4th ed. Academic Enterprises, Pullman, W. A. 194p.

Bedell, P. E. 1980. *Tree Breeding for Genetic Improvement of Tropical Tree Species*. Allied Publisher Pvt. Ltd., New Delhi, 201p.

Beyer, D. 2008. Components of phenotypic variance. *Nature Education* 1(1):161.

Bharti, A. K. 2007. Screening alternate pulp wood species and establishment of tree improvement strategies for the screened species. M.Sc Thesis, TNAU, Coimbatore, India.

Bhaumik, P. K., Sinha, M. K. and Banerjee, S. P. 1971. Genetic divergence among rice strains. *Theor. Appl. Genet*. 41: 31-35.

Blake, T. J. and Bevilacqua, E. 1995. Early selection of *Eucalyptus grandis* clones in central Brazil. *J. Trop. For. Sci*. 8:33-43.

Blake, T. J. and Yeatman, C. W. 1989. Water relations, gas exchange, and early growth rates of outcrossed and selfed *Pinus banksiana* families. *Can. J. Bot*. 67:1618–1623.

Bonner, F. T. 1984. Glossary of seed germination terms for Tree Seed Workers, USDA. Forest Service, Gen. Tech. Rep. Southern Forest Experiment Station, Stankville, Mississippi, USA, pp. 30-49.

Brown, C. L. and Goddard, R. E. 1961. Silvicultural considerations in the selection of plus phenotypes. *J. For*. 59: 420-426.

Bunce, J. A. 1988. Effects of boundary layer conductance on substomatal pressures of carbon dioxide. *Plant Cell Environ*. 11:205--208.

Burton, G. W. and De-Vane, E. W. 1953. Estimating heritability in fesue (*Festuca arundinacea*) from replicated clonal material. *Agron. J*. 45: 478-481.

Chander, V., Singh, R. R., Mandal B. S. and Chander, H. 1996. Effect of auxin on number of leaves per cutting and length of main branch in neem (*Azadirachta indica*). *Ann. Bot*. 12(1): 57-61.

Chaturvedi, A. J., Sivaji, P. and Jayaramprasad, D. V. 1989. *Eucalyptus* provenance trails in A. P. *Indian For*. 115(7): 445-454.

Chauhan, R. S., Jadeja, D. B., Thakur, N. S., Jha, S. K., and Sankanur, M. S. 2018. Selection of candidate plus trees (CPTs) of Malabar Neem (*Melia dubia* Cav.) for enhancement of farm productivity in South Gujarat, India. *Int. J. Curr. Microbiol. Appl. Sci*. *7*(5): 3582-3592.

Chauhan, S. and Kumar, A. A. 2014. Assessment of variability in morphological and wood quality traits in *Melia dubia* Cav. for selection of superior trees. *J. Indian Acad. Wood Sci. 11*(1):25-32.

Chauhan, S. K. and Sehgal, R. N. 2001. Genetic divergence among progenies of Himalayan long leaf pine. *Indian J. For*. 24: 65-71.

Chaves, M. M. 1991. Effects of water deficits on carbon assimilation. *J. Exp. Bot.* 42:1-16.

Chen, Y., Yuan, L. P., Wang, X. H., Zhang, D. Y., Chen, J., Deng, Q. Y., Zhao, B. R., and Xu, D. Q. 2007. Relationship between grain yield and leaf photosynthetic rate in super hybrid rice. *J. Plant Physiol. Mol. Biol*. 3: 235–243.

Chinnaraj, S., Malimuthu, C. and Subrahmanyam, S. V. 2011. Development of micropropagation and minicutting protocol for fast growing *Melia, Dalbergia* and *Eucalyptus*clones for pulpwood and bioenergy plantations. In: *Proceedings of IUFRO Tree Biotechnology Conference* Bahia, Brazil. pp. 332-334.

Chu, Y. G., Su, X. H., Huang, Q. J., and Zhang, X. H. 2010. Relationships between photosynthetic characteristics and growth traits in gene resources of *Populus nigra*. *Sci. Silvae Sin*. 46: 77–83.

Chuan, Z. Y., Der, C. J. and Zung, C. Z. 1995. Vegetative propagation of adult *Eucalyptus grandis* x *E.crophylla* comparison growth between micropropagated plantlets and root cuttings. *Plant Cell Rep*. 15 (3/4): 170-173.

Cornelius, J. 1994. The effectiveness of plus-tree selection for yield. *Forest Ecol. and Manag*. 67 (1–3) : 23-34.

Cornic, G. and Massacci, A. 2000. Leaf photosynthesis under drought stress. In: Baker, N. R. (ed.), Photosynthesis and the environment. Kluwer Academic Publishers, New York, pp. 346-366.

Cown, D. J. 1981. Use of the Pilodyn wood tester for estimating wood density in standing trees–influence of site and tree age. 7XVII IUFRO World Forestry Conference, Kyoto, Japan, Sept. 1981.

da Costa, C. T., de Almeida, M. R., Ruedell, C. M., Schwambach, J., Maraschin, F. S. and Fett-Neto, A. G. 2013. When stress and development go hand in hand: main hormonal controls of adventitious rooting in cuttings. *Front Plant Sci*. 4:133.

Daneva, V., Dhillon, R. S., and Johar, V. 2018. Plus tree selection and progeny testing of superior candidate plus trees (CPTs) of *Ailanthus excelsa*. *J. of pharmacology and phytochemistry* 7(2): 543-545.

Devagiri, G. M., Singh, J. M., Chand, R. and Srivastava, L. J. 1997. Genetic variability in *Heracleum candicans*. *Indian J. Genet*. 57(3): 280-286.

Dhillon, R. S., Bisla, S. S., Arya, S., and Hooda, M. S. 2003. Genetic variation, heritability and correlation for growth parameters in *Azadirachta indica* A. Juss. *Ann. For.* 11(2):215-221.

Dlamini, L. N., Pipatwattanakul, D., and Maelim, S. 2017. Growth variation and heritability in a second-generation *Eucalyptus urophylla* progeny test at Lad Krating Plantation, Chachoengsao province, Thailand. *Agric. Nat. Resour.* 51: 158-162.

Dorman, K. W. 1976. *The genetics and breeding of Southern Pines*. U.S. Dept. of Agril. For. Serv. Agric. Handbook No. 471. 407p.

Falconer, D. S. and Mackay, T. F. C. 1996. *Introduction to quantitative genetics*. 4th Edn., Longman Group Ltd., Essex, England.

Falk, D. A. and Holsinger, K. E. 1991. *Genetics and conservation of rare plants*. Oxford University Press, London.

Gago, J., de Menezes Daloso, D., Figueroa, C. M., Flexas, J., Fernie, A. R., and Nikoloski, Z. 2016. Relationships of leaf net photosynthesis, stomatal conductance, and mesophyll conductance to primary metabolism: a multispecies meta-analysis approach. *Plant Physiol. 171*(1): 265-279.

Gao, M., Ding, C. J., Su, X. H., and Huang, Q. J. 2014. Comparison of photosynthetic characteristics of *Populus deltoides* and their Fl hybrid clones. *For. Res*. 27: 721–728.

Garcia Cuevas, B., Bernaso Velazquez, B. B. and Maldonada, H. R. 1992. Genetic gains in *Eucalyptus camaldulensis* determined through provenance trials. *Revista Chapingo* 15(75): 34-39.

Gasper, T. and Hofinger, M. 1988. Auxin metabolism during adventitious rooting. In: Davis, T. D., Haissig, B. E. and Sankhla. (eds.). Adventitious root formation in cuttings. Portland, Dioscoride Press. Pp. 61-69.

Gera, M., Gera, N. and Sharma, S., 2001. Estimation of variability in growth characters of forty clones of *Tectona grandis* LF. *Indian For. 127*(6): 639-644.

Gera, M., Gera, N., Meena, S. L. and Singh, T. 1998. Variation in rooting response in the provenances of *Azadirachta indica* A. juss. *Indian For*. 124 (9): 696- 701.

Glover, N. 1987. Variation among provenances of *G. sepium* (Jacq.) Walp. And implications of genetic improvement. In: NFTA, *G. sepium* (Jacq.) Walp.: Management and improvement. Proc. Workshop held at CATIE, Turrialba, Costa Rica, June, 1987. NFTA SPl. Publ. 87(1): 168-173.

Goel, V. L., Bhel, H. M. and Hael, C. 1997. Propagation of *Prosopis juliflora* from rooted stem cuttings. *Inter. Tree Crop J. 2(4):* 193-201.

Govindachari, T. R. 1992. Chemical and biological investigation on *Azadirachta indica* (neem tree). *Curr. Sci.* 63: 117122.

Gradual, L., Kjaer, E. D., Suangtho P. and Kaosaard, A. 1999. Conservation of genetic resources of teak (*Tectona grandis*) in Thailand. Technical Note No. 52. Danida Forest Seed Centre, Denmark.

Greaves, B., Borralho, N. M. G., Raymond, C. A. and Farrington, A. 1996. Use of Pilodyn for the indirect selection of basic density in *Eucalyptus nitens*. *Can. J. For. Res*. 26:1643–1650.

Gunasena, H. P. M. and. Fernando, D. N. S. 1996. Preliminary results of *Casuarina equisetifolia* provenance trials in Sri Lanka. In: Pinyopusarer, K. K., Turnbull, J. W. and S. J. Midgley (eds.). *Recent Casuarina research and utilization.* Proceedings of the Third International *Casuarina* workshop held in Da Nang, Vietnam, March 4-7. pp. 171-174.

Gupta, K., Bharat, G. K., Wagle, D. S. and Chawla, H. K. L. 1989. Nutrient contents and antinutritional factors in conventional and non-conventional leafy vegetables. *Food Chem*. 31(2): 105-116.

Gupta, T., Tej, P. and Gupta, R. K. 2012. Genetic variability and correlation study in *Acacia catechu* seed source in Himachal Pradesh. *Range Manag. and Agrofor.* 33 (1): 47-52.

Gurumurthi, K. and Bhandari, H. C. S. 1988. Induction of rooting in cladode cuttings of *Casuarina equisetifolia*. Curr. Sci. 57: 958-959.

Haissib, B. E. and Davis, T. D. 1994. An historical evaluation of adventitious rooting research to 1993. In: Davis, T, D. Haissig, B. E. (ed.). Biology of adventitious root formation, New York, Plenum Publishing Corporation. Pp. 275-331.

Hamrick, J. L. 1979. Genetic variation and longevity. In: Solbrig, O., Jain, S. and Johnson, G.(eds.) *Topics in Plant Population Biology* pp.84–113.

Hamrick, J. L., Mitton, J. B. and Linhart, Y. B. 1979. Levels of Genetic Variation in Trees: Influence of life history characteristics. In: *Symposium on Isozymes of North American Forest Trees and Forest Insects*, July 27, 1979, Berkeley, Calif.

Hartmann, H. T., Kester, D. E. and Davies, F. T. 1990. *Plant Propagation-Principles and Practices.* Prentice Hall Inc, Englewood Cliffs, N. J.

Hatchell, G. E. 1985. Production of bare root seedlings. In: Should, E. (ed.) Proceedings of third *Biennial Southern Silviculture Research Conference*. 7-9 November 1984. Atlanta, pp. 395-402.

Hazel, L. N. and Lush, J. L. 1942. The efficiency of three methods of selection. *J. Heredity* 33: 393-399.

Heber, U., Neimanis, S. and Lange, O. L.1986. Stomatal aperture, photosynthesis and water fluxes in mesophyll cells as affected by the abscission of leaves. Simultaneous measurements of gas exchange, light scattering and chlorophyll fluorescence. *Planta.* 176:554--562

Heydecker, W. 1972. Vigour In: Roberts, E. H. (ed.). *Viability of seeds*. Chapman Hall, London. pp. 209-252.

Holzer, K. 1965. Standardization of methods for provenance research and testing In: *Proceedings of IUFRO Congress*, Munchen, Germany, 111(22): 672-718.

Hou, A. J. and Xu, D. C. 2005. Current advance of high photosynthetic efficiency breeding by gene engineer in plants. *China Biotechnol*. 25: 19–23.

Huang, G., Liang, K., Zhou, Z., Yang, G. and Muralidharan, E. M. 2019. Variation in photosynthetic traits and correlation with growth in Teak (*Tectona grandis* Linn.) Clones. *For.* 10(1): 44.

Husen, A, and Pal, M. 2007. Metabolic changes during adventitious root primordium development in *Tectona grandis* Linn. f. (teak) cuttings as affected by age of donor plants and auxin (IBA and NAA) treatment. *New For*. 33(3):309-323.

Ingvarsson, M. and Dahlberg, H. 2019. The effects of clonal forestry on genetic diversity in wild and domesticated stands of forest trees. *Scandinavian J. For. Res*. 4:202-215.

Jagatram, M., Surendran, C., Paramathma, M., Parthiban, K. T. and Sasikumar, K. 2003. Micropropagation of *Madhuca latifolia*. *Indian J. For*. 26(4): 445-448.

Jamaludheen, V., Gopikumar, K., and Sudhakara, K. 1995. Variability studies in *Lagerstroemia speciosa*. *Indian for.* 121(2):137 -141.

Jayaraj, R. S. C. 1997. Selection of candidate plus trees of *Eucalyptus* spp. for a large scale clonal forestry programme. In: Vivekanandan, K., Gurumurthi, K., and Jayaraj, R. S. C. (eds.), *Clonal Multiplication of Eucalypts*. Institute of Forest Genetics and Tree Breeding, Coimbatore. pp.34-47.

Jha, R. K., 2012. A study of variability, associations, and path analysis in poplar (*Populus deltoides* Bartr. ex Marsh). *J. Sustain. For.* 31(3): 185-204.

Johar, V., Dhillon, R. S., Bangarwa1, K. S., Ajit, and Handa, A. K. Phenological behaviour and reproductive biology of *Melia composita. Indian J. Agrofor.* 1(17): 62-67.

Johnsen, K. H. and Major, J. E. 1995. Gas exchange of 20-year-old black spruce families displaying a genotype ´ environment interaction in growth rate. *Can. J. For. Res*. 25:430-439.

Johnson, H. W., Robinson, H. F. and Comstock, R. E. 1955. Estimation of genetic and environmental variability in Soya beans. *Agron. J.* 47: 314-318.

Kant, A., Dutt, V. and Sharma, D. R. 2006. Genetic variability in phenotypic characters of Pinus gerardiana. *Indian For*. 132: 681-690.

Kapur, S. K. and Dogra, A. S. 1987a. Provenance trial of *E. tereticornis* in Punjab. *Indian For*. 113(1): 2-5.

Kapur, S. K. and Dogra, A. S. 1987b. Provenance trial of *Eucalyptus camaldulensis* in Punjab. *Indian For*. 113(1): 471-475.

Karoshi, V. R., Hegde, G. V. and Hiremath, S. M. 2000. Macro propagation of thornless *Prosopis alba* a report. *Indian For*. 126(4): 433-435.

Khobragade, N. D., Prasad, H., Prabha, S. A. C., and Mandal, A. K. 2013. Parameters for selection of candidate plus trees of *Terminalia chebula* and *Terminalia bellerica*. *Indian For.* 149 (9): 833-835.

Kiritkar, K. R. and Basu, B. D. 1999. Indian Medicinal Plants. In: Blatter, E., Caicus, J. F. and Mhaskar, K. S. (eds.), International Book Distributors, Dehradun, vol. 1, pp. 545-546.

Kokwaro, J. O. 1976. Medicinal plants of East Africa, East African literature Bureau, Nairobi, In: *Proceedings of the Kenyan Seminar on Agroforestry*. IARAF, Nairobi. Pp: 377-386.

Koul, O., Jain, M. P., and Sharma, V. K. 2000. Growth Inhibitory and Antifeedant Activity of Extracts from *Melia Dubia* to *Spodoptera Litura* and Helicoverpa Armigera larvae. *Indian J. Exp. Biol.* 38(1): 63-68.

Kulkarni, P. K. and Jakawale, P. S. 1999. Studies on rooting in juvenile cuttings of *Dalbergia sissoo. J. Trop. For*. 15(3): 178-181.

Kumar, A. and Gurumurthi, K. 1998. Genetic assessment of clonal material of *Casuarina equisetifolia*. *Indian For.* 124(3): 237-242.

Kumar, A., Shrivastava, P., Sharma, S., Dobhal, S., Rana, A., and Kumar, R. 2017. Development of High Yielding Varieties of *Melia dubia* Cav.(Syn. *M. composita* Benth.). *Indian For. 143*(11): 1203-1206.

Kumar, M. S., Parameswari, N., Chin, C. F. , Baharum, Z. , Olalekan, K. K., and Nor Aini, A. S. 2016. Selection and Screening of Superior Genotypes for Quality Planting Stock Based on Vegetative Growth Performance of Some Selected 12-Year-Old Acacia Species. *Open J. For*. 6,217-229 (Available from:https://www.researchgate.net/publication /304618704 Selection and Screening of Superior Genotypes for Quality Planting Stock Based on Vegetative Growth Performance of Some Selected 12-Year-Old Acacia Species [accessed Nov 05 2019].

Kumar, P., Parthiban, K. T., and Saravanan, V. 2013. Genetic variations among open pollinated families of selected better trees in *Melia dubia*. *Res. J. Recent Sci.* ISSN, 2277, p.2502.

Kumar, S. M., Parameswari, N., Chin, C. F., Baharum, Z., Olalekan, K. K., and Aini, N. A. S. 2016. Selection and screening of superior genotypes for quality planting stock based on vegetative growth performance od some selected 12- year old *Acacia* species. *Open J. For.* 6: 217-229.

Kumar, V. G. S. and Aishwarya, R. 2017. Development of Proliferation and Acclimatization of *Melia dubia*-Australian Teak Variety through Micropropagation. *Int. J. Innovative Res. Sci. Eng. Technology* 6(1): 1226-1236.

Kundu, S. K. and Tigerstedt, P. M. A. 1997. Geographic variation in seed and seedling traits of neem (*Azadirachta indica*) among 10 populations studied in growth chamber. *Silvae Genetica* 46(2-3): 129-137.

Kurepin, L., Haslam, T., Lopez-Villalobos, A,, Oinam, G. and Yeung, E. 2011. Adventitious root formation in ornamental plants: II. The role of plant growth regulators. *Propag Ornam Plants* 11: 161–171

Langner, C. C. 1960. Improvement through individual tree selection and testing seed stand and clonal seed orchards. In: 5th World Forestry Congress Seattle, Washington.

Leakey, R. R .B. 1987. Common Spatew. *For. Rev*. 66(1): 61-75.

Ledig, T. F. 1974. An analysis of methods for the selection of trees from wild stands. *For. Sci.* 20: 2-16.

Leela, G., Dayana, J., Monisha, S., Irudaya, I., Anitha, A. and Rosaline, J. V. 2016. Studies on phytochemical, nutritional analysis and screening of in vitro biological activities of *Melia dubia* leaf extract. *Int. J. Sci. Eng. Res.* 7(8): 56-68.

Lindgren, D., Wei, R. P and Lee, S. J. 1997. How to calculate optimum family number when starting a breeding programme. *F. Sci*. 43: 206-212.

Lone, A. and Tewari, S. K. 2008. Genetic variability and correlation studies in Poplar (*Populus deltoides* Bartr.) *Indian J. For*. Vol. 31(2): 193-196.

Long, S. P., Zhu, X. G., Naidu, S. L., and Ort, D. R. 2006. Can improvement in photosynthesis increase crop yields? *Plant Cell Environ*. 29: 315–330.

Lush, J. L. 1940. Intensive correlation and regression of offsprings of damsasa method of eliminating heritability characters. *Proc. Am. Soc. Anin. Prod*. 33: 293-301.

Luukkanen, O. and Kozlowski, T. T. 1972. Gas exchange in six Populus clones. *Silvae Genet.* 21:220--229.

Manjunatha, K. B. 2007. Clonal propagation of *Melia dubia* (Cav). *My For.* 43: 455-458.

Masilamani, P., Dharmalingam, C. and Annadurai, K. 1999. Provenance variation in seed and seedling attributes of teak (*Tectona grandis* Linn. f.). In: *National Symposium Forestry towards 21st Century* held at TNAU, Coimbatore, Sept. 27-28.

Mathur, R. S., Bharma, K. K. and Rawat. M. M. S. 1984. Germination behaviour of various provenances of *Acacia nilotica* spp. indica. *Indian For.* 111: 435-449.

Matsumoto, K., Ohta, T., and Tanaka, T. 2005. Dependence of stomatal conductance on leaf chlorophyll concentration and meteorological variables. *Agric. For. Meteorol.* 132. 10.1016/j.agrformet.2005.07.001.

McDermitt, D. K., Norman, J. M., Davis, J. T., Ball, T. M., Arkebaurer, T. J., Welles, J. M. and Roerner, S. R. 1989. Co_2 response curves can be measured with a field-portable closed loop phothosynthesis system. *Annales des Sciences Forestieres* 46:461-420.

McKown, A. D., Guy, R. D., Klapste, J., Geraldes, A., Friedmann, M., Cronk, Q. C., El-Kassaby, Y. A., Mansfield, S. D., and Douglas, C. J. 2014. Geographical and environmental gradients shape phenotypic trait variation and genetic structure in *Populus trichocarpa*. *New Phytologist 201*(4): 1263-1276.

Mebrahtu, T. and Hanover, J. W. 1991. Leaf age effects on photosynthesis and stomatal conductance of black locust seedlings. *Can. J. For. Res.* 21(11):1616-1621.

Meng, F. R. and Arp, P. A. 1992. Net photosynthesis and stomatal conductance of red spruce twigs before and after twig detachment. *Can. J. For. Res*. 23:716--721.

Mishra, C. M. and Banerjee, A. C. 1995. Provenance variation in *Casuarina* species with reference to germination and growth. *J. Trop. For*. 11(3): 209-211.

Mohapatra, K. P. Variability studies for seedling traits in *Acacia catechu* Willd. under nursery conditions. M.Sc. Thesis, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni-Solan, 1996.

Morgenstern, E. K., Holst, M. J., Telch, A. H., and Yeatman, C. W. 1975. Plus tree selection –Review and outlook. Department of Environment, Canadian Forest Service, Pub. No. 1347, Ottawa, Canada.

Mushtaq, T., Banyal, R., Mugloo, J., Mushtaq, T. and Aziz, M. A. 2017. Clonal forestry: An effective technique for increasing the productivity of plantations. *SKUAST J. Res.* 19(1): 22-28.

Nair, K. K. N., Mohanan, C., and Mathew, G. 2005. Plantation technology for selected indigenous trees in the Indian peninsula. *Bois et Forets des Tropiques*, 285: 17-23.

Nair, N. G. 1991. *Distribution of Important Forest Tree Species in Kerala* (*Souther Circle*). Research Report No. 75, Kerala Forest Research Institute, Peechi, 17p.

Namkoong, G., Barefoot, A. C. and Hitchings, R. G. 1969. Evaluating control of wood quality through breeding. *Tappi* 52(10): 1935-1938.

Otegbeye, G. O. 1985. Provenance productivity in *Eucalyptus camaldulensis* DEHNH and its implication to genetic improvement in Savanna Region of Nigeria. *Silvae Genet.* 34: 4-5.

Otegbeye, G. O. and Samarawira, I. 1992. Genetics of growth and quality characteristics of *E. camaldulensis*. *Silvae Genet*. 4(4-5): 249-252.

Packialakshmi, M and Sudhagar, R. J. 2019. Standardization of rooting hormone in mini clonal technology of *Tectona grandis* Linn. *Int. J. Chemical Studies* 7(3): 4398-4401.

Pacurar, D. I., Perrone, I., and Bellini, C. (2014). Auxin is a central player in the hormone cross-talks that control adventitious rooting. *Physiologia Plant.,* 151 (1): 83 - 96., DOI : 10.1111/ppl.12171 inra.fr/record/ 259700.

Padmini, S. and Banerjee, A. C. 1986. Proveance trials of *Acacia nilotica*. *J. Tree Sci.* 5: 53-56.

Pal, M., Mishra, M. and Bhandari, H. C. S. 1994. Effect of auxin on rooting branch cuttings of *Withania somnifera. Indian J. For*. 17: 32-34.

Palanisamy, K. and Bisen, S. S. 2001. Vegetative propagation technique for *Dendrocalamus asper*, *Indian For*. 127 (3): 363-364.

Palanisamy, K. and Kumar, P. 1996. Seasonal effect of induction of adventitious rooting in stem cuttings of Neem (*Azadirachta indica* A. Juss). Ind. J. For. 19 (2): 183-186.

Palanisamy, K., Ansari, S. A., Kumar, P. and Gupta, B. N. 1998. Adventitious rooting in shoot cuttings of *Azadirachta indica* and *Pongamia pinnata*. *New For.* 16(1): 81-88.

Pallardy, S. G. and Kozlowski, T. T. 1979. Frequency and length of stomata of 21 Populus clones. *Can. J. Bot*. 57:2519--2523.

Panse, V. G. and Sukhatme, P. V. 1961. Statistical Methods for Agricultural Workers. ICAR New, Delhi.

Paramathma, M. and Surendran, C. 2000. Exploitation of heterosis for afforestation in *Eucalyptus*. In: *Proceeding of the International Symposium on Hybrid Breeding and Genetics,* 9-14 April, Noose Lake, FRI, Australia.

Parthiban, K. T., Akilesh, K. B., Seenivasan, R., Kamala, K., and Govinda, R. M. 2009. *Integrating Melia dubia in agroforestry farms as an alternate pulpwood species.* Asia Pacific Agroforstry News Letter No.34, Thammada Press Co. Ltd., Bangkok, Thailand. pp. 3-4.

Parthiban, K. T., Surendran, C., Murugesh, M. and Buvaneswaran, C. 1999. Vegetative propagation of a few multipurpose tree species using stem cuttings. *Adv. Hor. For.* Jodhpur. 6(27):175-178.

Perry, D. R. 1978. A method of access into the crowns of emergent and canopy trees. *Biotropica* 10: 155-157.

Pijut, P. M., Woeste, K. E. and Michler, C. H. 2011. Promotion of adventitious root formation of difficult-to-root hardwood tree species. In: Janick, J., (ed.), *Horticultural Reviews*. John Wiley & Sons Inc., Hoboken, NJ, pp. 213–251.

Prabhakaran, P. 2013. Genetic analysis of *Lannea coromandelica* (Houtt.) Merr. M.Sc. Thesis, Tamil Nadu Agricultural University, Coimbatore, 2015.

Prasad and Kulkarni. H. D. 1988. Techniques of propagation of forest trees. Tissue culture Vs Mist propagation. *Vaniki Sandesh*. 11(4): 10-15.

Puri, S. 1990. Rooting of stem of *Casuarina equisetifolia* and their nodulation. *Int. Tree Crops J.* 6(10): 51-57.

Raghavendra, T. R., Priti, V., Swathi, H. K., Ramesha, B. T., Ravikanth, G., Ganeshaiah, K. N., Srikrishna, A., and Uma, S. R. 2009. Prospecting for alternate sources of shikimic acid, a precursor of Tami flu, a bird-flu drug. Scientific correspondence. *Curr. Sci*. 96 (6): 771 - 772.

Rajendran, P., Dasthagir, M. G., Yassin, M. M. and Divakara, B. N. 2002. Vegetative propagation of *Ceiba pentandra* (Linn.) Gaertn. By stem cuttings. *Indian J. Agrofor*. 4(1):67-70.

Rajkumar, R. 1999. Micropropagation and molecular characterization of Red Sanders (*Pterocarpus santalinus*). Ph.D. Thesis, Tamil Nadu Agricultural University, Coimbatore.

Rapparini, F. and Penuelas, J. 2014. Mycorrhizal fungi to alleviate drought stress on plant growth. In: *Use of Microbes for the Alleviation of Soil Stresses*. Vol. 1, Springer, New York, pp. 21-24.

Rawat, S., ArunKumar, A. N., Annapurna, D., Karaba, N. N., and Joshi, G. 2018. *Int. J. Genet.* 10 (9) : 490-494.

Rawat, S., Kumar, A. N., Annapurna, D., Karaba, N. N. and Joshi, G. 2018. Genetic diversity of *melia dubia* using ISSR markers for natural populations and plantations. *Int. J. Genet.*10 (9): 490-494.

Raymond C. A. 2002. Genetics of Eucalyptus wood properties. *Annals For. Sci*. 59:525-531.

Raymond, C. and MacDonald A. 1998. Where to shoot your Pilodyn: within-tree variation in basic density in plantation *E. globulus* and *E. nitens* in Tasmania. *New For.* 15:205–221.

Reddy, R. D., Srivasuki, K. P., Rajasekar, A. and Vijayakumar, R. 1992. Propagation of *Prosopis juliflora* Serg. from terminal cuttings. In: Reddy, K.(ed.). Vegetative propagation and biotechnologies for tree improvement Natraj Publications, Dehradun, pp. 35-40.

Reeves, K., Tomlinson, H., Lemma, T. 1996. Vegetative propagation of *Parkia biglobosa* (Jacq). *J. Hort. Sci.* 71(2):205-215.

Rudolf, P. O. 1956. *Guide for selecting superior forest trees and stands in the Lake States* (No. 40). Lake States Forest Experiment Station, US Department of Agriculture, Forest Service.

Saastamoinen, M. 2008. Heritability of dispersal rate and other life history traits in the Glanville fritillary butterfly. *Heredity* 100: 39-46.

Saini, R. P. 2001. Vegetative propagation in Silviculture (Hills) Division. Darjeeling (West Bengal). *Indian For.* 127(4): 389-408.

Saini, V., Kinger, H. K., Middha, A., and Rathore, G. S. 2007. Study of anti-bacterial and anti-fungal activity of *Melia dubia* leaves. *Inter. J. Plant Sci*. 2 (1): 239 - 240.

Salisbury, F. B. and Ross, C. W. 1992. *Plant physiology*, 4th Edn. Wadsworth Publishing Company, Belmont, CA, 682 p.

Saravanan, N and Sarumathi, A. 2013. Beneficial effect of centella asiatica and Asiatic acid in immobilization induced stress in rats: A FTIR study. *J. Global trends in Pharma. Sci.* 4 (4): 1279-1284.

Saravanan, V., Parthiban, K. T., Kumar, P., and Marimuthu, P. 2013. Wood characterization studies on *Melia dubia* Cav. for pulp and paper industry at different age gradation. *Res. J. Recent Sci.* 2: 183-188.

Schmutterer, H. 1995. The Neem Tree*, Azadirachta indica* and other meliaceous plants. VCH Verlagsgesellschaft, D-69451 Weinheim.

Schomaker, M. E., Zarnoch, S. J., Bechtold, W. A., Latelle, D. J., Burkman, W. G., and Cox, S. M. 2007. Crown-condition classification: a guide to data collection and analysis. *Gen. Tech. Rep. SRS-102. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station, 78* p., 102.

Scotti, I., González-Martínez, S. C., Budde, K. B. Lalagüe, H. 2015. Fifty years of genetic studies: what to make of the large amounts of variation found within populations? *Ann. For. Sci*. 73: 69-75.

Settle, D. J., Page, T., Bush, D, Doran, J., Sethy, M. and Viji, I. 2012. Basic density, diameter and radial variation of Vanuatu Whitewood (Endospermum medullosum): potential for breeding in a low density, tropical hardwood. *Int. For. Rev.* 14(4):463–475.

Sevik, H. and Guney, K., 2013. Effects of IAA, IBA, NAA, and GA3 on rooting and morphological features of Melissa officinalis L. stem cuttings. *Sci. World J. 2013*, https://doi.org/10.1155/2013/909507.

Shah, N. S., Wani, A. T., Ram, B., Koul, M., Awasthi, P., Rajput, D. S., and Reddy, G. R. S. 2016. An efficient protocol for in vitro organogenesis and antioxidant studies in *Melia dubia* Cav. *African J. Biotech*. 15(19): 768-775.

Shah, V. N., Chauhan and Sood, R. 1994. Propagating *Coriaria nepalensis*, *Woodfordia floribunda* through stem cuttings. *Van Vigyan* 32(4):102-107.

Shamet, G. S. and Kumar, S. 1988. Rooting studies of *Punica granatum* and *Dalbergia sissoo* cuttings under controlled phyto-environment conditions. *Indian For*. 114(6): 331-334.

Sharma, D., Sharma, K., Bhardwaj, R., and Prakask, P. 2019. Evaluation of growth performance of improved genotypes of Malabar Neem (*Melia dubia*) in low hills of Himachal Pradesh. *J. Pharmacognosy and Phytochem.* pp. 83-85.

Sharma, L. K. and Pandey, O. N. 1999. Effect of plant growth regulators on rooting behaviour of cuttings of *Dalbergia latifolia* Roxb and *Dalbergia sissoo* Roxb. *Indian For*. 125(4): 421-426.

Shearer, R. C. 1961. A method of overcoming seed dormancy in subalpine larch. *J. For*. 59: 513-514.

Shelbourne, C. J. A. 1969. Breeding for stem straightness in conifers. Doc. Second World Cons. *Forest Tree Breed*. 1: 2 93-302.

Sidhu, D. S. 1995. Methods of plus tree selection for raising first-generation populations for a tree breeding programme. *Indian For.* 476-485.

Singh, B. and Bhatt. 2009. Sprouting and Rooting response of *Dalgeria sissoo* stem cuttings collected from different altitudes. *Indian For*. 342-346.

Singh, B., Yadav, R and Bhatt, B. P. 2011. Effects of mother tree ages, different rooting mediums, light conditions and auxin treatments on rooting behaviour of *Dalbergia sissoo* branch cuttings. *J. For. Res*. 22(1): 53-57.

Singh, N. B. and V. K. Chaudhary. 1992. Multivariate analysis of genetic divergence in wild apricot (*Prunus armeniaca* Linn.). *Indian J. For*. 15: 211-216.

Singh, N. B., Sharma, J. P., Huse, S. K., Thakur, I. K., Gupta, R. K. and Sankhyan, H. P. 2012. Heritability, genetic gain, correlation and principal component analysis in introduced willow (*Salix* species) clones. *Indian For.*138 (12)1100-1109.

Singh, R. B., Gupta, M. P., Mor, B. R. and Jain, D. K., 1968. Variability and correlation studies on yield and quality characters in hirsutum cotton. *Indian J. Genet. Plant Breed* 28(2): 210-222.

Solanki, K. R., Muthana, K. D., Jindal S. K., and Arora G. D. 1984. Variability, heritability and correlations for growth parameters in *Prosopis* cineraria. *J. Tree Sci.*3: 86-88.

Stromquist, L. H. and Hansen, J. 1980. Effects of auxin of irradiance on the rooting of cuttings of *Pinus sylvstris*. *Physiologia Plantarum* 49:360-350.

Su, P. X., Zhang, L. X., Du, M. W., Bi, Y. R., Zhao, A. F. and Liu, X. M. 2003. Photosynthetic character and water use efficiency of different leaf shapes of Populus euphratica and their response to CO2 enrichment. *Acta Phytoecol.Sin*. 27: 34–40.

Subasini, H. D., Sekar, S., Shri, L. and Devi, V. R. 2007. Biodegradation of pesticidal rsidue using traditional plants with medicinal properties and Trichoderma. *J. Environ. Toxicology* 1(3): 124-130.

Subramanian, K. N., Mandal, A. K. Sasidharan, K. R., Govindaraj, P., Nicodemus, A. Nagarajan, B., Radhamani, A. and Durai, A. 1991. Provenance in *Eucalyptus microtheca*. *J. Tree Sci.* 10(2): 66-70.

Subramanian, K. N., Nicodemus, A. and Radhamani, A. 1994. Teak improvement in India. *For. Genet. Resour.* 22: 33-36.

Surendran, C. and Chandrasekaran, P. 1984. Heritable variation and genetic gain estimates in half-sib progenies of *Eucalyptus tereticornis*. *J. Tree Sci.* 3(1): 1-4.

Surendran, C., Paramathma, M. and Rai, R. S. V. 1993. Use of biometrical techniques in tree improvement. In: *Proceedings of the 14*th *Commonwealth Forestry Conference*, 13-18th September, Kuala Lumpur, Malaysia.

Surendran, C., Ravichandran, B. K. and Parthiban, K. T. 1996. Macro and micro propagation of *Casuarina junghuniana*. In: *Recent Casuarina Research and Development Proceeding of Third International Casuarina Workshop*, Vietnam. pp. 109-111.

Surendran, C., Sehgal, R. N. and Parmathma, M. 2003. *Textbook of Forest Tree Breeding*. Indian Council of Agricultural Research, New Delhi. 113 p.

Suresh, T and Devakumar, A. S. 2017. Morphological characterization of *Melia Dubia* seeds : implications to germination. *Mysore J. Agric. Sci.* 51(3): 721-735.

Susheela, T., Balaravi, P., Theophilus, J., Reddy, T. N. and Reddy, P. U. M. 2008. Evaluation of hypoglycaemic and antidiabetic effect of Melia dubia CAV fruits in mice. *Curr. Sci*. 94(9):1191-1195.

Taiz, L. and Zeiger, E. 2010. *Plant Physiol.* Sinauer Associates, Inc., USA, 746p.

Tak, A. and Jindal, S. 2014. Reproductive biology of *Acacia Senegal* (L.) Willd. *Int. J. Adv. Res.* 2(5): 498-502.

Tewari, J. C., Harsh, L. N., Sharma, N. K., Bohra, M. D., and Tripathi, D. 2012. Variation and interrelations among tree characters, pod-seed morphology and pod biochemical characters in *Prosopis juliflora* (sw) dc. *Forests, Trees and Livelihoods* 11(2): 113-126.

Thakur, I. K. and Thakur, S. 2015. Variability, Heritability, Genetic Advance and correlation in growth characteristics of *Melia Azedarach*. *Indian For.* 141(33): 247-253.

Tridasa, A. M., Hoon, K., and Cheol, K. Y. 2002. Increasing yield and quality improvement through clonal forestry and breeding program: case study in PT. Korintiga Huntani. In: Rinbawanto, A. and Susanto, M. (eds), *Advances in Genetic Improvement of Tropical Tree Species*. Proceedings of the International Conference PT BioHutanea, Jakarta, Indonesia, pp. 27-31.

Troup, R. S. 1921. *Silviculture of Indian Trees*. Clarendon Press. London, 3: 152.

Tuzet, A., Perrier A., and Leuning, R. 2003. A coupled model of stomatal conductance, photosynthesis and transpiration. *Pl. Cell Environ*. 26:1097-116.

Vallauri, D., Monteuis, O., Poupard, C. and Chauviere, M. 1995. Rooting of *Acacia mangium* cuttings of different physiological age with reference to leaf morphology as a phase change marker. *Silvae Genetica* 44: 150-154.

Vargas-Reeve, F., Mora, F., Perret, S., and Scapim, C. A. 2013. Heritability of stem straightness and genetic correlations in *Eucalyptus cladocalyx* in the semi-arid region of Chile. *Crop Breed. and Appl.Biol.* 13(2): 107-112.

Vasudeva, R., Shashidharan, G. B. and Haseeh, M. A. 1999. Identification of plus trees of *Albizzia lebbeck* (L.) Benth) in Karnataka. In: *National symposium on Forestry Towards 21st Century Forest College and Research Institute,* Mettupalayam – 641 301. Sept. 27-28. p.25.

Vavilo, N. L. 1951. The origin, variation, immunity and breeding of cultivated plants. Translated from Russia by Chester, K. S. *Chromica lamanica*. 13: 1-364.

Venkatesh, A. and Pandey, C. B. 2006. Rooting ability of Padauk (*Pterocarpus Dalbergioides*). *Indian J. For*. 29(2): 131-133.

Verma, R. C., Dhillon, R. S. and Singh, V. P. 1996. Effect of auxins on rooting of neem cutting in spring seasons. *Ann. Biol*. 12(1): 52-56.

Vidakovic, M. 1965. Selection of plus trees. Sumarski List, Internationalni simpozij, IUFRO, Zagreb. pp. 7-20.

Vijayan, P., Raghu, C., Ashok, G., Dhanaraj, S.A. and Suresh, B. 2004. Antiviral activity of medicinal plants of Nilgiris. *Indian J. Med. Res*. 120:24-29.

Waldmann, P. 2001. Additive and non-additive genetic architecture of two different-sized populations of *Scabiosa canescens*. *Heredity* 86:648–657.

Wang, T., Hagvist, R. and Tigerstedt, P. M. A. 1995. The relationships between yield and carbon fixation in selected hybrid families after crossing selfed lines of *Betula pendula* Roth. *For. Genet*. 2:77--86.

White, P. R. 1963. The cultivation of animal and plant cells. Ronald Press, New York. Pp. 1-239.

Wilcox, J. R. and Farmer, R. E. 1977. Variation and inheritance of juvenile characters of eastern cottonwood. *Silvae Genetica*. 16: 162-165.

Wong, S. C., Cowan, I. R., and Farquhar, G. D. 1979. Stomatal conductance correlates with photosynthetic capacity. *Nature* 1979(282):424-6.

Wright, J. W. 1960. Individual Tree Selection in Forest Genetics. In: Proceedings 4th Lakes States Forest Tree Improvement Conference. Paper No. 81. Lake States Forestry Experimental Station, pp.25-44.

Yeh, F. C. and Arnot, J. T. 1986. Electrophoretic and morphological differentiation of *Picea sitchensis*, *Picea glauca*, and their hybrids. *Can. J. For. Res.* 16(4): 791-798.

Zeng, X. and Lu, Q. N. 1988. *Application of Plant Growth Regulators in Fruit Trees*. Agricultural Publishing House, Beijing. 23p.

Zhang, W. X., Wu, J. S. and Cao, F. L. 2002. Influence of photosynthetically active radiation on photosynthesis and photochemistry efficiency in leaves of Ginkgo. J. Nanjing For. Univ. (Nat. Sci. Ed.) 26, 5–9.

Zhu, X. C., Song, F. B., Liu, T. D. and Zhou, X. 2012. Arbuscular mycorrhizae improves phothosynthesis and water status of Zea mays L. under drought stress. *Plant Soil Environ*. 58 (4): 186-191.

Zobel, B. J. and J. Talbert. 1984. *Applied tree improvement*. John Wiley & Co., New York, 505p.

Appendices

APPENDIX I			
GRADING OF THE TRAITS FOR SELECTION OF PLUS TREES			
Sl. No.	**Traits**	**Variations**	**Score**
1	Verticality	not vertical	1
		vertical	2
2	Straightness	very crooked with 2 serious bending	1
		slightly crooked with 2 small bends or less than 2 serious bends	2
		almost straight with 1-2 small bends	3
		completely straight	4
3	Cross section	not circular	1
		circular	2
4	Bole swelling	bole swelling present	1
		bole swelling absent	2
5	Branch angle	Upright < 60 ^{o}	6
		Horizontal > 60 ^{o}	12
6	Branching thickness	Very heavy > 2 branches with diameter>1/3rd of main stem	2
		Heavy, 2 branches with diameter>1/3rd of main stem	5
		Light, one branch with diameter>1/3rd of main stem	7
		Very light with with diameter>1/3rd of main stem	10
7	Self pruning	Poor, branches exists below 2/3rd of total height	1
		Good, branches exists below 2/3rd of total height	3
8	Apical dominance	Points for length (clean bole) expressed as percent of total height of the tree < 25%	0
		25-39 %	1
		40- 54 %	5
		55- 69 %	8
		>70 %	10
9	Forking	Forking above 10 meters	5
		Forking between 5-10 meters above	3
		Forking below 5 meters from ground	1
10	Foliar damage	Present	1
		Absent	4
11	Stem damage	Present	1
		Absent	6

APPENDIX II

Scoring for the quantitative characters of trees of *Meliadubia*

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
Thirunelly								
1	TNI-01	11°54'22" 75°59'34"	30	2.1	18	7	0.23	11
2	TNI-02	11°54'17" 75°59'37"	31	1.9	16.5	5	0.16	14
3	TNI-03	11°54'16.9" 76°59'59.77"	32	2.65	16.5	10	0.31	11
4	TNI-04	11°54'11" 76°3'48"	25	2.5	16	5	0.20	12
5	TNI-05	11°54'33" 76°0'2"	28	1.9	16.5	8	0.29	16
6	TNI-06	11°54'38" 76°0'2"	27	2.1	15.5	4	0.15	15
7	TNI-07	11°53'33" 76°0'2"	34	1.9	19	6	0.18	17
8	TNI-08	11°52'38" 76°0'2"	25	2.3	20	6	0.24	16
9	TNI-09	11°54'37.68" 76°00'02.4"	33	2.96	19	9	0.27	14
10	TNI-10	11°54'9" 76°3'38"	35	2.55	27.5	8.5	0.24	13
11	TNI-11	11°54'12" 76°3'39"	25	2.2	16	12	0.48	17
12	TNI-12	11°54'33" 76°0'2"	25	2.1	20.5	12	0.48	18
13	TNI-13	11°54'12" 76°3'41"	35	2.2	20.5	8	0.23	14
14	TNI-14	11°55'28" 76°3'31"	20	2.1	27.5	9	0.45	16
15	TNI-15	11°54'18" 76°3'31"	35	2.3	22.5	8	0.23	14
16	TNI-16	11°51'07" 76°3'31"	34	1.5	16.5	7	0.21	17
17	TNI-17	11°54'15" 76°3'31"	20	2.5	27.5	5	0.25	12
18	TNI-18	11°54'19" 76°3'27"	25	2	22.5	7	0.28	14
19	TNI-19	11°54'25" 76°3'13"	22	1.9	16	8	0.36	14

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
20	TNI-20	11°54'24" 76°3'12"	19	2.1	16	7	0.37	15
21	TNI-21	11°54'22" 76°3'37"	20	2.2	17.5	6.5	0.33	16
22	TNI-22	11°54'25" 76°3'11"	25	2.1	17.5	5.5	0.22	17
Tholpetty								
23	TPY-01	11°52'53" 76°4'39"	28	2.80	17.5	6	0.21	12
24	TPY-02	11°52'55" 76°4'43"	30	3.10	20	8	0.27	14
25	TPY-03	11°52'52" 76°4'28"	28	3.10	17.5	12	0.43	13
26	TPY-04	11°52'56" 76°4'41"	25	3.20	17	9	0.36	14
27	TPY-05	11°52'58" 76°4'38"	31	2.95	17	8	0.26	15
28	TPY-06	11°47'46.9" 76°05'4.1"	28	3.75	20	12	0.43	16
29	TPY-07	11°52'57" 76°4'38"	15	1.90	20	6	0.40	17
30	TPY-08	11°53'0" 76°4'38"	26	2.50	16.5	10	0.38	13
31	TPY-09	11°53'13.2" 76°4'34.7"	28	3.60	21	10	0.36	13
32	TPY-10	11°51'13" 76°4'35"	26	2.75	15.5	8	0.31	15
33	TPY-11	11°52'18" 76°4'35"	18	2.20	19	9	0.50	14
34	TPY-12	11°51'08" 76°4'35"	17	1.75	20.5	9	0.53	17
35	TPY-13	11°53'13" 76°4'34"	24	2.57	19	12	0.50	13
36	TPY-14	11°53'14" 76°4'32"	28	2.40	19	9	0.32	36
37	TPY-15	11°53'41" 76°4'18"	22	3.70	19.5	8	0.36	37
38	TPY-16	11°53'43" 76°4'19"	29	2.15	19	7	0.24	38

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
39	TPY-17	11°53'47" 76°4'21"	19	2.00	19	8	0.42	39
40	TPY-18	11°53'46" 76°4'19"	24	2.45	18	8	0.33	40
41	TPY-19	11°53'22" 76°4'43"	17	2.00	17.5	8	0.47	41
Dasanakkara								
42	DKA-01	11°47'47" 76°5'4"	29	2.90	19	6	0.21	42
43	DKA-02	11°47'41" 76°5'13"	20	1.90	15.5	8	0.40	43
44	DKA-03	11°47'30" 76°5'13"	25	2.20	17.5	7	0.28	44
45	DKA-04	11°47'28" 76°5'13"	23	1.60	13.5	10	0.43	45
46	DKA-05	11°47'30" 76°5'12"	22	1.80	17.5	9	0.41	46
47	DKA-06	11°48'11" 76°6'54"	23	2.40	16.5	8	0.35	47
48	DKA-07	11°45'45" 76°7'52"	22	2.40	15	7	0.32	48
49	DKA-08	11°45'57" 76°7'55"	18	1.50	16	6	0.33	11
50	DKA-09	11°45'52" 76°7'51"	28	2.50	20.5	8	0.29	12
51	DKA-10	11°52'53.1" 76°04'39.2"	27	3.35	21	13	0.48	14
Neykavala								
52	NKA-01	11°25'32.1" 76°06'02.3"	28	3.35	23.5	11.5	0.41	13
53	NKA-02	11°25'32.1" 76°06'04"	17	2.90	18	9	0.53	12
54	NKA-03	11°25'33" 76°06'03"	18	2.50	17	7	0.39	14
55	NKA-04	11°25'37" 76°06'03.3"	18	1.50	18	8.5	0.47	15
56	NKA-05	11°25'35.5" 76°06'01.4"	19	1.50	20	8	0.42	17
57	NKA-06	11°25'30" 76°06'4.3"	21	1.60	18	7.5	0.36	16

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
58	NKA-07	11°25'31.1" 76°06'05.2"	22	1.80	16	7	0.32	14
59	NKA-08	11°25'30.5" 76°06'04.3"	22	2.20	18.5	8	0.36	12
60	NKA-09	11°25'35" 76°06'05.2"	24	1.90	18.5	8	0.33	14
61	NKA-10	11°25'33.3" 76°06'04.8"	27	2.20	19.5	8	0.30	16
62	NKA-11	11°25'34" 76°06'07.2"	18	1.80	17.5	10.5	0.58	17
63	NKA-12	11°25'34" 76°06'05.2"	25	1.90	18	9	0.36	15
Dhoni								
64	DHI-01	10°25'1.1" 76°11'20.3"	30	2.1	18	7	0.23	11
65	DHI-02	10°26'0.1" 76°12'21.3"	31	1.9	16.5	5	0.16	14
66	DHI-03	10°27'2" 76°11'22.3"	32	2.65	16.5	10	0.31	11
67	DHI-04	10°25'1.1" 76°12'24.3"	25	2.5	16	5	0.20	12
68	DHI-05	10°27'2.8" 76°12'18.3"	28	1.9	16.5	8	0.29	16
69	DHI-06	10°26'1.8" 76°11'14.3"	27	2.1	15.5	4	0.15	15
70	DHI-07	10°27'1.1" 76°12'18.2"	34	1.9	19	6	0.18	17
71	DHI-08	10°28'2.5" 76°12'22.1"	25	2.3	20	6	0.24	16
72	DHI-09	10°27'2.8" 76°12'19.1"	33	2.96	19	9	0.27	14
Poothundy								
73	PDI-01	10°32'22" 76°37'16"	22	2.25	22.5	7	0.32	15
74	PDI-02	10°32'21" 76°37'18"	18	1.40	12.5	6	0.33	14
75	PDI-03	10°32'20" 76°37'15.5"	19	1.60	13	7	0.37	13

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
76	PDI-04	10°31'20" 76°37'16.7"	24	2.65	25	9	0.38	12
77	PDI-05	10°32'20" 76°37'18"	17	1.90	17.5	11	0.65	11
78	PDI-06	10°32'16.7" 76°36'.88"	21	2.85	19	8	0.38	14
79	PDI-07	10°31'0" 76°35'.42"	22	3.40	23.5	7	0.32	16
80	PDI-08	76°34'0" 10°32'0"	18	1.25	18	8	0.44	13
81	PDI-09	10°31'1" 76°36'2.4"	17	1.50	16.5	8	0.47	14
82	PDI-10	10°31'00.92" 76°37'00.28"	24	4.20	17.5	12	0.50	14
83	PDI-11	10°31'48" 76°37'0"	18	2.50	23.5	9	0.50	13
84	PDI-12	10°31'49" 76°36'41.4"	22	2.75	20.5	7	0.32	14
85	PDI-13	10°31'43" 76°37'42"	28	2.45	13.5	8	0.29	15
86	PDI-14	10°31'49" 76°3546"	14	1.35	16.5	6	0.43	18
87	PDI-15	10°31'56" 76°37'31"	17	1.75	16	7	0.41	14
88	PDI-16	10°31'56" 76°37'31"	18	1.95	13.5	8	0.44	15
89	PDI-17	10°31'56" 76°37'31"	19	1.75	13	9	0.47	12
90	PDI-18	10°32'3" 76°37'26"	19	2.10	18	9	0.47	11
Attappady								
91	ATY-01	11°5'31" 76°43'23"	18	2.40	12	8	0.44	14
92	ATY-02	11°5'26" 76°43'27"	17	1.90	15	7.5	0.44	12
93	ATY-03	11°5'31" 76°43'22.8"	14	1.50	14	6.5	0.46	13
94	ATY-04	11°5'25" 76°43'26.4"	18	2.50	15.5	7	0.39	15

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
95	ATY-05	11°5'23.4" 76°43'21.4"	18	1.20	13.5	6.5	0.36	14
96	ATY-06	11°5'26" 76°43'26.3"	19	1.50	14.5	7.5	0.39	13
97	ATY-07	11°5'31" 76°43'22.8"	15	1.85	16	8	0.53	12
98	ATY-08	11°5'24.3" 76°41'26.4"	17	2.50	13.5	9	0.53	13
99	ATY-09	11°4'31" 76°42'21"	21	3.10	16.5	12	0.57	15
Thiruvazhiyad								
101	TUD-01	10°31'14.3" 76°36'19"	22	2.40	16.5	9	0.41	15
102	TUD-02	10°31'15" 76°36'16.7"	17	1.90	17.5	8	0.47	13
103	TUD-03	10°31'57" 76°36'23"	16	1.50	18	8	0.50	17
104	TUD-04	10°31'2" 76°36'30"	29	3.10	19.5	12	0.41	13
105	TUD-05	10°31'12" 76°36'19"	21	1.50	20.5	8	0.38	15
106	TUD-06	10°31'11" 76°36'18"	19	1.50	17	6	0.32	11
107	TUD-07	10°31'47" 76°36'23"	19	2.50	14	5	0.26	15
Walayar								
110	WLY-01	10°51'42.5" 76°37'10.6"	22	1.50	16.5	8	0.36	14
111	WLY-02	10°51'46" 76°37'12"	25	2.55	16.5	5	0.20	11
112	WLY-03	10°51'32.3" 76°37'11.2"	20	2.20	19	6	0.30	12
113	WLY-04	10°51'36" 76°37'12.3"	28	3.05	19.5	12	0.43	13
114	WLY-05	10°51'32" 76°37'12.4"	20	3.20	23.5	9	0.45	13
115	WLY-06	10°51'22.3" 76°37'33"	18	1.20	17.5	9	0.50	14
116	WLY-07	10°51'24" 76°37'28"	18	1.50	23.5	8	0.44	12

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
117	WLY-08	10°50'28" 76°36'32"	19	1.40	22	9	0.47	13
118	WLY-09	10°51'22.3" 76°37'27"	18	1.50	21.5	7	0.39	15
119	WLY-10	10°51'33.2" 76°37'27"	22	1.25	21	6	0.27	15
120	WLY-11	10°51'34" 76°37'25,5"	24	2.35	15	8	0.33	13
121	WLY-12	10°51'32.1" 76°37'27"	20	1.29	17	9	0.45	12
122	WLY-13	10°51'26.4" 76°37'32"	22	3.10	18.5	9	0.41	14
123	WLY-14	10°51'21" 76°37'22"	29	3.50	19.5	8	0.28	14
124	WLY-15	10°51'31' 76°37'27"	25	2.80	23.5	10	0.40	13
Parambikulam								
125	PBM-01	10°26'53" 76°47'17"	19	2.20	17.5	8	0.42	14
126	PBM-02	10°26'53" 76°47'17"	20	2.50	20.5	5	0.25	13
127	PBM-03	10°26'52" 76°47'8"	28	3.05	20	6	0.21	12
128	PBM-04	10°26'52" 76°47'8"	27	3.25	20	7	0.26	11
129	PBM-05	10°26'52" 76°47'8"	22	3.10	18.5	7	0.32	13
130	PBM-06	10°26'50" 76°46'58"	25	2.85	17	6	0.24	14
131	PBM-07	10°26'54" 76°46'49"	28	3.05	19	8	0.29	13
132	PBM-08	10°23'27" 76°46'35"	25	2.85	16.5	8	0.32	12
133	PBM-09	10°23'22.5" 76°46'35"	26	3.05	16	9	0.35	12
134	PBM-10	10°23'22" 76°46'36"	22	2.80	16.5	7	0.32	14
135	PBM-11	10°22'50" 76°45'52"	19	2.50	15.5	9	0.47	12

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
136	PBM-12	10°22'55" 76°45'44"	32	2.95	17	14	0.44	12
137	PBM-13	10°22'57" 76°45'46"	35	3.45	**17.5**	7	0.20	13
138	PBM-14	10°22'57" 76°45'45"	25	2.85	24	8	0.32	13
139	PBM-15	10°22'58" 76°45'44"	24	2.40	15.5	7	0.29	14
140	PBM-16	10°22'56" 76°45'41"	23	3.20	16	6	0.26	14
141	PBM-17	10°22'57" 76°45'39"	23	2.65	15.5	7	0.30	11
142	PBM-18	10°23'2" 76°45'43"	28	2.30	19	8	0.29	12
143	PBM-19	10°23'8" 76°46'52"	25	2.80	15.5	7	0.28	13
144	PBM-20	10°23'20" 76°46'30"	24	2.90	20	8	0.33	13
145	PBM-21	10°23'20" 76°46'30"	18	1.50	13.5	9	0.50	14
146	PBM-22	10°22'55" 76°45'44"	18	1.90	14	7	0.39	12
147	PBM-23	10°22'57" 76°45'46"	22	2.60	16	7	0.32	15
148	PBM-24	10°22'57" 76°45'45"	24	1.80	17	8	0.33	16
150	PBM-26	10°23'22" 76°46'36"	29	3.15	20	8	0.28	15
151	PBM-27	10°23'33" 76°46'39"	17	2.25	16.5	5	0.29	13
152	PBM-28	10°26'40" 76°49'32"	15	1.50	14.5	6	0.40	16
153	PBM-29	10°24'40" 76°49'27"	14	2.60	23.5	7	0.50	14
154	PBM-30	10°24'40" 76°49'5"	32	3.30	22.5	12	0.38	13
155	PBM-31	10°24'0" 76°46'15"	22	4.46	21.5	5	0.23	14

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
156	PBM-32	10°24'22.7" 76°45'42.2"	19	2.80	19	6	0.32	13
157	PBM-33	10°24'12" 76°43'18"	22	3.25	20	7	0.32	13
158	PBM-34	10°23'24" 76°43'40.5"	22	2.50	16.5	9	0.41	15
159	PBM-35	10°23'22" 76°42'42"	25	2.25	16.5	10	0.40	14
160	PBM-36	10°23'22" 76°42'41.3"	12	2.00	16.5	7	0.58	14
161	PBM-37	10°23'22" 76°42'43.2"	14	1.60	17	5	0.36	16
162	PBM-38	10°23'22" 76°42'2"	17	2.00	18	7	0.41	12
163	PBM-39	10°22'50" 76°40'52.1"	22	2.00	17	12	0.55	13
164	PBM-40	10°23'0" 76°39'53"	24	2.40	16	11	0.46	14
165	PBM-41	10°24'23" 76°45'43"	26	2.30	17.5	10	0.38	13
166	PBM-42	10°24'12" 76°43'18"	22	2.90	17	14	0.64	14
167	PBM-43	10°23'24" 76°43'41"	27	2.80	17.5	14	0.52	13
168	PBM-44	10°23'22" 76°42'40.3"	25	3.75	22.5	9	0.36	14
169	PBM-45	10°23'21" 76°42'42"	23	1.50	16	8	0.35	15
170	PBM-46	10°23'21.5" 76°42'42"	20	2.40	16	8	0.40	15
171	PBM-47	10°23'0" 76°39'53"	22	2.20	16	14	0.64	14
172	PBM-48	10°23'39" 76°46'53"	20	2.30	13	12	0.60	16
173	PBM-49	10°23'39" 76°46'53"	21	2.40	19	10	0.48	13
174	PBM-50	10°23'39" 76°46'53"	19	2.10	20	7	0.37	12
175	PBM-51	10°23'39" 76°46'53"	21	2.80	18.5	8	0.38	14

Chinnar								
178	CNR-01	10°19'46" 77°13'2"	18	2.00	16.5	5	0.28	12
179	CNR-02	10°20'21" 77°13'23"	15	1.50	14	7	0.47	11
180	CNR-03	10°20'8" 77°13'26"	19	2.00	21.5	8	0.42	13
181	CNR-04	10°20'8" 77°13'27"	19	1.90	19.5	5	0.26	11
182	CNR-05	10°20'3" 77°13'21"	22	1.80	21	8	0.36	14
183	CNR-06	10°21'15" 77°12'4"	20	1.40	15	5	0.25	12
184	CNR-07	10°21'19" 77°11'11"	18	1.50	15	10	0.56	16
185	CNR-08	10°21'18" 77°11'14.2"	17	1.30	14	11	0.65	14
186	CNR-09	10°21'19" 77°11'16"	18	1.30	13.5	8	0.44	15
187	CNR-10	10°21'17.5" 77°11'20"	18	1.90	17.5	8	0.44	16
188	CNR-11	10°21'17" 77°11'18"	18	2.00	16	9	0.50	13
189	CNR-12	10°21'19" 77°11'21"	12	2.00	20	5	0.42	14
190	CNR-13	10°19'41" 77°13'2"	22	2.00	16	12	0.55	14
191	CNR-14	10°21'19'' 77°11'16''	18	2.00	21	11	0.61	13
192	CNR-15	10°21'18'' 77°11'20''	17	1.40	14.5	10	0.59	13
193	CNR-16	10°21'17'' 77°11'14''	16	2.00	17	9	0.56	16
194	CNR-17	10°21'19'' 77°11'23''	21	2.00	16.5	8	0.38	11
195	CNR-18	10°21'18'' 77°11'26''	22	2.00	19.5	9	0.41	12
196	CNR-19	10°21'18'' 77°11'26''	22	1.25	16	8	0.36	14
197	CNR-20	10°21'18'' 77°11'26''	18	1.30	13.5	11	0.61	13
198	CNR-21	10°21'18'' 77°11'26''	19	1.70	18.5	10	0.53	14

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
199	CNR-22	10°21'18" 77°11'26"	20	1.15	16	7	0.35	13
200	CNR-23	10°21'17" 77°11'27"	28	2.25	19	8	0.29	14
201	CNR-24	10°21'16" 77°11'28"	27	1.35	14.5	9	0.33	12
202	CNR-25	10°21'16" 77°11'30"	23	1.90	16.5	11	0.48	11
203	CNR-26	10°21'16" 77°11'30"	18	1.30	14.5	11	0.61	13
204	CNR-27	10°21'16" 77°11'30"	21	2.00	16	10	0.48	14
205	CNR-28	10°21'16" 77°11'30"	18	1.50	14	8	0.44	11
206	CNR-29	10°21'16" 77°11'30"	18	2.05	18	9	0.50	13
207	CNR-30	10°21'15" 77°11'32"	17	1.50	16.5	11	0.65	14
208	CNR-31	10°21'15" 77°11'32"	18	1.50	23	6	0.33	12
209	CNR-32	10°21'15" 77°11'32"	15	1.50	19	5	0.33	15
210	CNR-33	10°21'17" 77°11'31"	18	1.50	18.5	5	0.28	14
211	CNR-34	10°21'16" 77°11'31"	15	1.50	19	6	0.40	13
212	CNR-35	10°21'17" 77°11'31"	16	1.40	16.5	8	0.50	12
213	CNR-36	10°21'17" 77°11'31"	18	1.60	19	9	0.50	15
214	CNR-37	10°21'17" 77°11'31"	12	1.30	17.5	8	0.67	13
215	CNR-38	10°21'15" 77°11'33"	18	1.90	16.5	7	0.39	14
216	CNR-39	10°21'15" 77°11'32"	16	1.25	15.5	8	0.50	15
217	CNR-40	10°21'16" 77°11'30"	17	1.50	17.5	7	0.41	12
218	CNR-41	10°21'16" 77°11'32"	19	1.80	17.5	7	0.37	11

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
219	CNR-42	10°21'16'' 77°11'32''	23	2.45	15.5	8	0.35	15
220	CNR-43	10°21'16'' 77°11'28.5''	21	2.10	21.5	8	0.38	13
221	CNR-44	10°21'11.5'' 77°11'30''	15	1.90	17.5	6	0.40	13
222	CNR-45	10°21'15'' 77°11'28''	25	2.25	17	8	0.32	13
223	CNR-46	10°21'16'' 77°11'29''	21	2.45	23	8	0.38	14
224	CNR-47	10°21'13'' 77°11'38''	17	2.10	19.5	7	0.41	12
225	CNR-48	10°21'13'' 77°11'40''	18	1.90	16.5	9	0.50	13
226	CNR-49	10°21'13'' 77°11'43''	19	1.80	16	9	0.47	14
227	CNR-50	10°22'16'' 77°11'52.4''	16	1.30	18.5	11	0.69	11
228	CNR-51	10°21'16'' 77°11'51''	15	1.40	18.5	10	0.67	12
229	CNR-52	10°21'16'' 77°11'53''	12	1.30	14.5	7	0.58	13
230	CNR-53	10°23'15.2'' 77°11'48''	10	1.30	14.5	6	0.60	14
Peechi								
231	PCI-01	10°32'0'' 76°22'30.2''	25	2.35	20	7.5	0.30	14
232	PCI-02	10°31'0'' 76°22'31.3''	24	2.00	19	8	0.33	16
233	PCI-03	10°31'0'' 76°22'32''	22	1.75	16.5	5	0.23	18
234	PCI-04	10°31'56.4'' 76°22'21''	20	1.50	13	8	0.40	12
235	PCI-05	10°31'52'' 76°22'22''	19	2.20	17	7	0.37	13
236	PCI-06	10°31'52'' 76°22'19''	19	2.10	16	6.5	0.34	11
237	PCI-07	10°31'53'' 76°22'20''	27	3.20	19	10	0.37	13
238	PCI-08	10°29'1'' 76°22'0''	26	3.10	19	11	0.42	12

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
239	PCI-09	10°29'1'' 76°22'0''	28	3.10	20	7.5	0.27	15
240	PCI-10	10°31'0'' 76°22'32''	23	2.50	21	6.5	0.28	17
241	PCI-11	10°31'52'' 76°22'21''	18	1.65	22.5	8	0.44	15
242	PCI-12	10°31'51'' 76°22'19''	21.5	1.85	16	8	0.37	17
243	PCI-13	10°31'51'' 76°22'17.5''	26.5	2.20	17.5	9.5	0.36	15
244	PCI-14	10°31'0'' 76°22'32''	22	1.75	15	7	0.32	18
Akamala								
245	AKA-01	10°41'13'' 76°17'26''	22	2.10	17.5	9	0.41	14
246	AKA-02	10°41'19'' 76°16'51''	25	2.20	21.5	7.5	0.30	12
247	AKA-03	10°41'34'' 76°16'40''	26	1.80	16.5	8	0.31	12
248	AKA-04	10°41'35'' 76°16'32.8''	28	2.10	18	8	0.29	11
249	AKA-05	10°41'35'' 76°16'31''	27	1.80	17.5	7	0.26	14
250	AKA-06	10°40'1'' 76°18'0''	30	2.40	18.5	6.5	0.22	13
251	AKA-07	10°40'2'' 76°17'0''	28	2.10	21.5	7	0.25	14
252	AKA-08	10°40'1'' 76°16'0''	27	2.20	16	8	0.30	11
253	AKA-09	10°40'51'' 76°18'11''	24	2.00	16.5	9	0.38	13
254	AKA-10	10°40'51'' 76°18'11''	19	2.20	18	7.5	0.39	15
255	AKA-11	10°38'2'' 76°17'0''	22	1.75	19	7.5	0.34	16
256	AKA-12	10°29.'1'' 76°16'0''	28	2.90	18.5	11.5	0.41	14
Kulathupuzha								
257	KPA-01	8°51'21'' 77°4'35''	17	1.30	20.5	8	0.47	14
258	KPA-02	8°52'34'' 77°5'0''	18	1.30	22.5	8.5	0.47	15

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
257	KPA-01	8°51'21'' 77°4'35''	17	1.30	20.5	8	0.47	14
258	KPA-02	8°52'34'' 77°5'0''	18	1.30	22.5	8.5	0.47	15
259	KPA-03	8°52'40'' 77°5'58''	19	1.30	18.5	6.5	0.34	17
260	KPA-04	8°52'30'' 77°5'58''	27	3.10	24.5	13.5	0.50	13
261	KPA-05	8°52'29'' 77°5'54''	19	2.55	17.5	8	0.42	13
262	KPA-06	8°52'43'' 77°5'24''	23	1.80	17	8	0.35	16
263	KPA-07	8°52'51'' 77°5'9''	20	2.15	14.5	9.5	0.48	14
264	KPA-08	8°50'0'' 77°1'1''	25	1.85	17.5	7	0.28	17
265	KPA-09	8°50'14'' 77°2'4''	20	2.00	17	8	0.40	14
266	KPA-10	8°50'13'' 77°2'1''	26	2.25	16.5	5	0.19	13
267	KPA-11	8°50'14'' 77°2'26''	20	1.85	15.5	4.5	0.23	16
268	KPA-12	8°50'14'' 77°2'26''	22	2.00	17	8.5	0.39	15
269	KPA-13	8°50'14'' 77°2'26''	27	2.75	21	8.5	0.31	14
270	AYU-01	8°57'3'' 77°8'2''	20	2.50	17.0	6.0	0.30	15
271	AYU-02	8°57'3'' 77°8'2''	19	2.25	17.0	8.0	0.42	16
272	AYU-03	8°56'1'' 77°8'2''	15	1.85	18.0	7.0	0.47	14
273	AYU-04	8°56'1'' 77°8'49''	25	3.10	26.5	10.0	0.40	17
274	AYU-05	8°55'55'' 77°8'39''	15	1.50	18.0	9.0	0.60	13
275	AYU-06	8°55'55'' 77°8'39''	26	2.60	14.0	8.0	0.31	19

Sl. No.	Tree id. No.	Location	Height (m)	GBH (m)	Crown width (m)	Clean Bole height (m)	Clean bole height: Tree height	Pilodyn penetration depth (mm)
276	AYU-07	8°59'22'' 77°8'43''	21	2.50	16.0	7.0	0.33	18
277	AYU-08	8°59'22'' 77°8'43''	14	1.50	17.0	6.0	0.43	15
278	AYU-09	8°59'24'' 77°8'41''	15	1.30	17.0	8.0	0.53	13
279	AYU-10	8°59'24'' 77°8'41''	18	1.30	15.0	7.0	0.39	14
280	AYU-11	8°59'26'' 77°8'34''	20	2.40	16.5	8.0	0.40	15
281	AYU-12	8°57'29'' 77°8'18''	22	2.85	15.0	8.0	0.36	15

APPENDIX III

Scoring for the qualitative characters of trees of *Melia dubia*

Sl. No.	Tree ID. No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
Thirunelly													
1	TNI-01	1	4	0	3	6	5	3	2	4	1	2	31
2	TNI-02	1	3	0	1	6	7	3	2	4	1	1	29
3	TNI-03	2	4	1	5	12	7	3	2	4	2	2	44
4	TNI-04	1	4	0	1	6	7	3	2	4	2	2	32
5	TNI-05	2	3	1	3	6	5	3	2	4	1	2	32
6	TNI-06	1	4	0	1	6	5	3	2	4	1	2	29
7	TNI-07	1	4	0	3	12	5	1	2	4	1	2	35
8	TNI-08	2	3	0	3	6	5	3	2	4	2	2	32
9	TNI-09	2	4	1	3	12	7	3	2	4	2	2	42
10	TNI-10	1	3	0	3	6	5	3	2	4	2	2	31
11	TNI-11	1	3	5	5	6	5	3	2	4	2	2	38
12	TNI-12	1	3	5	5	6	5	3	2	4	1	1	36
13	TNI-13	1	2	0	3	6	7	1	2	4	1	2	29
14	TNI-14	1	3	5	3	6	7	3	2	4	1	2	37
15	TNI-15	2	3	0	3	6	7	3	2	4	2	2	34
16	TNI-16	2	2	0	3	6	5	3	2	4	2	2	31
17	TNI-17	2	4	1	1	6	7	3	2	4	2	2	34
18	TNI-18	1	3	1	3	6	5	3	2	4	1	2	31
19	TNI-19	1	4	1	3	12	7	3	2	4	2	2	41
20	TNI-20	1	1	1	3	6	7	3	2	4	2	2	32
21	TNI-21	1	4	1	3	6	7	3	2	4	2	2	35
22	TNI-22	1	1	0	1	6	7	3	2	4	1	2	28

Sl. No.	Tree ID. No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
Tholpetty													
23	TPY-01	1	3	0	3	6	10	1	2	4	1	2	33
24	TPY-02	1	3	1	3	6	7	3	2	4	1	1	32
25	TPY-03	2	3	5	3	6	7	3	2	4	1	2	38
26	TPY-04	2	3	1	3	6	5	1	2	4	2	1	30
27	TPY-05	1	3	1	3	6	5	3	2	4	1	2	31
28	TPY-06	2	4	5	5	12	10	3	2	4	2	2	51
29	TPY-07	2	3	5	5	6	5	3	2	4	1	2	38
30	TPY-08	1	3	1	5	12	10	3	2	4	1	2	44
31	TPY-09	2	3	1	5	12	10	3	2	4	2	2	46
32	TPY-10	1	2	1	3	6	7	3	2	4	1	2	32
33	TPY-11	1	1	5	3	6	7	3	2	4	1	2	35
34	TPY-12	1	3	5	5	6	10	1	2	4	1	2	40
35	TPY-13	1	3	5	5	12	7	3	2	4	1	2	45
36	TPY-14	2	3	1	3	6	7	3	2	4	1	1	33
37	TPY-15	2	4	1	3	6	5	3	2	4	1	2	33
38	TPY-16	1	3	0	3	12	10	3	2	4	1	2	41
39	TPY-17	1	3	5	3	6	7	1	2	4	1	1	34
40	TPY-18	1	3	1	3	6	7	3	2	4	1	2	33
41	TPY-19	1	3	5	3	6	7	3	2	4	1	2	37
Dasanakkara													
42	DKA-01	1	2	0	5	6	7	1	2	4	1	1	30
43	DKA-02	1	3	5	3	6	7	3	2	4	1	1	36
44	DKA-03	1	3	1	1	6	10	3	2	4	2	1	34
45	DKA-04	2	4	5	3	6	7	3	2	4	1	2	39
46	DKA-05	1	2	5	3	12	7	1	2	4	2	1	40

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
47	DKA-06	1	1	1	3	6	7	1	2	4	1	2	29
48	DKA-07	1	1	1	3	6	7	3	2	4	1	2	31
49	DKA-08	2	4	1	3	6	7	3	2	4	1	2	35
50	DKA-09	1	4	1	5	6	7	3	2	4	2	2	37
51	DKA-10	1	3	5	5	12	10	3	2	4	1	1	47
Neykavala													
52	NKA-01	1	1	1	3	6	7	1	2	4	1	2	29
53	NKA-02	1	1	1	3	6	7	3	2	4	1	2	31
54	NKA-03	2	4	1	3	6	7	3	2	4	1	2	35
55	NKA-04	1	4	1	5	6	7	3	2	4	2	2	37
56	NKA-05	1	3	5	5	12	10	3	2	4	1	1	47
57	NKA-06	1	1	1	3	6	7	1	2	4	1	2	29
58	NKA-07	1	1	1	3	6	7	3	2	4	1	2	31
59	NKA-08	2	4	1	3	6	7	3	2	4	1	2	35
60	NKA-09	1	4	1	5	6	7	3	2	4	2	2	37
61	NKA-10	1	3	5	5	12	10	3	2	4	1	1	47
62	NKA-11	1	1	1	3	6	7	1	2	4	1	2	29
63	NKA-12	1	4	1	3	6	7	3	2	4	2	1	34
Dhoni													
64	DHI-01	1	3	8	3	6	7	1	2	4	1	1	37
65	DHI-02	1	3	8	3	6	7	1	2	4	1	2	38
66	DHI-03	2	4	1	3	12	10	3	2	4	1	2	44
67	DHI-04	2	3	1	1	6	5	1	2	4	1	1	27
68	DHI-05	1	3	5	3	6	5	3	2	4	1	1	34
69	DHI-06	1	2	1	3	6	7	3	2	4	1	2	32
70	DHI-07	1	2	1	5	12	5	3	2	4	1	1	37

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
71	DHI-08	2	4	1	3	6	10	3	2	4	1	1	37
72	DHI-09	2	1	0	3	6	7	3	2	4	1	2	31
Poothundy													
73	PDI-01	1	4	1	3	6	7	3	2	4	1	2	34
74	PDI-02	1	4	1	3	6	7	1	2	4	1	2	32
75	PDI-03	1	3	1	3	6	7	3	2	4	1	1	32
76	PDI-04	1	3	1	3	12	10	3	2	4	1	2	42
77	PDI-05	1	3	8	5	6	5	1	2	4	1	2	38
78	PDI-06	2	4	1	3	6	2	3	2	4	1	2	30
79	PDI-07	1	4	1	3	6	5	3	2	4	1	2	32
80	PDI-08	1	4	5	3	12	7	3	2	4	1	2	44
81	PDI-09	1	4	5	3	6	7	1	2	4	1	2	36
82	PDI-10	2	3	5	3	12	7	3	2	4	1	2	44
83	PDI-11	1	4	5	5	6	7	1	2	4	1	1	37
84	PDI-12	2	3	1	3	12	10	3	2	4	1	2	43
85	PDI-13	2	3	1	3	6	5	3	2	4	1	1	31
86	PDI-14	1	3	5	3	6	5	3	2	4	1	2	35
87	PDI-15	2	2	5	3	6	5	3	2	4	1	2	35
88	PDI-16	1	1	5	3	6	10	3	2	4	1	1	37
89	PDI-17	1	4	5	3	12	5	3	2	4	1	2	42
Attappady													
90	ATY-01	1	2	5	3	6	7	3	2	4	1	2	36
91	ATY-02	1	2	5	3	6	7	3	2	4	1	2	36
92	ATY-03	1	3	5	1	12	7	1	2	4	1	1	38

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
93	ATY-04	2	3	1	3	6	5	3	2	4	1	2	32
94	ATY-05	1	1	1	3	6	5	3	2	4	1	1	28
95	ATY-06	2	2	1	3	12	2	1	2	4	1	2	32
96	ATY-07	2	4	5	5	12	10	3	2	4	1	2	50
97	ATY-08	2	1	5	5	6	5	3	2	4	1	2	36
98	ATY-09	1	2	8	3	6	10	3	2	4	1	2	42
99	ATY-10	1	2	8	3	6	5	3	2	4	1	2	37
Thiruvazhiyad													
100	TUD-01	1	3	5	3	6	7	1	2	4	1	1	34
101	TUD-02	1	3	5	3	6	5	3	2	4	1	1	34
102	TUD-03	1	3	5	3	6	7	3	2	4	1	1	36
103	TUD-04	2	4	5	5	12	7	1	2	4	1	2	45
104	TUD-05	1	4	1	3	12	10	3	2	4	1	2	43
105	TUD-06	1	2	1	3	6	7	1	2	4	1	1	29
106	TUD-07	1	2	1	3	12	10	3	2	4	1	2	41
107	TUD-08	1	1	1	3	6	7	3	2	4	1	1	30
108	TUD-09	1	1	1	3	6	7	3	2	4	1	1	30
109	TUD-01	1	3	5	3	6	7	1	2	4	1	1	34
110	TUD-02	1	3	5	3	6	5	3	2	4	1	1	34
Walayar													
111	WLY-01	1	3	1	3	6	7	3	2	4	1	1	32
112	WLY-02	1	3	0	1	6	7	3	2	4	1	1	29
113	WLY-03	2	3	1	3	6	7	3	2	4	1	1	33
114	WLY-04	1	3	5	3	12	10	1	2	4	1	1	43
115	WLY-05	1	3	5	3	6	5	3	2	4	1	2	35
116	WLY-06	1	3	5	3	6	5	3	2	4	1	1	34

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
117	WLY-07	2	3	5	3	6	7	3	2	4	1	1	37
118	WLY-08	2	3	5	1	12	10	1	2	4	1	1	42
119	WLY-09	2	3	1	3	6	5	3	2	4	1	1	31
120	WLY-10	1	2	1	3	12	5	1	2	4	1	1	33
121	WLY-11	1	2	1	3	6	7	3	2	4	1	1	31
122	WLY-12	1	1	5	3	12	10	3	2	4	1	2	44
123	WLY-13	2	1	5	5	6	7	3	2	4	1	2	38
124	WLY-14	1	3	1	5	12	7	3	2	4	1	2	41
125	WLY-15	2	4	5	5	6	7	3	2	4	1	2	41
Parambikulam													
126	PBM-01	1	2	5	1	6	7	3	2	4	1	2	34
127	PBM-02	1	2	1	3	12	10	3	2	4	1	2	41
128	PBM-03	2	4	0	3	12	10	1	2	4	1	2	41
129	PBM-04	2	3	1	5	6	7	3	2	4	1	1	35
130	PBM-05	1	3	1	3	6	7	3	2	4	1	2	33
131	PBM-06	1	3	1	3	6	7	3	2	4	1	1	32
132	PBM-07	1	3	1	5	6	7	3	2	4	1	2	35
133	PBM-08	2	3	1	5	6	7	3	2	4	1	2	36
134	PBM-09	2	2	1	3	6	7	1	2	4	1	1	30
135	PBM-10	1	3	1	3	6	5	3	2	4	1	2	31
136	PBM-11	2	1	5	3	6	7	3	2	4	1	2	36
137	PBM-12	2	3	5	5	12	10	3	2	4	1	2	49
138	PBM-13	1	**3**	0	5	6	7	3	2	4	1	2	34
139	PBM-14	1	3	1	5	12	10	3	2	4	1	2	44
140	PBM-15	1	3	1	5	6	7	1	2	4	1	1	32

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
141	PBM-16	2	3	1	3	6	7	3	2	4	1	2	34
142	PBM-17	2	3	1	3	12	7	1	2	4	1	2	38
143	PBM-18	2	3	1	3	12	10	3	2	4	1	2	43
144	PBM-19	1	3	1	5	6	7	3	2	4	1	2	35
145	PBM-20	2	2	1	5	12	7	3	2	4	1	2	41
146	PBM-21	2	1	5	5	6	7	3	2	4	1	2	38
147	PBM-22	2	2	1	3	12	7	1	2	4	1	1	36
148	PBM-23	1	2	1	3	6	5	3	2	4	1	2	30
149	PBM-24	1	3	1	3	12	10	3	2	4	1	2	42
150	PBM-25	1	3	5	5	6	5	1	2	4	1	2	35
151	PBM-26	1	3	1	3	12	10	3	2	4	1	2	42
152	PBM-27	2	3	1	5	6	7	3	2	4	1	2	36
153	PBM-28	2	3	5	3	6	7	3	2	4	1	2	38
154	PBM-29	2	3	5	3	6	7	3	2	4	1	1	37
156	PBM-30	2	3	1	5	12	10	3	2	4	1	1	44
157	PBM-31	1	3	0	3	6	7	3	2	4	1	2	32
158	PBM-32	1	3	1	3	6	7	3	2	4	1	2	33
159	PBM-33	2	2	1	3	6	7	3	2	4	1	2	33
160	PBM-34	1	2	5	3	12	10	3	2	4	1	2	45
161	PBM-35	2	2	5	3	6	7	3	2	4	1	2	37
162	PBM-36	1	4	8	3	12	7	3	2	4	1	2	47
163	PBM-37	2	3	1	3	6	7	3	2	4	1	2	34
164	PBM-38	2	3	5	3	12	10	3	2	4	1	2	47
165	PBM-39	2	3	8	3	6	5	3	2	4	1	2	39
167	PBM-40	1	3	5	3	6	5	3	2	4	1	2	35
168	PBM-41	1	3	1	3	6	5	3	2	4	1	2	31

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
169	PBM-42	1	4	8	5	12	10	3	2	4	1	2	52
170	PBM-43	1	3	5	3	6	7	3	2	4	1	2	37
171	PBM-44	2	4	1	5	6	5	3	2	4	1	2	35
172	PBM-45	1	3	1	5	12	7	3	2	4	1	2	41
173	PBM-46	2	3	5	3	12	2	3	2	4	1	2	39
174	PBM-47	1	3	8	3	6	5	3	2	4	1	2	38
175	PBM-48	1	2	8	3	6	5	3	2	4	1	2	37
176	PBM-49	1	3	5	3	6	5	3	2	4	1	2	35
178	PBM-50	1	3	1	5	6	10	3	2	4	1	2	38
179	PBM-51	1	3	1	3	6	7	3	2	4	1	2	33
180	PBM-52	1	3	1	5	6	7	3	2	4	1	2	35
181	PBM-53	1	3	0	3	6	5	3	2	4	1	2	30
Chinnar													
182	CNR-01	1	3	1	3	6	7	1	2	4	1	2	31
183	CNR-02	1	1	5	3	6	10	3	2	4	1	2	38
184	CNR-03	1	3	5	3	12	10	3	2	4	1	2	46
185	CNR-04	2	3	1	3	12	10	3	2	4	1	2	43
186	CNR-05	1	3	1	3	12	5	3	2	4	1	2	37
187	CNR-06	2	3	0	3	6	7	3	2	4	1	2	33
188	CNR-07	1	3	8	3	12	10	1	2	4	1	2	47
189	CNR-08	2	2	8	3	6	2	3	2	4	1	2	35
190	CNR-09	1	3	5	1	6	7	3	2	4	1	2	35

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
191	CNR-10	1	3	5	5	6	7	1	2	4	1	2	37
192	CNR-11	1	3	5	3	6	5	1	2	4	1	2	33
193	CNR-12	2	2	5	3	6	5	1	2	4	1	2	33
194	CNR-13	1	3	8	3	12	5	3	2	4	1	2	44
195	CNR-14	2	2	8	3	6	7	3	2	4	1	1	39
196	CNR-15	1	4	8	3	12	10	3	2	4	1	2	50
197	CNR-16	2	2	8	3	6	5	1	2	4	1	2	36
198	CNR-17	2	1	1	3	6	7	1	2	4	1	2	30
199	CNR-18	1	4	5	3	6	7	3	2	4	1	2	38
200	CNR-19	1	4	1	3	12	10	1	2	4	1	2	41
201	CNR-20	2	1	8	3	6	7	3	2	4	1	2	39
202	CNR-21	1	4	5	3	6	7	3	2	4	1	1	37
203	CNR-22	2	3	1	3	6	7	1	2	4	1	2	32
204	CNR-23	2	4	1	3	6	5	3	2	4	1	2	33
205	CNR-24	1	3	1	3	12	10	3	2	4	1	2	42
206	CNR-25	1	3	5	3	12	2	1	2	4	1	2	36
207	CNR-26	1	4	8	3	12	10	3	2	4	1	2	50
208	CNR-27	1	3	5	3	6	5	3	2	4	1	2	35
209	CNR-28	1	1	5	3	6	10	3	2	4	1	2	38
210	CNR-29	2	3	5	3	6	5	3	2	4	1	2	36
211	CNR-30	1	3	8	3	6	5	1	2	4	1	2	36
212	CNR-31	1	1	1	3	12	10	3	2	4	1	2	40
213	CNR-32	2	4	1	3	6	2	3	2	4	1	1	29
214	CNR-33	1	4	1	3	6	7	3	2	4	1	2	34

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
215	CNR-34	2	3	5	3	6	7	3	2	4	1	2	38
216	CNR-35	2	1	5	5	12	10	3	2	4	1	2	47
217	CNR-36	1	1	5	3	12	10	3	2	4	1	1	43
218	CNR-37	1	3	8	3	12	10	3	2	4	1	2	49
219	CNR-38	1	3	1	3	6	5	1	2	4	1	2	29
220	CNR-39	2	3	5	5	12	7	3	2	4	1	2	46
221	CNR-40	1	3	5	5	6	10	3	2	4	1	2	42
222	CNR-41	1	3	1	5	6	7	1	2	4	1	1	32
223	CNR-42	2	3	1	5	12	10	3	2	4	1	2	45
224	CNR-43	1	3	1	3	6	7	3	2	4	1	2	33
225	CNR-44	1	3	5	3	6	5	1	2	4	1	2	33
226	CNR-45	2	4	1	5	6	5	3	2	4	1	2	35
227	CNR-46	1	3	1	3	6	5	3	2	4	1	1	30
228	CNR-47	1	3	5	3	6	7	3	2	4	1	1	36
229	CNR-48	1	2	5	3	6	7	3	2	4	1	2	36
230	CNR-49	1	1	5	3	6	5	3	2	4	1	2	33
231	CNR-50	1	3	8	3	12	10	3	2	4	1	2	49
232	CNR-51	2	4	8	5	6	7	3	2	4	1	2	44
233	CNR-52	1	1	8	3	12	10	3	2	4	1	1	46
234	CNR-53	1	3	8	5	6	7	3	2	4	1	2	42

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
Peechi													
235	PCI-01	1	2	1	3	6	7	3	2	4	1	2	32
236	PCI-02	1	2	1	3	6	7	1	2	4	1	2	30
237	PCI-03	1	3	0	1	12	7	3	2	4	1	2	36
238	PCI-04	2	3	5	3	6	5	3	2	4	1	2	36
239	PCI-05	1	1	1	3	6	5	1	2	4	1	2	27
240	PCI-06	2	2	1	3	12	2	3	2	4	1	2	34
241	PCI-07	2	4	1	5	12	10	3	2	4	1	2	46
242	PCI-08	2	1	5	5	6	10	3	2	4	1	2	41
243	PCI-09	1	2	1	3	6	7	3	2	4	1	2	32
244	PCI-10	1	2	1	3	6	5	3	2	4	1	2	30
245	PCI-11	1	2	5	1	6	7	3	2	4	1	2	34
246	PCI-12	2	3	1	3	6	7	3	2	4	1	2	34
247	PCI-13	1	3	1	5	6	5	1	2	4	1	2	31
248	PCI-14	2	3	1	3	6	5	3	2	4	1	2	32
Akamala													
249	AKA-01	1	1	5	3	6	7	3	2	4	1	2	35
250	AKA-02	1	1	1	3	12	10	3	2	4	1	2	40
251	AKA-03	1	3	1	3	12	10	3	2	4	1	1	41
252	AKA-04	2	3	1	3	6	5	3	2	4	1	2	32
253	AKA-05	1	2	1	3	6	2	1	2	4	1	2	25
254	AKA-06	2	4	0	3	6	7	3	2	4	1	2	34
255	AKA-07	1	2	1	3	12	5	3	2	4	1	2	36
256	AKA-08	1	3	1	3	6	7	3	2	4	1	1	32

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
257	AKA-09	2	3	1	3	6	7	3	2	4	1	2	34
258	AKA-10	2	1	1	3	6	7	3	2	4	1	2	32
259	AKA-11	1	2	1	3	12	7	1	2	4	1	1	35
260	AKA-12	2	3	5	3	12	10	3	2	4	1	1	46
Kulathupuzha													
261	KPA-01	1	4	5	3	6	10	3	2	4	1	2	41
262	KPA-02	1	4	5	3	6	7	3	2	4	1	1	37
263	KPA-03	2	2	1	3	6	7	3	2	4	1	2	33
264	KPA-04	1	4	5	5	12	10	3	2	4	1	2	49
265	KPA-05	1	2	5	5	6	7	3	2	4	1	1	37
266	KPA-06	1	3	1	5	6	7	3	2	4	1	1	34
267	KPA-07	2	3	5	5	6	7	1	2	4	1	2	38
268	KPA-08	2	1	1	5	12	10	3	2	4	1	1	42
269	KPA-09	2	2	5	5	6	7	3	2	4	1	1	38
270	KPA-10	1	2	0	1	6	7	1	2	4	1	1	26
271	KPA-11	1	3	0	3	12	10	3	2	4	1	2	41
272	KPA-12	1	3	1	3	6	7	3	2	4	1	1	32
273	KPA-13	1	3	1	3	12	7	1	2	4	1	1	36

Sl. No.	Tree ID No.	Verticality	Straightness	Apical dominance	Forking	Branch angle	Branch thickness	Self pruning ability	Foliar	Stem damage	Cross section	Bole swelling	Total Score
Aryankavu													
274	AYU-01	1	4	1	3	6	7	3	2	4	1	1	33
275	AYU-02	1	4	5	5	6	7	3	2	4	1	2	40
276	AYU-03	2	2	5	3	6	7	1	2	4	1	2	35
277	AYU-04	2	2	5	5	6	5	3	2	4	1	2	37
278	AYU-05	1	3	8	5	6	7	3	2	4	1	1	41
279	AYU-06	2	3	1	5	12	10	3	2	4	1	2	45
280	AYU-07	2	1	1	5	6	7	3	2	4	1	1	33
281	AYU-08	2	2	5	5	6	7	3	2	4	1	1	38
282	AYU-09	1	2	5	1	6	7	3	2	4	1	1	33
283	AYU-10	1	3	1	3	12	10	3	2	4	1	2	42
284	AYU-11	1	3	5	3	12	10	3	2	4	1	1	45
285	AYU-12	1	3	1	3	12	10	3	2	4	1	2	42

Abstract

Genetic variability and plus tree selection in natural populations of *malaveppu* (*Melia dubia* Cav.)

BY

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ABSTRACT OF THE THESIS

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DOCTOR OF PHILOSOPHY IN FORESTRY

Faculty of Forestry
Kerala Agricultural University

DEPARTMENT OF FOREST BIOLOGY AND TREE IMPROVEMENT
COLLEGE OF FORESTRY
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2019

ABSTRACT

Melia dubia commonly known as Malabar neem is a fast growing indigenous species. It is considered as a major wood in plywood and paper industries and the plant is put into various medicinal uses, preferred for use in packing cases, cigar planks etc. There are no identified genotypes of melia, suitable for Kerala. This is one of the reasons which has made a dearth in the availability of good planting material. Hence, a study was conducted to determine the genetic diversity of the trees and select plus trees from the forests of Kerala. Fifteen locations spread over eighteen localities where the species is common were identified from secondary data and reconnaissance survey. In total 281 trees were selected for the survey. The important quantitative and qualitative characters of the trees were determined. Based on baseline selection system, a regression analysis was done between the $(DBH)^2$ x height and $(\text{crown width})^2$ x crown length separately for each location and the trees above the regression line having highest score for the qualitative characters were selected. This was to ensure that a minimum of one tree got selected from a locality to ensure diversity in selection. The study showed that variability existed for all the qualitative characters and it was more within the localities when compared to between localities. In total twenty five trees were selected. Clustering done for the twenty five plus showed that *Melia dubia* genetic resources resolved the trees into seven clusters and it was found that grouping were independent to the geographic locations. Inter and intra cluster divergence were also studied.

The evaluation of the seedling progenies from the twenty five plus trees were done in the nursery for five months. Significant differences among the progenies of the selected trees were observed for various morphological and physiological characters studied. The performance of the progenies of two trees from Tholpetty (FCV-MD-03 and FCV-MD-04) were the best in most of the parameters studied. The genetic analysis of the causes of variation for the morphological and physiological traits were studied. The values for the phenotypic coefficient of variations ranged from 12.62 per cent for height to 24.53 per cent for biovolume.

The result indicated that the values for genotypic coefficient of variation was less than the phenotypic coefficient of variations for all the traits studied, indicating existence of environmental effect on these characters. Heritability estimates in broad sense were observed higher than 50 per cent for the quantitative characters such as height, collar diameter, number of leaves, AGR and biovolume. Heritability was also higher for all the physiological characters studied. The genetic gain was also high indicating possibilities of using selections for further breeding. The correlation studies on the morphological and physiological characters showed that the height was positively correlated with all the morphological and physiological characters studied except leaf temperature. Photosynthetic rate was positively correlated with the height, chlorophyll and relative water content of the leaves.

For standardization of clonal progenies, cuttings from the seedlings, semi hardwood cuttings from mature trees and root suckers by damaging the roots were taken to develop a method for mass multiplication of the *Melia dubia*. Three different auxins IBA, NAA, IAA at different concentrations were administered. The result showed that the best treatment for the cuttings and rootsuckers were IBA at 1000 ppm. For the semihardwood cuttings, miniclonal technology was used and the best treatment observed was IBA at 6000 ppm.