DIVERSITY ANALYSIS AND SELECTION OF CANDIDATE PLUS TREES OF *Swietenia macrophylla* FROM SELECTED DISTRICTS OF NORTH KERALA

by

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(2018-17-003)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Diversity analysis and selection of candidate plus trees of *Swietenia macrophylla* from selected districts of North Kerala"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Abbreviation	**Explanation**
ANOVA	Analysis of variance
C.V	Coefficient of variation
C.D	Critical difference
SEM	Standard error of mean
SD	Standard deviation
Df	Degrees of freedom
R	Replication
viz.	Namely
i,e.	That is
etc.	Etcetera
cm	Centimeter
cm^2	Centimeter square
cm^3	Cubic centimetre
m	Meter
Fig.	Figure
^{o} C	Degree Celsius
et al.	And co-workers
EL	Elathur
K	Kalpetta
SB	Sulthan Bthery
PE	Peruvennamuzhi
P	Padinjarethara
ER	Eeramanellur
KO	Kottayam
TA	Taliparamba
KH	Koorachundu
TR	Trikaripur
N	Neeleswaram
PD	Padne
V	Vadakara

M	Mananthavady
PU	Puduppady

1. INTRODUCTION

Increase in the economic and industrial development diverted foresters from traditional forest management system to forest production. This included introduction of new species. Often selection and improvement of indigenous tree species fail to meet the required character of higher yield in shorter period. These lead to the introduction of the exotic species. In the 18th century, new species were introduced for the enhancement of parks, botanical collections, and gardens. But in the 19th century introduction was mainly done to meet the elevated demand in the forest production. In short, plant introduction was mainly to enrich local flora, to get superior growth rate, enhance wood quality, and to get trees resistant to diseases and another unfavorable environment.

Honduras or big leaf mahogany (*Swietenia macrophylla* King, Meliaceae) is a valuable neotropical timber species. Mahogany became the first extensively traded timber species to be listed in Appendix II of the CITES in 2002 (Blundell, 2004). The tree is usually found in dry, moist and wet lowland tropical and subtropical forests up to an altitude of 1400 m. The tree is naturally distributed from southern Mexico southward to Colombia, Venezuela, and parts of the upper Amazon and its tributaries in Peru, Bolivia and Brazil (Cespedes *et al*., 2003). Mahogany was introduced to India in 1872, from Belize (Soerianegara and Lemmens, 1994). *Swietenia macrophylla* and *Swietenia mahogany* were planted in South Malabar in 1872. As a plantation it was raised in Edacode, North Forest Division, Kerala in 1893.The tree attains a height of 30 m and can grow to more than a diameter of 1.5 m at breast height. Mahogany has a straight and cylindrical trunk with well-developed spurs. Its leaves are either paripinnate or imparipinnate. The fruits are capsular, oblong or ovoid and seeds are samaroid. The major pests attacking the species are *Hypsiphyla robusta* and *Hypsiphyla grandella.* Mahogany is a shade-intolerant climax species with a strong light demand. Regeneration occurs primarily from non-dormant, wind-dispersed seeds. The timber is rather soft, medium-weighted with reddish or pinkish heartwood. The wood density is in the range of 485-850 kg/m^3 at 15 % moisture content. The tree can be grown in wide range of soils including alluvial soils, heavy clays, volcanic soils, lateritic soils and soils derived from limestone, granite and other sedimentary, igneous or metamorphic rock formations.

In every tree improvement program genetic variability studies have to be done which often but not always depends on the extent of the area of the growth. Genetic variation is essential to maintain an evolutionarily viable natural population to get adapted to changing conditions in long run. Some exotics may have naturalised over decades through naturalization. Many agricultural lands are tree rich but poor in species diversity. For this reason, it is important to examine and ameliorate tree species diversity for improvement of a single species. Every tree breeding program for the improvement of timber quality depends on the identification of the best parents, which become a genetic base for further improvements in form and vigor of trees.

The phenotypic character of the tree species depends on the genetic factor, the environmental factor and also in the interaction of these two factors. Mahogany is a species which grow in wide range of environment conditions. Trees of the same species growing in different edaphic and climatic conditions of different regions tend to adapt to those environmental conditions. Tree improvement focusing on exploiting these adaptations may bring genetic combinations of better character for higher yield and sustainable production. Wood density is often genetically determined and is an economically important trait. Wood density has been a major trait in many tree improvement programs. Therefore, it is desirable to include in tree improvement programs in combination with other characters like growth, quality and pest resistance. The same species which is growing in largely different environments may show difference in growth traits as well as in wood quality.

Various studies have shown that the physiological character of a species is also adaptive to the existing climate. The physiological characters like photosynthetic rate, stomatal conductance, transpiration, and leaf temperature of species can adapt to the prevailing climatic conditions of the region where it is grown. These variations can be exhibited by the seedlings of these species. Therefore, to study the adaptive nature of the species it is relevant to evaluate the variations in the seedlings of each plus trees. Some of these variations can be attributed to the altitudinal differences of the region of growth. There are evidences stating differences in the temperature, wind speed, atmospheric pressure, irradiance level across different altitudes. When trees grow in these varied climatic conditions, they tend to adapt to these environmental conditions.

In this study to analyse diversity and selection of candidate plus trees of *Swietenia macrophylla*, the objectives were set as,

1. To study the morphological characters of *Swietenia macrophylla* across North Kerala and select candidate plus trees among them.

2. Conduct Progeny trials to study the presence and intensity of genetic variability in the species. For the same, morphological and physiological characters were studied.

2. REVIEW OF LITERATURE

2.1. DESCRIPTION OF THE SPECIES

Swietenia macrophylla King, a member of Meliaceae family is a large deciduous tree. The tree is usually found in dry, moist and wet lowland tropical and subtropical forests up to an altitude of 1400 m. The tree is naturally distributed from southern Mexico southward to Colombia, Venezuela, and parts of the upper Amazon and its tributaries in Peru, Bolivia and Brazil (Cespedes *et al*., 2003).

Mahogany was introduced to India in 1872, from Belize. It is then spread through South Asia, South-East Asia, the Pacific and to tropical Africa (Soerianegara and Lemmens, 1994). *Swietenia macrophylla* and *Swietenia mahagony* were planted in South Malabar in 1872. It was planted in Edacode, North Forest Division, Kerala in 1893. It is known as Honduran mahogany, big leaf mahogany, and green gold (Rodan *et al*.,1992).

The tree has an umbrella shaped crown reaching up to a height of 30 m and attains a diameter of more than 1.5 m at breast height. Young trees have narrow crown, but older trees have a broad, dense and highly branched crown. The tree has a straight and cylindrical trunk which is slightly grooved with well-developed spurs. The outer bark of older trees is scaly, deeply longitudinally furrowed and brownish-grey to reddish-brown in colour. The leaves are usually paripinnate, sometimes imparipinnate, 12-45 cm long and are made of 3-6 pairs of lanceolate or ovate leaflets. The flowers are unisexual, 0.5-1.0 cm in length, and are borne in large, branched inflorescences including both male and female. The fruits are capsular, oblong or ovoid and seeds are samaroid (Soerianegara and Lemmens, 1994).

Mahogany is a climax species with a strong light demand (Snook, 1994). Mahogany is a shade-intolerant species which is distributed through the seasonal American tropics (Gullison *et al.,* 1996). Regeneration occurs primarily from non-dormant, wind-dispersed seeds. The tree can be grown in wide range of soils including alluvial soils, heavy clays, volcanic soils, lateritic soils and soils derived from limestone, granite and other sedimentary, igneous or metamorphic rock formations (Whitmore, 1992). The timber is rather soft, medium-weighted with reddish or pinkish heartwood. The wood density is in the range of 485-850 kg/m^3 at 15 % moisture content. The species also have lower ash content (Shanavas and Kumar, 2003).

Hypsiphyla robusta, H.grandella are the major pests. Shoot borers especially *Hypsipyla spp.* are the main factor limiting cultivation of mahoganies in their native areas. Larvae of this moth lives inside stem and tunnel into the pith, killing the apical parts of the shoot. Even though this rarely kills the tree, the stem forks or branches reducing the economic value of the timber (Chacko *et al*., 2002; Entwistle, 1967). Attributing to its beautiful pattern, Mahogany timber is usually used as a carpentry wood and thus it comes under fancy wood category (Bramasto *et al.*, 2017). *Swietenia macrophylla* is considered threatened among the timber species by the international timber trade (Cespedes *et al*., 2003) due to its heavy logging in the native areas.

2.2. GENETIC VARIATIONS AND ITS IMPORTANCE.

From the genetic perspective mahogany is important, because genetic viability underpins both environmental and economic viability. From the environmental view, genetic variation is essential to maintain an evolutionarily viable natural population to get adapted to changing conditions in the long run. From the economic view point, sustainable production is threatened if genetic characteristics like wood quality or pest resistance, are lost.

Genetic variability is a complex. But if its magnitude and types are known, genetic variation can be manipulated to obtain good gains in some tree characteristics. Individual trees of a species show variations from each other even if grown in same stands. This is the major type of variations the geneticist uses in a selection and breeding program (Zobel and Talbert, 1984). Every tree breeding program for the improvement of timber quality depends on the identification of the best parents, which become a genetic base for further improvements in form and vigour of trees (Clark and Wilson, 2005).

The main objective of any tree improvement program is to identify promising species or provenances and genotype which are capable of providing maximum yield per unit area in the shortest possible time. This can be achieved by screening intra specific genetic variations (Goel and Behl, 2001).

The progeny tests and provenance studies of *Swietenia macrophylla*, established in Costa Rica and Trinidad (Newton, 1990; Newton *et al*., 1992) indicated a variation in height growth between half-sib families by up to a factor of two suggesting an extent of genetic variation in mahogany which is comparable with that of other tropical tree species. The study also revealed that there existed genetic variations within *S. macrophylla* in terms of susceptibility to pest attack. Progeny experiments conducted in Mesoamerican population of mahogany showed high levels of genetic variation for height and diameter growth on two levels *i.e*., population and family (Navarro and Hernandez, 2004).

Genetic diversity is necessary for the long-term survival of tree species. There are four life history traits that can affect the partitioning of genetic diversity in various tree species. First, tropical tree species show lower variations than the temperate trees. Second, species with wide spread geographical distribution shows greater variations than those with limited range. Third, outcrossing taxa has higher levels of genetic diversity than those which are autogamous. Selfing species show diversity among populations rather than within populations (Gillies *et al*., 1999).

For a particular species, heterogeneity in environmental factors can influence the distribution of genetic variations among populations (Mitton, 2000; Antonovics, 1971). Genetic heterogeneity can be created by environmental heterogeneity via several micro evolutionary processes (Linhart and Grant, 1996). Firstly, natural selection helps population to get acquainted to the local environment. This results in a fine-scale micro geographical variation. This has been demonstrated for single or few locus traits like pathogen tolerance (Dirzo and Harper, 1982), quantitative traits (Dudley, 1996), single locus allozymes like stomatal size (Mitton *et al*., 1998) and multi locus allozymes like soil moisture and temperature (Allard *et al.*, 1972). Secondly, genetic heterogeneity can be resulted by differential gene exchange, and differences in flowering phenology among local habitats. According to Mitton *et al*. (1980), ecological barriers can prevent genetic exchange among populations along elevational gradients. Also, within a region differences in phenological characters like flowering time which is associated with local habitats may create genetic barriers which in turn exacerbate differences in local population. Third, genetic drift or founder effects can cause chance associations which can create genetic heterogeneity as they colonize several sites and gene flow may not be sufficient to homogenize differences (Husband and Barrett, 1996).

To identify genetic differences, it is advisable to simultaneously examine multiple loci (Taylor and Mitton, 1974). This helps in detecting allelic differences that accumulate across loci (Smouse *et al.*, 1982). Multivariate analysis is better than univariate analysis as one analysis is required for all variable. Even if one independent variable is creating the pattern, this will be clearly shown in multivariate analysis structure. Furthermore, single loci will not reveal differentiation pattern, even if they are significant (Thorpe, 1985).

2.3. GENETIC VARIATION IN AGROFORESTRY ECOSYSTEM

According to Simons *et al.* (2000), in future it will only be possible to conserve tree species in farm lands, if current negative trend of human activity on forest land continues. Unless productivity in farmlands are not maintained, farmers won't be benefited. Productivity depends both on genetic variation (intraspecific) and tree species diversity. A wide genetic base is necessary to surpass inbreeding depression and make trees adapt to changing environmental conditions and to alter markets for tree products. Interventions facilitating access to a wide range of germplasm is necessary to maintain local tree domestication activities. Genetic variation that is already present in farmland helps farmers adapt to changing market demand.

High grades of genetic diversity between trees in discrete populations are important for two reasons. First, the tree species in tropics are semi domesticates. So, if a wide genetic base is not maintained, it will lead to inbreeding depression reducing individual fitness increasing the possibility of population or /and species extinction (Charlesworth and Charlesworth, 1987). Inbreeding may lead to embryo abortion, limited fruit set, reduced seed yield, and lower germination rates and less productive when they reach maturity (Hardner and Potts, 1997; Gigord *et al.*, 1998; Koelewijn *et al.,* 1999; Stacy, 2001). Inbreeding is worsened if there are large variations in fecundity (small number of trees contribute disproportionately to seed crop) is observed in tree species. This will result in the effective population size (size of idealized population that would have same genetic properties as that observed for a real population) lower than the census size and that required to maintain heterozygosity and productivity (Lengkeek *et al.*, 2005). Second, genetic variation help tree species adapt to changing environments like shifting climate, variable weather conditions, migration of better suited provenances along ecological gradients (Bawa and Dayanandan, 1998; Attah-Krah *et al.,* 2004; Aitken *et al.,* 2008). In order to increase the productivity of agroforestry system it is essential to select the best seed source of any species for a given region.

Phenotypic variations have been extensively studied in farmer's fields and natural forest for a number of commercially and historically important fruit trees in West Africa, including bush mango (*Irvingia gabonensis*) and safou (*Dacryodes edulis*) (Leakey *et al*., 2004). Researches have shown that genetic variation in commercially important traits can be identified at an early stage in farmer's field (Hodge *et al.,* 2002; Boivin-Chabot *et al*., 2004; Rochon *et al*., 2007). Selection from farmland may be more genetically efficient as they are more environmentally uniform than natural forest and this may lead to more dysgenic selection in farmland (Dawson *et al.,* 2008).

In rural areas, with the absence of formal tree improvement, informal selection by farmers dominate. Researchers have begun to learn the techniques and traits sought by farmers (Lovett and Haq, 2000). It is also important to note that poor results from farmer selection is due to narrow founder populations inbreeding through propagation from a limited number of parents. This was evident from the superiority of wild population of many species that were compared with exotic landraces such as in *Gliricidia* (Simons and Stewart, 1994). Concerns regarding genetic diversity and the way to help farmers attain maximum gains through plus tree selection depends on how farmers perceive variation. Quantitative studies in tree to tree variations in fruit and nut characteristics in village levels have shown that there is significant intra specific variation in each characteristic and many of these traits are not related (Atangana *et al*., 2001).

Exotic tree species may have properties like superior growth, fast growth which make them superior to indigenous trees. Some exotics may have turned indigenous over decades. Whether naturalized or indigenous, many agricultural lands are tree rich but poor in species diversity (Lengkeek *et al*., 2005). For this reason, it is important to examine and ameliorate tree species diversity for improvement of a single species.

2.4. GEOGRAPHICAL VARIATIONS IN TREE GROWTH

Tree growth is the product of interaction between genes and environment. However, these genes, environment, and interaction are not the same for all individuals of a species. Genes control the mechanism of a tree to respond to an environment and in utilizing the existing environment in growth. For a more desirable growth to occur the range in environmental variation must lie within the range of genotypic tolerance. Each individual tree is adapted in particular to the extreme environmental variation and attains a balance with its environment. Tree populations are described in terms of average values and these values are closely related to the local environment (Callaham, 1959).

Control of genes over the growth of trees have extensive differences among wide spread populations of tree. Whenever seeds from wide sources are planted in one location, the observer can see the genetic differences in germination behaviour, in morphology of foliage, in the rate of shoot and root growth and many other characters (Critchfield, 1957). The closer the populations are, the more obscure the differences between them occur. Genetics of growth does not vary much between neighbouring trees in a transect.

In progeny tests, the inbred or selfed lines show a depressed vigour (Orr-Ewing, 1957). This is interpreted as the deleterious genes become homozygous. It is important to note that progenies from selfing does not give a true representation of the seed tree. So, seeds from the isolated tree must be taken in caution, as they may be self-pollinated ones and produce slow growing seedlings (Callaham and Hasel, 1961). In many forest trees, self-pollination might be a general problem. However, outcrossing is favoured over selfing through a process called selective fertilization (Squillace and Bingham, 1958).

The germination rate of tree seedlings is determined primarily by temperature given adequate moisture and light. A rapid germination is obtained at an optimum temperature which is different from the optimum temperature for other growth characters. Moreover, the genetically fixed germination temperature for all trees of a population in a species will be different (Critchfield, 1957). Studies of ponderosa pine was done by Callaham (1959), in lots of 10 seeds representing up to five wind pollinated progenies from different source. Incubation was done at five constant temperatures -8°C, 16°C, 24°C, 30°C, and 36°C. He found that the optimum temperature was between 24°C and 30°C. Variations among progenies from the same source although subtle showed different optimum temperatures for individuals.

Seedling growth and its development is determined by temperature and light conditions, provided adequate moisture. Photoperiod influences the inception and cessation of growth; the onset and cessation of growth can be genetically fixed in relation to a particular photoperiod. Likewise, the length of the growth period is fixed by some inherent "time clock". This mechanism may have evolved in response to a particular length of growing season (Critchfield, 1957). All individuals of a population in a species, respond differently to change in photoperiod. Evolution has facilitated different genetic adaptation of tree to utilize the native photoperiod in setting up their clock for growth (Vaartaja, 1959).

2.5. TREE IMPROVEMENT PROGRAMS AND PLUS TREE SELECTION.

Tree improvement programs are that particular in exploiting geographic variation by selecting superior provenances and establishing seed collection zones. Genetic variations can also be expressed between individuals (Wright, 1976) which may be a partial result of selection pressure facilitated by inter tree competition (Stern, 1971). The methodology for the phenotypic selection is to screen candidates with desirable characters. The candidate trees which satisfies the criteria are called "plus trees" (Wright, 1976). The philosophical approach towards plus tree selection is that a favourable deviation from the population mean is partly due to genetic rather than environmental or random effects (Falconer, 1981).

According to Zobel and Talbert (1984), the selection of plus trees is the first step in the establishment of an improvement programme. The basis of every selection is the availability of information on the magnitude of variability in a population. A variable that can strongly predict growth and mortality is growth history or autocorrelation (Terborgh *et al.,* 1997). Growth autocorrelation is the strong tendency of individual trees to maintain growth rates relative to other trees in population from one year to the next. This can be attributed to little change in tree level variable over time and inherent genetic and site differences such as soil fertility and water availability among trees.

Candidate Plus Trees (CPT) are selected on the basis of phenotypic characteristics (Ledig, 1974). Breeding programme for the improvement of timber quality depends on the identification of the best parent trees. Tree attributes which can be taken into consideration for the selection of CPT can vary with species and these include stem straightness, tree height, crown dimensions, diameter at breast height, forking and diseases (Clark and Wilson, 2005). Individuals having dead branches, diseases and attacked by pests and pathogen should be rejected in the first stage of selection.

Selection can change genetic characteristics of a population, by choosing the best individuals to produce the next generation offspring and also by controlling the mating system (Falconer *et al*., 1996). Selection helps in maintaining individuals with the most favourable combination of alleles in the existing population (White *et al.,* 2002). The selection of trees depends on different factors like species attributes, current forest status, and evolutionary pattern. It also takes into consideration the availability of pedigree information variability and inheritance pattern of important characteristics along with the aim of tree improvement programme (Zobel and Talbert, 1984).

Though the principle of candidate plus tree selection vary with species, major quantitative characters like GBH and height are considered for selection as they are correlated to biomass productivity. Certain qualitative traits like apical dominance, stem straightness, forking, spiral bole, twists are also considered. Depending on the purpose of selection a maximum of three to five most important characters and a few other lesser important characters should be identified. The most important traits include those which are highly correlated to the objective of breeding and are highly heritable and possess a higher economic importance. The success of any phenotypic selection depends on the quantity of available genetic variability in the population for a particular economic character and intensity of their interrelationship (Lone and Tewari, 2008).

Quantitative traits like height growth are controlled by multiple genes which have additive effects that can be subjected to a huge amount of environmental modifications

(Wright, 1976). Wood properties such as fibre length, density, pulpability and chemical constituents are also considered if trees are selected for some specific purposes. Studies have shown that basic density had a very high heritability (Settle *et al*., 2012).

In India, the method followed for candidate plus tree selection is comparison tree method. In this method the tree is compared with its nearest neighbours and tree with superior phenotype is selected as plus trees. This method is more efficient in plantations than any other methods if neighbouring trees are related (Ledig, 1974). To get maximum gain from the genetic makeup of the trees, individuals should be selected from population with minimum environmental differences. Even individuals growing under different environmental conditions show higher heritability for these characters. However, selection of individual becomes difficult in uneven aged stands as the growth characteristics are highly affected by age.

Candidate plus tree selection is difficult in uneven aged stands and trees grown in isolation. Isolated trees having an inherent character suitable for selection but lack expression due to unfavourable environmental condition should also be selected. The commonly followed method in uneven aged stands is base value method or regression method. In this method, the observations of characteristics of economic interest are recorded from sample plots. These recorded values are plotted against the age of the tree and regression lines are prepared for the population. The position of trees on the regression lines show the superiority of the trees. This method is difficult in uneven aged forest (Zobel and Talbert, 1984). Plus trees identified by their superior basal area increment (b.a.i) per unit crown area (c.a) obtained from linear regressions may provide stock that are inherently superior in growing space efficiency (Thomas, 1980; Brown and Goddard, 1961). Base line method of tree selection depends upon the sampling of a segment of the parent population. A base line is constructed from the least squares regression where the character of interest (usually height growth) is the dependent variable (Ledig, 1974). The base line gives the population mean and plus trees will be the greatest positive residuals. An alternative approach to plus tree selection and to improve tree growth is to improve growing space efficiency of trees. In this the focus is transferred from individual tree improvement to stand improvement. The plus trees would have the potential to produce more volume per unit of crown size or growing space than the competing trees of same age (Van Damme, 1985). Growing space is the tree's horizontal crown projection plus its appropriate allocation of unoccupied area (Assman, 1970).

In an attempt to select candidate plus trees of black spruce the correlation of crown area to point density ($R^2 = 0.09$) was weakly significant ($P < 0.05$). But crown radius × crown length had shown a strong correlation ($R^2 = 0.51$). It was conjectured that selection by b.a.i. vs. c.a. baseline would be free of competitive advantage and possess superior growing space efficiency. A strong relationship between b.a.i. and c.a. ($R^2 =$ 0.45 or 0.52) is expected because the crown produces the photosynthate which is necessary for cambial growth of the stem. Volumes or surface areas of the crown can calculate if crowns are considered as cones, cylinders or parabola. If crown volumes are calculated, one crown parameter is squared and this exponential increase may turn a linear relation into a curvilinear relation (Van Damme, 1985). Exponential increase in the crown parameters reduces the coefficient of determination by 10% compared with the regression of crown length × radius on b.a.i. (Thomas, 1980).

Selection for the growth rate should not be based on the largest trees, but the trees, which have utilized the growing spaces, nutrients and space more efficiently. This requires identifying trees with better growth in relation to its leaf surface area (Brown and Goddard, 1961; Bedell, 2006). This method is known as Base Line System. In this method a regression of diameter at breast height (DBH) squared × height on crown width squared × crown length is determined. The trees lying above the regression lines indicate higher vigour and those trees can be selected. This can be done separately for each stand. It is always better to start with a large number of initial selections to allow more intense selection to ensure early gain (Lindgren and Mullin, 1997).

2.6. WOOD PIN PENETRATION DEPTH MEASUREMENT

Wood specific gravity (wood density) is an important factor to determine timber and pulpwood value of a tree. Wood density is determined by many factors like cell diameter, cell wall thickness, proportions of early wood and late wood, cellulose and lignin content, as well as content of extractives (Hansen, 2000).

Wood density is heritable and is an economically important trait. Therefore, it is desirable to include in tree improvement programs in combination with other characters like growth, quality and pest resistance. Wood density has been a major trait in many tree improvement programs. The same species which is growing in largely different environments may show difference in growth traits as well as in wood quality (Zobel and Van Buijtenen, 1989)

The pilodyn wood tester helps to measure a large number of trees in a non-destructive way and at a reduced cost. Pilodyn gives more extensive and accurate studies on genetic control of wood density across sites. It is a hand held devise which inserts a steel pin into the wood with a known force. This has been used as an effective method to measure wood density in a standing tree (Sprague *et al*., 1983; King *et al*., 1988). The depth to which pin penetrates is inversely proportional to the density of wood. Pilodyn provides an estimate of relative wood density, which can be used to rank various genetic units with regards to wood density (Hansen, 2000). Since the pilodyn penetrates only a few outer growth rings and the wood density varies from pith to bark (Zobel and Van Buijtenen, 1989), an accurate relationship between the wood density and the pin penetration is lacking. Even so pilodyn wood tester is being used to rank genotypes for wood density in breeding programs.

Ponneth *et al*. (2014) observed a highly significant negative correlation between specific gravity and penetration depth in *Swietenia macrophylla*. They also observed a linear relationship between average oven dry specific gravity and penetration depth in this species. Hence, they concluded that pilodyn has a great potential for rapid screening of logs for wood specific gravity.

Hernandez and Rasteropo (2007) observed that, the effect due to altitude was non-significant for wood density in *Alnus sps.* of Colombia within the same hydrographic basin. But the variation between trees within the same region was significant. Altitude and height of the tree have effect on wood density. As the mean sea level increases the wood density and cell wall thickness of trees also increases (Kiaei, 2011).

2.6. PROGENY EVALUATION

Seeds with good genetic potential are needed to maximise adaptability and yield potential in a stressed condition. Studies related to this are important to trace the available genetic variation and utilize them to produce the best trees. Seed vigour is an important parameter that gives an insight into the performance of seed lots in the field. Seed vigour is defined as the sum total of those properties of the seed which determine the level of activity and performance of the seed or seed lot during germination and seedling emergence. Several factors like genetic constitution, maturity at harvest, seed weight and size, mechanical integrity, deterioration and ageing and pathogen attacks are known to influence seed vigour (Perry, 1980).

The broadness of genetic diversity in seed source population will decrease inbreeding and improve the seed quality. Establishment of a good plantation should be supported by the availability of a good seed source. Seeds produced from populations having high genetic diversity will be improved ones. The quality of seeds produced depends on the genetic diversity of a population, and will continue to affect productivity of forest plantations (Bramasto *et al*., 2017).

Since the genetic contribution to the phenotypic characters is unknown (Stern, 1971), it can be identified by progeny trials. Variation in seed traits within species are crucial for establishment of seedlings in different habitats. Germination traits can evolve in response to the selection pressures of different habitats producing genetic differentiation. Seeds from higher elevations can germinate faster and in a better way because of their lower dormancy compared with seeds from low elevation (Vera, 1997). Quicker germination facilitates emergence, establishment, growth and survival of seedlings at higher elevations. Dormancy is a genetically controlled trait for plants (Meyer and Allen, 1999).

Mahogany disseminates in early mid dry season (June-August) and most seeds begin to germinate at the start of the following wet season (October-November). Typical regeneration of mahogany in even aged mixed species stands takes place after natural or human caused disturbances (Stevenson, 1927; Lamb, 1966). The tree being a shade intolerant species possess seed viability for a few months (Morris *et al.*, 2000) and its understory is deficient of a seed and/or seedling bank (Snook, 1994). Primarily regeneration takes place from non-dormant, wind dispersed seeds. The seedlings and saplings of mahogany that occur below a closed canopy and also in felling and natural gaps are comparatively small. Seedlings below a closed canopy are accompanied with reduced survival and low growth rate (Dickinson *et al*., 1999). Researchers have reported difficulties and the need for natural regeneration of mahogany (Gullison and Hubbell, 1992). Early survival and vigorous growth are required to establish mahogany (Lamb, 1966). Navarro and Hernandez (2004) cited that growth can be fast if root collar diameter increases by 20 mm/year and height over 1 cm/year. Mahogany trees in plantations have exhibited diameter growth of more than 1 cm/year during the early years (Lamb, 1966).

2.7. PHYSIOLOGICAL TRAITS OF PROGENIES

Studies showing a range of interspecific and intraspecific variations and their pattern of variation in traits give the idea that the physiological traits are adaptive (Sultan, 1995). Teramura and Strain (1979) grew populations of *Plantago lanceolata* from three different environments and found that seedlings from sunnier site had higher photosynthetic rate than those from shadier sites. Similar differences were observed by Sims and Kelly (1998) across an irradiance gradient. There are also studies by Zhang *et al*. (2009) in which no genetic differentiation for photosynthetic traits was observed. Also, in most of these cases phenotypic differences among these populations were having plasticity.

Stomatal conductance depends on a complex of factors like leaf irradiance, atmospheric water vapour pressure deficit, leaf temperature and CO_2 concentration (Cowan, 1978), on guard cells and epidermal turgor (Comstock and Mencuccini, 1998). Regulation of turgor in these cells require metabolic energy (Netting, 2000) and depends on balance between water lose through leaves and water supply to leaves from soil (Cowan, 1978).

The potential increase in transpiration with altitude when the average temperature is less than the ambient temperature *i.e.*, 0.6^{o}C/ 100 m at mid-latitudes was predicted and demonstrated by Gale (1972). This is attributed to the higher total radiation absorbed by leaves, enhanced diffusion coefficient of water vapour in air at reduced biometric pressure and a higher density gradient of water vapour from leaf to ambient air.

For early selection, gas exchange and photosynthesis have been reported to enhance the efficiency of breeding program. Wide variations and high heritability (h^2) for growth and physiological traits like chlorophyll fluorescence, gas exchange and growth parameters had observed in clones of *Tectona gradis* (Huang *et al*., 2019). They also opined that such characters are important for improving efficiency in teak breeding. *Azadirachta indica* from ten provenances had shown genetic variation in physiological traits such as CO_2 exchange, net photosynthesis, stomatal conductance, leaf area and seedling dry weight (Kundu and Tigerstedt, 1999).

2.8. STUDIES ON MAHOGANY

Negreros-Castillo *et al.* (2003) evaluated germination percentage of mahogany for five months after seeding for three clearing treatments *i.e*., (1) slash, fell and burn (2) slash, fell and leave (3) machine cleared and two sowing treatment *i.e*., buried and surface sown. The data were recorded every 15-20 days. The buried seeds had a much higher germination rate (20%) than surface sown seeds (6%). The seeds lost due to predation averaged 20% for first five months and there was no significant difference among clearing treatments or between sowing treatments. The total number of seeds that died after germination during the first six months averaged 24% and did not vary among treatments and sowing methods. The average height measured for buried and surface sown seeds were 27.6 cm and 25.3 cm respectively. Burying seeds allow faster root growth and allows utilising extra energy from seeds to be used for leaf development.

Gullison *et al*. (1996) observed little regeneration in four out of five studied forests in Bolivia, even though only saplings (individuals >2.5 cm DBH), not seedlings, were enumerated. Regeneration in these forests were conjectured to happen after logjam – induced flooding.

Escalante *et al.* (2012) evaluated differences in seedling performances among five provenances of big-leaf mahogany in Bolivia. Mean height of provenances after four months was 29.5±0.3 cm. Significant differences among provenances were also identified. Collar diameter and vigour index of seedlings after four months among provenances were at par.

Wood density of mahogany from fourteen locations in Mexico and central America, planted in seven locations in Puerto Rico shown a significant difference between the values ranging from 0.48 – 0.57 g cm^{-3} (Chudnoff and Geary, 1973).

Climate related variations in the functional traits of tree species can result from both physiological acclimation and genetic adaptation of local population to their biophysical environment. The present study will improve our understanding of different kinds of adaptation and variations in relation to morphological and physiological functions and its implication in tree improvement programs.

3. MATERIALS AND METHODOLOGY

3.1. STUDY AREA

Being packed between the Arabian Sea in the west, Western Ghats in the east and a network of forty-four rivers, Kerala has a diverse geographical feature. Based on the historical and cultural similarity the districts of Kerala are generally divided into North Kerala (Kasaragode, Kannur, Wayanad, Kozhikode, Malappuram), Central Kerala (Palakkad, Thrissur, Ernakulam, Idukki) and South Kerala (Thiruvananthapuram, Kollam, Alappuzha, Pathanamthitta, Kottayam). The geographical location of Kerala is between 8°8' and 18°48' North latitudes and 74°4' to 77°50' East longitude. The state is located in the tropical region of Indian Peninsula and the area extends to about 38863 km^2. Physiographical division of the terrain are lowland (below 20 m), midland (20-100 m), and highland (above 100 m) (ENVIS, 2019).

Altitudinal variations affect temperature regime. High altitude creates temperate climatic conditions in high ranges like Wayanad and Idukki. The low altitude regions experience humid tropical climate. The annual precipitation received in the state is around 2600 mm. The annual precipitation is concentrated in lesser periods in northern part of the Kerala whereas it is spread over longer periods in southern parts. The state is divided into two parts-south and north of 11°N latitudes (approximately North and South of Thrissur) with rainfall pattern I and II (Table 1) respectively (ENVIS, 2019).

Table 1. Rainfall pattern in Kerala

Pattern	Description
Pattern I	Both the Southwest and northern monsoons are active and moderately distributed. Southwest monsoon maximum in June (South of 11°N latitude)
Pattern II	Poorly distributed rainfall; Southwest monsoon maximum in July. The rainfall is concentrated in three-four months. Relatively weak Northeast monsoon (North of 11°N latitude).

Soil type is an important factor distinguishing specific zones. The major soil type found in Kerala is laterite and its variations. In midland region the dominant soil is laterite with B-horizon. The high lands have lateritic soil with no B-horizon. The coastal areas have sandy loam or sandy soil. For the study purpose the candidate plus tree selection was carried out in North Kerala. The area is divided into three altitudinal regimes - low land, midland, and highland. The various altitudinal regimes were selected from four districts - Kasaragode, Kannur, Kozhikode and Wayanad. Based on the altitude, rainfall, soil and topography the Kerala state is divided into thirteen agro-climatic zones. Block panchayats have been taken as the basis of separation. The agro ecological division of the selected areas of four districts is given in Table 2 (KAU, 2011).

Table 2: Agro-ecological zone of surveyed area.

Agro-ecological Zones	**Areas**
Northern midlands	Perambra, Vadakara, Taliparamba, Balusseri, Talassery
Malapuram type	Neeleswaram, Kozhikode, Kanhangad
High ranges	Kalpetta, Sulthan Bathery, Mananthavady.

3.2. GENERAL DESCRIPTION OF STUDY AREA

3.2.1. Kasargode

Kasargode covers an area of 1961 km^2. The area receives an annual rainfall of about 3500 mm. The average monthly maximum temperature ranges from 29.2-33.4°C and the monthly minimum temperature ranges from 19.7-25°C. The relative humidity ranges from 54.4% to 98.7%. Sunshine hours range from 3.2 to 10.2 hours/day. The maximum during February and minimum during June to August. The most predominant soil is lateritic soil in mid land and hilly areas (10-100 m above MSL). Brown hydromorphic soil is found in valleys in the undulating topography of midlands and in low lands. Mixed alluvium is found in areas below 20 m MSL (GoK, 2016)

3.2.2. Kannur

Kannur covers an area of 2966 km^2 and is located between 11°40’ and 12°48’ N latitudes and 74°52’ and 75°56’ E longitudes. The year to year variability of rainfall is approximately 28.2%. The area falls under wet type climate. The maximum average monthly temperature varies from 28.4-36.9°C and the minimum average monthly temperature varies from 19.7-23.9°C. The relative humidity is between 77-88%. The predominant soil type found in the area is lateritic soil. The maximum sunshine hours are more than 9.1% during January to March. The minimum sunshine hours are recorded during June to August (GoK, 2016).

3.2.3. Kozhikode

Kozhikode lies between North latitudes 11°08’ and East longitudes 75°8’. The district spread over an area of 2344 Km^2. The average annual rainfall here is 3600 mm. The maximum temperature ranges between 28.2°C to 32.9°C. The minimum temperature ranges between 22°C and 25.8°C. The relative humidity varies from 74% to 92% in the morning hours and 64% to 89% in the evening hours. Lateritic soil is found in the midland portion of the district. The soil contains very less organic matter with moderate nitrogen, phosphorous and potash. The pH of the soil ranges between 5.3 to 6.5. The other types of soil found here are riverine alluvium and forest loam (GoK, 2016).

3.2.4. Wayanad

This is a small hill district in Kerala with an area of 2131 Km^2. Wayanad receives a mean annual rainfall of 2786 mm. The climate is generally hot and humid. The maximum and minimum temperatures vary between 28.9°C to 36.2°C and 17.0°C to 23.4°C. Laterite soil is seen in some of the areas. Forest soil is seen in Mananthavady, Kalpetta, and Sulthan Bathery blocks. They are rich in organic matter, nitrogen and humus. Forest loam is dark reddish brown in colour with loamy to silty loam texture. The pH of the soil ranges between 5.3 to 6.3 (GoK, 2016).

3.3. PLUS TREE SELECTION.

A total of 15 locations were randomly selected from four districts, such that five locations from each of the altitudinal regimes *i.e.* low land, mid land, and high land were identified. These locations were categorized based on their altitudinal values into low land mid land and high land (Table 3). Forty to fifty trees were enumerated from each location and their morphological characters were studied.

Table 3. Locations surveyed for plus tree selection.

Altitudinal regimes	Locations	Elevation (m)
Low Land (Below 20m)	Elathur (Kozhikode)	10- 13
	Vadakara (Kozhikode)	11-15
	Trikaripur (Kasaragode)	12- 15
	Neeleswaram (Kasaragode)	5-10
	Padne (Kasargode)	10-13
Mid Land (20 – 100m)	Puduppady (Kozhikode)	35 – 78
	Peruvannamuzhi (Kozhikode)	45- 52
	Koorachundu (Kozhikode)	40-50
	Kottayam (Kannur)	22-25
	Taliparamba (Kannur)	48-55
High Land (above 100 m)	Kalpetta (Wayanad)	750-780
	Sulthan Bathery (Wayanad)	880-900
	Padinjarethara (Wayanad)	710-720
	Eramanellur (Wayanad)	700-750
	Mananthavady (Wayanad)	730-760

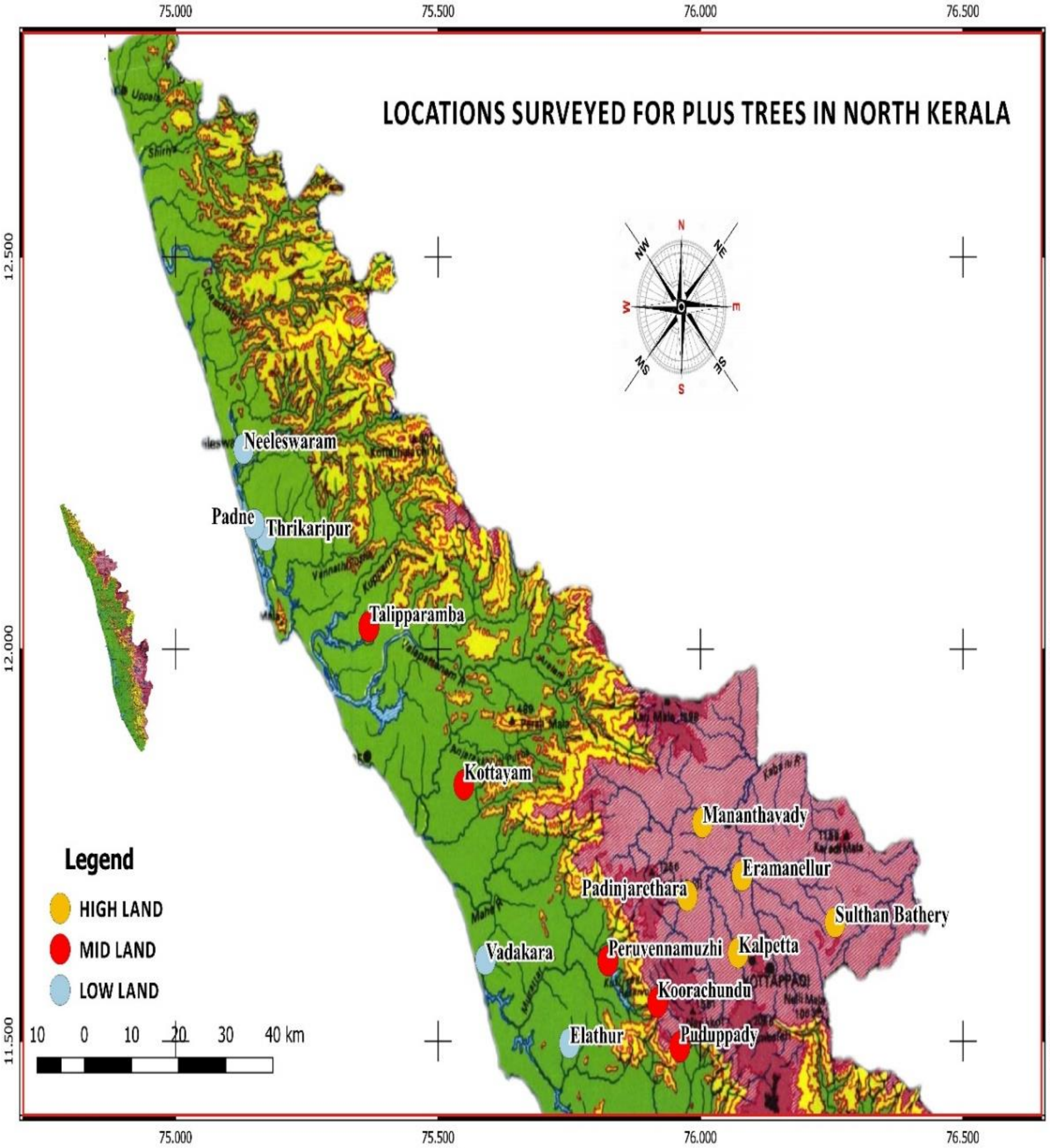

Fig. 1. Study area in North Kerala.

3.4. OBSERVATIONS TAKEN FROM THE FIELD

3.4.1. Quantitative traits

3.4.1.1. Total height (m)

The total height and the bole height were measured using vertex IV ultrasound instrument. The instrument is used along with a transponder which gives an accurate measurement in any climate, and in any terrain. The height was measured from the base to the end of the leading shoot of the tree.

3.4.1.2. Bole height (m)

Using the same Vertex IV instrument, the bole height was measured. The distance from base of the tree to the point of first branching was taken as the bole height.

3.4.1.3. Girth at breast height (m)

Girth at breast height was measured using tape at a height of 1.37 m from the ground. Care was taken to prevent the twisting of tape. Two measurements were taken at right angles and their mean value is taken as the GBH.

3.4.1.4. Wood quality measurement

The wood quality of the selected plus trees was measured using pilodyn with 2.5 mm steel needle. Over bark measurement was taken by removing a small section of bark at 1.37 m height. The average value of two pilodyn shots was taken as the reading.

3.4.2. Qualitative Traits

3.4.2.1. Bole form

It is the rate of diminution of diameter with height. Shape and branching habit vary with species. This can be influenced by environmental and contextual factors. Bole straightness, swellings etc. were recorded. Branching habit based on the height of first branch, branching angle, branch thickness, apical dominance, forking, self-pruning ability were also noted.

3.4.2.2. Health Status

Presence of foliar and stem damages were taken into consideration. The differences in the qualitative traits were examined using scoring method formulated by Jayaraj (1997). The scoring format is given in appendix I.

3.5. PLUS TREE SELECTION

Forty-five plus trees were selected from fifteen locations in North Kerala. The selection was done using base line method (Bedell, 2006). The base line is constructed by doing regression of (crown diameter $)^2$ × crown length and (DBH $)^2$ × height. Then the trees showing positive deviation from the base line is selected as plus trees. The dependent variable (DBH ^{2}× height) is taken on the y-axis and the independent variable on the x-axis. If more trees were showing positive variation from the base line, then the trees were selected using the scoring method. The trees which have the best scores for different qualitative parameters were selected. Following this method, three plus trees from fifteen locations were selected.

3.6. PROGENY EVALUATION

3.6.1. Seed collection

The fruits were collected during the months of December, 2019 and January, 2020. Fruits were collected from the trees either directly or from the grounds if found fresh. The collected fruits were sun dried and stored. After the seeds were collected from all the locations, they were sown in the nursery bed. The nursery bed was of the size 12 m × 1 m. Before sowing, the seeds were dewinged and water soaked overnight and were sown in three replications. The nursery bed was mulched to protect the seeds from scorching sun.

3.6.2. Germination percentage

The germination of seeds started after three weeks. The number of seeds germinated on each day were counted for fifteen days. A seed was recognized as germinated when the radicle had emerged about two mm long (Murillo-Amador *et al*., 2002). The germination percentage was calculated by counting the total number of seeds germinated from each replication at final count.

3.6.3. Seedling shoot length

Seedling shoot length was measured from the collar portion to the tip of the stem. The measurement was taken in cm. The value was an average of five seedlings from each replication of candidate plus tree.

3.6.4. Seedling root length

Seedling root length was calculated from the collar to the tip of the root and the average value of five seedlings from each replication of each candidate plus tree was taken. The measurement was taken in cm.

3.6.5. Seedling height

Seedling height is the total of seedling shoot length plus seedling root length.

3.6.6. Collar diameter

The collar diameter of the seedlings was measured using Vernier Callipers (least count = 0.02 mm). The measurements were taken in two diametrically opposite directions. The measurements were expressed in millimeters.

3.6.7. Number of leaves

The total number of healthy leaves retained were counted. Leaves were counted from five seedlings from each replication of each candidate plus tree and their average was taken as the value.

3.6.7. Seed vigor Index

For the calculation of the seed vigor index I, germination percentage and seedling length of the same lot is determined. Seed vigor index I is calculated by multiplying germination percentage and seedling length. The seed lot having the higher seed vigor index value is considered to be more vigorous (Abdul-Baki and Anderson, 1973). For calculating vigor index five seedlings from each replication were collected and seedling height was measured. This is calculated as per the following formula:

Germination percentage × average seedling height.

3.7. PHYSIOLOGICAL READINGS

A portable steady-state flow through chamber connected to an Infra-Red Gas Analyser (IRGA) along with humidity, temperature, light and CO_2 control modules was used to record physiological readings. Net gas exchange of seedlings from each replication were measured using a sealed 2.5 cm^2 cuvette, and an initial CO_2 concentration of 37.5±0.3 Pa, a temperature of 25±0.3°C and a RH of 70±20%, regulated by controlling the flow which is diverted through the desiccant. Differential calibrations were performed in the field after each set of four measurements. Readings recorded in IRGA include photosynthetic rate, stomatal conductance, transpiration, internal CO_2 concentration, transpiration, vapour pressure difference.

3.8. STATISTICAL ANALYSIS

Plus tree selection was done using regression analysis in excel. R^2 value was checked for finding the fitness of the model. The data were assessed using analysis of variance.

Table 4. Analysis of variance (ANOVA)

Source of variation	Degree of freedom	Mean sum of squares	F calculated
Replication	(r-1)	M_r	
Treatments	(t-1)	M_t	M_t/M_e
Error	(r-1) (t-1)	M_e	
Total	(rt-1)		

Where,

r = No. of replications

t = No. of treatments

M_r = Mean sum of squares due to replication

M_t = Mean sum of squares due to treatment

M_e = Mean sum of squares due to error

The calculated F value were compared with tabulated F values at appropriate degrees of freedom.

3.8.1. Critical difference

CD is calculated by the following formula:

CD = SE × $t_{0.05}$ (error degrees of freedom).

Where,

SE = Standard Error of the difference of means to be compared.

SE = $(2M_e/r)^{1/2}$

Me = Error mean sum of squares.

r = No. of replication.

t = Tabulated value of t at 5% level of significance.

Mean difference between any two locations and trees within location greater than CD value was taken as significant difference.

3.8.2. Cluster analysis

Hierarchial clustering based on morphological characters was done for the plus trees selected using Minitab software based on squared Euclidean distance.

3.8.3. Principal component analysis

Principal component analysis was done on morphological characters of selected plus trees using Minitab software.

3.9. ESTIMATION OF GENETIC PARAMETERS

3.9.1. Variance Component

Variance: Phenotypic variance (σ^2p), Genotypic variance (σ^2g), and Environmental variance (σ^2e) was calculated as:

σ^2p = $\sigma^2g + \sigma^2e$

σ^2g = $(Mt – Me)/r$.

σ^2e = Me

Where Mt is the treatment mean sum of squares

Me = error mean sum of squares.

R = replication

3.9.2. Coefficient of variation:

Coefficient of variation was calculated as per Burton and Devane (1953)

PCV (%) = $\sqrt{\sigma^2 p}$/ X × 100

GCV (%) = $\sqrt{\sigma^2 g}$/ X × 100

ECV (%) = $\sqrt{\sigma^2 e}$/ X × 100

X = mean of the character

3.9.3 Heritability in broad sense (H^2):

Heritability is measured as the ratio of total genotypic variance to total phenotypic variance as suggested by Burton and Devane, 1953.

$$H^2\ (\%) = \frac{\sigma 2g}{\sigma 2p} \times 100$$

Where h^2 = broad sense heritability in percentage

$\sigma^2 g$ = genetic variance

$\sigma^2 p$ = phenotypic variance

3.9.5. Genetic advance

It is the magnitudinal enhancement of a particular trait in response to the chosen intensity of selection pressure. Genetic advance was calculated as per the equation given by Johnson *et al*. (1955)

Genetic advance (GA) = k. $\sqrt{\sigma^2 p} * H^2$

Where,

K= selection intensity at 5% which is equal to 2.06 (Allard, 1960)

σ^2p = phenotypic variance

H^2 = broad sense heritability (%)

3.9.6. Genetic gain

It is calculated by using formula given by Johnson *et al*. (1955)

Genetic gain $= \frac{GA}{X} \times 100$

GA = genetic advance

X = mean of the character

4. RESULTS

The present study on "Diversity analysis and selection of candidate plus trees of *Swietenia macrophylla* from selected districts of North Kerala" was carried out to select plus trees from four districts of North Kerala and investigate the presence and extent of variation between different seed sources. The result obtained from the selection based on phenotypic characters are presented as tables in this section. The data on progeny testing of the CPTs are also presented. The results obtained are presented under following heads:

4.1. General characteristics of *Swietenia macrophylla* observed in fifteen locations

4.2. Plus tree selection

4.3. Variations in the characters observed in the selected plus trees

4.4. Diversity analysis

4.5. Progeny evaluation

4.1. GENERAL CHARACTERISTICS OF *Swietenia macrophylla* OBSERVED IN FIFTEEN LOCATIONS.

The range of tree characteristics observed in fifteen locations on North Kerala are given in Table 5. In Kalpetta, a total number of fifty trees were enumerated. The maximum and minimum GBH measured were 1.85 m and 0.70 m respectively. Clean bole height (CBH) ranged between 3 m to 10 m. Crown width ranged between 6.2 m to 15 m. Crown length ranged between 8.9 m to 22 m. In Sulthan Bathery, fifty trees were enumerated and their GBH ranged between 0.65 m to 1.9 m. Clean bole height varied from 2.9 m to 12.9 m. The crown width and crown length ranged from 5.5 m to 15 m and 5 m to 18 m respectively. A total number of thirty-five trees were enumerated in Padinjarethara. GBH and CBH ranged from 0.75 m to 1.5m and 3.9 m to 10 m respectively. The crown width ranged from 7 m to 13.2 m. The crown length ranged from 8 m to 21.2 m. Thirty-five trees were enumerated in Eramanellur. The GBH and CBH of the trees ranged from 0.65 m to 1.7 m and 3 m to 12.1 m respectively. Thirty-seven trees were enumerated in Mananthavady. The GBH and CBH ranged from 0.75 m to 1.6 m and 4.3 m to 15 m respectively. The crown width and crown length varied from 6 m to 14 m and 6 m to 28 m respectively. In Puduppady, a total number of fifty trees were enumerated. The maximum and minimum GBH measured were 1.85 m and 0.80 m respectively. Clean bole height (CBH) ranged between 2.5 m to 13 m. Crown width ranged between 4.5 m to 11.5 m. Crown length varied from 6 m to 27 m. In Peruvennamuzhi, a total number of fifty trees were enumerated. The maximum and minimum GBH measured were 1.7 m and 0.79 m respectively. CBH ranged from 3.7 m to 15 m. Crown width ranged between 4 m to 15 m. Crown length varied from 6 m to 20 m. A total number of thirty-six trees were enumerated in Kottayam. The maximum and minimum GBH measured were 1.89 m and 0.76 m respectively. CBH ranged between 3.5 m to 11.6 m. Crown width ranged between 4.5 m to 11.5 m. Crown length ranged between 4.3 m to 12.5 m. In Taliparamba, a total number of thirty-seven trees were enumerated. The maximum and minimum GBH measured were 1.8 m and 0.79 m respectively. Clean bole height (CBH) ranged between 3 m to 16 m. Crown width ranged between 5 m to 19.4 m. Crown length ranged between 9 m to 22 m. In Koorachundu, a total number of thirty-four trees were enumerated. The maximum and minimum GBH measured were 1.35 m and 0.60 m respectively. Clean bole height (CBH) ranged between 3 m to 12 m. Crown width ranged between 6 m to 13 m. Crown length ranged between 4.8 m to 16 m. A total number of thirty-five trees were enumerated in Elathur. The maximum and minimum GBH measured were 1.65 m and 0.75 m respectively. Clean bole height (CBH) ranged between 4m to 10 m. Crown width ranged between 5 m to 13 m. Crown length ranged between 9 m to 23 m. In Vadakara, a total number of forty trees were enumerated. The maximum and minimum GBH measured were 1.85 m and 0.75 m respectively. Clean bole height (CBH) ranged between 2.9 m to 11.5 m. Crown width ranged between 4.5 m to 10 m. Crown length ranged between 6 m to 28 m. In Trikaripur a total number of thirty-four trees were enumerated. The maximum and minimum GBH measured were 1.54 m and 0.71 m respectively. Clean bole height (CBH) ranged between 6 m to 15 m. Crown width ranged between 5 m to 13.4 m. Crown length ranged between 4 m to 9 m. In Neeleswaram, a total number of thirty five trees were enumerated. The maximum and minimum GBH measured were 1.5 m and 0.78 m respectively. Clean bole height (CBH) ranged between 5 m to 13.4 m. Crown width ranged between 4.9 m to 15 m. Crown length ranged between 6.5 m to 11 m. A total number of thirty-five trees were enumerated in Padne. The maximum and minimum

GBH observed were 0.6 m to 1.4 m respectively. The CBH ranged from 5 m to 12.1 m. the crown width ranged from 6 m to 12 m and crown length ranged from 4 m to 12 m.

Altogether 593 trees were enumerated. The overall average GBH, clean bole height, crown width and crown length of the trees were 1.19 m, 8.21 m, 9.42 m and 12.7 m respectively. The maximum standard deviation was seen for the character crown length and minimum was observed for GBH.

Table 5. Details of the morphological parameters of *Swietenia macrophylla* in North Kerala.

Sl.No	Locations	Number of trees measured	GBH (m)		Clean bole height (m)		Crown width (m)		Crown length (m)	
			max	min	max	min	max	min	max	min
1	Kalpetta	50	1.85	0.70	10.00	3.00	15.00	6.20	22	8.90
2	Sulthan Batherry	50	1.90	0.65	12.90	2.90	15.00	5.50	18	5.00
3	Padinjarethara	35	1.50	0.75	10.00	3.90	13.20	7.00	21	8.00
4	Eramanellur	35	1.70	0.65	12.10	3.00	12.00	5.50	18	6.00
5	Mananthavady	37	1.60	0.75	15.00	4.30	1.40	6.00	28	6.00
6	Puduppady	50	1.85	0.80	13.00	2.50	11.50	4.50	27	6.00
7	Peruvennamuzhi	50	1.70	0.79	15.00	3.70	15.00	4.00	20	6.00
8	Kottayam	36	1.89	0.76	11.60	3.50	11.50	4.50	13	4.30
9	Taliparamba	37	1.80	0.79	16.00	3.00	19.40	5.00	22	9.00
10	Koorachundu	34	1.35	0.60	12.00	3.00	13.00	6.00	16	4.80
11	Elathur	35	1.65	0.75	10.00	4.00	13.00	5.00	23	9.00
12	Vadakara	40	1.85	0.75	12.50	2.90	10.00	4.50	28	6.00
13	Trikaripur	34	1.54	0.71	15.00	6.00	13.40	5.00	9	4.00

14	Neeleswaram	35	1.50	0.78	13.40	5	15	4.90	11	6.50
15	Padne	35	1.40	0.76	12.10	5	12	6	12	4
	Total	593								
Mean			1.19		8.21		9.42		12.70	
SD			0.49		4.81		4.49		7.90	

4.2. PLUS TREE SELECTION.

Plus trees of *Swietenia macrophylla* were selected from fifteen locations based on their quantitative and qualitative characters. The selection method followed was Base line method with tree scoring. The quantitative characters considered include tree height, girth at breast height, crown length and crown volume. Regression graph was prepared by plotting trunk volume in Y-axis and crown volume in X- axis. The R^2 value ranged from 0.54 to 0.78. The trees above the base line were selected and scored for their qualitative characters as shown in Table 8. Three trees having highest scores were selected from each locality.

Regression analysis of fifty trees from locality Kalpetta had R^2 value 0.7 ($p<0.05$) (Fig.1). A total number of nine trees (K-01, K-05, K-11, K-14, K15, K-20, K-23, K-41, and K-47) fall above the base line. So as to select the best three trees tree scoring was done. Trees numbered K-01, K-14, K-15 having highest scores 39, 39, 37 respectively were selected (Table 8). Regression analysis of fifty tree form Sulthan Batherry had R^2 value 0.62 ($p<0.05$) (Fig. 2). Ten trees (SB-03, SB-05, SB-11, SB-20, SB-27, SB-30, SB-31, SB-37, SB- 40 and SB-41) in total were placed above the base line. Trees SB - 20, SB- 31, SB-37, having scores 42, 37, 39 were selected (Table 8). Regression analysis of thirty-five trees from Padinjarethara had R^2value 0.63 ($p<0.05$) (Fig. 3). Seven trees (P-03, P-07, P11, P-18, P-24, P-25, and P-27) were above the base line. Based on the scoring three trees P-11, P-18, P-24 with scores 37, 39, 34 respectively were selected (Table 8). Regression analysis of thirty-five trees from the locality Eramanellur had R^2 value 0.54 ($p<0.05$) (Fig. 4). A total of seven trees (ER-02, ER-06, ER-08, ER-13, ER-20, ER-25 and ER-30) fall above the base line. Trees ER-13, ER-20, ER-25 with highest scores 38,39,42 respectively were selected as plus trees (Table 8). Regression analysis of thirty-seven trees from location Mananthavady had R^2 value 0.56 ($p<0.05$) (Fig. 5). Totally ten trees (M-02, M-05, M-07, M-11, M-18, M-19, M-20, M-23, M-35 and M-36) were above the base line. Trees M-11, M-18, M-35 with scores 37, 42, 42 were selected (Table 8).

Regression analysis of fifty trees from locality Puduppady had R^2 value 0.58 ($p<0.05$) (Table 8). A total number of ten trees (PU- 05, PU-06, PU-10, PU-11, PU-15, PU-17, PU- 20, PU-30, PU-35, and PU-37) fall above the base line. So as to select the best three trees tree scoring was done. Three trees PU-15, PU-20, PU-35 having highest scores 35, 32, 37 respectively were selected (Table 8). Regression analysis of fifty trees from locality Peruvennamuzhi had R^2 value 0.58 ($p<0.05$) (Fig. 7). Eight trees (PE-05, PE-10, PE-11, PE-12, PE-23, PE-25, PE-30 and PE-31) were placed above the base line. Trees PE-12, PE- 25, PE-30 having scores 41, 42, 42 respectively were selected (Table 8). Regression analysis of thirty-six trees from locality Kottayam had value 0.58 ($p<0.05$) (Fig.8). Ten trees (KO-11, KO-14, KO-17, KO-21, KO-26, KO-27, KO-29, KO-31, KO-34 and KO-37) were above the base line. Based on the scoring of each tree three trees were selected with scores 42, 39, 36 for trees KO-21, KO-26, KO-29 respectively (Table 8). Regression analysis of thirty-seven trees from the locality Taliparamba had R^2 value 0.58 ($p<0.05$) (Fig. 9). A total of eight trees (TA-11, TA-13, TA-16, TA-18, TA-20, TA-33 TA-36 and TA-37) fall above the base line. Trees TA-11, TA-16, TA-20 with scores 36, 37, 42 respectively were selected as plus trees (Table 8). Regression analysis of thirty-four trees from the locality Koorachundu had R^2 value 0.56 ($p<0.05$) (Table 8). Totally seven trees (KH-01, KH-05, KH-07, KH-10, KH-21, KH-28 and KH-30) were above the base line. Trees KH-21, KH- 28, KH- 30 with scores 42, 39, 42 respectively were selected (Table 8).

Regression analysis of thirty-five trees from locality Elathur had R^2 value 0.78 ($p<0.05$) (Fig.11). A total number of nine trees (EL-03, EL-05, EL-15, EL-16, EL-17, EL-20, EL-22, EL-29 and EL-30) fall above the base line. So as to select the best three trees tree scoring was done. Three plus trees having highest scores *i.e.* EL-05 (37), EL-15 (34), EL 30 (42) were selected (Table 8). Regression analysis of forty trees form Vadakara had R^2 value 0.63 ($p<0.05$) (Fig. 12). Fifteen trees in total (V-01, V-03, V-04, V-05, V-08, V-10, V-11, V-12, V-15, V-17, V- 20, V-23, V-24, V-30 and V-31) were placed above the base line. Trees V-12, V-15, V-17 having scores 42, 42, 41 were selected (Table 8). Regression analysis of thirty-four trees from the locality Trikaripur had R^2 value 0.63 ($p<0.05$) (Fig. 13). Ten trees (TR-01, TR-06, TR-08, TR-11, TR-13, TR-19, TR-23, TR-30, TR-33 and TR-35) were above the base line. Based on the scoring of each tree three trees TR-08, TR-13 and TR-23 were selected with scores 36, 36, and 42 respectively (Table 8). Regression analysis of thirty-five trees from Neeleswaram had R^2 value 0.73 ($p<0.05$) (Fig. 14). A total of eleven trees (N-02, N-04, N-05, N-06, N-08, N-10, N-12, N-13, N-16, N-21, and N-22) fall above the base line.

Trees N-12, N-16, and N-21) with scores 42, 41, and 42 respectively were selected as plus trees (Table 8). Regression analysis of thirty-five trees from Padne had R^2 value 0.66 ($p<0.05$) (Fig. 15). Totally ten trees (PD-05, PD-07, PD-11, PD-13, PD-15, PD-18, PD-19, PD-21, PD-23, and PD- 25) were above the base line. Trees PD-11, PD-18, PD-25 with scores 42, 31, 42 were selected (Table 8).

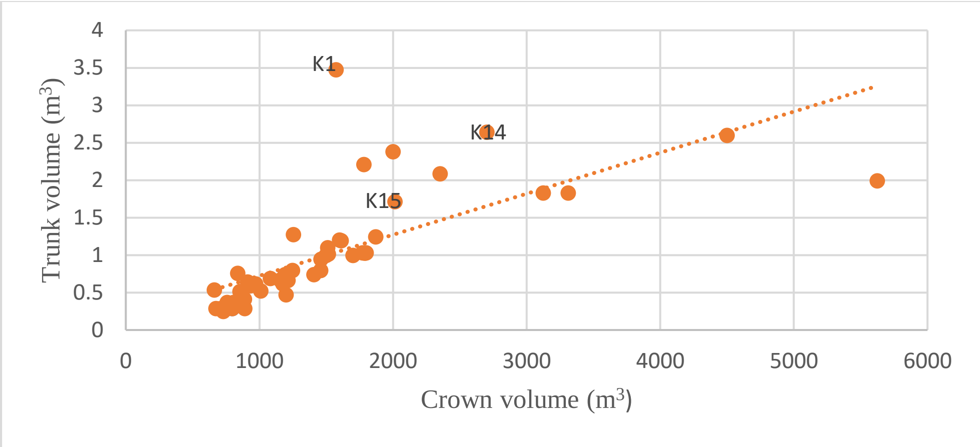

Fig. 2 Regression of *Swietenia macrophylla* trees enumerated from Kalpetta

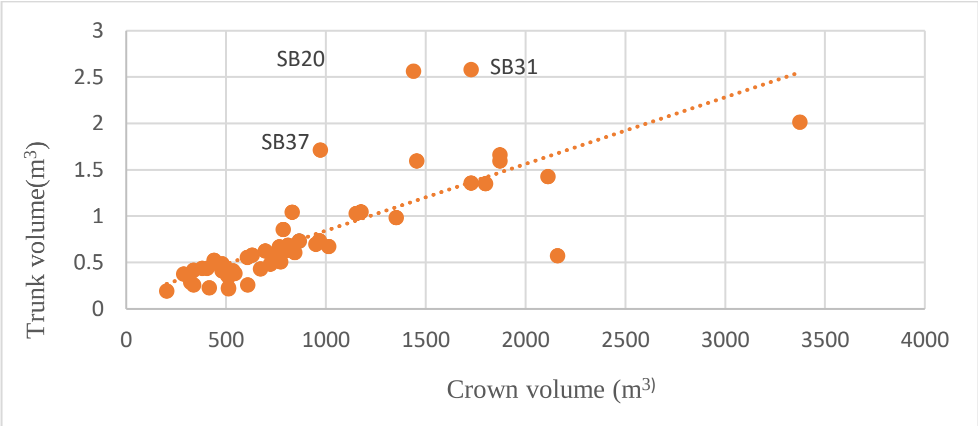

Fig. 3 Regression of *Swietenia macrophylla* trees enumerated from Sulthan Bathery

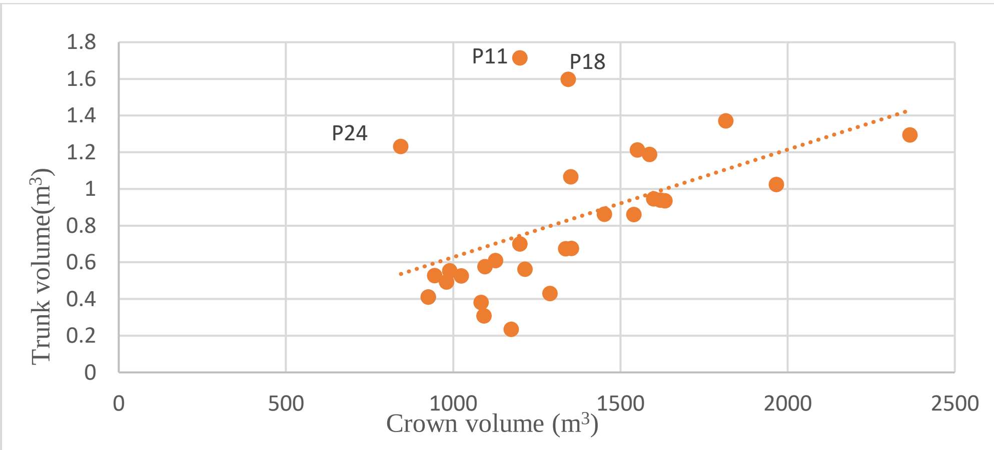

Fig.4 Regression of *Swietenia macrophylla* trees enumerated from Padinjarethara

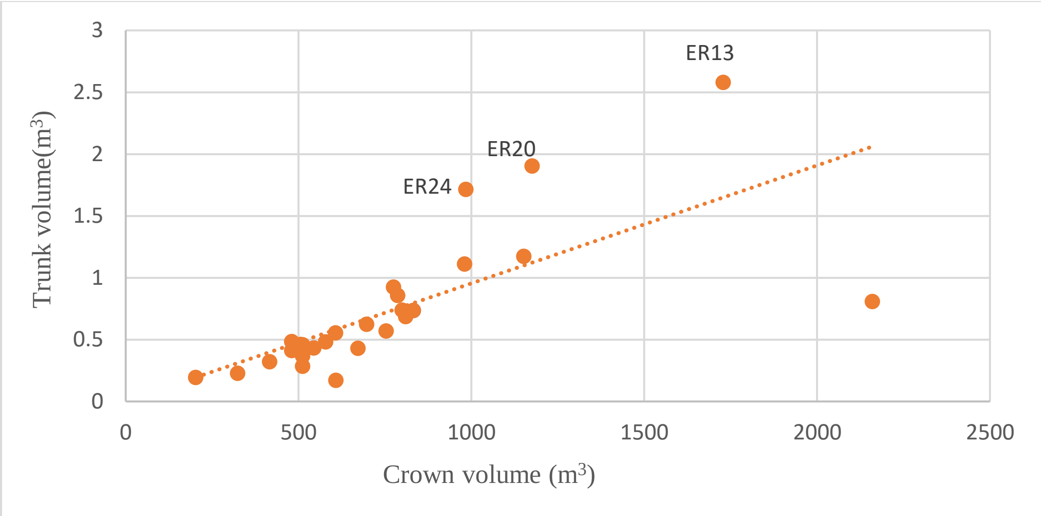

Fig.5 Regression of *Swietenia macrophylla* trees enumerated from Eramanellur

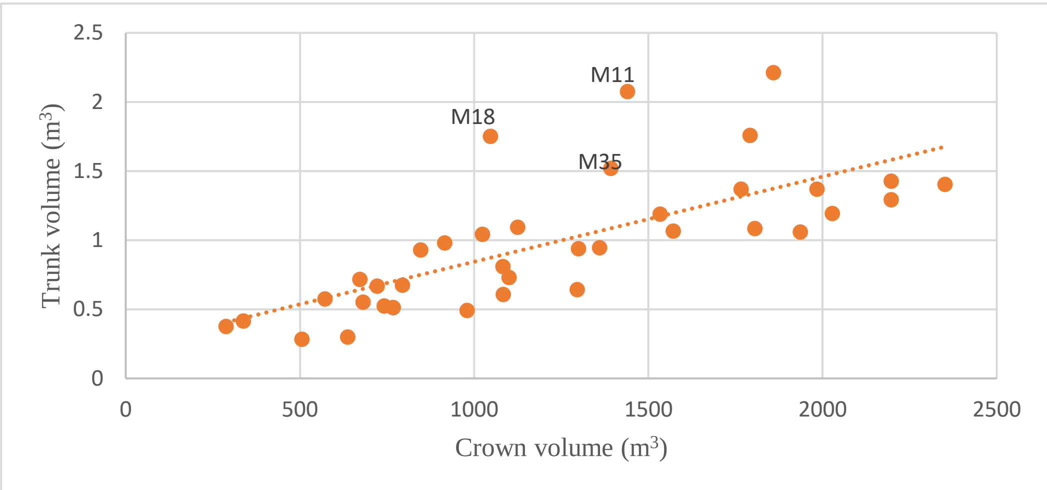

Fig. 6 Regression of *Swietenia macrophylla* trees enumerated from Mananthavady

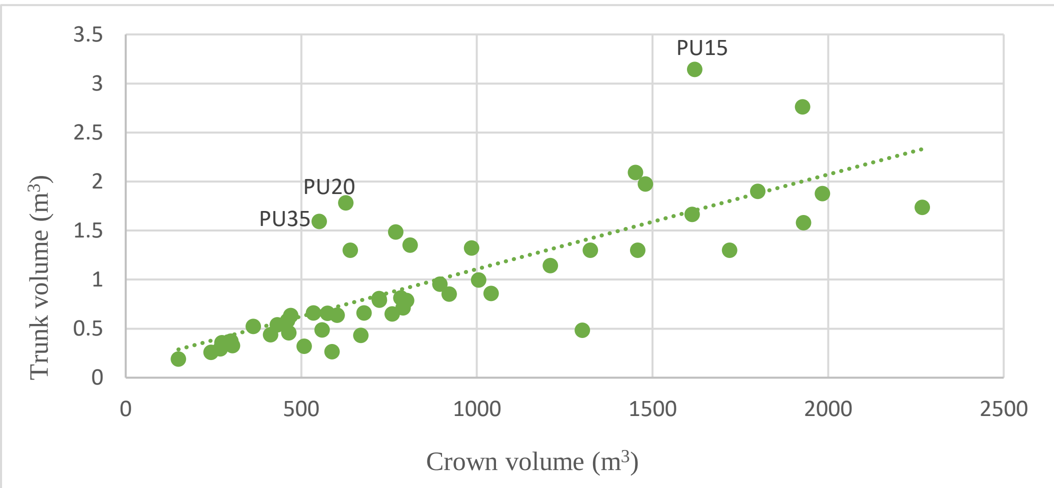

Fig. 7 Regression of *Swietenia macrophylla* trees enumerated from Puduppady

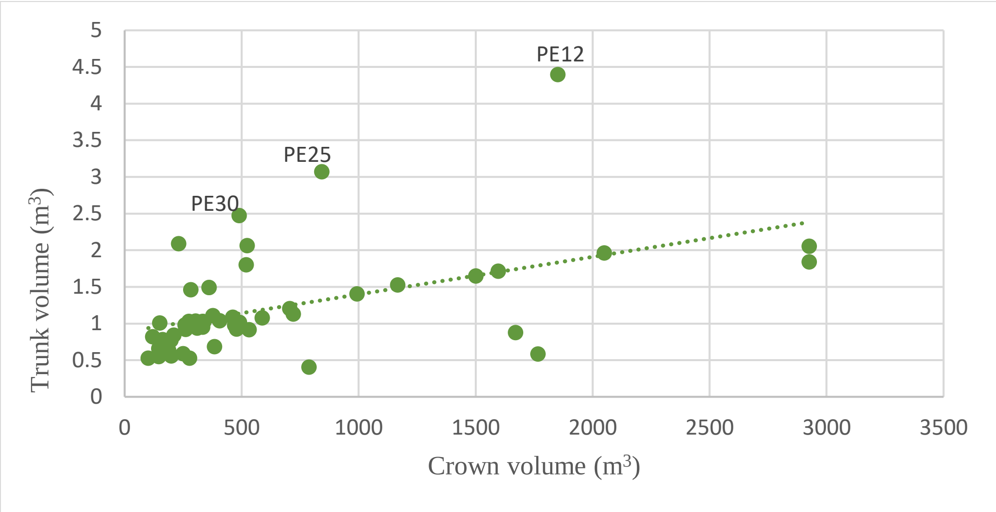

Fig.8 Regression of *Swietenia macrophylla* trees enumerated from Peruvennamuzhi

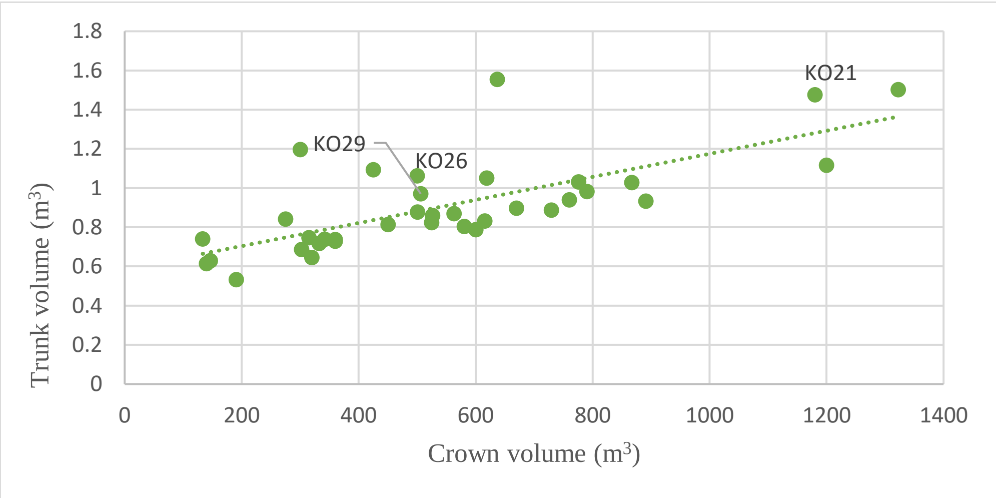

Fig. 9 Regression of *Swietenia macrophylla* trees enumerated from Kottayam village

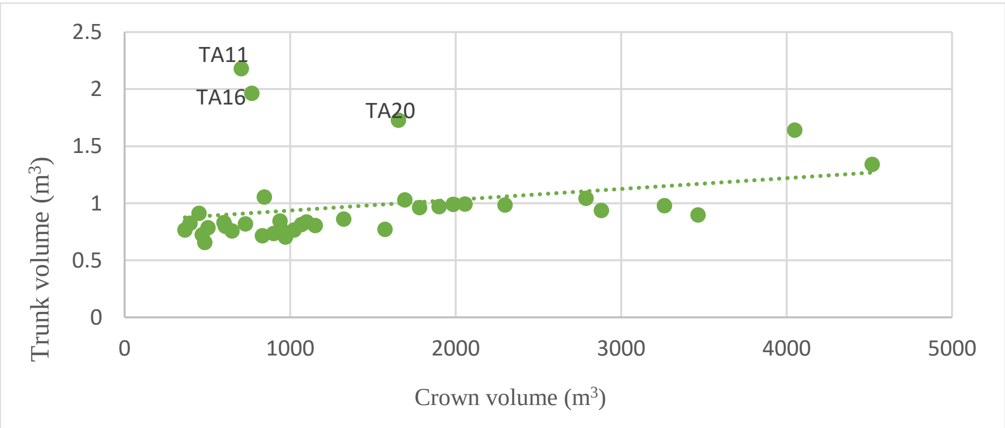

Fig.10 Regression of *Swietenia macrophylla* trees enumerated from Taliparamba

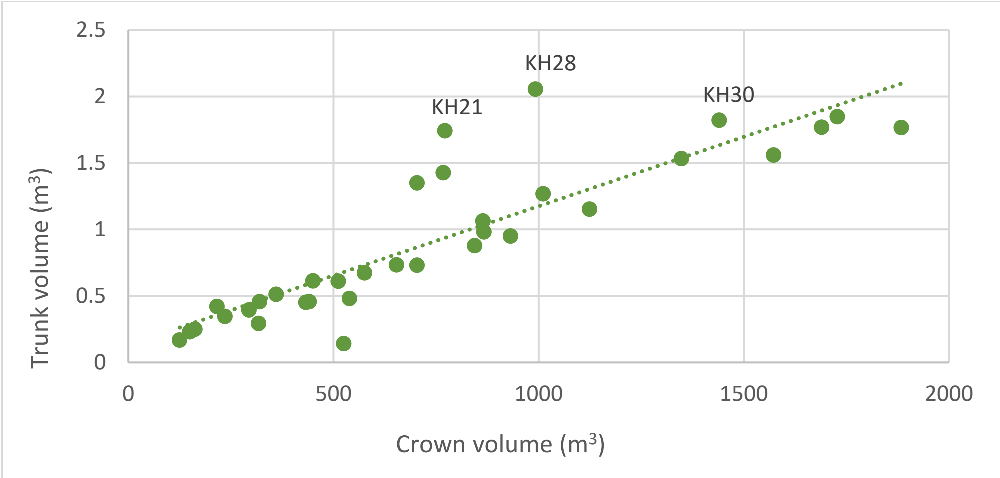

Fig. 11 Regression of *Swietenia macrophylla* trees enumerated from Koorachundu

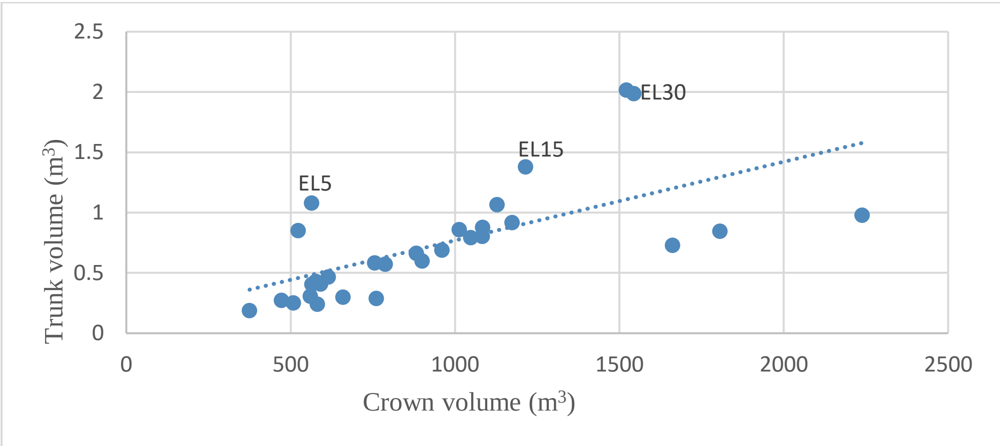

Fig. 12 Regression of *Swietenia macrophylla* trees enumerated from Elathur

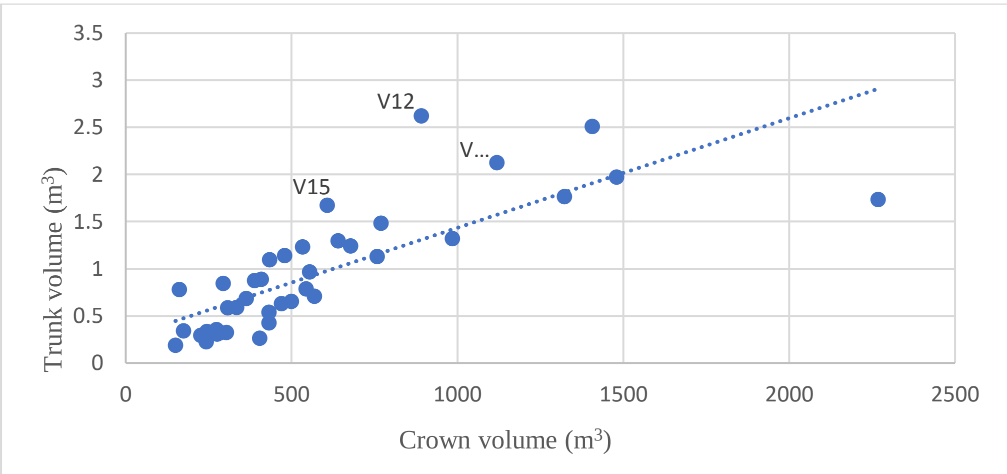

Fig. 13 Regression of *Swietenia macrophylla* trees enumerated from Vadakara

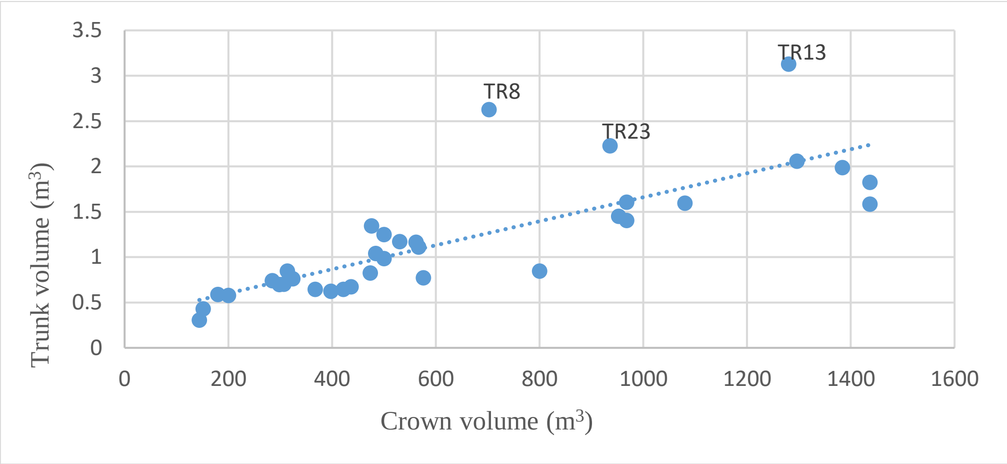

Fig. 14 Regression of *Swietenia macrophylla* trees enumerated from Trikaripur

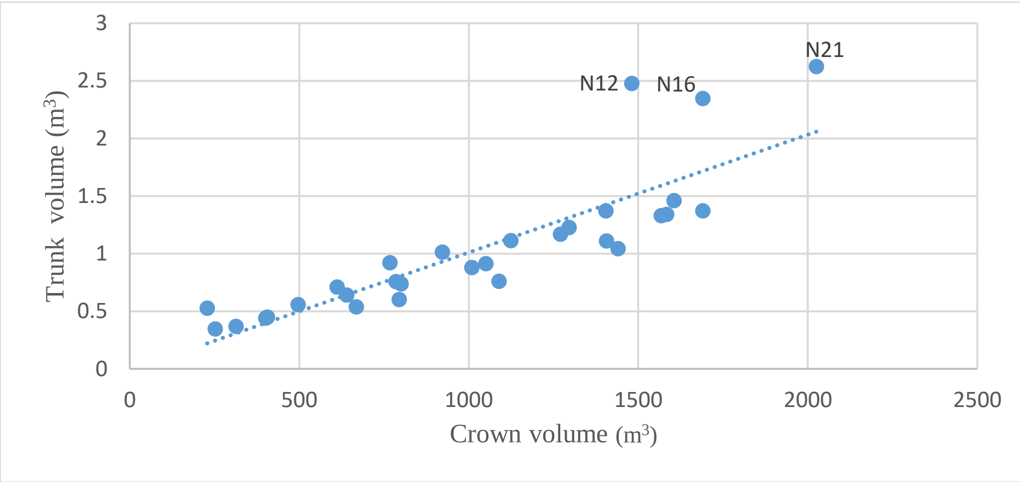

Fig.15 Regression of *Swietenia macrophylla* trees enumerated from Neeleswaram

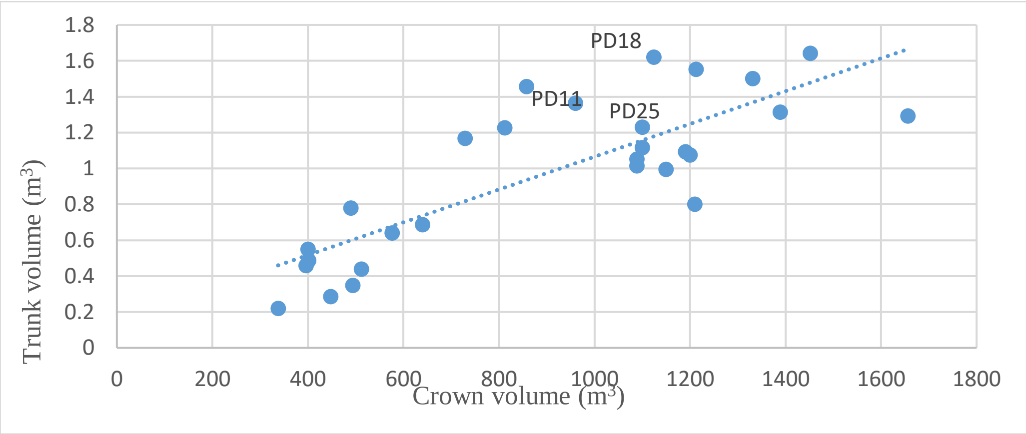

Fig. 16 Regression of *Swietenia macrophylla* trees enumerated from Padne

Table 6. Morphological characters of forty-five CPTs of *Swietenia macrophylla* from different locations

Altitude (m)	Locality	Tree Id No	Accession No.	Location	Clean bole ht (m)	GBH (m)	Crown width (m)	Crown length (m)	Pin* (mm)
High land (above 100m)	Kalpetta	K-01	FCV-SM-01	11°36'43"N 76°04'14"E	9.50	1.55	9.50	13.00	21.00
		K-14	FCV-SM-02	11°36'45"N 76°05'18"E	10.40	1.30	9.00	14.00	23.00
		K-15	FCV-SM-03	11°36'30"N 76°04'22"E	9.20	1.40	10.50	16.00	22.00
	Sulthan Bathery	SB-20	FCV-SM-04	11°41'25"N 76°15'23"E	11.40	2.00	9.00	10.00	22.50
		SB-31	FCV-SM-05	11°41'22"N 76°15'24"E	7.50	1.70	9.50	13.00	21.00
		SB-37	FCV-SM-06	11°41'21"N 76°15'23"E	6.50	1.55	8.00	12.00	21.00
	Padinjarethara	P-11	FCV-SM-07	11°40'12"N 75°58'29"E	11.60	0.95	12.00	12.50	22.50
		P-18	FCV-SM-08	11°40'28"N 75°58'26"E	10.60	0.95	11.30	12.00	21.50
		P-24	FCV-SM-09	11°40'31"N 75°58'22"E	11.00	1.15	12.00	15.00	23.00
	Eramanellur	ER-13	FCV-SM-10	11°41'52"N 76°06'17"E	11.80	1.35	15.00	15.50	22.00
		ER-20	FCV-SM-11	11°41'57"N 76°06'18"E	9.50	0.94	12.90	13.00	22.00
		ER-25	FCV-SM-12	11°42'01"N 76°06'16"E	13.20	1.10	13.00	12.00	21.00
	Mananthavady	M-11	FCV-SM-13	11°48'33"N 75°56'57"E	11.00	1.25	10.00	9.50	21.00

		M-18	FCV-SM-14	11°48'43"N 75°56'58"E	10.00	1.32	11.00	11.10	22.50
		M-35	FCV-SM-15	11°48'45"N 75°56'45"E	12.00	1.30	11.50	8.30	21.00
Mid land (20 – 100m)	Puduppady	PU-15	FCV-SM-16	11°27'11"N 75°59'48"E	6.00	1.85	11.00	10.50	22.50
		PU-20	FCV-SM-17	11°27'18"N 75°59'46"E	10.40	1.65	12.00	12.40	21.50
		PU-35	FCV-SM-18	11°27'54"N 75°59'27"E	6.00	1.70	13.00	15.30	21.50
	Peruvennamuzhi	PE-12	FCV-SM-19	11°36'07"N 75°49'24"E	12.30	1.20	12.00	8.70	22.00
		PE-25	FCV-SM-20	11°36'09"N 75°49'30"E	11.50	1.10	8.00	11.10	22.00
		PE-30	FCV-SM-21	11°36'08"N 75°49'23"E	12.50	1.30	9.00	10.40	21.00
	Kottayam	KO-21	FCV-SM-22	11°49'13"N 75°32'59"E	12.00	0.75	8.90	9.00	21.00
		KO-26	FCV-SM-23	11°49'08"N 75°32'59"E	11.50	1.30	10.00	9.00	22.00
		KO-29	FCV-SM-24	11°49'03"N 75°32'55"E	13.00	1.24	10.00	11.80	21.00
	Taliparamba	TA-11	FCV-SM-25	12°10'09"N 75°23'18"E	11.50	1.30	8.70	11.00	22.00
		TA-16	FCV-SM-26	12°10'10"N 75°23'20"E	13.40	1.35	9.50	10.00	21.00
		TA-20	FCV-SM-27	12°10'25"N 75°23'30"E	11.00	1.45	12.00	12.00	21.00
	Koorachundu	KH-21	FCV-SM-28	11°30'47"N 75°53'18"E	11.00	1.20	10.50	7.00	22.00
		KH-28	FCV-SM-29	11°30'41"N 75°53'19"E	10.00	1.00	11.20	12.00	21.00
		KH-30	FCV-SM-30	11°30'26"N 75°53'34"E	11.10	0.85	9.00	9.00	21.00
Low land (Below 20m)	Elathur	EL-5	FCV-SM-31	11°20'25"N 75°44'20"E	10.00	0.95	10.50	12.00	22.00
		EL-15	FCV-SM-32	11°20'02"N 75°44'17"E	10.00	1.10	9.00	11.50	23.00

		EL-30	FCV-SM-33	11°20'06"N 75°44'12"E	9.00	1.40	9.50	14.00	23.00
	Vadakara	V-12	FCV-SM-34	11°35'31"N 75°35'20"E	8.00	1.45	9.00	11.00	22.00
		V-15	FCV-SM 35	11°35'27"N 75°35'22"E	11.50	1.35	11.5	12.40	21.00
		V-17	FCV-SM-36	11°35'26"N 75°35'27"E	10.00	1.15	9.00	9.50	23.00
	Trikaripur	TR-8	FCV-SM-37	12°08'48"N 75°10'42"E	9.70	1.30	10.00	9.00	21.00
		TR-13	FCV-SM-38	12°08'45"N 75°10'37"E	10.00	1.50	9.50	9.00	21.00
		TR-23	FCV-SM-39	12°08'45"N 75°10'46"E	8.50	1.30	11.50	10.00	22.00
	Neeleswaram	N-12	FCV-SM-40	12°15'23"N 75°07'41"E	10.50	1.50	8.00	9.00	21.00
		N-16	FCV-SM-41	12°15'28"N 75°07'41"E	10.30	1.35	11.00	8.90	21.00
		N-21	FCV-SM-42	12°15'37"N 75°07'40"E	12.10	1.45	8.00	10.00	21.50
	Padne	PD-11	FCV-SM-43	12°15'10"N 75°06'52"E	12.00	1.05	10.50	11.00	21.50
		PD-18	FCV-SM-44	12°15'06"N 75°06'49"E	12.50	0.90	11.60	9.50	22.00
		PD-25	FCV-SM-45	12°14'58"N 75°06'49"E	9.80	0.98	10.50	8.50	21.00
			Mean		10.49	1.33	10.43	10.89	21.60
			CV		11.90	17.29	15.23	3.50	3.25
			SD		1.25	0.23	1.60	0.386	0.704

*Pin penetration depth

4.3. VARIATIONS IN THE CHARACTERS OBSERVED IN THE SELECTED PLUS TREES.

4.3.1. Quantitative characters

The quantitative characters observed for forty-five plus trees is provided in the Table 6.

4.3.1.1. Clean bole height (CBH)

The average clean bole height measured for forty-five plus trees was 10.49 m. The maximum clean bole height measured was 13.4 m (FCV-SM-26) and the minimum was 6 m (FCV-SM-18 and FCV-SM-16). A total number of twenty-two trees had clean bole height above the mean value. The standard deviation (SD) from the mean value is 1.25 and the coefficient of variation was 11.9%.

4.3.1.2. Girth at breast height

The average girth at breast height measured was 1.33 m. The maximum GBH measured was 2.00 m (FCV-SM-04) and the minimum value was 0.75 m (FCV-SM-22). Eighteen CPTs were having the value above the mean GBH. The standard deviation from the mean and coefficient of variation were 0.23 and 17.29% respectively.

4.3.1.3. Crown width

The average crown width for forty-five CPTs was 10.43 m. The maximum value for crown width observed was 15 m (FCV-SM-10) and the minimum value measured was 8 m (FCV-SM-06 and FCV-SM-20). A total number of twenty-three CPTs were having the measurements above the average value. The standard deviation from the mean was 1.6 and the coefficient of variation was 15.23%

4.3.1.4. Crown length

The average value of the crown length measured for the CPTs was 10.89 m. The maximum value was 16 m (FCV-SM-03) and the minimum value was 7 m (FCV-SM-28). A total number of twenty-five CPTs were having the crown length value above the mean. The SD and coefficient of variation were 0.38 and 3.54% respectively indicating relatively low variability in this character.

4.3.1.5. Pilodyn pin penetration depth

Wood penetration depth of forty-five plus trees did not show much variation (CV of 3.25). The average pin penetration depth was 21.6 mm. The maximum pin penetration depth was measured at 23 mm (FCV-SM-02 and FCV-SM-09). The minimum value was 21 mm was observed for 19 CPTs (FCV-SM-01, FCV-SM-05, FCV-SM-06, FCV-SM-12, FCV-SM-13, FCV-SM-15, FCV-SM-21, FCV-SM-22, FCV-SM-24, FCV-SM-26, FCV-SM-27, FCV-SM-29, FCV-SM-30, FCV-SM-35, FCV-SM-37, FCV-SM-38, FCV-SM-40, FCV-SM-41 and FCV-SM-45). A total number of twenty-one trees were having the pin penetration depth above the average value.

4.3.2. Correlation between quantitative characters.

The correlation between all the quantitative characters are shown in Table 7. A negative significant correlation was observed between CBH and GBH at 0.01 level. The clean bole height had no significant correlation with any other characters.

Table 7. Correlation of quantitative characters of CPTs of *Swietenia macrophylla*

Parameters	Clean bole height (m)	GBH (m)	Crown width(m)	Crown length (m)	Pin penetration depth (mm)
Clean bole height (m)	1				
GBH (m)	-.444**	1			
Crown width(m)	.045	.112	1		
Crown length (m)	.286	.167	.259	1	
Pin penetration depth (mm)	.147	.001	0.38	.284	1

** Correlation is significant at 0.01 level

4.3.3. Qualitative characters

The score of all forty-five plus trees for the qualitative characters are shown in Table 8. Aggregate score for characters like verticality, apical dominance, forking, branch angle, self-pruning ability, foliar, stem damage, bole swelling showed less variations among the CPTs from different locations. The maximum value and the minimum value observed was 42 and 36 respectively. The maximum scoring was obtained for CPTs FCV-SM-04 (Sulthan Bathery), FCV-SM-12 (Kaniyambetta), FCV-SM-22 (Kottayam), FCV-SM-42 (Neeleswaram), FCV-SM-39 (Trikaripur). The minimum score was obtained for CPTs FCV-SM-17 (Puduppady), FCV-SM-24 (Kottayam), FCV-SM-25 (Trikaripur). The maximum variations were observed for apical dominance and forking. There was no variability observed in verticality and stem damage among the CPTs.

Table 8. Scoring for qualitative characters of CPTs of *Swietenia macrophylla*.

Tree Id No.	Verticality	Apical dominance	Forking	branch angle	Self-pruning ability	Foliar	Stem damage	Bole swelling	Total score
FCV-SM-01	2	5	5	12	3	4	6	2	39
FCV-SM-02	2	5	5	12	3	4	6	2	39
FCV-SM-03	2	5	3	12	3	4	6	2	37
FCV-SM-04	2	8	5	12	3	4	6	2	42
FCV-SM-05	2	5	3	12	3	4	6	2	37
FCV-SM-06	2	5	5	12	3	4	6	2	39
FCV-SM-07	2	5	3	12	3	4	6	2	37
FCV-SM-08	2	5	5	12	1	1	6	2	39
FCV-SM-09	2	8	5	12	3	4	6	2	37
FCV-SM-10	2	5	5	12	3	4	6	2	39
FCV-SM-11	2	5	5	12	3	4	6	2	39
FCV-SM-12	2	8	5	12	3	4	6	2	42
FCV-SM-13	2	5	3	12	3	4	6	2	37
FCV-SM-14	2	8	3	12	3	4	6	2	40
FCV-SM-15	2	5	5	12	3	4	6	2	39

FCV-SM-16	2	8	3	12	3	4	6	2	40
FCV-SM-17	2	8	5	6	3	4	6	2	36
FCV-SM-18	2	5	3	12	3	4	6	2	37
FCV-SM-19	2	8	3	12	3	4	6	2	40
FCV-SM-20	2	8	3	12	3	4	6	2	40
FCV-SM-21	2	8	5	12	3	4	6	1	41
FCV-SM-22	2	8	5	12	3	4	6	2	42
FCV-SM-23	2	5	5	12	3	4	6	2	39
FCV-SM-24	2	8	5	12	3	4	6	1	41
FCV-SM-25	2	8	5	6	3	4	6	2	36
FCV-SM-26	2	5	3	12	3	4	6	2	37
FCV-SM-27	2	8	5	12	3	4	6	1	41
FCV-SM-28	2	8	3	12	3	4	6	2	40
FCV-SM-29	2	5	5	12	3	4	6	2	39
FCV-SM-30	2	8	5	12	3	4	6	1	41
FCV-SM-31	2	5	3	12	3	4	6	2	37
FCV-SM-32	2	5	3	12	3	4	6	2	37
FCV-SM-33	2	8	3	12	3	4	6	2	40
FCV-SM-34	2	8	5	12	3	4	6	2	42
FCV-SM-35	2	8	5	12	3	4	6	1	41
FCV-SM-36	2	8	5	12	3	4	6	2	42
FCV-SM-37	2	8	3	12	3	4	6	2	40
FCV-SM-38	2	8	5	12	3	4	6	2	42
FCV-SM-39	2	8	5	12	3	4	6	2	42
FCV-SM-40	2	8	5	12	3	4	1	2	37
FCV-SM-41	2	8	3	12	3	4	6	2	40
FCV-SM42	2	8	5	12	3	4	6	2	42
FCV-SM-43	2	8	3	12	3	4	6	2	40
FCV-SM-44	2	5	3	12	3	4	6	2	37
FCV-SM-45	2	8	3	12	3	4	6	2	40

FCV-SM-01

(Kalpetta)

FCV-SM-05

(Sulthan Bathery)

FCV-SM-09

(Padinjarethara)

FCV-SM-11

(Eramanellur)

FCV-SM-15

(Mananthavady)

FCV-SM-16

(Padne)

Plate 1. Plus trees selected from different districts

FCV-SM-33

(Elathur)

FCV-SM-35

(Vadakara)

FCV-SM-26

(Koorachundu)

FCV-SM-19

(Chakkittapar)

FCV-SM-22

(Kottayam)

FCV-SM-26

(Talipparamba)

Plate 2. Plus trees selected from different districts

4.4. DIVERSITY ANALYSIS OF PLUS TREES

4.4.1 Cluster analysis

Hierarchial cluster analysis was done for all the quantitative characters of the selected forty-five plus trees using squared Euclidean distance. Forty-five plus trees were grouped into five clusters. Qualitative characters like verticality, apical dominance, forking, branch angle, self-pruning ability, foliar, stem damage, bole swelling and quantitative characters like clean bole height, GBH, crown length and crown height were considered for clustering and using the same dendrogram was prepared (Fig. 17).

The plus trees coming under different clusters are given in Table 9. The CPTs coming under the same cluster have similar morphological characters, while it differs between trees in two different clusters. The result shows that the cluster II had the maximum number of CPTs with 35 members and cluster III and cluster IV had the minimum number of CPTs with one member each.

The average clean bole height, GBH, crown width, crown length and mode value of scores for verticality, apical dominance, forking, branch angle, self-pruning, foliar damage, stem damage, bole swelling of cluster I were 7.45, 1.62, 10.25, 21, 2, 5, 3, 12, 3, 4, 6 and 2 respectively (Table 10). The lowest clean bole height and the highest GBH and crown length were observed in the cluster I. The average clean bole height, GBH, crown width, crown length and most frequent scores of verticality, apical dominance, forking, branch angle, self-pruning, foliar damage, stem damage, bole swelling of cluster II were 10.95, 1.22, 10.28, 10.71, 2, 8, 5, 12, 3, 4, 6 and 2 respectively (Table 10). The average clean bole height, GBH, crown width, crown length and most frequent score for verticality, apical dominance, forking, branch angle, self-pruning, foliar damage, stem damage, bole swelling of cluster III were 11, 1.15, 12, 15, 2,8,5,12,3,4,6 and 2 respectively (Table 10). The lowest GBH and highest pin penetration depth were observed in cluster III. The average clean bole height, GBH, crown width, crown length and most frequent scores for verticality, apical dominance, forking, branch angle, self-pruning, foliar damage, stem damage, bole swelling of cluster IV were 12.05, 1.27, 13.5, 12.1, 2,5&8, 5&3, 12, 3,4, 6 and 2 respectively. The highest clean bole height and crown width were observed in cluster IV. The average clean bole height, GBH, crown width, crown length and most frequent scores for verticality, apical dominance, forking, branch angle, self-pruning, foliar damage, stem damage, bole swelling of cluster V were 10.5, 1.5, 8, 9, 2, 8, 5, 12, 3, 4, 1 and 2 respectively. The lowest crown width, crown length and pin penetration depth were found in cluster V.

The CV values were classified following Garcia (1989). Where they were as low when CV < (m-1SD), moderate when CV is between (m-1SD) and (m+1SD), high when CV is between (m+1SD) and (m+2SD) and very high when CV is more than (m+2SD). According to this classification parameter like clean bole height, GBH, crown width and crown length have very high coefficient of variation (Table 10). Among qualitative characters branch angle and pin penetration had low variability.

Table 9. Clusters of *Swietenia macrophylla* CPTs based on their morphological characters.

CLUSTERS				
I	II	III	IV	V
FCV-SM-01	FCV-SM-02	FCV-SM-09	FCV-SM-10	FCV-SM-40
FCv- SM-06	FCV-SM-33		FCV-SM-19	
FCV-SM-03	FCV-SM-14			
FCV-SM-05	FCV-SM-39			
FCV-SM-18	FCV-SM-34			
FCV-SM-16	FCV-SM-36			
	FCV-SM-08			
	FCV-SM-29			
	FCV-SM-11			
	FCV-SM-23			
	FCV-SM-12			
	FCV-SM-27			
	FCV-SM-35			
	FCV-SM-15			
	FCV-SM-41			

	FCV-SM-28			
	FCV-SM-38			
	FCV-SM-20			
	FCV-SM-21			
	FCV-SM-42			
	FCV-SM-22			
	FCV-SM-30			
	FCV-SM-45			
	FCV-SM-43			
	FCV-SM-04			
	FCV-SM-17			
	FCV-SM-24			
	FCV-SM-25			
	FCV-SM-37			
	FCV-SM-07			
	FCV-SM-31			
	FCV-SM-32			
	FCV-SM-13			
	FCV-SM-26			
	FCV-SM-44			

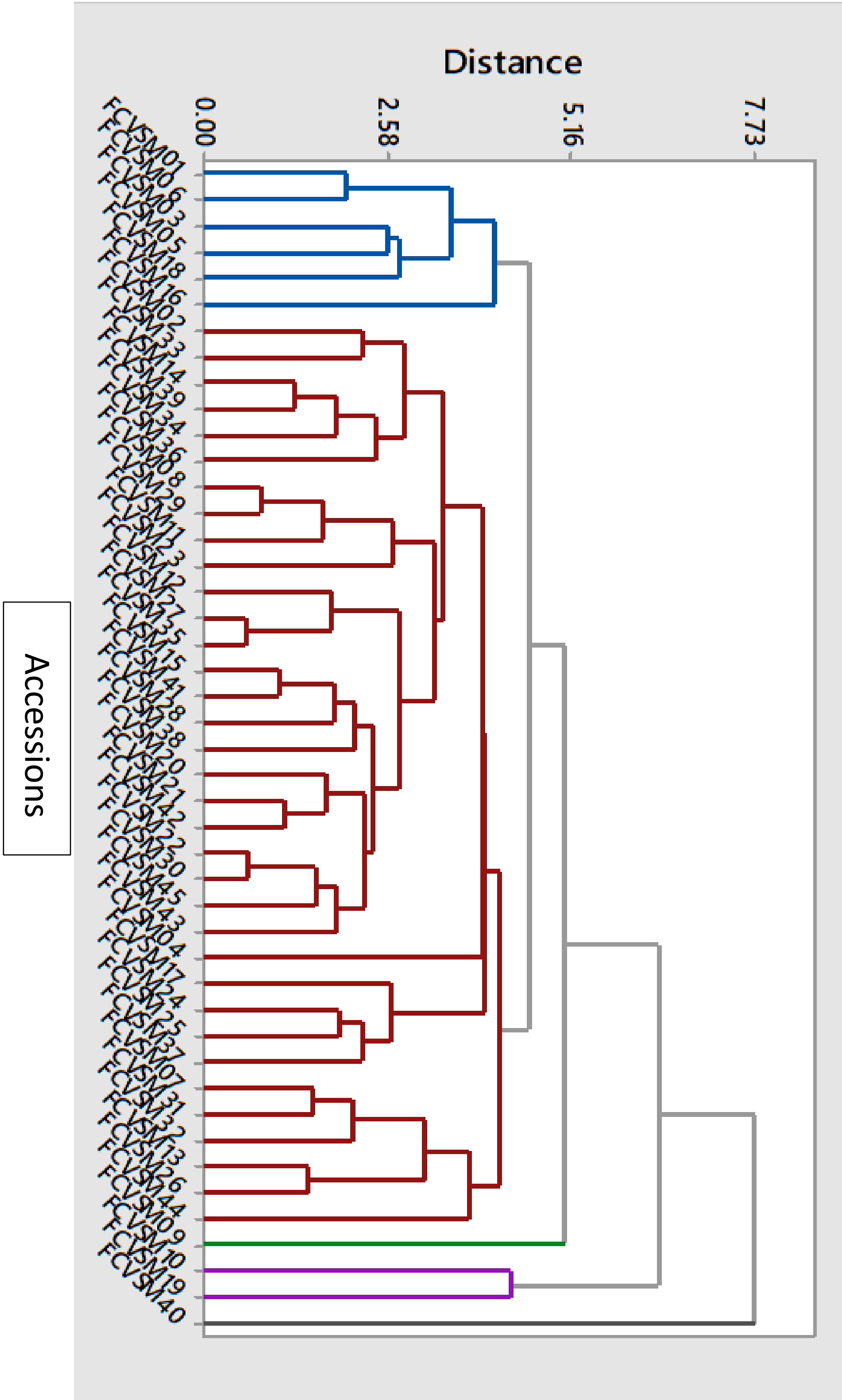

Fig. 17 Dendrogram on morphological characters of forty-five CPTs of *Swietenia macrophylla*.

Table 10. Mean of quantitative characters among the clusters of CPTs of *Swietenia macrophylla*.

Variables	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Mean	SD	CV (%)
Clean bole height (m)	7.45	10.95	11.00	12.05	10.50	10.39	1.73	16.70
GBH (m)	1.625	1.22	1.15	1.27	1.50	1.35	0.19	14.70
Crown width (m)	10.25	10.28	12.00	13.50	8.00	10.80	2.07	19.10
Crown length (m)	21.00	10.71	15.00	12.10	9.00	13.56	4.70	34.60
Pin penetration depth (mm)	21.50	21.69	23.00	22.00	21.00	21.83	0.74	3.40

Table 11. Mode value of scores of qualitative characters among the clusters of CPTs of *Swietenia macrophylla*.

Variables	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Most frequent scores
Verticality	2	2	2	2	1	2
Apical dominance	5	6	8	6	8	8
Forking	3	4	5	4	5	5
Branch angle	12	11	12	12	12	12
Self-pruning	3	3	1	3	3	3
Foliar	4	4	1	4	4	4
Stem damage	6	6	6	6	1	6
Bole swelling	2	1	2	2	2	2

Table 12. Classification of CV of clusters (Garcia, 1989)

Variables	Mean	SD	CV (%)	Classification
Clean bole height	10.39	1.73	16.70	Very high
GBH	1.35	0.19	14.70	Very high
Crown width	10.8	2.07	19.10	Very high
Crown length	13.56	4.70	34.60	very high
Pin penetration depth (mm)	21.83	0.74	3.40	low

Table 13. Matrix showing inter and intra cluster distance.

	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
Cluster I	2.21				
Cluster II	3.19	2.45			
Cluster III	5.06	4.37	0.00		
Cluster IV	6.28	5.37	6.57	2.15	
Cluster V	7.7	7.11	9.12	9.33	0.00

Table 12 gives the inter and intra cluster distances. Intra cluster distance gives the mean distance between the elements within a cluster, whereas the inter cluster distance gives the distance between two clusters. The intra cluster distance was maximum for cluster II (2.45) and minimum for cluster IV (2.15). No intra cluster distance was observed for clusters III and IV as they had only one member. The highest inter cluster distance was observed between cluster IV and cluster V (9.33). The lowest inter cluster distance was observed between cluster I and cluster II (3.19)

4.4.2. Principal component analysis (PCA)

4.4.2.1. Morphological features.

PCA is a technique which attempts to analyze and simplify the inter relationship among large set of variables in terms of a relatively small set of variables or components without losing any necessary information from the data. From the scree plot it was evident that four components had eigen value greater than one which accounts for 63.7% of the total variability (Fig. 18). The explanation was done only by using two components (Table 13). The two principle components together accounted for 39.9% of the total variability. PC 1 accounted for 22.7% of the total variability which was mainly contributed positively by characters like GBH, crown width, crown length, pin penetration depth, verticality and branch angle. The PC 2 contributes for 17.2% of the total variability which is mainly contributed positively by clean bole height, crown width, crown length, pin penetration depth, verticality and forking.

The loading plot (Fig.19) shows the inter relationship between various variables and the how they influence the principle component. More the distance of vectors from the PC origin more is their influence on PC. If two variables form an angle less than 90° they are more positively correlated. If the angle between the variables is 180° they exhibit a negative correlation. The two variables will exhibit no correlation if the angle is 90°. The loading plot showed a positive correlation between pin penetration depth and crown length, verticality and crown width, GBH and branch angle, forking and clean bole height. A negative correlation was observed between apical dominance and crown length.

Table 14. Contribution of various morphological characters of CPTs of *Swietenia macrophylla* to principal components.

Variable	PC1	PC2
Clean bole height	0.515	-0.072
GBH	-0.364	0.156
Crown width	0.003	-0.529
Crown length	-0.312	-0.493
Pin penetration depth	-0.117	-0.347
Apical dominance	0.534	0.087
Forking	0.452	-0.27
Branch angle	-0.007	0.104

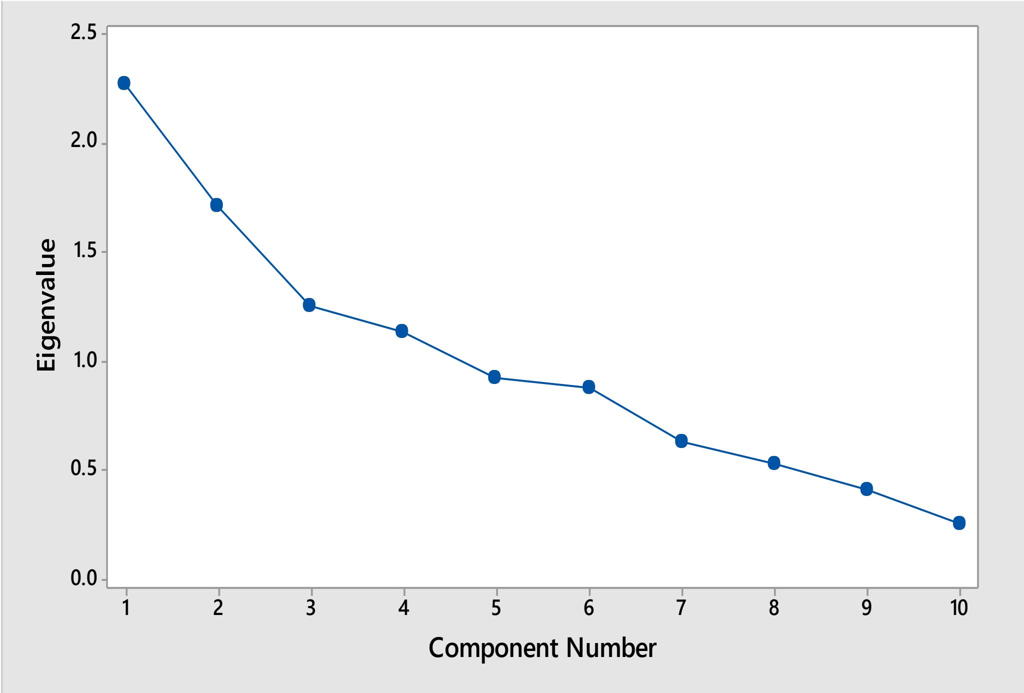

Fig. 18 Scree plot of morphological characters of CPTs of *Swietenia macrophylla*

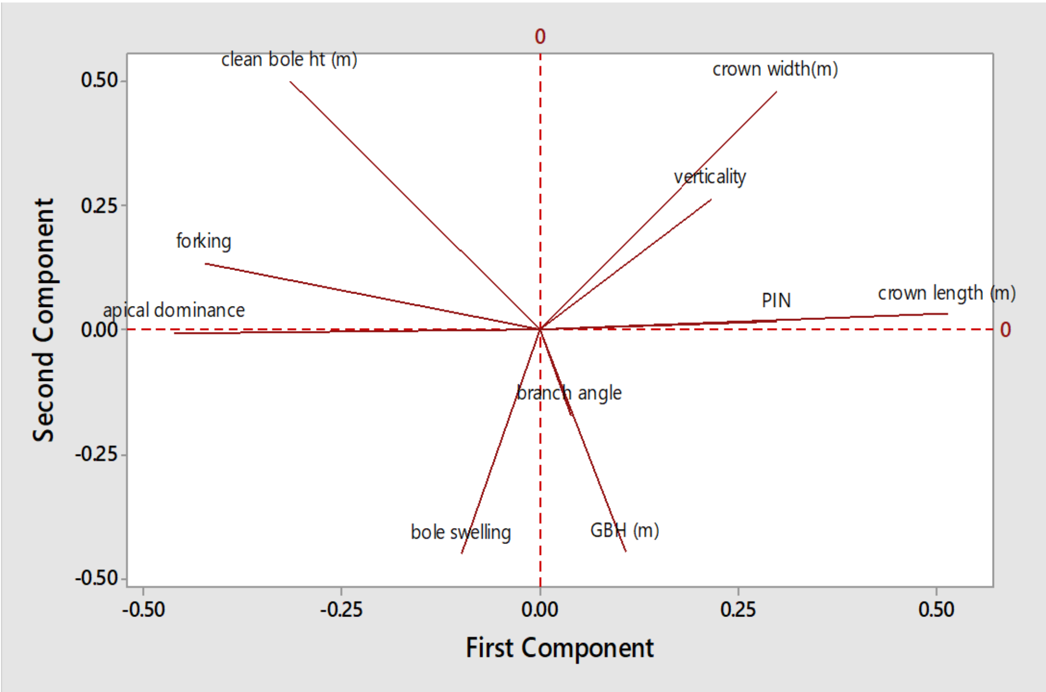

Fig. 19 Loading plot of morphological characters of CPTs of *Swietenia macrophylla*

4.4.3. Selection index

The selection index value is calculated for CPTs based on the morphological character of the trees using principal component analysis table (Table 14). The PC1 is taken as the index value for selection.

Selection Index = -0.315 × Clean bole height + 0.108 × GBH +0.298 × Crown width + 0.514×Crown length + 0.298 × Pin penetration value + 0.215 × Verticality + -0.422 × Forking + 0.038× Branch angle + -0.099 × Bole swelling.

Table 15. Selection Index of selected plus trees of *Swietenia macrophylla* using Principal component analysis

CPT	PC 1
FCV-SM-01	11.52
FCV-SM-02	12.17
FCV-SM-03	14.58
FCV-SM-04	9.73
FCV-SM-05	13.01
FCV-SM-06	11.50
FCV-SM-07	12.57
FCV-SM-08	11.28
FCV-SM-09	14.22
FCV-SM-10	13.99
FCV-SM-11	12.76
FCV-SM-12	10.83
FCV-SM-13	10.21
FCV-SM-14	12.10
FCV-SM-15	8.88
FCV-SM-16	13.11
FCV-SM-17	11.60
FCV-SM-18	15.86

FCV-SM-19	10.28
FCV-SM-20	10.56
FCV-SM-21	9.16
FCV-SM-22	8.41
FCV-SM-23	9.25
FCV-SM-24	10.01
FCV-SM-25	9.67
FCV-SM-26	9.57
FCV-SM-27	11.37
FCV-SM-28	9.36
FCV-SM-29	11.29
FCV-SM-30	8.83
FCV-SM-31	12.22
FCV-SM-32	11.83
FCV-SM-33	13.61
FCV-SM-34	11.10
FCV-SM-35	11.25
FCV-SM-36	10.39
FCV-SM-37	10.37
FCV-SM-38	9.72
FCV-SM-39	11.16
FCV-SM-40	8.58
FCV-SM-41	10.43
FCV-SM-42	8.85
FCV-SM-43	10.94
FCVSM-44	10.47
FCV-SM-45	10.19

Plate 3. Seeds of *Swietenia macrophylla*

Plate 4. Two-month old seedling of *Swietenia macrophylla* in nursery

Plate 5. Seedling height measurement of *Swietenia macrophylla* using measuring scale

4.5. PROGENY EVALUATION

4.5.1. Morphological characters

Seeds from forty-five plus trees were raised in the nursery bed and different seedling parameters were studied after two months. The seedling growth parameters of forty-five CPTs are given in Table 15. The seed germination rate and number of leaves of CPTs showed significant difference at level 0.05.

4.5.1.1. Seed germination percentage

The analysis of variance of seed germination is presented in Table 15. The result indicated a significant difference in the seed germination of forty-five plus trees at 0.05 level. The maximum germination was 43.3%. The higher germination percentage was obtained for CPT FCV-SM-43 at 43.3%. The lower germination percentage was obtained for CPT FCV-SM-15 and FCV-SM-26 at 10%.

4.5.1.2. Number of leaves

The result shows that the mean difference of number of leaves of forty-five plus trees were significant at 0.05 level (Table 15). The average number of leaves of selected plus trees ranged from 3.67 (FCV-SM-27) to 9.67 (FCV-SM-08).

4.5.1.3. Collar diameter

The analysis of variance for collar diameter showed significant difference at 0.05 level. The average collar diameter of forty-five plus trees ranged from 1.61 mm (FCV-SM-15) to 2.97 mm (FCV-SM-37).

4.5.1.4. Seedling height

The seedling height of forty-five plus trees obtained by adding seedling shoot height and seedling root length is shown in Table 15. The mean difference is significant at 0.05 level. The value ranges from 15.4 cm for plus tree FCV-SM -23 to 24.5 cm for plus tree FCV-SM-08.

4.5.1.5. Seedling vigor index

The seedling vigor index of forty-five plus trees are shown in Table 15. The mean difference in the vigor index is significant at 0.05 level. The value ranges from 198 for plus tree FCV-SM-15 to 842.6 for plus tree FCV-SM-08.

Table 16. Germination and morphological characters of *Swietenia macrophylla* progenies of forty-five plus trees

Accesssion No.	Seedling Height (cm)	Number of Leaves	Collar Diameter (mm)	Germination percentage	Vigour Index 1
FCV-SM-01	20.56±5.20^{abc}	6.40±0.72^{bcdefg}	2.23±0.42^{abcde}	13.30±0.58^{cd}	273±35.70^{de}
FCV-SM-02	21.86±1.26^{abc}	7.00±0.72^{abcdef}	2.506±0.17^{abcd}	16.70±1.15^{bcd}	365±24.50^{de}
FCV-SM-03	22.40±1.94^{abc}	7.67±2.16^{abcde}	2.07±0.06^{bcde}	20.00±1.00^{bcd}	448±18.60^{cde}
FCV-SM-04	19.70±2.11^{c}	7.00±3.02^{abcdef}	1.86±0.48^{cde}	20.00±1.53^{bcd}	394±28.10^{bcde}
FCV-SM-05	22.50±1.53^{abc}	8.00±0.80^{abc}	1.88±0.28^{bcde}	13.30±1.00^{cd}	265±21.40^{de}
FCV-SM-06	19.90±0.59^{c}	7.60±1.40^{abcde}	2.00±0.40^{bcde}	13.30±1.00^{cd}	265±19.50^{de}
FCV-SM-07	21.60±4.94^{abc}	5.33±2.14^{bcdefg}	1.87±0.03^{bcde}	20.00±1.53^{bcd}	432±36.70^{cde}
FCV-SM-08	24.50±3.85^{a}	9.67±3.11^{a}	2.27±0.34^{bcde}	16.70±1.15^{bcd}	409±20.40^{bcde}
FCV-SM-09	23.10±0.93^{abc}	5.60±1.25^{bcdefg}	2.55±0.55^{abcd}	16.70±1.73^{bcd}	385±38.70^{de}
FCV-SM-10	22.30±3.20^{abc}	5.80±0.53^{bcdefg}	2.08±0.67^{bcde}	20.00±2.31^{bcd}	446±52.90^{cde}
FCV-SM-11	22.40±1.80^{abc}	5.83±0.29^{bcdefg}	2.08±0.73^{bcde}	20.00±0.58^{bcd}	448±18.40^{cde}
FCV-SM-12	20.30±2.63^{c}	4.20±0.87^{fg}	1.75±0.25^{cde}	20.00±1.15^{bcd}	406±26^{cde}
FCV-SM-13	19.80±2.27^{c}	4.60±0.70^{fg}	1.83±0.66^{cde}	20.00±2.08^{bcd}	396±27.50^{cde}
FCV-SM-14	21.40±1.91^{abc}	5.13±2.72^{cdefg}	2.06±0.15^{bcde}	26.70±1.53^{abcd}	571±37^{abcde}
FCV-SM-15	19.80±1.99^{c}	4.27±1.22^{fg}	1.61±0.30^{e}	10.00±0.00^{d}	198±19.80^{de}
FCV-SM-16	21.20±1.33^{abc}	6.00±3.54^{bcdefg}	2.16±0.45^{bcde}	26.70±2.08^{abcd}	566±44.80^{abcde}

FCV-SM-17	21.40± 3.61^{abc}	4.53±0.61^{fg}	1.66±0.19^{e}	20.00±0.58^{bcd}	428±10.20^{cde}
FCV-SM-18	23.60±1.78^{ab}	4.67±1.36^{efg}	1.92±0.12^{bcde}	16.70±0.58^{bcd}	394±15.90^{bcde}
FCV-SM-19	18.60±3.23^{bcd}	7.93±2.34^{abc}	2.49±0.34^{abcd}	16.70±0.58^{bcd}	310±58.90^{bcde}
FCV-SM-20	21.60±3.90^{abc}	4.20±1.86^{fg}	2.15±0.38^{bcde}	20.00±2.65^{bcd}	432±72.50^{cde}
FCV-SM-21	21.40±4.45^{abc}	4.20±0.20^{fg}	2.08±0.67^{bcde}	26.70±0.58^{abcd}	571±14.40^{abcde}
FCV-SM-22	18.70±1.15^{bcd}	4.60±0.40^{fg}	1.99±0.67^{bcde}	20.00±1.53^{bcd}	374±27.50^{cde}
FCV-SM-23	15.40±0.12^{d}	4.13±0.42^{fg}	2.49±0.42^{abcd}	20.00±0.58^{bcd}	308±88.20^{de}
FCV-SM-24	20.06±1.50^{c}	7.00±1.31^{abcdef}	1.69±0.32^{de}	16.70±1.15^{bcd}	335±21de
FCV-SM-25	20.66±2.31^{abc}	5.13±0.61^{cdefg}	1.93±0.06^{bcde}	23.30±0.58^{abcd}	481±11.70^{bcde}
FCV-SM-26	19.80±1.03^{c}	4.93±0.20^{defg}	1.92±0.20^{bcde}	10.00±1.53^{d}	198±29.10^{de}
FCV-SM-27	21.50±2.61^{abc}	3.67±0.76^{g}	1.71±0.20^{de}	20.00±1.00^{bcd}	430±21.70^{cde}
FCV-SM-28	20.26±2.21^{c}	5.80±1.40^{bcdefg}	1.68±0.29^{de}	26.70±2.08^{abcd}	540±37.80^{abcde}
FCV-SM-29	22.80±1.25^{abc}	8.40±0.20^{ab}	1.77±0.18^{cde}	13.30±1.53^{cd}	303±33.10^{bcde}
FCV-SM-30	20.60±3.61^{abc}	5.67±1.29^{bcdefg}	1.84±0.26^{cde}	13.30±0.58^{cd}	273±13de
FCV-SM-31	19.60±0.31^{abcd}	5.93±1.81^{bcdefg}	2.41±0.50^{abcde}	13.30±1.73^{cd}	260±21.60^{de}
FCV-SM-32	19.50±2.74^{abcd}	6.60±0.87^{bcdefg}	2.27±0.37^{abcde}	36.70±2.08^{ab}	715±14.90^{abcd}
FCV-SM-33	20.40±1.42^{abcd}	6.27±0.40^{bcdefg}	2.29±0.49^{abcde}	30.00±1.15^{abcd}	612±19^{abcd}
FCV-SM-34	18.20±2.23^{cd}	4.60±0.50^{fg}	2.21±0.17^{abcde}	33.30±0.58^{abc}	606±11^{abcd}
FCV-SM-35	19.40±2.34^{abcd}	4.67±1.25^{efg}	2.15±0.21^{bcde}	30.00±0.58^{abcd}	582±66.50^{abcde}

FCV-SM-36	$21.50±0.86^{abc}$	$5.33±0.90^{cdefg}$	$2.39±0.38^{abcde}$	$36.70±2.65^{ab}$	$789±56.40^{abcd}$
FCV-SM-37	$19.60±3.16^{abcd}$	$6.20±0.90^{bcdefg}$	$2.97±0.20^{a}$	$36.70±1.00^{ab}$	$719±11.30^{abcd}$
FCV-SM-38	$20.23±2.96^{abcd}$	$6.87±0.64^{abcdef}$	$1.95±0.70^{bcde}$	$33.30±2.31^{abc}$	$673±53^{abc}$
FCV-SM-39	$18.50±0.42^{bcd}$	$6.73±0.53^{bcdef}$	$2.21±0.30^{abcde}$	$36.70±2.52^{ab}$	$678±47.90^{abcd}$
FCV-SM-40	$21.50±2.23^{abc}$	$6.07±1.31^{bcdefg}$	$2.18±0.45^{abcde}$	$23.30±0.58^{abcd}$	$500±11.20^{bcde}$
FCV-SM-41	$18.50±1.58^{bcd}$	$4.87±1.01^{defg}$	$2.43±0.30^{abcde}$	$23.30±0.00^{abcd}$	$431±63.20^{bcde}$
FCV-SM-42	$18.20±0.10^{cd}$	$5.60±0.64^{bcdefg}$	$2.30±0.24^{abcde}$	$30.00±1.53^{abcd}$	$546±34.80^{abcde}$
FCV-SM-43	$19.60±2.82^{abcd}$	$5.93±0.76^{bcdefg}$	$2.20±0.13^{abcde}$	$43.30±2.52^{a}$	$848±62.40^{abcde}$
FCV-SM-44	$20.10±2.66^{abcd}$	$5.27±0.64^{cdefg}$	$2.69±0.26^{ab}$	$30.00±3.61^{abcd}$	$603±70.10^{abcde}$
FCV-SM-45	$21.80±1.85^{abc}$	$5.87±1.70^{bcdefg}$	$2.34±0.33^{abcde}$	$26.70±2.08^{abcd}$	$582±45.70^{abcde}$
Mean	23.11	5.56	2.11	20.65	521.53
SEM	6.75	0.27	0.06	2.46	23.29
CD	7.41	1.48	0.71	4.48	373.12

Values with same superscript in column for different parameters are homogenous

4.5.2. Genetic variability study on seedling parameters

The genetic variability measurements like genotypic coefficient of variability, phenotypic coefficient of variability, environmental coefficient of variability, broad sense heritability were estimated for morphological parameters of seedlings of forty-five plus trees under study (Table 17). The phenotypic coefficient of variation, and genotypic coefficient of variation were categorized as suggested by Sivasubramanian and Madhavamenon (1973).

Low : less than 10%

Moderate: 10-20%

High : More than 20%

4.5.2.1. Seed germination

The genetic parameters for the growth rates of mahogany seedlings of two months older are shown in Table 17. The GCV, PCV and ECV for seed germination observed was 5.7, 14.3 and 13.1 respectively. The genetic advance and genetic gain obtained were 0.3 and 13 respectively. The genetic gain obtained for the seed germination had the highest value. The broad sense heritability obtained was 0.15.

4.5.2.2. Collar diameter

The GCV, PCV and ECV obtained for collar diameter was 8.7, 21 and 19.1 respectively. The heritability obtained was 0.15. The genetic advance of the collar diameter was 0.13 which was the least among that for all the morphological parameters of seedlings. The genetic gain obtained was 6.1.

4.5.2.3. Seedling height

Seedling height of forty-five CPTs had GCV value 1.4, ECV value 3.9 and PCV value 4.2%. The broad sense heritability value obtained was 0.12 which was the least among all other parameters. The genetic gain and genetic advance values observed for the seedling height were 3.1 and 0.64 respectively. The genetic gain for the seedling height was the highest among that for all other parameters.

4.5.2.4. Number of leaves

ECV, GCV, PCV for number of leaves were 25.5, 11.9 and 28.1. Broad sense heritability obtained was 0.17, which was the highest value. The genetic gain and genetic advance values obtained were 9.8 and 0.58 respectively.

Table 17. Genetic parameters of morphological characters of *Swietenia macrophylla* progenies

Variances	Germination	Collar diameter	Seedling height	Number of leaves
ECV	13.10	19.10	3.90	25.50
GCV	5.70	8.70	1.40	11.90
PCV	14.30	21.00	4.20	28.10
Heritability	0.15	0.15	0.12	0.17
Genetic advance	0.30	0.13	0.64	0.58
Genetic gain	13.00	6.10	3.10	9.80

4.5.3. Physiological parameters

There were significant differences for physiological parameters like photosynthetic rate, stomatal conductance, leaf temperature and transpiration rate ($P<0.05$) for the two-month-old seedlings of forty-five plus trees selected from different localities (Table 18).

4.5.3.1. Photosynthetic rate

The photosynthetic rate (μ mol CO_2 m^{-2} s^{-1}) observed for the progenies of forty-five plus trees are shown in Table 18. Among the selected plus trees FCV-SM-18 showed highest photosynthetic rate (6.1) followed by FCV-SM-17 and FCV-SM-20 (5.9) and plus tree FCV-SM-28 had shown the lowest value (0.6).

4.5.3.2. Stomatal conductance

The data presented in Table 18 is the estimated value of stomatal conductance (m mol H_2O m^{-2} s^{-1}) of the progenies of forty-five plus trees. The highest value was observed for the plus tree FCV-SM- 40 (0.86) followed by FCV-SM-25 (0.85) and FCV-SM-24 (0.84). The plus trees FCV-SM-26, FCV-SM-29, FCV-SM-30, FCV-SM-42, FCV-SM-45 had the lowest value (0.10)

4.5.3.3. Transpiration rate

The transpiration rate (mmol H_2O cm^{-2} s^{-1}) observed for the progenies of forty-five plus trees are shown in Table 6. The highest value observed was 2.6. Plus trees FCV - SM- 02, FCV- SM -03, FCV- SM- 16, FCV- SM -17, FCV- SM-18, FCV-SM-19, FCV-SM- 20, FCV- SM-21, FCV- SM-22, FCV- SM-23, FCV- SM-24, FCV- SM- 27, FCV-SM-31, FCV- SM- 32, FCV- SM-33, FCV- SM -34, FCV- SM- 35, FCV-SM-36, FCV-SM- 37, FCV- SM-38, FCV- SM -39 had the highest value. The lowest value observed was 0.24 for FCV -SM -05, FCV-SM-06, FCV-SM-07, FCV-SM-08, FCV-SM-09, FCV-SM-10, FCV-SM-11, FCV-SM-12, FCV-SM-13 and FCV -SM- 14.

4.5.3.4. *Leaf temperature*

The leaf temperature (°C) observed for the progenies of forty-five plus trees are shown in Table 17. The highest value for the leaf temperature was observed for FCV - SM-42 and FCV- SM-43 (35.56). The lowest value was observed for FCV- SM- 44 (33.03).

Table 18. Physiological characters of *S. macrophylla* progenies from forty-five plus trees

Accesssion No	Leaf Temperature (°C)	Transpiration (mmol H_2O m^{-2} s^{-1})	Photosynthesis (µmol CO_2 m^{-2} s^{-1})	Stomatal conductance (m mol H_2O m^{-2} s^{-1}) (SD=0)
FCV-SM-01	33.40±0.03[rs]	1.83±0.01[ab]	2.00±0.02[abcde]	0.12[a]
FCV-SM-02	33.50±0.02[rs]	2.60±0.01[a]	2.10±0.01[abcde]	0.12[a]
FCV-SM-03	33.50±0.03[rs]	2.60±0.00[a]	2.20±0.05[abcdef]	0.12[a]
FCV-SM-04	33.70±0.03[q]	0.25±0.00[c]	1.70±0.05[abcd]	0.12[c]
FCV-SM-05	33.78±0.03[q]	0.24±0.01[c]	1.80±0.03[abcde]	0.11[c]
FCV-SM-06	33.80±0.02[q]	0.24±0.00[c]	2.70±0.07[bcdef]	0.11[c]

FCV-SM-07	33.80±0.04^{q}	0.24±0.01^{c}	1.70±0.05^{abcd}	0.11^{c}
FCV-SM-08	33.90±0.08^{p}	0.24±0.00^{c}	3.40±0.07^{defg}	0.11^{c}
FCV-SM-09	34.00±0.02^{op}	0.24±0.01^{c}	2.20±0.06^{abcdef}	0.10^{c}
FCV-SM-10	34.10±0.02^{nop}	0.24±0.01^{c}	3.80±0.06^{fgh}	0.10^{c}
FCV-SM-11	34.10±0.03^{nop}	0.24±0.00^{c}	3.65±0.03^{efgh}	0.11^{c}
FCV-SM-12	34.10±0.02^{nop}	0.24±0.00^{c}	2.50±0.05^{bcdef}	0.11^{c}
FCV-SM-13	34.20±0.04^{mn}	0.24±0.01^{c}	2.60±0.08^{bcdef}	0.11^{c}
FCV-SM-14	34.30±0.01^{m}	1.05±0.01^{b}	3.10±0.14^{bcdef}	0.48^{bc}
FCV-SM-15	34.30±0.04^{m}	2.60±0.00^{a}	3.10±0.05^{bcdef}	0.12^{a}
FCV-SM-16	34.80±0.04^{l}	2.60±1.48^{a}	4.40±0.37^{hijk}	0.13^{a}
FCV-SM-17	34.90±0.03^{kl}	2.60±0.01^{a}	5.90±0.08^{jk}	0.12^{a}
FCV-SM-18	35.00±0.03^{jkl}	2.60±0.01^{a}	6.10±0.08^{k}	0.12^{a}
FCV-SM-19	35.05±0.02^{ijk}	2.60±0.01^{a}	4.30±0.03^{hijk}	0.12^{a}
FCV-SM-20	35.05±0.04^{ijk}	2.60±0.01^{a}	5.90±0.01^{jk}	0.12^{a}
FCV-SM-21	35.09±0.03^{ijk}	2.60±0.01^{a}	5.80±0.06^{jk}	0.12^{a}
FCV-SM-22	35.09±0.07^{ijk}	2.60±0.01^{a}	4.90±0.03^{ijk}	0.12^{a}
FCV-SM-23	35.10±0.00^{hij}	2.60±0.01^{a}	5.14±0.15^{ijk}	0.12^{a}
FCV-SM-24	35.10±0.02^{hij}	2.60±0.01^{a}	4.30±0.07^{hijk}	0.84^{ab}
FCV-SM-25	35.10±0.06^{1hij}	1.87±0.01^{ab}	4.90±0.10^{ijk}	0.85^{ab}
FCV-SM-26	35.25±0.05^{ghi}	0.24±0.01^{c}	3.10±0.13^{bcdef}	0.10^{c}
FCV-SM-27	35.30±0.04^{fgh}	2.60±0.00^{a}	1.40±0.04^{abc}	0.12^{a}
FCV-SM-28	35.30±0.03^{fgh}	1.06±0.00^{bc}	0.60±0.13^{a}	0.49^{bc}
FCV-SM-29	35.30±0.02^{1fgh}	0.24±0.00^{c}	1.70±0.13^{abcd}	0.10^{c}
FCV-SM-30	35.33±0.13^{efg}	0.24±0.00^{c}	2.20±0.18^{abcdef}	0.10c
FCV-SM-31	35.34±0.03^{efg}	2.60±0.00^{a}	1.80±0.07^{abcde}	0.12^{a}
FCV-SM-32	35.34±0.06^{efg}	2.60±0.00^{a}	2.10±0.07^{abcde}	0.12^{a}
FCV-SM-33	35.35±0.01^{efg}	2.60±0.01^{a}	2.40±0.01^{bcdef}	0.12^{a}
FCV-SM-34	35.35±0.04^{efg}	2.60±0.00^{a}	3.90±0.09^{ghij}	0.12^{a}
FCV-SM-35	35.37±0.02^{def}	2.6±0.01^{a}	1.4±0.06^{abc}	0.11^{a}
FCV-SM-36	35.38±0.05^{def}	2.60±0.00^{a}	2.60±0.06^{bcdef}	0.12^{a}

FCV-SM-37	35.40±0.03^{abc}	2.60±0.01^{a}	3.20±0.09^{cdefg}	0.12^{a}
FCV-SM-38	35.40±0.25^{abc}	2.60±0.01^{a}	2.80±0.01^{bcdef}	0.12^{a}
FCV-SM-39	35.47±0.02^{ab}	2.60±0.01^{a}	2.40±0.02^{bcdef}	0.12^{a}
FCV-SM-40	35.47±0.03^{ab}	1.88±0.01^{ab}	3.30±0.07^{defg}	0.86^{ab}
FCV-SM-41	35.53±0.06^{a}	1.05±0.01^{b}	2.80±0.05^{bbcdef}	0.48^{bc}
FCV-SM-42	35.56±0.03^{a}	0.24±0.00^{c}	2.60±0.05^{bcdef}	0.10^{c}
FCV-SM-43	35.56±0.05^{a}	0.24±0.01^{c}	2.9±0.07^{bcdef}	0.11^{c}
FCV-SM-44	33.03±0.08^{t}	0.24±0.01^{c}	1.4±0.03^{abc}	0.11^{c}
FCV-SM-45	33.30±0.48^{s}	0.24±0.01^{c}	1.3±0.03^{ab}	0.10^{c}
Mean	0.07	0.30	1.60	34.65
SEM	0.002	0.01	1.33	0.49
CD	0.15	0.39	3.29	2.01

4.5.4. Genetic parameters for physiological traits

The genetic variation in the physiological characters of the two-month-old progenies of forty-five plus trees are shown in Table 19.

4.5.4.1. Photosynthetic rate

The genetic variability study of the progenies of forty-five plus trees showed the broad sense heritability for the photosynthetic rate as 0.62. The genetic gain and genetic advance for the photosynthetic rate observed were 0.19 and 61.4 respectively.

4.5.4.2. Stomatal conductance

The heritability value observed for the progenies of forty-five plus trees was 0.66. The values observed for the genetic gain and genetic advance were 0.07 and 93.4 respectively.

4.5.4.3. Transpiration

The genetic variability study of transpiration rate (Table 19) had given the heritability value as 0.82. The values for genetic gain and genetic advance are 0.07 and 93.4 respectively.

4.5.4.4. Leaf temperature.

The leaf temperature had the broad sense heritability value as 0.82. The genetic gain and genetic advance values for the leaf temperature were observed as 1.32 and 3.8 respectively.

Table 19. Genetic parameters estimated for the physiological traits of *Swietenia macrophylla* progenies

Variances	Photosynthetic rate	SC	Transpiration	Leaf Temperature
ECV	29.50	32.10	32.20	0.90
GCV	37.80	70.10	69.40	2.00
PCV	48.03	77.10	76.50	2.20
Heritability	0.62	0.66	0.82	0.82
Genetic gain	0.19	0.07	0.06	1.32
Genetic advance	61.40	93.40	121.00	3.80

4.5.5. Correlation study of the morphological and physiological characters of *Swietenia macrophylla progenies*.

Correlation data of physiological and morphological data for the progenies of *Swietenia macrophylla* are shown in Table 20. It is observed that the number of leaves of the seedlings have a positive correlation with photosynthetic rate (0.438). The photosynthetic rate has also showed a significant positive correlation with stomatal conductance (0.433), leaf temperature (0.312) and transpiration rate (0.412). Stomatal conductance of the seedlings had a significant positive correlation with leaf temperature (0.912) and transpiration rate (0.999). It was also observed that leaf temperature had a significant positive correlation with transpiration (0.921). Germination percentage had shown a significant negative correlation with seedling height and showed correlation with any other traits. Collar diameter had no correlation with any of the morphological and physiological characters.

Table 20. Correlation of morphological and physiological characters of *S. macrophylla* progenies

Parameters	Collar diameter (mm)	Germination	Number of leaves	Seedling height (cm)	Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})	Stomatal conductance (mmol H_2O m^{-2} s^{-1})	Leaf temperature (°C)	Transpiration rate (µmol H_2O m^{-2} s^{-1})
Collar diameter (mm)	1							
Germination	-.215	1						
Number of leaves	.078	.130	1					
Seedling height (cm)	.099	-.340*	.215	1				
Photosynthetic rate (µmolCO_2 m^{-2} s^{-1})	.190	-.147	0.438**	.110	1			
Stomatal conductance	.008	.052	.196	.264	.433**	1		

(mmol H_2O cm s^{-1})								
Leaf temperature (°C)	.060	.158	.199	.253	.312*	.912**	1	
Transpiration rate (mmol H_2O cm^{-2} s^{-1})	.009	.065	.189	.268	.412**	.999**	.921**	1

** correlation significant at 0.01 level

*correlation significant at 0.05 level

5. DISCUSSION

Information on magnitude and nature of variability and heritability are prerequisites for a successful breeding program involving the selection of genotypes with desirable characters. Insufficient genetic variability hampers the productivity of any tree species, as this restricts the intensity of selection from base population. To expand the genetic base of the tree species, it is necessary to evaluate the population of wide geographical distribution. Exploration of existing variability gives a scope to the tree breeder to make a rapid genetic advance at relatively low cost.

The results of "Diversity analysis and selection of candidate plus trees of *Swietenia macrophylla* from selected districts of North Kerala" are discussed below.

Successful phenotypic selections depend on the magnitude of the genetic variation available in the population (Lone and Tewari, 2008). Variations among populations are expected for species having widespread natural distribution due to genetic and environmental variations. A total number of 593 trees of *Swietenia macrophylla* were enumerated from fifteen locations of North Kerala. The average GBH of the trees encountered was 1.19 m and they ranged from 0.65 m to 1.9 m. The average CBH was 8.21 m and ranged from 2.9 m to 16 m. The average crown width was 9.42 m and it ranged from 4.5 m to 19.4 m. The average crown length observed was 12.7 m and it varied widely from 4 m to 28 m. The percentage CV observed for GBH and CBH were 41.1 percent and 58.5 percent respectively. From the 593 enumerated trees forty-five CPTs were selected. Goel and Behl (2001) selected forty candidate trees of *Prosopis juliflora* from a base population of 1564 trees. Comparing to their study, the present base population is too lower for selecting forty-five plus trees. Hence, a further selection needs to be done based on the field performances of the selected trees.

5.1. PLUS TREE SELECTION

In the present study, the regression analysis of *Swietenia macrophylla* from fifteen locations had shown a strong relationship between crown volume and trunk volume (R^2 = 0.58 to 0.78). The differences in R^2 value for different locations indicate the differences in sites, different tree forms, different sample numbers, age and differences in climatic conditions. As the crown volume increases the photosynthate production increases, leading to its deployment to the trunk making the base line a positively sloping one. The species may also have different adaptive features which may also influence the base line. A comparatively smaller value of R^2 was explained by Brown and Goddard (1961). According to them, an exponential increase in the crown parameters reduce the R^2 by 10 percent. In estimating crown volume, crown parameter is squared, and this leads to an increased exponential value. A fundamental problem associated with plus tree selection is differentiating environmental effects from that of genotypic effects. According to Van Damme (1985), a major disadvantage in selecting plus trees using height vs. age selection method in plantations is a competitive disadvantage. Trees growing in plantations will be having the same competition for space for growth. So, an exceptional increase in height can be attributed to the genetic effects. But the trees growing outside plantations may be experiencing different space competition. In these cases, the height cannot be taken as a parameter for the selection.

Tree level productivity is largely explained by crown size and above ground vigor. Tree canopy characteristics are directly related to tree growth and productivity, and hence can be used to estimate trunk volume and long-term productivity. Allometric equations have been developed to estimate tree and canopy volume as well as the biomass of several tree components from either DBH, tree height or both (Eamus *et al*., 2000 and Keith *et al*., 2000). Estimating canopy volume is important for managing trees in an agroforestry system. A relation between crown volume and trunk volume gives a better picture of the vigor of the tree in converting photosynthate to useful products.

Several scientists had worked in plus tree selection of hardwood using base line method. Plus trees of *Melia dubia* from different parts of Kerala have been selected using base line method (Binu and Santhoshkumar, 2019). Candidate plus trees of *M. azedarach* have been selected from different agro-climatic areas of Punjab by Dhillon *et al*. (2009). Plus trees of black spruce in Ontario was selected by Van Damme (1985)

In the present study, the plus trees were selected in two stages. First was based on the base line method, in which better trees with vigor were selected based on their crown volume to trunk volume relationship. In the second stage, further selection among the trees were made based on the scoring of qualitative characters. In the present study, forty-five plus trees were selected from fifteen different locations across the districts of North Kerala based on the base line method together with the scoring of qualitative characters.

5.2. MORPHOLOGICAL VARIATIONS IN THE PLUS TREES OF *Swietenia macrophylla*

For a successful tree improvement program, exploring the existing variations in the tree species is important. The genotypic variations might have evolved in trees having a wide geographic distribution. Therefore, identifying the genotypic influence on various morphological characters is necessary for future tree improvement of such trees.

In the present study, the morphological characters of forty-five plus trees had shown significant variations in CBH, GBH and crown width. Not much variation was observed in pin penetration depth and crown length. The CBH, GBH, crown width had measurements ranging from 6 m to 13.4 m, 0.75 m to 1.85 m and 8 m to 15 m, respectively. The crown length and pin penetration value ranged from 7 m to 16 m and 21 mm to 23 mm, respectively. These differences may be due to genetic factors, age differences, differences in the geographic conditions like soil, irradiance, altitude, differences in silvicultural practices, etc. Plus tree selection was also done in trees like *Melia dubia* (Chauhan *et al.*, 2018). In case of *Melia dubia,* the minimum tree height was 14.2 m and the maximum height was 26.2 m. The minimum GBH measured was 101.1 cm and the maximum was 170 cm.

Stem quality is mainly determined by stem form and by growth and development of the branches. For saw timber production, a tall, straight, healthy tree with fine, flat angled limbs and well pruned stem is desirable. Progeny tests with half sib, full sib and selfed progenies have given valuable information on the variation of stem and branch properties among natural populations, stands, progenies, and individual trees (Toda, 1958). Studies of stem and branch properties and their effect on wood quality are reported in conifers and some hard woods (Campbell, 1961; Goggans, 1961). Stem straightness is important as a deviation from straightness like a crook, sweep, twist can reduce the volume of commercially useful parts and increase the cost of transport and handling. The age at which the lower branches of a tree begin to die and fall off and the capacity of the tree rapidly to occlude scars and stumps are of great importance. Forking and fasciation in annual shoots can disturb the normal growth and lead to the development of two or more stems and heavy branches and crookedness of stem. All these characters affect the timber quality and hence, assessing the qualitative characters of the trees are important in selecting the plus trees

The qualitative characters of the plus trees like verticality, straightness, cross section, forking, foliar damage, stem damage, branch angle, and self-pruning ability were analyzed and observed that the variations for these characters were very less among the selected plus trees (Table 8). The scores of the qualitative characters of the plus trees ranged from 42 for CPTs FCV-SM-04, FCV-SM-12, FCV-SM-22, FCV-SM-42 and FCV-SM-39. The minimum score of 36 was obtained for CPTs FCV-SM-17, FCV-SM-24 and FCV-SM-25 indicating much lower variations in qualitative characters of trees and these are mostly genetically determined. Daneva *et al*., (2018) selected twenty-one plus trees of *Ailanthus excelsa* Roxb. from Haryana, Rajasthan, and Gujarat based on the qualitative characters like self-pruning ability, stem straightness, disease resistance, branching habit, clean bole height etc. Similar selections based on apparent growth, clean bole and stem straightness and other important traits have been used in trees like *Azadirachta indica* (Dhillon *et al*., 2003), *Dalbergia sissoo* (Bangarwa, 1993; Yadav *et al*., 2005).

Deformities due to the effect of one or a few recessive or dominant genes are reported by Eklundh- Ehrenberg (1963). The straight stem form in *Populus nigra* is inherited as a dominant character and depends on more than two loci (Zufa, 1970). Forking and fasciation of annual shoots in *Pinus sylvestris* were observed in progenies obtained after open pollination or after controlled crossings among parent trees, which showed the same abnormal growth. The production of lemmas shoots which leads to the formation of forks of a different nature is a genetically controlled feature that probably has a more complicated genetic background (Eklundh-Ehrenberg, 1963; Rudolf, 1964; West and Ledig, 1964). Evidences of dominant gene action (high specific combining ability) was found in characters like straightness and volume (Nikles, 1965). Therefore, due consideration to these characters during selection for tree improvement are desirable.

5.3. CLUSTER ANALYSIS

In the present study, hierarchial clustering was done. Forty-five plus trees were grouped into five clusters (Table 9). Plus trees coming in the same clusters have similar characters and trees in different clusters have different characters. Cluster II had the maximum number of trees with 35 accessions and cluster III and cluster IV had only one accession each. Single accession cluster can be either inferior or superior in nature. The average values of CBH, GBH, crown width, crown length, pin penetration depth of accession in all five clusters were 10.39 m, 1.35 m, 10.80 m, 13.56 m, 21.83 mm, respectively. The most frequent scores of verticality, apical dominance, forking, branch angle, self-pruning, foliar, stem damage and bole swelling of five clusters were 2, 8, 5, 12, 3, 4, 6 and 2 respectively (Table 11).

Trees from different regions were grouped in one cluster, indicating that the variation in geographic regions was not consistent with the genetic diversity. Kaushik *et al*. (2007) has also observed the same pattern in *Jatropa curcas.* The cluster II had the maximum intra cluster distance (2.45), followed by cluster I (2.21) and cluster IV (2.15). The results indicate that the cluster that had the maximum intra cluster distance have greater genetic distance within the cluster, which can be attributed either to genetic or environmental factors. The highest inter cluster distance was observed between cluster IV and cluster V (9.33). and the lowest between cluster I and cluster II (3.19). According to Ghaderi *et al.* (1984) in pedigreed populations, higher inter cluster distance indicates a greater number of contrasting alleles at the desired loci and these loci recombines in F_2 and F_3 generation following a cross of distantly related parents and there will be great opportunities for the effective selection for yield factors.

Based on cluster means, accessions from cluster IV is important for clean bole height and crown width and accessions from cluster I are important for GBH and crown length, accessions from cluster III is important for pin penetration depth. Crossing parents belonging to more divergent clusters would result in maximum heterosis and wide variability in genetic structure (Singh and Choudary, 1985). In the present study, cluster II is more divergent than others. The selection of parents for breeding should also account for the special advantage of each cluster and each genotype within a cluster based on the objectives of hybridization (Chahal and Gosal, 2002). Studies conducted in *Pinus gerardiana* (Kant *et al*., 2006) and *Melai dubia* (Binu and Santhoshkumar, 2019) also had shown similar trends. Therefore, genetic diversity should be given due consideration while selecting plus trees.

5.4. PRINCIPAL COMPONENT ANALYSIS

Principal component analysis indicates the importance of the largest contributor to the total variation at each axis of differentiation (Sharma, 1998). The first PC of the observation is the one whose variance is greatest among all the other principal components, contributing 22.7 percent. According to Chahal and Gosal (2002), characters having the largest absolute value closer to unity within the first principal component influence the analysis more than those which have a lower absolute value closer to zero. Hence, differentiation of accessions to various clusters was because of the relatively high contribution of few characters rather than the small contribution from each character.

In the present study, characters like GBH, crown length, pin penetration depth had high positive component loading in PC 1 and apical dominance and forking have higher negative component loading in PC1. The crown width and verticality had high positive component loading in PC 2 and GBH and bole swelling had higher negative component loading in PC II (Table 14).

5.4. EVALUATION OF PROGENIES OF SELECTED PLUS TREES

5.4.1. Morphological character

In the present study, the morphological characters like collar diameter, germination percentage, seedling height, number of leaves among progenies of 45 plus trees exhibited significant variations at 0.05 level (Table 15).

The seed germination rate of different trees ranged from 10 % (FCV-SM-15 and FCV-SM-26) to 43.3 percent (FCV-SM-43). The germination rate of mahogany seeds obtained in the study was inconsistent with the study done by Negreros-Castillo *et al*. (2003) in Indonesia, where he observed that the buried seeds of mahogany gave a germination percentage of 34 percent and the germination rate of surface sown mahogany seeds were 15 percent. But the germination rate obtained in the present study was too low when compared to the value obtained by Abarquez *et al*. (2015) in Philippines. In his study, he got a germination rate of 70%. The variation in seed germination may be attributed to adverse environmental factors and differences in the distribution range of the seeds which in turn affect seed germination (Devagiri *et al*., 1997).

Progenies of plus tree FCV-SM-41 had the lowest standard deviation (0.00%) and had an average germination of 23.3 percent. Plus tree FCV-SM-35 also had a standard deviation 0.58 percent and average germination of 30 percent. FCV-SM-34 had a standard deviation of 0.58% and average germination of 33.3 percent (Table 16). So, these plants can be described as trees which produce seeds with good germination.

The average height of the seedling after 30 days was 11.45 cm. The maximum was observed for FCV-SM-08 (24.5 cm) and minimum for FCV-SM-23 (15.4 cm). This observation was in line with the studies done by Negreros- Castillo *et al*. (2003) where he obtained the average seedling height of four-month old mahogany seedling as 19 cm. Lower standard deviation obtained for progenies of FCV-SM-06, FCV-SM-09, FCV-SM-31, FCV-SM-36 were 0.59, 0.93, 0.31, 0.86 respectively and the mean seedling height obtained for these plus trees were comparatively higher among other progenies *i.e*. 19.9 cm, 23.1 cm, 19.6 cm, 21.5 cm respectively (Table 18).

The average number of leaves obtained for the progenies was 5.56. The maximum value was observed for FCV-SM-08 (9.67) and minimum for FCV-SM-27 (3.67). This observation was similar to that of Negreros-Castillo *et al*. (2003) who obtained the number of leaves of four-month-old mahogany seedlings in the range of 5 to 6. A lower standard deviation was obtained for plus trees FCV-SM-29, FCV-SM-26, FCV-SM-05, FCV-SM-11 *i.e*. 0.20, 0.20, 0.80 and 0.29 respectively. They had a comparatively higher average number of leaves *i.e*. 8.40, 4.93, 8, 5.83 respectively. These plus trees may perform better than other plus trees by giving progenies without high variation.

The average value for the collar diameter obtained for the progenies of the plus trees was 2.1mm and the value ranged from 1.61 mm (FCV-SM-15) to 2.97 mm (FCV-SM-37). The minimum standard deviation was obtained for plus trees FCV-SM-03 (0.06), FCV-SM-07 (0.03), FCV-SM-25 (0.06) and the mean collar diameter obtained for the progenies of these plus trees were 2.07 mm, 1.87 mm and 1.93 mm respectively, which were relatively higher among others. The plus trees having relatively lower standard deviation and a higher mean collar diameter can be taken as the potential parent trees.

Comstock and Moll (1963) categorized the external conditions that affect the expression of the genes into two – macro environment and the micro environment. The variations in the seedling character can be attributed to the microclimate variations the trees have been experiencing. In this study, different seedling growth parameters showed differences among parents and no character showed a perfect difference. Therefore, all characters should be taken into consideration for selection as one character may not help in selecting superior genotypes. Various studies conducted in *Ailanthus triphysa* (Abhijith, 2018), *Melia dubia* (Binu and Santhoshkumar, 2019) and *Acacia mangium* (Salazar, 1989) also showed similar kind of variations.

5.4.2. Physiological traits

The physiological parameters of progenies of CPTs were significantly different at 0.05 level (Table 17). Among the progenies the photosynthetic rate was found higher for the plus tree FCV-SM-18 (6.1 μmol CO_2 m^{-2} s^{-1}) and lower for the plus tree FCV-SM-28. (0.6 μmol CO_2 m^{-2} s^{-1}). The stomatal conductance ranged from 0.86 mmol H_2O m^{-2} s^{-1} (FCV-SM-40) to 0.10 mmol H_2O m^{-2} s^{-1} (FCV-SM-26, FCV-SM-29, FCV-SM-30, FCV-SM-42, FCV-SM-45). The highest value for transpiration observed was 2.6 mmol H_2O m^{-2} s^{-1} (FCV-SM-02, FCV-SM-03, FCV-SM-16, FCV-SM-17, FCV-SM-18, FCV-SM-19, FCV-SM-20, FCV-SM-21, FCV- SM-22, FCV-SM-23, FCV-SM-24, FCV-SM-27, FCV-SM-31, FCV-SM-32, FCV -SM-33, FCV-SM-34, FCV-SM-35, FCV-SM-36, FCV-SM-37, FCV-SM-38 FCV-SM-39). The lowest value observed was 0.24 mmol H_2O m^{-2} s^{-1} for FCV-SM-05, FCV-SM-6, FCV-SM-7, FCV-SM-07, FCV-SM-08, FCV-SM-09, FCV-SM-10, FCV-SM-11, FCV-SM-12, FCV-SM-13 and FCV SM 14. The highest value for the leaf temperature was observed for FCV-SM-42 and FCV-SM-43 (35.56 °C). The lowest value was observed for FCV-SM-44 (33.03 °C).

The lower standard deviation for photosynthesis was observed for FCV-SM- 22 (0.03), FCV-SM-20 (0.01), FCV-SM-25 (0.10), FCV-SM-21 (0.06) and FCV-SM-23 (0.15) with mean photosynthetic value 4.9 μmol CO_2 m^{-2} s^{-1}, 5.9 μmol CO_2 m^{-2} s^{-1}, 4.9

μmol CO_2 m^{-2} s^{-1}, 5.8 μmol CO_2 m^{-2} s^{-1}, 5.14 μmol CO_2 m^{-2} s^{-1}. For stomatal conductance, the standard deviation was 0.00 and the progenies with highest stomatal conductance are FCV-SM-25 (0.85 mmol H_2O m^{-2} s^{-1}), FCV-SM-24 (0.84 mmol H_2O m^{-2} s^{-1}), FCV-SM-40 (0.86 mmol H_2O m^{-2} s^{-1}), FCV-SM-28 (0.49 mmol H_2O $m^{-2}s^{-1}$), FCV-SM-41(0.48 m mol H_2O m^{-2} s^{-1}), FCV-SM-14 (0.48 m mol H_2O $m^{-2}s^{-1}$). The lower standard deviation for leaf temperature was observed for plus trees FCV-SM-14(0.01), FCV-SM-23(0.00), FCV-SM-33(0.01), FCV-SM-02(0.02) having leaf temperatures 34.3°C, 35.1°C, 35.35°C and 33.5°C respectively. Standard deviation for transpiration was lowest for FCV-SM- 03 (0.00), FCV-SM- 15 (0.00), FCV-SM- 27 (0.00), FCV-SM- 31 (0.00), FCV-SM-32 (0.00), FCV-SM- 34 (0.00), FCV-SM- 36 (0.00) having value 2.6 mmol H_2O m^{-2} s^{-1} for all. Therefore, these plus trees have a potential to give progenies with the desirable characters without much extremes.

The variations in physiological factors observed in the trees are a complex one. A large number of environmental and genetic factors can be attributed to the cause of variation in the same species from different regions. The genetic factors that cause variation in photosynthesis are largely unknown. Like in all cellular processes, photosynthesis is genetically controlled, and the genetic mechanism of photosynthesis varies between and within species (Hikosaka, 2010). The adaptive potential of photosynthesis to the changing environment depends on the level of genetic variation for photosynthesis that is present within a population. It is important to note that essential photosynthesis genes are encoded in the chloroplasts, for which there is a natural genetic variation (Sun *et al*., 2009). Stomatal conductance is directly involved in modifying plant water relations and photosynthesis. Temperature dependence of stomatal opening can be explained to some extent by the increase in xylem and mesophyll hydraulic conductance coming from lower water viscosity. Stomatal regulation is one of the main factors which determine local growth and survival of plants (Ball *et al*., 1987). It is well established that plants regulate rates of transpiration and photosynthesis in parallel, maintaining a balance between photosynthesis and stomatal conductance (Lawson *et al*., 2010). Various studies conducted by Binu and Santhoshkumar (2019), in *Melia dubia*, Johnsen and Major (1995) reported significant variations in photosynthesis, stomatal conductance and leaf temperature in the progenies of black spruce.

5.5. GENETIC ANALYSIS

The genetic coefficient of variation for all seedling morphological characters was lower than the phenotypic coefficient of variation (Table 16). A lower GCV value than the PCV value indicates that the character is governed by the environment and not by the genetic factors. The heritability, genetic advance and genetic gain value for the germination were 0.15, 0.3, and 13 respectively. A lower heritability value indicates that the character is least influenced by the genetic character and its more influenced by environment. So, selection for such character is not useful. A lower genetic advance value indicates that the character is governed by non-additive genes. Heritability values for collar diameter and seedling height were 0.15 and 0.64 respectively. Abarquez *et al*. (2015) in his studies in mahogany obtained heritability value for collar diameter 0.29 and for seedling height as 0.37. The heritability values for the seedling parameters were also very less indicating that the characters are very much influenced by the environment rather than by the genetic factors. Genetic advance values for the collar diameter was very low but for seedling height and number of leaves had a moderate value indicating that the character is governed by additive genes and the selection based on this character will be useful.

The coefficient of variation studies in mahogany revealed PCV values were slightly higher than the GCV values for all physiological parameters. This indicated that these traits are more influenced by the environmental factor than the genetic factor. This justifies the need to explore more genetic parameters to ascertain the traits to be considered. The heritability value for photosynthesis, stomatal conductance, transpiration, and leaf temperature was observed to be 0.62, 0.66, 0.821, 0.82 respectively, indicating the variability for these traits are under genetic control and therefore heritable. The genetic advance values for photosynthesis, stomatal conductance, transpiration and leaf temperature was observed to be 61.4, 93.4, 121, 3.8 respectively. Except for leaf temperature, all other physiological parameters had moderate to higher genetic advance value. This indicates that the characters like photosynthesis, stomatal conductance, and transpirations have some amount of heritable additive genetic components. Leaf temperature had higher heritability value with lower genetic gain indicating that this trait has more non additive genetic effects than the additive genetic effects. Since the leaf temperature had the narrower difference between the PCV (2.2) and GCV (2) the leaf temperature can also be taken as a parameter for the selection of trees.

5.6. CORRELATION STUDIES

It is observed that the number of leaves of the seedlings have a positive correlation with the photosynthetic rate (Table 19). The photosynthetic rate has also had a significant positive correlation with stomatal conductance, leaf temperature and transpiration rate. The stomatal conductance of the seedlings has a significant positive correlation with leaf temperature and transpiration rate. It was also observed that leaf temperature has a significant positive correlation with transpiration. Germination percentage has shown a significant negative correlation with seedling height and shown no significant correlation with any other traits. Collar diameter has shown no correlation with any of the morphological and physiological characters. In the case of physiological studies, photosynthesis exhibited a significant positive correlation with stomatal conductance, leaf temperature and transpiration rate. Stomatal conductance also had a significant positive correlation with leaf temperature and transpiration and internal CO_2 level. This indicates that the physiological parameters are correlated to each other in a complex way. The interdependence of the physiological parameters can be explained as an increase in the stomatal conductance which can regulate gas exchange will allow plants to increase their CO_2 uptake and enhance photosynthesis.

From the present study, progenies of the plus trees, FCV-SM-08 showed better performances in the number of leaves, seedling height, and vigor index. Progenies of plus tree FCV-SM-43 showed better performances in germination percentage and leaf temperature. Progenies of FCV-SM-37 showed better performances in collar diameter and transpiration whereas progenies of FCV-SM-18 and FCV-SM-17 showed good performance in photosynthetic rate and transpiration. It is also noted that all these plus trees fall in the cluster II which is more divergent. Therefore, these CPTs can be used for further tree improvement programs.

6. SUMMARY

The experiment was conducted to examine the genetic diversity of the trees and to select plus trees of *Swietenia macrophylla* from the selected districts of North Kerala. A total of 593 trees were studied during the survey. Forty-five trees were selected from the enumerated trees based on the baseline regression selection system. Seedlings of the selected forty-five plus trees were evaluated for their growth and physiological characteristics. The nursery experiment was conducted in the nursery of the College of Forestry.

The salient findings of the study are given below.

1. A total of 593 trees were enumerated from different locations of North Kerala. The plus tree selection was carried out using the baseline regression system followed by scoring for qualitative traits. Forty-five trees were selected as CPTs from the total trees enumerated.
2. Selected CPTs were assigned with the accession number as FCV-SM (FORESTRY COLLEGE VELLANIKKARA-*Swietenia macrophylla*).
3. Variation in clean bole height ranged from 6 m (FCV-SM-18 and FCV-SM-16) to 13.4 m (FCV-SM-26). The average clean bole height for all the CPTs was 10.49 m.
4. The variation in girth at breast height was in the range of 0.75 m (FCV-SM-22) to 1.85 m (FCV-SM-16). Average girth estimated was 1.33 m.
5. The variation in crown length was in the range of 7 m (FCV-SM-28) to 16 m (FCV-SM-03). Average crown length measured for the plus trees was 10.89 m.
6. The average crown width for CPTs was 10.43 m and the variation ranged from 8 m (FCV-SM-06 and FCV-SM-20) to 15 m (FCV-SM-10).
7. The variation in pin penetration depth as measured by pilodyn ranged from 21 mm for 19 CPTs (FCV-SM-01, FCV-SM-05, FCV-SM-06, FCV-SM-12, FCV-SM-13, FCV-SM-15, FCV-SM-21, FCV-SM-22, FCV-SM-24, FCV-SM-26, FCV-SM-27, FCV-SM-29, FCV-SM-30, FCV-SM-35, FCV-SM-37, FCV-SM-38, FCV-SM-40, FCV-SM-41 and FCV-SM-45) to 23 mm (FCV-SM-02 and FCV-SM-09).

8. The correlation matrix between the quantitative characters of all the plus trees showed that there was a significant relation between crown length and crown width and also between clean bole height and GBH.

9. For the qualitative characters, it was observed that the variations were very less among the trees located. Maximum variations were shown for the character apical dominance, and forking. The highest score 42 was obtained for the plus trees FCV-SM-04, FCV-SM-12, FCV-SM-22, FCV-SM-42, FCV-SM-39, FCV-SM-34 and FCV-SM-36. The tree FCV-SM-17, FCV-SM-25 and FCV-SM-24 had the lowest score (36).

10. A hierarchial cluster analysis was carried out for morphological characters of the forty-five selected candidate plus trees using squared Euclidean distance. Forty-five candidate plus trees were grouped into five clusters. The grouping was not following geographic locations trends. The cluster II had maximum number of CPTs with 35 accessions, whereas the least number observed for the cluster III and IV with one accession each.

11. The principal component analysis showed that four components had eigen value greater than one which accounts for 63.7 % of the total variability. First two components together accounted for 39.9 % of the total variability. PC1 accounted for 22.7 % of the total variability, which was mainly contributed positively by GBH, crown width, crown length, pilodyn pin penetration depth, verticality and branch angle. PC2 accounted for 17.2 % of the total variability, which was mainly contributed positively by clean bole height, crown width, crown length, pin penetration depth, verticality and forking. The selection index value was also worked out for the best plus trees based on the morphological characters of the trees using PC2.

12. The nursery performance of the progenies of plus trees also showed significant differences in collar diameter, number of leaves, germination percentage, seedling height and seedling vigour index. The highest germination percentage was obtained for FCV-SM-43 (43.3%), CPT FCV-SM-08 showed the highest number of leaves (9.67), FCV-SM-37 had highest collar diameter (2.97mm), seedling height was highest for FCV-SM-08 (24.5 cm), vigour index was highest for CPT FCV-SM-08 (842).

13. The genetic parameters for morphological and growth traits of seedlings after two months showed that the broad sense heritability values for different characters were 0.12 for seedling height, 0.15 for collar diameter, 0.17 for the number of leaves, and

0.15 for germination percentage. Highest genetic gain (13) was observed in germination percentage and least value (3.1) was observed in seedlings height.

14. Variations were also observed among the progenies of the selected plus trees for the physiological characters. It was observed that the progenies of the plus tree FCV-SM-17 showed the highest photosynthetic rate, highest stomatal conductance by FCV-SM-40, highest transpiration rate by FCV-SM-02, FCV-SM-03, FCV-SM-16, FCV- SM -17, FCV- SM-18, FCV-SM-19, FCV- SM- 20, FCV- SM-21, FCV- SM-22, FCV- SM-23, FCV- SM-24, FCV- SM- 27, FCV- SM-31, FCV- SM- 32, FCV- SM-33, FCV- SM -34, FCV- SM- 35, FCV-SM-36, FCV- SM- 37, FCV- SM-38, FCV- SM -39 , highest leaf temperature recorded by FCV-SM-42 and FCV-SM-43.

15. The genetic parameters for physiological traits after two months showed that the broad sense heritability values for different characters were 0.82 for transpiration rate, 0.66 for stomatal conductance, 0.62 for photosynthetic rate and 0.82 for leaf temperature. Highest genetic gain 121 was observed in transpiration rate and the least value 3.8 was observed in leaf temperature.

16. Correlation analysis of the morphological and physiological traits of progenies of the selected plus trees showed that there were positive and significant relations between germination and seedling height, photosynthetic rate and number of leaves. Photosynthesis was also correlated with transpiration, stomatal conductance and leaf temperature. Stomatal conductance was correlated with transpiration and leaf temperature. Leaf temperature was correlated with transpiration.

17. It can be concluded from the results that considerable morpho-physiological variations existed in selected candidate plus trees of *Swietenia macrophylla*.

18. The physiological characters showed higher heritability. Therefore, using these characters for selection program could help the breeder. Heritability value along with genetic advance is more useful in selecting best trees.

19. Progenies of the plus trees, FCV-SM-08 showed better performances in the number of leaves, seedling height, and vigor index, and FCV-SM-43 showed better performances in germination percentage and leaf temperature. Progenies of FCV-SM-37 showed better performances in collar diameter and transpiration whereas progenies of FCV-SM-18 and FCV-SM-17 showed good performance in photosynthetic rate and

transpiration. It is also noted that all these plus trees fall in cluster II which is more divergent. Therefore, these CPTs can be used for further tree improvement programs.

20. Results obtained and information gathered in this study can be utilised for further breeding programmes to improve the yield in *Swietenia macrophylla.*

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APPENDIX I

GRADING OF THE TRAITS FOR SELECTION OF PLUS TREES			
Sl. No.	**Traits**	**Variations**	**Score**
1	Verticality	Vertical	2
		Not vertical	1
2	Straightness	Very crooked with 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	Circular	2
		Not circular	1
2	Bole swelling	Present	1
		Absent	2
3	Branch angle	Upright <60°	6
		Horizontal>60°	12
4	Self-pruning	Poor, branches exists below 2/3rd of total height	1
		Good, branches exist above 2/3rd of total height	3
5	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
6	Forking	Above 10 m	5
		Between 5-10 m	3
		Below 5 m	1
7	Foliar damage	Present	1
		Absent	4
8	Stem damage	Present	1
		Absent	6

APPENDIX II

Quantitative characters of *Swietenia macrophylla*

KALPETTA				
Tree Id No.	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
K01	0.75	5	6.5	18.9
K02	0.82	4.5	7	15.9
K03	1.25	5	8	19.5
K04	1.9	6.5	10	20
K05	1.1	5	9	12
K06	1.3	7	10	16
K07	0.7	7.5	7.5	15
K08	0.95	7	7.5	16.2
K09	0.75	5	9	11
K10	0.7	5.7	7.5	12
K11	1.4	5	10	15
K12	1.4	6.4	9	15.5
K13	0.9	8.1	8.5	16
K14	1.1	9.7	8	20
K15	0.8	8	8.5	14
K16	0.95	5.8	6.5	15.7
K17	1.6	8.5	9	22
K18	1.2	7.5	11	12.5
K19	1	5.8	8.5	12.9
K20	1.6	3.9	9.5	16.8
K21	1.3	6	10	18
K22	1.4	5	10	17
K23	1.85	6	14	12
K24	1.65	4.5	12	13
K25	1.35	4	8.5	16.5
K26	0.78	4	7.5	13
K27	0.95	4	6.6	18.5
K28	1.25	6.5	9	15
K29	1.3	5.5	7.5	19
K30	0.75	5	6.2	18.5
K31	1.1	6	8	17
K32	1.2	7	11	14.8
K33	1.4	10	15	11

K34	1.85	10	11	13
K35	1.5	8	12	23
K36	1.4	4	9	18
K37	0.9	5	7.7	15
K38	1.65	6.2	12	14
K39	1.5	8	12.5	20
K40	1.2	3.2	10	12
K41	0.95	4.5	9	10.6
K42	1.23	4	11.5	8.9
K43	1.2	3.5	7.5	15.2
K44	1.6	10	15	20
K45	1.7	9	13	16
K46	0.75	6.4	8.5	10.5
K47	0.95	3.8	8.5	12
K48	1.5	2.9	9	15
K49	1.5	3.3	8	13.1
K50	1.5	3	9.5	12

SULTHAN BATHERY				
Tree Id No.	GBH (m)	CBH (m)	Crown width(m)	Crown length (m)
SB01	1.2	5	8.5	12
SB02	1.1	6	10	8
SB03	1.5	7	11.5	11
SB04	1.4	6.8	15	8
SB05	0.95	4.5	7.5	9.5
SB06	1.2	9.3	12	12
SB07	1.5	7	12	13
SB08	1.4	12.9	12	10
SB09	0.85	6	6.5	9
SB10	1	5.7	9.5	7
SB11	0.9	6.4	7	9
SB12	1.6	6.4	12	13
SB13	1.9	5.5	15	15
SB14	1	9.7	13	8
SB15	0.85	6	9	5
SB16	0.75	4.5	7.5	6
SB17	1.2	4.6	13	6

SB18	0.75	7.3	7.5	6
SB19	0.8	5.8	6	8
SB20	1.3	3.9	9.5	8.5
SB21	1.6	5.5	13	12.5
SB22	1	6	7.5	15
SB23	1.1	8.5	8	13
SB24	1.3	6	8	18
SB25	1.2	3.3	8.5	10
SB26	1.2	4.3	10	8
SB27	0.9	5	8	7.5
SB28	1.3	10	9	12
SB29	0.85	6	7	10
SB30	0.95	5.3	8	7.5
SB31	0.75	5	6	9
SB32	0.95	7.6	10	9.5
SB33	1	10.3	9.51	13
SB34	1.45	12.1	12	12
SB35	1.6	3.3	11	6.5
SB36	0.95	2.5	8	8
SB37	0.85	5	8.5	7
SB38	0.78	6.2	8	8.5
SB39	0.65	5.3	8	6.5
SB40	1.33	3.2	12	15
SB41	0.75	4.5	8	9.5
SB42	1.1	3.5	9	8.3
SB43	1.25	3.5	9	7.5
SB44	1	5	11	6.4
SB45	0.93	6.5	9	9.3
SB46	0.98	6.4	9	8.6
SB47	0.95	3.8	8	8
SB48	0.86	2.9	8	8
SB49	0.76	3.3	5.5	6.7
SB50	1.3	4	9	10

PADINJARETHARA				
Tree Id No	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
P1	0.85	5.6	7	18.9
P2	0.9	6	8.5	20
P3	1.1	5.5	9.5	15

P4	1.5	7	9.8	14
P5	1.45	5	13	8
P6	1.2	4.8	10	12
P7	1.3	8	11	15
P8	1.15	7	10	16.2
P9	0.89	7	9	15
P10	0.98	5.4	8	16
P11	1.2	6.4	10.8	14
P12	1.35	7	13	14
P13	1.06	8.3	10	16
P14	0.75	9.7	8.9	12.5
P15	0.89	8.4	8.5	18.5
P16	0.95	6.3	8.3	15.9
P17	1	8.5	11	12
P18	1.25	7.5	11.5	12
P19	1.32	5.8	12.3	13
P20	0.77	3.9	9.5	13
P21	0.94	6.8	8.5	15.6
P22	0.69	7.9	8.5	15
P23	1.28	7.3	13.2	9
P24	1.21	5.8	12	10.7
P25	0.78	5	8.5	15.12
P26	1.1	4.3	7.5	16.8
P27	0.92	5	7.8	21.2
P28	1.3	10	10	12
P29	1.24	7.9	7.5	15
P30	1.1	7	8	10

KANIYAMBETTA				
Tree Id No.	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
KA01	1.1	6	8	13
KA02	1.7	4	8	18
KA03	1.2	3.3	8.5	8
KA04	1.3	4.3	10	8
KA05	0.9	5	8	7.5
KA06	1.3	10	8.7	13
KA07	0.85	6	7	10
KA08	0.95	5.3	8	7.5
KA09	0.75	4	6	9
KA10	1.2	7.6	10	9.8
KA11	1.35	10.3	9.51	13

KA12	1.45	12.1	12	12
KA13	1.6	3.3	11	6.5
KA14	0.95	4	8	8
KA15	0.85	6.3	8.5	7
KA16	0.78	7	8	8.5
KA17	0.65	7.5	8	6.5
KA18	1.33	4.5	12	15
KA19	0.75	3	8	9.5
KA20	1.1	3.5	9	8.3
KA21	1.25	3.5	9	7.5
KA22	1.35	5	11	6.5
KA23	0.93	6.5	9	9.3
KA24	0.98	6.4	9	8.6
KA25	0.95	5	8	8
KA26	0.86	3.8	8	8
KA27	0.76	3.3	5.5	6.7
KA28	1.3	4	9	10
KA29	0.95	5	7	6.5
KA30	1	6.4	7.3	6

MANANTHAVADY				
Tree Id No.	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
M01	0.95	5.6	8	12
M02	0.9	6	8.5	20
M03	1.1	6.6	9.5	12
M04	1.5	4.3	9	11.3
M05	1.45	5	13	9.3
M06	1.2	5	10	11
M07	1.3	8	11	14.6
M08	1.15	7	10	13
M09	0.89	8	9	16
M10	0.98	5.4	8	11.6
M11	1.2	12	10.5	9.5
M12	1.35	7	13	13
M13	1.06	8.3	10	13.6
M14	0.75	9.7	8.9	8.6
M15	0.89	8.4	8.5	11
M16	0.95	6.3	8.3	8.3
M17	1	15	11.2	11.1

M18	1.25	7.5	11.5	11.6
M19	1.32	6	11	16
M20	0.77	5	7	13
M21	0.94	6.8	8.5	15
M22	1.3	8	11.5	15
M23	1.28	5.6	11	7
M24	1.6	8	12	10
M25	1.3	8.2	14	12
M26	1.5	9.7	13	11
M27	0.85	9.8	9	8.3
M28	0.75	5	7.5	9
M29	1.6	4.6	13	12
M30	0.75	7.3	7.5	6
M31	0.8	5.8	6	8
M32	1.3	3.9	9.5	8
M33	1.6	5.5	13	13
M34	1.2	7.5	7.5	20
M35	1.1	8.5	8	16
M36	1.7	6	8	28
M37	1.8	4.5	8.5	25

PUDUPPADY				
Tree Id No.	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
PU01	1.6	4.4	8	18.9
PU02	1.25	6	7.5	15.9
PU03	1.6	5	9	18
PU04	2	6.8	11	15.8
PU05	1.8	4.8	10	19.3
PU06	1	8	7	16
PU07	0.7	8.8	4.5	6
PU08	1.55	12.9	8	16.2
PU09	1.2	4.5	7.5	9.5
PU10	0.8	5.7	5	12
PU11	1.7	6.4	11.5	15
PU12	1.1	6.4	10	8
PU13	0.88	8.1	7.5	10.7
PU14	1.3	9.7	8	25.2
PU15	1.45	9.8	11	12
PU16	1.3	5.8	8	15.7

PU17	1.35	4.6	6	25.6
PU18	1.35	7.3	9	10
PU19	0.88	5.8	6	12.9
PU20	0.9	5	5.5	16.8
PU21	0.87	6.8	5.5	12
PU22	0.85	7.9	6	12.8
PU23	0.93	9	8.5	10
PU24	1.15	6	9.5	8
PU25	1.2	4.6	8.5	18
PU26	1.6	5	11.5	13
PU27	1.3	5	7.5	18.5
PU28	1.3	10.4	6	17.4
PU29	1.4	8	6.5	15.3
PU30	0.95	5.3	5.5	18.5
PU31	1.85	5	9	28
PU32	1.6	7.6	10	14.8
PU33	1.2	13	10	18
PU34	1.6	5	7	27
PU35	1.4	3.3	5	23
PU36	1.3	2.5	6	18.6
PU37	0.8	5	4.5	15
PU38	1.45	6.2	7	20.1
PU39	1.15	5.3	6.5	18.7
PU40	0.9	3.2	7	12
PU41	1.2	4.5	8	10.6
PU42	0.85	4	5.5	8.9
PU43	0.85	3.5	4	15.2
PU44	1.6	5	5	25.6
PU45	1.5	6.5	7	15.7
PU46	1	6.4	8.5	10.5
PU47	1.28	3.8	8.5	6.5
PU48	1.1	2.9	6	7.6
PU49	0.75	3.3	5	6
PU50	1.33	3	6	12

CHAKKITTAPARA				
Tree Id No.	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
CH01	1.4	7.5	6	10
CH02	1.33	6	7	12

CH03	1.2	6	12	11.6
CH04	1.32	14	8	8.7
CH05	1.1	15	15	13
CH06	1.3	10	11.3	12.5
CH07	1.35	6.5	7	14.4
CH08	1.2	7	6.5	8
CH09	1.4	5.1	7	10
CH10	1	6.5	4	9.1
CH11	0.99	5.3	5	11.1
CH12	0.95	11	5	12.3
CH13	0.9	13.5	5	15.1
CH14	0.98	10	5	18.8
CH15	1.5	9	15	13
CH16	1.9	4.5	10	15
CH17	1.3	6	7	5.6
CH18	1.6	4	6.5	9.6
CH19	1.7	5.2	12	8.1
CH20	1.7	15	11.5	14
CH21	1.32	12.6	12	10
CH22	1.35	7.6	9.5	11
CH23	1.2	4	12.5	11.3
CH24	1.15	8.4	6	20
CH25	1	4	7.5	14
CH26	1.7	3.7	8.5	6.4
CH27	1.45	9.2	11.5	15.5
CH28	1.3	10.5	6.5	12.3
CH29	1.1	8.4	5.5	10
CH30	0.95	10	8	8.3
CH31	1.25	6	5.5	11
CH32	0.89	7.3	5	10
CH33	0.98	8	4.5	8
CH34	0.92	6.4	4.5	7.2
CH35	1.35	5	6	13.3
CH36	1.36	11	6.5	12.4
CH37	1.4	10.5	5	9.2
CH38	1.2	10	5	11.3
CH39	1.1	7.5	5	10.4
CH40	1.05	5	4.5	9.8
CH41	0.85	10.5	5	7.9
CH42	1.1	8	5	10.3

CH43	1.3	6	5.5	11
CH44	1.2	6.4	5	12.4
CH45	0.79	10	4.5	9.3
CH46	0.82	12	4	7.5
CH47	0.93	6	4	6.3
CH48	1	8.3	5	8.4
CH49	1.15	7.5	4.5	7.4
CH50	1.3	4	8	6

KOTTAYAM				
Tree Id No.	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
KO01	1	11	10	12
KO02	0.82	9	5	5.6
KO03	0.92	10	9	6.5
KO04	0.95	9	11	4.3
KO05	1.1	8	10	7.9
KO06	0.95	11.6	10	5
KO07	1.35	4	4.5	8.9
KO08	0.94	10	8	6.7
KO09	1.2	6	7.5	8.9
KO10	1.54	3.5	5	11
KO11	1.32	8.5	11.5	10
KO12	1.15	7	10	7.6
KO13	0.88	9.5	7.5	5.6
KO14	0.94	9.7	8	8.8
KO15	0.89	10	11	4.8
KO16	0.76	11	8	5
KO17	1.1	6	6	10
KO18	1.1	7.6	9	11
KO19	1.05	6.6	6	9.5
KO20	1.3	4	5.5	10
KO21	0.88	8	5.5	6.1
KO22	0.79	8.4	6	5.3
KO23	0.94	9.9	8	11.4
KO24	1.1	8.4	9.5	8.6
KO25	1.23	6.7	8.5	12
KO26	1.15	11	10	11.8
KO27	0.95	10.6	7.5	9
KO28	1.32	4.6	6	12.5

KO29	1.1	8.9	6	11.8
KO30	1.33	4	5.5	11
KO31	1.28	5	9	7.6
KO32	0.84	11	10	6
KO33	1.11	8.4	7.5	11
KO34	1.42	7.6	7	13
KO35	1.89	3.3	5	12
KO36	1.34	4	6	10

TALIPARAMBA				
Tree Id No.	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
TA01	1.15	7	12	20
TA02	1.3	4.5	11	13
TA03	0.92	8.2	9	12
TA04	0.84	10	8	13
TA05	1.3	4.3	10	9
TA06	1.15	6.7	15	15.4
TA07	1.25	6.6	13.2	16
TA08	1.5	4.3	15	14.5
TA09	2.1	3	19.4	12
TA10	1.8	5	15	18
TA11	1.34	4.6	10	11
TA12	1.36	4.6	10.5	12
TA13	0.94	11	11	19
TA14	0.94	9	8	18
TA15	0.99	10	11	17
TA16	0.87	10	8	16
TA17	0.88	10	6	14
TA18	0.79	12	9	11.8
TA19	1.35	11.8	12	11
TA20	0.83	9.4	5.5	16
TA21	1.12	6.3	5.5	20.1
TA22	1.45	3.4	6	13
TA23	1.35	4.4	8	16.7
TA24	1.02	9.4	9.5	22
TA25	1.1	6.9	8.5	13
TA26	0.94	11.5	11	14
TA27	1.1	16	13	12

TA28	0.79	12	6	18
TA29	0.88	10.5	6	11
TA30	1.34	9.5	10.5	15
TA31	1.54	4	9	22
TA32	1.32	5.5	10	19
TA33	1.22	7	7.5	15
TA34	1.17	5.9	7	14.9
TA35	1.5	4	5	18
TA36	0.84	11.6	6	16.7
TA37	0.87	10	4.5	18

KOORACHUNDU				
Tree Id No	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
KH01	0.85	7	6	10
KH02	0.89	6	7	11
KH03	0.95	8	8	11
KH04	1.1	8	8.5	12
KH05	1.25	6	9	11.5
KH06	1.3	10	10.5	9
KH07	0.85	10	11	5.4
KH08	1.25	11	10.5	7
KH09	0.68	3	8	8.2
KH10	0.95	5	7	9
KH11	0.95	4.6	6	6
KH12	0.92	4.6	7	6
KH13	1.1	11	8	11
KH14	1.25	9	8	12
KH15	1.23	10	10.6	12
KH16	1.24	10	11	13
KH17	1.32	10	11.6	14
KH18	0.85	12	7.5	15
KH19	0.75	11.8	6	16
KH20	1.1	9.4	11.5	8.5
KH21	0.6	6.3	5	6
KH22	0.7	3.4	5	5
KH23	0.75	4.4	5	6.5
KH24	0.8	9.4	8	8
KH25	0.75	8	8	5
KH26	1.34	10	12	10

KH27	1.35	10	12	12
KH28	1.4	8.9	13	10
KH29	1	10.5	9.8	9
KH30	1.25	8	10.6	9
KH31	0.85	4	6.3	8
KH32	0.9	5.5	7.6	7.5
KH33	0.86	4.6	7	4.8
KH34	1.1	5	7.5	8

ELATHUR				
Tree Id No	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
EL01	0.75	4.8	5	18.9
E02	0.82	6	6.5	14
E03	0.96	7.1	7	18
E04	1	6.8	8	15
E05	0.98	4.8	6.4	15
E06	0.95	9.3	6.6	12
E07	1.25	8.8	7	11.5
E08	0.94	6.5	6	21
E09	1.25	5	8.5	14.5
E10	0.68	4	5	15
E11	0.94	6.4	7.5	14
E12	1.15	6.4	7.5	18
E13	1.32	7.8	9	15
E14	0.86	8	7.5	16
E15	0.77	5	6.5	15.6
E16	0.83	5.8	6	15.7
E17	1.34	4	8.5	23
E18	1.2	7.3	9.5	12.5
E19	1.25	5.8	9.5	13
E20	0.8	3.9	5.5	16.8
E21	0.79	6.8	6	16
E22	0.69	5	5.5	19.2
E23	1.65	7.3	13	9
E24	1.15	6	9.5	12
E25	0.93	3.3	6.5	18
E26	1.42	4.3	8.5	15
E27	0.78	5	5.5	18.5

E28	1.4	10	10.5	15
E29	1.2	5.8	8.5	25
E30	1.35	5.3	11	18.5

VADAKARA				
Tree Id No.	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
V01	1.45	12.3	9	11
V02	0.89	7.3	5	12.3
V03	0.98	8	4.5	8
V04	0.92	4	4.5	8.6
V05	1.5	5	6	13.3
V06	1.35	11.5	9.5	12.4
V07	1.15	12.5	8	9.5
V08	1.2	7.5	6.2	11.3
V09	1.1	7.9	7.3	10.4
V10	1.05	3	4.5	12.1
V11	0.85	4.4	6	7.9
V12	1.1	4.8	5.7	10.3
V13	1.3	5.2	6.1	11
V14	1.2	6	5.6	12.4
V15	0.79	3.6	4.5	12
V16	0.82	4.3	5.5	7.5
V17	0.93	3.5	5.6	8.8
V18	1.24	7.9	7.3	10
V19	1.15	6.3	6.3	7.4
V20	1.3	4.6	7.2	10.5
V21	1.85	5	9	28
V22	1.6	7.6	10	14.8
V23	1.55	10.3	7.5	25
V24	1.6	6.8	7	27
V25	1.4	3.3	5	20
V26	1.3	2.5	6	12
V27	0.8	5	4.5	15
V28	1.45	6.2	7	20.1
V29	1.15	5.3	6	15.8
V30	0.9	3.2	5.8	12
V31	1.65	4.5	8	10.6
V32	1.3	4	5.5	12
V33	0.85	3.5	4	15.2

V34	1.6	5	5	25.6
V35	1.5	6.5	7	15.7
V36	1.32	6.4	8.5	10.5
V37	1.28	3.8	8.5	6.5
V38	1.1	2.9	6	7.6
V39	0.75	3.3	5	6
V40	1.33	3	6	12

TRIKARIPUR				
Tree Id No.	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
TR01	0.85	8	6	5
TR02	0.94	8.5	9	4
TR03	0.85	9.5	7.8	4.9
TR04	1.3	12	12	9
TR05	1.5	8	13	8.5
TR06	1.1	13	12	7.5
TR07	1.54	13	12	5
TR08	1.2	11	11	8
TR09	0.96	15	11	8
TR10	0.87	11	8	4.9
TR11	0.75	7.5	5.5	5
TR12	0.92	9	8	9
TR13	0.98	12	9.4	6
TR14	1.1	8	10	5
TR15	0.72	11	5	8
TR16	0.94	11.6	11	4
TR17	0.71	6	4	9
TR18	0.94	15	12.6	3
TR19	1.25	10	13.4	8
TR20	1.11	10	10	5
TR21	0.94	12.4	5.6	7
TR22	0.89	8.7	6.4	7.5
TR23	0.87	8.4	6	7.5
TR24	0.86	8.6	8.6	7.5
TR25	0.87	11	10	8
TR26	0.83	10.6	9.1	7.9
TR27	0.81	12.4	8.6	6.4
TR28	0.74	11.2	9.4	4.5
TR29	0.94	13	10.6	5

TR30	1.05	6	8.6	5.9
TR31	1.4	10	12.4	9
TR32	1.5	11.5	11.3	5.5
TR33	1.3	13	12	6.5
TR34	1.1	11.8	12.6	6

NEELESWARAM				
Tree Id No.	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
N01	0.78	5.6	6	7
N02	0.85	6	6.5	9.5
N03	0.95	7	8	10
N04	0.89	7.5	8.5	11
N05	0.8	8.6	7.6	8.6
N06	0.93	6	4.9	9.5
N07	0.86	4.9	6	8.7
N08	0.94	5	6.5	9.6
N09	0.94	6	9.5	7.4
N10	1.02	7	10	8
N11	1	7.5	11	9
N12	1.3	6.5	11.5	8.5
N13	1.25	7	12.5	9
N14	0.98	7.3	9.7	6.5
N15	0.95	9.6	11.3	7.9
N16	0.96	8.1	9.5	8.7
N17	1.23	8	12	9
N18	1.1	8.5	12	10
N19	1.2	8	11	10.5
N20	1.3	8	11.3	11
N21	1.24	8.6	12	11
N22	1.35	7.9	13	9.5
N23	1.2	9.1	13.5	8.6
N24	1.1	7.5	9.5	8.5
N25	1	10	9.6	10
N26	1	9	10	10.5
N27	1.3	8	13	10
N28	1.5	11.5	15	9
N29	1.35	13.4	12.9	8.9
N30	1.45	11	13	10

PADNE				
Tree Id No	GBH (m)	CBH (m)	Crown width (m)	Crown length (m)
PA01	0.85	6	8	8
PA02	0.95	7	8	9
PA03	0.86	6.5	6.5	9.5
PA04	0.98	8	7	10
PA05	0.75	5	8	7
PA06	0.65	8.1	8.4	7
PA07	0.6	6	7.5	6
PA08	1.1	10	9.5	9
PA09	1.05	11	10	11
PA10	1.15	9.8	11.5	10.5
PA11	0.95	7.5	8	10
PA12	1.2	8	9	9
PA13	1.3	8.5	9.5	9.5
PA14	1.25	8.6	9.8	10
PA15	1.1	9.1	10	11
PA16	1	10.6	10	12
PA17	1.35	8.4	10.5	11
PA18	1	7.9	11	10
PA19	1.2	11.1	11.5	8.5
PA20	0.9	12.1	11	9.5
PA21	1	10	11	9
PA22	1.05	9.4	11	9
PA23	1.1	8.9	11.5	9
PA24	0.85	7.5	10	4
PA25	0.95	5	6	11
PA26	1.4	6.5	12	11.5
PA27	1.36	8	11	11
PA28	1.38	8.5	11	12
PA29	1	7	10	9
PA30	0.85	8	9.5	8.5

APPENDIX III

Scoring for qualitative characters of *Swietenia macrophylla*

Tree Id No.	verticality	apical	forking	branch angle	self-pruning	foliar	stem damage	bole swelling	total scores
KALPETTA									
K01	2	5	5	12	3	4	6	2	39
K02	1	1	1	6	1	1	6	2	19
K03	1	8	1	6	1	1	6	2	26
K04	1	1	1	6	1	1	6	2	19
K05	2	1	1	6	1	1	6	2	20
K06	1	1	5	6	1	4	6	2	26
K07	1	5	1	6	1	1	6	2	23
K08	2	1	1	6	1	1	1	1	14
K09	1	1	3	6	1	1	6	2	21
K10	1	1	1	6	1	1	6	2	19
K11	1	5	1	6	1	1	6	2	23
K12	1	1	1	6	1	4	6	2	22
K13	1	1	1	6	1	1	6	2	19
K14	2	5	5	12	3	4	6	2	39
K15	2	5	3	12	3	4	6	2	37
K16	1	1	3	6	1	1	6	2	21
K17	1	1	1	6	1	1	6	2	19
K18	2	5	1	6	1	1	1	2	19
K19	1	1	1	6	1	4	6	2	22
K20	1	1	1	6	3	1	6	2	21
K21	1	8	1	6	1	1	1	1	20
K22	1	1	5	6	1	1	6	2	23
K23	1	1	1	6	1	1	6	2	19
K24	1	1	1	6	1	1	6	2	19
K25	2	1	1	6	3	1	6	2	22
K26	1	1	3	6	1	1	6	2	21
K27	1	8	1	6	1	4	6	2	29
K28	2	1	1	6	1	1	6	2	20
K29	1	8	3	6	1	1	6	2	28

K30	1	1	1	6	3	4	6	2	24
K31	1	5	1	6	1	1	6	2	23
K32	2	1	3	6	3	1	6	2	24
K33	1	5	1	6	1	1	6	2	23
K34	1	1	1	6	3	4	6	2	24
K35	2	5	3	6	1	1	6	2	26
K36	1	8	1	6	3	1	6	2	28
K37	1	1	1	6	1	1	6	2	19
K38	1	1	3	6	1	4	6	2	24
K39	2	5	1	6	3	1	6	2	26
K40	1	1	1	6	1	1	6	2	19
K41	1	1	1	6	1	4	6	2	22
K42	1	5	3	6	3	1	6	2	27
K43	2	1	1	6	1	4	6	2	23
K44	1	8	1	6	1	1	6	2	26
K45	1	1	3	6	1	4	6	2	24
K46	2	1	1	6	1	1	6	2	20
K47	1	5	1	6	1	4	6	2	26
K48	1	1	1	6	1	1	6	2	19
K49	2	5	1	6	3	4	6	2	29
K50	1	1	1	6	1	1	6	2	19

SULTHAN BATHERY									
SB01	1	8	1	6	1	1	6	2	26
SB02	1	8	1	6	1	1	6	2	26
SB03	1	8	3	6	1	1	6	2	28
SB04	1	8	1	6	1	1	6	2	26
SB05	2	8	1	6	1	1	6	2	27
SB06	2	8	1	6	1	1	6	2	27
SB07	1	8	1	6	1	1	6	2	26
SB08	1	8	1	6	1	4	1	1	23
SB09	1	8	5	6	1	1	6	2	30
SB10	1	8	5	6	1	1	6	2	30
SB11	2	8	1	6	1	4	6	2	30
SB12	1	8	1	6	1	4	6	2	29
SB13	1	8	5	6	1	1	6	2	30
SB14	1	8	1	6	1	1	6	1	25
SB15	1	8	1	6	3	4	6	2	31
SB16	2	8	1	6	1	1	6	2	27
SB17	1	8	5	6	1	1	6	2	30

SB18	1	8	5	6	1	1	1	2	25
SB19	1	8	5	6	1	4	6	2	33
SB20	2	8	5	12	3	4	6	2	42
SB21	2	8	5	6	1	1	1	1	25
SB22	2	8	5	6	1	1	6	2	31
SB23	1	1	5	6	1	1	6	2	23
SB24	1	1	5	6	1	1	6	2	23
SB25	2	1	1	6	3	1	6	2	22
SB26	1	8	3	6	1	1	6	2	28
SB27	1	5	1	6	1	4	6	2	26
SB28	1	1	1	6	1	1	6	2	19
SB29	2	5	3	6	1	1	6	2	26
SB30	1	1	1	6	3	4	6	2	24
SB31	2	5	3	12	3	4	6	2	37
SB32	1	5	3	6	3	1	6	2	27
SB33	1	8	1	6	1	1	6	2	26
SB34	1	1	1	6	3	4	6	2	24
SB35	2	8	3	6	1	1	6	2	29
SB36	1	1	1	6	3	1	6	2	21
SB37	2	5	5	12	3	4	6	2	39
SB38	1	8	3	6	1	4	6	2	31
SB39	1	1	1	6	3	1	6	2	21
SB40	2	1	1	6	1	1	6	2	20
SB41	2	5	1	6	1	4	6	2	27
SB42	1	5	3	6	3	1	6	2	27
SB43	1	1	1	6	1	4	6	2	22
SB44	1	1	1	6	1	1	6	2	19
SB45	1	1	3	6	1	4	6	2	24
SB46	1	1	1	6	1	1	6	2	19
SB47	2	1	1	6	1	4	6	2	23
SB48	1	5	1	6	1	1	6	2	23
SB49	1	5	1	6	3	4	6	2	28
SB50	1	1	1	6	1	1	6	2	19

PADINJARETHARA									
P1	1	5	1	6	1	4	6	2	26
P2	1	1	1	6	1	4	6	2	22
P3	1	8	1	6	1	4	6	2	29
P4	2	1	1	6	1	4	6	2	23
P5	2	1	1	6	1	4	6	2	23

P6	2	1	5	6	1	4	6	2	27
P7	2	5	5	6	1	4	6	2	31
P8	2	1	5	6	1	4	1	1	21
P9	2	1	5	6	1	4	6	2	27
P10	2	1	5	6	1	4	6	2	27
P11	2	5	3	12	3	4	6	2	37
P12	2	1	5	6	1	4	6	2	27
P13	1	1	5	6	1	4	6	2	26
P14	1	8	3	6	1	4	6	1	30
P15	1	8	1	6	3	4	6	2	31
P16	1	8	3	6	3	1	6	2	30
P17	1	8	1	6	3	4	6	2	31
P18	2	5	5	12	3	4	6	2	39
P19	1	8	1	6	3	4	6	2	31
P20	1	8	1	6	3	4	6	2	31
P21	1	8	1	6	1	1	1	1	20
P22	2	8	5	6	1	4	6	2	34
P23	1	8	1	6	1	4	6	2	29
P24	2	8	5	12	3	4	6	2	37
P25	1	8	1	6	3	4	6	2	31
P26	1	8	3	6	1	4	6	2	31
P27	1	8	1	6	1	4	6	2	29
P28	1	1	1	6	1	4	6	2	22
P29	1	8	1	6	1	4	6	2	29
P30	1	1	1	6	3	1	6	2	21

KANIYAMBETTA									
KA01	2	5	3	6	3	4	6	2	31
KA02	2	1	3	6	3	4	6	2	27
KA03	2	8	1	6	3	4	6	2	32
KA04	2	1	1	6	3	4	6	2	25
KA05	2	1	1	6	3	4	6	2	25
KA06	2	1	3	6	3	4	6	2	27
KA07	2	5	3	6	3	4	6	2	31
KA08	2	1	3	6	3	4	1	1	21
KA09	1	1	3	6	1	4	6	2	24
KA10	1	1	3	6	1	4	6	2	24
KA11	1	5	1	6	1	4	6	2	26
KA12	2	1	5	6	1	4	6	2	27
KA13	2	5	5	12	3	4	6	2	39

KA14	2	5	3	6	1	4	6	1	28
KA15	1	5	1	6	3	4	6	2	28
KA16	1	5	3	6	3	1	6	2	27
KA17	1	5	1	6	3	4	6	2	28
KA18	2	1	3	6	3	4	1	2	22
KA19	1	8	1	6	3	4	6	2	31
KA20	2	5	5	12	3	4	6	2	39
KA21	1	8	3	6	1	1	1	1	22
KA22	1	8	5	6	1	4	6	2	33
KA23	1	5	1	6	1	4	6	2	26
KA24	1	5	1	6	1	4	6	2	26
KA25	2	8	5	6	3	4	6	2	42
KA26	2	8	3	6	1	4	6	2	32
KA27	2	8	1	6	1	4	6	2	30
KA28	2	1	1	6	1	4	6	2	23
KA29	2	1	1	6	1	4	6	2	23
KA30	1	1	3	6	3	1	6	2	23

MANATHAVADY									
M01	2	5	3	6	1	4	6	2	29
M02	2	1	3	6	3	4	6	2	27
M03	1	8	1	6	3	4	6	2	31
M04	2	1	1	6	3	4	6	2	25
M05	2	1	1	6	3	4	6	2	25
M06	1	1	3	6	3	4	6	2	26
M07	2	5	3	6	3	4	6	2	31
M08	2	1	3	6	3	4	6	2	27
M09	2	1	3	6	3	4	6	2	27
M10	1	1	3	6	3	4	6	2	26
M11	2	5	3	12	3	4	6	2	37
M12	1	1	5	12	1	1	6	1	28
M13	1	1	5	6	1	4	6	2	26
M14	2	5	3	6	1	4	6	2	29
M15	2	5	1	6	3	4	6	2	29
M16	1	5	3	6	3	4	6	2	30
M17	1	5	1	6	3	4	6	2	28
M18	2	8	3	12	3	4	6	2	40
M19	1	8	1	12	3	1	6	1	33
M20	1	8	1	6	3	4	6	1	30
M21	2	8	3	6	1	4	6	2	32

M22	1	8	5	6	3	4	6	2	35
M23	1	5	1	6	3	4	6	2	28
M24	2	5	1	6	3	4	6	2	29
M25	1	5	3	6	3	4	6	1	29
M26	2	8	3	6	3	4	6	2	34
M27	2	8	1	6	3	1	6	2	29
M28	2	1	1	6	3	4	6	1	24
M29	2	8	1	6	3	4	6	2	32
M30	1	5	3	6	3	1	6	2	27
M31	1	5	1	12	1	4	6	2	32
M32	2	1	3	6	3	4	6	2	27
M33	1	5	3	6	3	1	6	2	27
M34	1	1	1	6	1	4	6	2	22
M35	2	5	5	12	3	4	6	2	39
M36	1	1	3	6	1	4	6	2	24
M37	1	1	3	6	3	4	6	2	26

PUDUPPADY									
PU01	2	5	1	6	1	4	6	2	27
PU02	2	1	1	6	1	4	6	2	23
PU03	1	5	1	6	1	4	6	2	26
PU04	1	1	1	6	1	4	6	2	22
PU05	1	1	1	6	1	4	6	2	22
PU06	2	1	1	6	1	4	6	2	23
PU07	2	5	1	6	1	1	6	2	24
PU08	1	1	1	6	1	4	1	1	16
PU09	2	1	3	6	1	4	6	2	25
PU10	2	1	1	6	1	4	6	2	23
PU11	1	5	1	6	1	4	6	2	26
PU12	2	1	3	6	1	4	6	2	25
PU13	1	1	1	6	1	4	6	2	22
PU14	1	5	3	6	1	4	6	1	27
PU15	2	8	3	12	3	4	6	2	40
PU16	2	1	3	6	1	1	6	2	22
PU17	2	1	1	6	1	4	6	2	23
PU18	1	5	3	6	1	4	1	2	23
PU19	1	1	1	6	1	4	6	2	22
PU20	2	8	5	6	3	4	6	2	36
PU21	1	8	1	6	1	4	1	1	23
PU22	2	1	1	6	1	4	6	2	23

PU23	1	1	1	6	1	4	6	2	22
PU24	2	1	1	6	1	1	6	2	20
PU25	1	1	1	6	3	1	6	2	21
PU26	2	1	1	6	1	1	6	2	20
PU27	1	8	3	6	1	4	6	2	31
PU28	2	1	1	6	1	4	6	2	23
PU29	1	8	1	6	1	4	6	2	29
PU30	2	1	1	6	3	4	6	2	25
PU31	2	1	1	6	3	4	6	2	25
PU32	2	1	1	6	3	4	6	2	25
PU33	2	1	3	6	3	4	6	2	27
PU34	2	1	1	6	3	4	6	2	25
PU35	2	5	3	12	3	4	6	2	37
PU36	2	1	5	6	3	4	6	2	29
PU37	2	1	1	6	3	4	6	2	25
PU38	2	1	1	6	3	4	6	2	25
PU39	2	1	3	6	3	4	6	2	27
PU40	2	1	1	6	3	4	6	2	25
PU41	2	1	1	6	3	1	6	2	22
PU42	2	1	1	6	3	1	6	2	22
PU43	2	1	1	6	3	4	6	2	25
PU44	2	1	3	6	3	4	6	2	27
PU45	2	1	1	6	3	4	6	2	25
PU46	2	1	1	6	3	4	6	2	25
PU47	2	1	1	6	3	4	6	2	25
PU48	2	1	3	6	3	4	6	2	27
PU49	2	1	1	6	3	4	6	2	25
PU50	2	1	1	6	3	4	6	2	25

CHAKKITTAPARA									
CH01	2	8	1	6	1	4	6	1	29
CH02	2	1	1	6	1	4	6	2	23
CH03	1	5	1	6	1	4	6	1	25
CH04	1	1	1	6	1	4	6	2	22
CH05	1	5	1	6	1	4	6	2	26
CH06	2	1	1	6	1	4	6	2	23
CH07	1	5	1	6	1	4	6	2	26
CH08	1	1	1	6	1	4	6	2	22

CH09	2	1	3	6	1	4	6	2	25
CH10	2	1	1	6	1	4	6	2	23
CH11	1	5	1	6	1	1	6	2	23
CH12	2	8	3	12	3	4	6	2	40
CH13	1	1	1	6	1	4	6	2	22
CH14	1	5	3	6	1	4	6	1	27
CH15	2	8	3	6	3	4	6	2	34
CH16	2	1	3	6	1	4	6	2	25
CH17	2	1	3	6	3	4	6	2	27
CH18	1	5	3	6	1	4	6	1	27
CH19	1	1	3	6	1	4	6	2	24
CH20	2	1	1	6	1	4	6	2	23
CH21	1	8	3	6	1	4	6	2	31
CH22	2	1	1	6	1	4	6	2	23
CH23	2	1	1	6	1	4	6	2	23
CH24	2	1	3	6	1	4	6	2	25
CH25	2	8	3	12	3	4	6	2	40
CH26	2	1	3	6	1	4	6	2	25
CH27	2	8	1	6	3	4	6	2	32
CH28	2	1	1	6	1	4	6	2	23
CH29	2	8	5	6	1	4	6	2	34
CH30	2	8	5	12	3	4	6	1	41
CH31	1	1	1	6	3	4	6	2	24
CH32	2	1	1	6	1	4	6	2	23
CH33	2	1	3	6	3	4	6	2	27
CH34	2	1	5	6	1	4	6	2	27
CH35	1	1	1	6	3	4	6	2	24
CH36	2	5	5	6	3	4	6	2	33
CH37	2	1	5	6	1	4	6	2	27
CH38	2	5	1	6	3	4	6	2	29
CH39	2	1	3	6	3	4	6	2	27
CH40	2	1	1	6	1	4	6	2	23
CH41	1	1	1	12	1	1	6	2	25
CH42	2	8	1	6	1	4	6	2	30
CH43	2	1	1	6	3	1	6	2	22
CH44	2	1	3	6	3	4	6	2	27
CH45	2	1	1	6	3	4	6	2	25
CH46	2	8	1	6	3	4	6	2	32
CH47	2	1	1	6	3	4	6	2	25
CH48	2	1	3	6	3	1	6	2	24

CH49	2	5	1	6	3	4	6	2	29
CH50	2	1	1	6	3	4	6	2	25

KOTTAYAM									
KO01	2	1	3	6	3	4	6	2	27
KO02	2	1	1	6	1	4	6	2	23
KO03	2	8	3	6	1	4	6	2	32
KO04	2	1	1	6	3	4	6	2	25
KO05	2	1	1	6	1	4	6	2	23
KO06	1	1	3	6	1	4	6	2	24
KO07	2	1	1	6	1	1	6	2	20
KO08	2	1	1	6	1	4	1	2	18
KO09	1	1	1	6	1	4	6	2	22
KO10	2	8	3	6	1	4	6	2	32
KO11	2	1	1	6	1	4	6	2	23
KO12	2	1	1	6	1	4	6	2	23
KO13	2	8	1	6	3	4	6	2	32
KO14	1	5	3	6	1	4	6	2	28
KO15	2	1	1	6	1	4	6	2	23
KO16	1	1	1	6	1	1	6	2	19
KO17	2	5	1	6	3	4	6	2	29
KO18	2	5	3	6	1	4	1	2	24
KO19	2	5	1	6	1	4	6	2	27
KO20	2	1	1	6	1	4	6	2	23
KO21	2	8	5	12	3	4	6	2	42
KO22	2	1	1	6	1	4	6	2	23
KO23	2	1	1	6	3	4	6	2	25
KO24	2	5	1	6	1	1	6	2	24
KO25	2	1	1	6	3	1	6	2	22
KO26	2	5	5	12	3	4	6	2	39
KO27	2	1	3	6	1	4	6	2	25
KO28	2	1	1	6	3	4	6	1	24
KO29	2	8	5	12	3	4	6	1	41
KO30	1	1	1	6	3	4	6	2	24
KO31	2	5	1	6	3	4	6	2	29
KO32	1	1	1	6	1	4	6	1	21
KO33	2	5	3	6	1	4	6	2	29
KO34	1	1	1	6	1	4	6	2	22
KO35	2	8	1	6	3	4	6	2	32

KO36	1	1	5	6	3	4	6	1	27

TALIPARAMBA									
TA01	1	5	1	6	1	4	6	1	25
TA02	2	1	1	6	3	4	6	2	25
TA03	1	1	3	6	3	4	6	2	26
TA04	2	1	5	6	3	4	6	2	29
TA05	2	1	1	6	3	4	6	2	25
TA06	2	8	3	6	1	4	6	2	32
TA07	2	1	1	6	1	4	6	2	23
TA08	1	5	5	6	3	1	1	2	24
TA09	2	1	5	6	1	4	6	2	27
TA10	2	5	3	6	1	1	6	1	25
TA11	2	8	5	6	3	4	6	2	36
TA12	1	1	1	6	3	4	6	2	24
TA13	2	1	3	6	3	1	6	2	24
TA14	2	5	3	6	1	4	6	2	29
TA15	2	1	1	6	3	4	6	2	25
TA16	2	5	3	12	3	4	6	2	37
TA17	2	1	1	6	3	4	6	1	24
TA18	1	5	3	6	1	4	6	2	28
TA19	2	1	1	6	1	4	6	2	23
TA20	2	8	5	6	3	4	6	1	41
TA21	2	1	3	6	3	4	6	2	27
TA22	1	5	3	6	1	4	6	2	28
TA23	2	1	1	6	1	4	6	2	23
TA24	2	5	3	6	1	4	6	1	28
TA25	2	1	1	6	1	4	6	2	23
TA26	2	5	3	6	1	4	6	2	29
TA27	2	5	5	6	3	4	6	2	33
TA28	2	1	5	6	1	1	6	2	24
TA29	2	5	3	6	1	4	6	2	29
TA30	2	1	5	6	3	4	1	2	24
TA31	1	5	3	6	3	4	6	2	30
TA32	2	5	1	6	1	1	6	2	24
TA33	2	5	3	6	1	4	6	2	29
TA34	1	1	1	6	1	4	6	2	22
TA35	2	8	5	6	1	4	6	2	34
TA36	2	1	5	6	3	1	6	2	26
TA37	1	1	1	6	3	1	1	2	16

KOORACHUNDU									
KH01	2	8	3	6	1	1	6	2	29
KH02	2	5	1	6	3	4	6	2	29
KH03	1	1	5	6	5	4	6	1	29
KH04	2	1	5	6	3	4	6	2	29
KH05	1	5	1	6	3	4	6	2	28
KH06	2	5	1	6	1	4	6	2	27
KH07	2	1	1	6	1	4	6	1	22
KH08	2	1	3	6	3	1	6	2	24
KH09	2	1	5	6	1	4	6	2	27
KH10	1	5	3	6	3	4	6	2	30
KH11	2	1	1	6	1	4	6	2	23
KH12	2	1	1	6	3	4	1	2	20
KH13	2	1	3	6	1	4	6	1	24
KH14	2	8	1	6	1	4	6	2	30
KH15	1	1	3	6	3	4	6	2	26
KH16	2	1	1	6	1	4	6	2	23
KH17	2	1	1	6	3	1	6	1	21
KH18	2	1	3	6	3	4	6	2	27
KH19	2	8	3	6	1	4	6	2	32
KH20	2	8	1	6	3	4	6	2	32
KH21	2	8	3	12	3	4	6	2	40
KH22	2	5	1	6	1	4	6	2	27
KH23	2	8	1	6	1	4	6	2	30
KH24	2	5	3	6	3	4	6	2	31
KH25	1	5	1	6	1	1	6	2	23
KH26	2	5	3	6	1	4	6	2	29
KH27	2	5	5	6	1	4	1	2	26
KH28	2	5	5	12	3	4	6	2	39
KH29	1	5	3	6	3	4	6	1	29
KH30	2	8	5	12	3	4	6	2	41
KH31	2	5	3	6	1	4	6	1	28
KH32	2	8	1	6	1	1	6	2	27
KH33	2	5	3	6	1	4	6	2	29
KH34	2	8	1	6	1	4	1	1	24

ELATHUR									
EL01	1	5	1	6	1	4	6	2	26
EL02	1	8	1	6	1	4	6	1	28
EL03	2	1	3	6	5	4	6	2	29
EL04	2	1	5	6	3	1	1	2	21
EL05	2	5	3	12	3	4	6	2	37
EL06	1	5	5	6	3	4	6	2	32
EL07	2	1	1	6	1	4	1	2	18
EL08	1	1	1	6	1	4	6	2	22
EL09	2	1	1	6	1	4	6	2	23
EL10	1	5	3	6	3	4	6	2	30
EL11	2	1	1	6	5	4	6	2	27
EL12	1	1	1	6	3	4	6	2	24
EL13	2	1	5	6	5	4	6	2	31
EL14	2	5	1	6	5	4	6	2	31
EL15	2	12	3	6	3	4	6	2	37
EL16	1	1	1	6	3	4	6	2	24
EL17	2	1	1	6	3	4	6	2	25
EL18	2	1	5	6	1	4	1	2	22
EL19	1	5	3	6	1	4	6	1	27
EL20	2	8	1	6	1	4	6	2	30
EL21	1	1	5	6	1	1	6	2	23
EL22	2	5	1	6	1	4	6	2	27
EL23	2	1	1	6	1	4	1	2	18
EL24	1	5	3	6	3	4	6	2	30
EL25	1	8	1	6	1	4	6	2	29
EL26	2	5	3	6	1	4	6	2	29
EL27	2	1	1	6	5	4	6	2	27
EL28	1	1	5	6	5	4	6	2	30
EL29	1	5	1	6	5	4	6	2	30
EL30	2	8	3	12	3	4	6	2	40

VADAKARA									
V1	1	5	1	6	1	4	6	2	26
V2	1	1	1	6	1	4	6	2	22
V3	1	8	1	6	1	4	6	2	29
V4	1	1	1	6	1	4	6	2	22
V5	2	1	1	6	1	4	6	2	23
V6	2	1	5	6	1	4	6	2	27
V7	1	5	1	6	1	4	6	2	26

V8	1	1	1	6	1	4	1	1	16
V9	2	1	3	6	1	4	6	2	25
V10	2	1	1	6	1	1	6	2	20
V11	1	5	1	6	1	1	6	2	23
V12	2	8	5	12	3	4	6	2	37
V13	2	1	1	6	1	4	6	2	23
V14	2	8	3	6	1	4	6	1	31
V15	2	8	5	12	3	4	6	1	41
V16	2	1	3	6	1	4	6	2	25
V17	2	8	5	12	3	4	6	2	42
V18	2	5	1	6	1	1	1	2	19
V19	1	1	1	6	1	4	6	2	22
V20	2	1	1	6	3	4	6	2	25
V21	1	8	1	6	1	4	1	1	23
V22	2	1	5	6	1	4	6	2	27
V23	1	1	1	6	1	4	6	2	22
V24	1	1	1	6	1	4	6	2	22
V25	2	1	1	6	3	4	6	2	25
V26	2	1	3	6	1	4	6	2	25
V27	2	8	1	6	1	4	6	2	30
V28	2	1	1	6	1	4	6	2	23
V29	2	8	1	6	1	4	6	2	30
V30	2	8	1	6	3	4	6	2	32
V31	2	8	3	6	3	1	6	2	31
V32	2	1	3	6	3	4	6	2	27
V33	2	8	3	6	3	4	6	2	34
V34	1	5	5	6	3	4	6	2	32
V35	2	8	1	6	1	4	6	2	30
V36	2	1	5	6	3	1	6	2	26
V37	2	8	5	6	3	4	6	2	36
V38	1	5	3	6	3	4	6	2	30
V39	2	5	3	6	3	4	6	2	31
V40	2	5	3	6	3	1	6	2	28

TRIKARIPUR									
TR01	1	1	3	6	1	4	6	2	24
TR02	1	5	5	6	1	4	6	1	29
TR03	2	8	5	6	5	4	6	2	38

TR04	2	1	5	6	3	1	1	2	21
TR05	2	1	5	6	3	4	6	2	29
TR06	2	8	1	6	3	4	6	2	32
TR07	1	8	1	6	1	4	1	2	24
TR08	2	8	3	12	3	4	6	2	40
TR09	2	5	1	6	1	4	6	2	27
TR10	2	1	5	6	3	4	6	2	29
TR11	2	5	1	6	5	4	6	2	31
TR12	1	5	5	6	3	4	6	2	32
TR13	2	8	5	12	5	4	6	2	42
TR14	2	1	5	6	5	4	6	2	31
TR15	2	8	3	6	5	4	6	2	36
TR16	2	1	5	6	3	4	6	2	29
TR17	2	1	3	6	3	4	6	2	27
TR18	2	1	5	6	1	4	1	2	22
TR19	2	1	3	6	1	4	6	1	24
TR20	2	5	5	6	1	4	6	2	31
TR21	2	8	5	6	1	1	6	2	31
TR22	2	5	5	6	1	4	6	2	31
TR23	2	8	5	12	3	4	6	2	42
TR24	1	5	3	6	3	4	6	2	30
TR25	1	8	3	6	1	4	6	2	31
TR26	1	1	3	6	1	4	6	2	24
TR27	2	5	5	6	5	4	6	2	35
TR28	2	1	5	6	5	4	6	2	31
TR29	2	5	5	6	5	4	6	2	35
TR30	1	5	5	6	1	4	1	2	25
TR31	1	5	1	6	1	4	6	1	25
TR32	2	8	1	6	1	1	6	2	27
TR33	2	5	3	6	1	4	6	2	29
TR34	1	8	1	6	1	4	1	1	23

NEELESWARAM									
N01	1	1	1	6	3	4	6	2	24
N02	1	1	3	6	1	4	6	1	23
N03	1	1	5	6	1	4	6	2	26
N04	1	1	5	6	1	1	1	2	18
N05	1	1	3	6	1	4	6	1	23
N06	1	5	1	6	1	4	6	2	26
N07	1	5	1	6	1	4	1	2	21

N08	2	5	3	6	1	4	6	1	28
N09	2	5	1	6	1	4	6	2	27
N10	2	5	5	6	1	4	6	2	31
N11	2	5	1	6	1	4	6	2	27
N12	2	8	5	12	3	4	1	2	37
N13	1	5	5	6	1	4	6	2	30
N14	1	5	5	6	1	4	6	2	30
N15	1	5	5	6	1	4	6	2	30
N16	2	8	3	12	3	4	6	2	40
N17	2	5	3	6	3	4	6	2	31
N18	1	1	5	6	1	4	1	1	20
N19	1	1	3	6	1	4	6	2	24
N20	2	5	3	6	1	4	6	2	29
N21	2	8	5	12	3	4	6	2	42
N22	2	5	3	6	1	4	6	2	29
N23	1	5	5	6	1	4	1	2	25
N24	1	5	3	6	3	4	6	2	30
N25	1	8	3	6	1	4	6	1	30
N26	1	1	3	6	1	4	6	2	24
N27	2	5	5	6	5	4	6	2	35
N28	2	1	5	6	5	4	6	2	31
N29	2	5	5	6	5	4	6	1	34
N30	1	5	5	6	1	4	1	2	25

PADNE									
PD01	1	5	1	6	1	1	6	2	23
PD02	1	1	1	6	1	1	6	2	19
PD03	1	8	1	6	1	1	6	2	26
PD04	2	1	1	6	1	1	6	2	20
PD05	2	1	1	6	1	1	6	2	20
PD06	1	1	5	6	1	4	6	2	26
PD07	1	5	1	6	1	1	6	2	23
PD08	1	1	1	6	1	1	1	1	13
PD09	1	1	3	6	1	1	6	2	21
PD10	2	1	1	6	1	1	6	2	20
PD11	2	8	3	12	3	4	6	2	40
PD12	1	1	1	6	1	4	6	2	22
PD13	1	1	1	6	1	1	6	2	19
PD14	1	8	3	6	1	1	6	1	27
PD15	1	1	1	6	3	1	6	2	21

PD16	1	1	3	6	1	1	6	2	21
PD17	1	1	1	6	1	1	6	2	19
PD18	2	5	3	12	3	4	6	2	37
PD19	1	1	1	6	1	4	6	2	22
PD20	1	1	1	6	3	1	6	2	21
PD21	1	8	1	6	1	1	1	1	20
PD22	2	1	5	6	1	1	6	2	24
PD23	1	1	1	6	1	1	6	2	19
PD24	1	1	1	6	1	1	6	2	19
PD25	2	8	3	12	3	4	6	2	40
PD26	1	1	3	6	1	1	6	2	21
PD27	1	8	1	6	1	4	6	2	29
PD28	1	1	1	6	1	1	6	2	19
PD29	1	8	1	6	1	1	6	2	26
PD30	1	1	1	6	3	1	6	2	21

DIVERSITY ANALYSIS AND SELECTION OF CANDIDATE PLUS TREES OF *Swietenia macrophylla* FROM SELECTED DISTRICTS OF NORTH KERALA

by

Aleena Thomas Moor

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ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN FORESTRY

Faculty of Forestry

Kerala Agricultural University

DEPARTMENT OF FOREST BIOLOGY AND TREE IMPROVEMENT

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KERALA, INDIA

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ABSTRACT

Big leaf mahogany (*Swietenia macrophylla*, King) is a valuable Neotropic timber species. It is the first extensively traded timber species to be listed in Appendix II of the CITES in 2002. The tree was introduced to India in 1795 and to Malabar in 1872. The study was aimed at selecting plus trees of *Swietenia macrophylla* and evaluate genetic variability of the selected plus trees and their progeny.

Forty-five plus trees were selected from 593 candidate trees spread over fifteen locations in North Kerala. The plus tree selection was done based on base line regression of trunk volume to crown volume, followed by tree scoring for qualitative characters. The clean bole height, GBH, crown width, crown volume and wood density of CPTs ranged from 6 m to 13.4 m, 0.75 m to 2.00 m, 8 m to 15 m, 7 m to 16 m and 21 mm to 23 mm respectively. Forty-five plus trees were grouped into five clusters based on their quantitative and qualitative characters. Cluster II had the maximum number of plus trees with thirty-five accessions, and cluster III and cluster IV had the minimum number of plus trees with one accession each. The plus trees of different geographic origin were clustered into same cluster indicating that geographic location was inconsistent with the genetic diversity. Cluster II had the maximum intra cluster distance (2.45) which may be attributed to the environmental factors.

Progeny evaluation of the seedlings of *Swietenia macarophylla* plus trees was done. The observation showed significant differences for seedling height, germination percentage, number of leaves, collar diameter, photosynthetic rate, transpiration, stomatal conductance and leaf temperature and they ranged from 15.4 cm to 24.5 cm, 10 percent to 43.3 percent, 3.67 to 9.67, 1.61 mm to 2.97 mm, 0.6 µmol CO_2 m-^{2} s^{-1} to 6.1 µmol CO_2 m-^{2} s^{-1}, 0.24 mmol H_2O m^{-2} s^{-1} to 2.6 mmol H_2O m^{-2} s^{-1}, 0.10 m mol H_2O m-^{2} s^{-1} to 0.86 m mol H_2O m-^{2} s^{-1} and 33.03°C to 33.56°C respectively. Progenies of plus trees FCV-SM-08 showed better performances in the number of leaves, seedling height, and vigor index. Progenies of FCV-SM-43 showed better performances in germination percentage and leaf temperature. Progenies of FCV-SM-37 showed better performances in collar diameter and transpiration, whereas

progenies of FCV-SM-18 and FCV-SM-17 showed good performance in photosynthetic rate and transpiration. It was also noted that all these plus trees belonged to cluster II, which was the most divergent. Therefore, these CPTs can be used for further tree improvement programs. The principal component analysis revealed that the grouping of accessions into various clusters was because of the relatively high contribution of characters like GBH, crown length, pin penetration depth, apical dominance and forking.

The genetic coefficient of variation for the seedling morphological character was lower than the seedling phenotypic variation. The heritability value was also less except for seedling height indicating variations in the progeny characters are more influenced by environmental factors rather than genetics. The seedling height had a narrow difference between the GCV (1.4) and PCV (4.2) indicating the variation is due to genetic factors rather than environmental factors. The genetic advance value for seedling height and the number of leaves was moderate indicating that the characters were governed by additive genes. Hence, seedling height can be taken as a parameter for selection. For physiological parameters, GCV was higher than PCV for all characters

Correlation analysis of the morphological and physiological traits of progenies of the selected plus trees showed that there were positive and significant relations between germination and seedling height, photosynthetic rate and number of leaves. Photosynthesis was also correlated with transpiration, stomatal conductance and leaf temperature. Stomatal conductance was correlated with transpiration and leaf temperature. Leaf temperature was correlated with transpiration

From the result, can be concluded that there existed considerable variations among the plus trees of *Swietenia macrophylla*, King. These heritable variations can be utilized for the selection of trees and thereby help in the future breeding program.