Selection for drought tolerance and wood quality traits from selected accessions of *Tectona grandis* Linn. f.

By

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2020

DECLARATION

I, hereby declare that this thesis entitled **"Selection for drought tolerance and wood quality traits from selected accessions of *Tectona grandis* Linn. f."** is a bonafide record of research 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, associate ship, fellowship or other similar title, of any other University or Society.

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TABLE OF CONTENTS

CHAPTER NO. 1	TITLE	PAGE NUMBER
1.	INTRODUCTION	1-2
2.	REVIEW OF LITERATURE	3-18
3.	MATERIALS AND METHODS	19-35
4.	RESULTS	36-68
5.	DISCUSSION	69-92
6.	SUMMARY	93-97
7.	REFERENCES	i-xviii

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
1	Details of accessions of teak used for the study	20
2	Weather parameters measured during days of drought	23
3	Variations in height, girth, pilodyn penetration depth, specific gravity and stress wave velocity among accessions of *Tectona grandis*	28
4	Correlation between growth parameters and wood properties among accessions of *Tectona grandis*	39
5	Soil moisture content among accessions of *Tectona grandis* during normal condition of growth and drought stress	40
6	Number of leaves withered during drought among the accessions of *Tectona grandis*	42
7	Effect of physiological characters under three stages of drought stress in *Tectona grandis*	46
8	Physiological response of *Tectona grandis* accessions under normal condition of growth	49-50
9	Correlation between physiological parameters of *Tectona grandis* under normal condition of growth	52
10	Clusters for physiological parameters among *Tectona grandis* accessions during normal condition of growth	53
11	Distance between cluster centroids among accessions of *Tectona grandis* under normal condition of growth	54

12	Physiological response of *Tectona grandis* accessions during drought stress	56-57
13	Correlation between physiological parameters of *Tectona grandis* accessions under stress	59
14	Clusters for physiological parameters during stress condition among the accessions of *Tectona grandis*	60
15	Distance between cluster centroids during drought stress among accessions of *Tectona grandis*	61
16	Physiological response of *Tectona grandis* accessions after regain	63-64
17	Correlation analysis between physiological parameters among Tectona grandis accessions after regain	66
18	Clusters for physiological parameters among accessions of *Tectona grandis* during regain	67
19	Distance between cluster centroids among accessions of *Tectona grandis* during regain	68

LIST OF FIGURES

Figure No.	Title	Page No.
1	Variation of soil moisture content during drought stress amongtheaccessions of *Tectonagrandis*	41
2	Dendrogram of cluster analysis among accessions of *Tectona grandis* during normal condition of growth	53
3	Dendrogram of cluster analysis among accessions of *Tectona grandis* during drought stress	60
4	Dendrogram of cluster analysis among accessions of Tectona grandis during regain	67
5	Variations in rate of transpiration among the accessions of *Tectona grandis* during normal, stress and recovery	75
6	Variations in stomatal conductance among the accessions of *Tectona grandis* during normal, stress and recovery	75
7	Variations in rate of photosynthesis among the accessions of *Tectona grandis* during normal, stress and recovery	79
8	Variations in relative water content among the accessions of T*ectona grandis* during normal, stress and recovery	79
9	Variations in Membrane stability index among the accessions of *Tectona grandis* during normal, stress and recovery	82
10	Variations in chlorophyll a content among the accessions of *Tectona grandis* during normal, stress and recovery	82

11	Variations in chlorophyll b content among the accessions of *Tectona grandis* during normal, stress and recovery	84
12	Variations in total chlorophyll content among the accessions of *Tectona grandis* during normal, stress and recovery	84
13	Variations in chlorophyll stability index among the accessions of *Tectona grandis* during normal, stress and recovery	88
14	Variations in chlorophyll fluorescence among the accessions of *Tectona grandis* during normal, stress and recovery	88
15	Variations in canopy air temperature difference among the accessions of *Tectona grandis* during normal, stress and recovery	90

LIST OF PLATES

Plate No.	Title	Page No.
1	View of provenance trial plantation, Thiruvizhamkunnu	**21**
2	Evaluation of growth parameters and wood properties from field	**26**
3	Stages of vegetative propagation on teak	**28**
4	Determination of physiological observations	**33**
5	Instruments for measuring physiological parameters	**35**
6	Variation in morphological character during period of drought	**43**
7	Response of different accessions during stress and regain	**92**

Introduction

1. INTRODUCTION

Teak (*Tectona grandis* Linn. f.) is an important hardwood timber in the tropic. It is considered as noblest among all the timber because of its golden hue and wonderful texture and also durability. Due to the reduced availability of teak from natural forests andtomeethugeglobaldemandforteakproducts,plantingofteakprovedtobeimportant in meeting the growing demand for teak. The area under planted teak forests in 38 countrieswasestimatedtobe4,346millionha,ofwhich83% inAsia,11%inAfrica,and 6% in tropical America (Sandermann and Dietrichs, 1959). Most teak-growing countries arenowperformingtreeimprovementprograms,toachievehighergrowthrateandbetter timber quality through selection andbreeding.

InIndiaprogrammestogeneticallyimproveteakstarted60yearsago(Kedharnath, 1984). The main objective of these activities was to enhance the growth rate and treeform for higher volumes with longer length of clear bole to be available in short rotation. To achieve this, selection and evaluation of plus trees through progeny trials followed by identification of elite trees or clones were performed (Ugalde, 2013). These tree breeding programmes of teak primarily aimed at achieving superior growth characteristics, such as diameter, height, stem form, and pest resistance (Callister and Collins, 2008). These may have indirect effect on wood properties. So it is essential to include wood quality traits in breeding ofteak.

Among the wood quality traits wood density is considered as the most heritable and economically important trait. Therefore it is essential to incorporate wood density along with other growth parameters in tree improvement programs of teak. Wood density and modulus of elasticity measurement in standing trees is costly in terms of man power and money. This was due to time consumed in extraction and collection of samples. In contrast, Non- Destructive Evaluation (NDE) of wood properties evolved world-wide, helped in saving money and also avoid unnecessary sacrifice of valuable timber resource. AmongNDE,pilodynandtreesonictimerwerewidelyused.Pilodynpenetrationgivesan estimate of relative density. Several scientists performed comparative studies on wood density estimates and pilodyn estimates and it was revealed that high correlation exist between these two parameters. This conforms the utility of pilodyn in measuringrelative density of wood. Along with that, tree sonic timer gives estimates of stress wave velocity which can be used in detecting defects and decay in trees.

Like many other trees grown in tropical environment teak plantations are also exposed to drought stress. As teak requires long nursery period which extends to almost oneyearandanydecline inmoistureduringthisperiod maycausedecline ininitialgrowth and may eventually lead to death of teak (Rajendrudu and Naidu, 1998). Many scientists studied the effect of water stress on growth and development of forest trees (White *et al*., 2000; Chaves *et al*., 2009). Drought adversely affect physiological and morphological process in plants which in turn results in inhibition of photosynthesis, stomatal conductance, transpiration, decrease of chlorophyll pigments and an increased canopy temperature.Asstated,mostofthebreedingactivitiesthathavebeendoneonteakinvolved selecting plus trees based only on quantitative and qualitative traits. Till now, very few work was done on screening teak for drought tolerance. An in-depth understanding about drought, its effects and related physiological changes helps to use the same characters as selection criteria in breeding for drought tolerance in teak. Hence the present study will initially evaluate growth parameters and wood properties among the teak accessions from the Plantation in Thiruvazhamkunnu. Later on, for screening drought tolerant accessions of teak physiological responses during drought stress and recovery will bestudied.

The study was carried out with following objectives.

1. To evaluate variation in wood properties and growth characters among the accession ofteak.

2. Tostudythephysiologicalresponsesamongdifferentaccessionsofteakduring normal, stress andrecovery.

Review of literature

2. REVIEW OF LITERATURE

2.1 Description ofspecies

Teak (*Tectona grandis* Linn. f.) is a large deciduous tree, and a renowned species globally because of its attractiveness and durability of its wood. Teak is naturally distributed throughout South and South East Asia including India, Myanmar, Thailand, Laos, and Indonesia and is naturalized in Java, where it was probably introduced some 400 to 600 years ago (Kaosa- ard, 1981). It occurs in an area ofabout 29.04 million hectare in natural forest around the world (Kollert and Cherubini,2012).

The first teak plantation was started in 1680 in Sri Lanka. It has also been established throughout tropical Asia, as well as in tropical Africa (including Nigeria in 1902,TanzaniaandTogoin1905)andLatinAmerica(includingCostaRica,Columbia, Ecuador, Trinidad and Tobago in 1913) (Keogh, 1979). Increase in establishment of teak plantations is due to its premier wood quality and huge global demand. These plantations are distributed in an area of about 4.35- 6.89 million hectare and they compriseeightpercentofthetotalplantationarea incountriesthatsupportteakgrowth (Tewari,1992).

Teak occurs in moist and dry deciduous forest in an elevation below 1,000 m. Annual rainfall requirement of teak is 1,250-3750 mm with a significant dry spells for at least 3 months, and temperature range of 13-43°C (Troup, 1921). Teak prefers ell-drained calcium rich alluvial soil with slightly acidic to slightly alkaline nature with a pH of 6.5-7.5 (Seth and Yadav, 1959). Teak is a strong light demanding species, and it demands an unhindered overhead light at all stages of its life for proper growth and development (Pandey and Brown 2000). It can be easily propagated through seeds,but its low germination percentage leads to large seed demand (Kaosa-ard *et al.*, 1998). Teak is an outcrossing species mainly pollinated by insects (Bryndum and Hedegart, 1969).

Teak timber is unrivalled due to its significant mechanical and physical properties particularly strength, elasticity, and durability. It has an appealing colour, texture grain, and ease in woodworking. Among tropical hardwood species, teakwood possesses unique qualities that increase its demand in the construction industry, furniture manufacturing, and luxury markets. Studies specify that, in more than 20 countries, teak takes a lead in the list of tree species included in national priority for conservation and management of genetic resources (Somaiya, 2005).

2.2 Genetic improvement work onteak

The understanding that the characters of trees are not merely a combination of environmental pressures but also an expression of their genetic component, has given way to the genetic improvement of trees, as in other crops and animals (Hedegart, 1976).Workonthegeneticimprovementoftreesstartedduring the19thcentury.Teak is considered to be a much-studied species in terms of genetic improvement in India and elsewhere. The research and development activities in teak began more than a hundred years ago, long after the species was introduced from Asia to other places around the world. But the interest in studying the genetic improvement of teak goes back to a few decades (Hansen *et al.*,2015).

Programs to genetically improve and conserve teak were initiated 60 years ago (Kedharnath and Mathews, 1962; Kaosa-ard, 1981; Kedharnath 1984).The main objective of these activities was to enhance the growth rate and tree form for higher volumes with longer length of clear bole to be available in short rotation. To achieve this, selection and evaluation of plus trees through progeny trials followed by identification of elite trees/ clones were performed (Ugalde, 2013).

Provenance trial was known to be the initial stage of all genetic improvement activities. The collection and systematic genetic breeding of teak provenance for the first time was carried out under international provenance trials since 1970. DANIDA Forest Tree Seed Centre conducted provenance trials of teak in eight countries comprising 75 provenances over 21 sites (Suangtho *et al*., 1999). A total of 64 provenance samples were collected from Indonesia, Thailand, Laos and India. Characters were selected for evaluation based on utilization point of view. These characters were superior in terms of vigour (height and girth), straightness, persistence of axis, crown compactness, mode of branching and incidence of pests and diseases.

But provenance variation on wood properties was not evaluated in this study. While performing this study, substantial variations in growth between different provenances as well as individual trees within provenances were observed.

Later on, researchers found out that wood properties seemed to vary from provenancetoprovenance.Sallenave(1958)reportedthatteakwoodfromWestAfrica were harder than that from Asian region. On the other hand, the mechanical properties of 51-year-old Tanzanian grown teak were 15 per cent inferior to teak wood of same age tested from Myanmar and Trinidad (Bryce, 1966). Similarly, teak is known to exhibit wide geographic provenance variations in India for wood figure and strength properties (Tewari, 1994). For example, the Nilambur teak from the Western Ghats is reputed for good growth and log dimensions with desired wood figure and central Indian teak from the drier region is reputed for its better tree form, deeper colour and wavy grain. Bhat and Priya (2004) suggested that the geographical trend of increasing mechanical strengths associated with a greater cell wall percentage while moving latitudinally towards the southern geographical location (Konni) in Western Ghats region ofIndia.

Plus tree selection of teak started during 1960, and since then, more than 700 plus trees were selected, 5185 ha of SPA and 1022 ha of CSO was established (Sreekanth and Balasundaran, 2013). Selection is considered as first step in every tree improvement programme and it helps in manipulating the variability in biological population towards the required direction (Zobel and Talbert, 1984). Selected trees are called plus trees. They are the outstanding individuals that occur in natural stands or plantations, combining in themselves several desirable features (Wright, 1976). These trees occur in low frequency and forms the foundation of the tree improvement programme. Usually, the ideal tree in any improvement programme is the straightest, fast growing and most resistant to pest and disease (Von Gadow and Bredenkamp, 1992). Plus trees perform better than other trees when all criteria are considered together.

In India, the comparison tree method is mostly used for selecting trees. Quantitativetraitsofthecandidatetreealongwithfiverepresentativetrees(checktrees) are measured. Scoring to each of these traits is given based on a comparison of the candidatetreewithanaverageoffivechecktrees.Aftergrading,thescoreisaddedand those with the highest score are selected as a plus tree (Ledig, 1974). Qualitative and quantitative traits used for selection and relative weightage are given to various scores for these traits depend on the objectives of breeding (Lone and Tewari, 2008). For example, in a fruit crop, a branchy tree may be far more desirable for the production of fruit than a tall tree. Therefore, the total height may not be an important trait unless the tree is to be used both for timber and fruit. Mishra, 2009 while selecting plus trees of *Jatropha curcus* for biodiesel, observed quantitative traits like total height, collar diameter, crown size, seed yield, oil content and qualitative traits like flowering, fruitingandhealthstatus.Asthepurposeofbreedingwastoobtaingoodseedyieldand oil content, seed traits were given high relative weightage of 23 per cent in scoring while growth characters were given relative weightage of 2 per cent inscoring.

Thebreedingprogramforimprovingtimberqualityhighlydependsonselecting plus trees by consideringquantitative

,forking,pruningability,apicaldominanceandhealthstatus(ClarkandWilson, 2005). Individuals with bad architecture and dead branches are rejected in the first stage.Mostlygeneticimprovementstudiesonteakfocusedonselectingplustreebased on growth characters like superiority in height and length of clear bole, branching habits, bole form, disease and other defects (Callister and Collins, 2008; Monteuuis *et al*., 2011). Palanisamy and Hegde (2009) experimented with selecting superior treesof teak. In this selection method, a total of 41 outstanding trees were selected from plantations in different parts of Kerala with a selection intensity of 0.3 to 0.5 per cent, outofwhich13treesshowedsignificantlysuperiorheight(30–35m)andgirthatbreast height (151–220 cm) in comparison with the checktrees.

Fifty clones of teak from nine provenances of Karnataka have been evaluated for their resistance or susceptibility against *Hyblea purea* and the clones showed significant variation. Clones STG-3 and STG-12 were found to be the most resistant and susceptible, respectively. The resistant clone, *viz*., STG-3 showed a significantly higher concentration of phenol and most susceptible clone, STG-12 contained a very low amount of phenol (0.02 per cent) (Vinutha, 2013).

The states like Andhra Pradesh, Kerala, Madhya Pradesh, Maharashtra and TamilNaduhavemadegoodprogressinplustreeselectionandestablishmentofclonal seedorchard(RawatandKedharnath,1968;Kumaravelu,1979;Venkatesh*etal.*,1986; Gogate and kumar,1993).

2.3 Non-destructive evaluation of woodproperties

Zobel and van Bujitenen (1989) emphasised wood quality improvementshould be included as an integral part of any tree breeding program. Lateron, there has been a focus on incorporating wood properties in tree breeding in several hardwood species including teak (Kjaer *et al.*, 1999). Many of the tree improvement programmes have wooddensityasoneselectioncriteriaandmeasuringthisinstandingtreesisconsidered a crucial step in improvement programme (Zobel and Jett,1995).

Measurement of wood properties in standing trees seems to be more expensive as it requires a larger input of labour and money because it involves several extraction and processing techniques. In contrast with that Non- Destructive evaluation of timber evolved worldwide, which gives a reasonably good indicator of wood propertiesunder field condition and detection of decay (Brashaw *et al.*, 2009). Non-destructive evaluation is the science of identifying the mechanical properties of a material without alteringitsend-use(RoseandPellerin,1994;Wang*etal*.,2007).Thesetechniqueshave contributed to the advancement of knowledge of the variability of wood, allowing the identification of wood material that is free from internal defects which helps in proper use. Pilodyn wood tester and tree sonic timer are two instruments that are widely used in non-destructive evaluation wood properties in standingtrees.

Pilodyn is extensively used in assessing the wood density of hardwood and softwood.Twoobservationspertreeusingpilodynissufficientforindirectselectionof treesfordensity(Greaves*etal*.,1996).Thepenetrationdepthobtainedgivesanindirect measureforthedensityoftheoutersectionofstem(Cown,1978).Pilodynprovidesan estimateofrelativewooddensity,whichcanbeusedtorankvariousgeneticunitsabout wood density (Hansen,2000).

Several studies have shown a high correlation between pilodyn estimates and wood density estimates. In radiate pine of different ages, pilodyn readings and outer wooddensityshowanegativecorrelationwithacorrelationcoefficientof-0.97(Cown, 1978). Comparative studies between pilodyn penetration and actual specific gravity determined from core samples in white spruce shows, high correlation and study confirmedthatpilodyntestercanbeusedinestimatingtreespecificgravityasapartof the selection for tree improvement (Micko *et al*., 1982). Pilodyn penetration depth and wood density from wooden blocks of *Cryptomeria japonica*, shows a high negative correlationof-0.82andthiscorrelationwasstrongerinsapwoodthanheartwood,which was in agreement with the fact that pilodyn penetration restricts largely outside trunk of the tree (Yamashita *et al.*, 2007). Ponneth *et al*. (2014) suggested a high negative correlationof-0.94obtainedfor pilodynpenetrationdepthandspecificgravityinteak. Fukatsu *et al.* (2011) assessed the genetic correlation of 12 clones of *Cryptomeria japonica* and obtained a genetic correlation of -0.88 and a genetic gain of 87 percent.

Tree sonic timer is another instrument used in non-destructive evaluation of wood properties (Todoroki, 2010). This instrument uses a non-destructive techniqueto determinestiffnessandmodulusofelasticityoftrees.(Wang*etal*.,2001,Grabianowski *et al*., 2006). This provides an opportunity in early screening for genetic heritability in trees (Kumar *et al*., 2002). Dickson *et al*. (2003) evaluated the efficiency of microsecond timer as a direct measurement of wood stiffness using two age classes of *Eucalyptus dunni*. The speed of sound along logs was sufficiently highly correlated withwoodstiffness.Ponneth*etal*.(2014)studiednon-destructivetestingoncommonly usedtimberspecies:acacia,ayani,jackwood,pyinkado,rubberandteak.Higheststress wave velocity was recorded for acacia and lowest for jackwood. The study also gives evidence that stress wave velocity is positively correlated with tangential hardness, modulus of rupture, modulus of elasticity, tensile stress. This in turn revealed the suitability of stress wave velocity for making a reliable prediction in detecting defects and decay inwood.

2.4 Screening for drought tolerance

Like many other tree species that grow in a tropical environment, teak plantations are also exposed to drought stress and they are very sensitive too. Drought causeslargescalemortalityofteakseedlings inthenurseryduringtheirinitialgrowing period (Kadambi, 1972). As stated, most of the breeding activities on teak involve selecting plus trees based on qualitative and quantitative traits. Few studies were done till now on screening of drought tolerance on teak. An in-depth understanding about drought, its effects and related physiological changes helps to use the same characters as selection criteria in breeding for drought tolerance inteak.

2.4.1 Effect of drought stress ontrees

Distribution and abundance of plant species are largely determined by environmentalconditions,astheestablishmentofyoungseedlingsare limitedbybiotic and abiotic factors (Kitajima and Fenner, 2000). When these factors adversely affect plant growth, it is termed as stress. Stress is characterized by deviation from normal growth and development which induces various structural and functional responses in anorganism(Kranner*etal.*,2010).Drought(SausenandRosa,2010),salinity(Ahmad *et al*., 2010) and extreme temperatures (Keles and Oncel, 2002) are the major environmental stresses that harm plantgrowth.

Drought stress is one of the most critical among the abiotic stresses that limits theyieldoftreesaswellascrops.Itischaracterizedbylowrainfallandcausesdepletion of soil moisture due to high evaporative demand (Moles and Westoby, 2004; Peng *et al.*,2011).InIndia,droughtsaremorefrequentsince1965,withrecentacuteoccurrence being in 2009. It is more prominent in arid than in humid and per humid regions (Sharma and Majumdar,2017).

Many scientists have studied the adverse effects of water stress on growth and productivityofplants(Ahuja*etal.*,2010;Oskabe*etal.*,2011;Nishiyame*etal.*,2013). It acts as a major limiting factor for all the plant growth and developmental processes and also causes cell death. The severity of stress damage is determined by intensity, rate and duration of drought exposure and also the stage of plantgrowth (Brar *et al.,* 1990). Seedlings are more prone to drought damage due to their shallow root system, minimalresourceportioning,andsmallersize(Zhang *etal.*,2004).Anexperimentwas carried out to compare the performance of one month old seedlings of five tree species *viz. Albizzia lebbeck, Dalbergia sisso, Leucaena leucocephala, Shorea robusta* and *Tectona grandis,* under simulated moisture stress conditions (Rao *et al*., 2008). They were subjected to four different frequencies of irrigation, of 1, 7, 14 and 21 days interval. In all the five species, stress caused a significant reduction in height and dry biomass, with a maximum reduction of 75.8 per cent and 99.8 per cent exhibited by *Leucaena* and minimum of 53.8 per cent and 81.6 per cent by *Albizzia lebbeck* compared with control,respectively.

The direct effect of drought stress was a reduction in the rate of growth and photosynthesis, which in turn reduced the carbon assimilation and metabolism (Souza *et al*., 2004). It also created an imbalance in PS II activity, electron transfer to Calvin cycle and reduction in photosynthetic enzymes (Lawlor and Cornic, 2002, Chaves *et al.,* 2003).

Plants have several mechanisms to avoid drought, which come under three categories: escape, avoidance and tolerance (Turner, 1986). Plants which escape drought complete their whole life cycle before water deficit occurs. Plants can also overcomedroughtbyavoidancemechanismbymaintainingtissuehydrationunderlow water potential by minimising water loss and maximizing uptake (Mittler *et al.,* 2001). Finally, the tolerance mechanism helps plants to perform an osmotic adjustment, changes in growth, cellular structure and physico-biochemical responses during the period of drought (Chaves *et al.,* 2003). Plants adapt stomatal closure as a prime response against drought, along with which they also make osmotic adjustments by accumulatingcompatiblesoluteswithinthecytosoltoreducewaterpotential(Pessarkli, 1999). Osmotic adjustment helps to access water under moisture stress and maintains the viability of cells and thereby the growth of plants duringstress.

2.4.2 Drought stress and morphologicalcharacters

Itisawell-establishedfactthatdroughtstressisanimportantlimitingfactorfor plant growth during its initial stage of establishment. Water stress limits the height increment and collar diameter due to a reduction in turgor pressure which in turn reducescellexpansionandcellelongation(Anjum*etal*.,2003;Shao*etal*.,2008).Stem length of soybean shows considerable reduction during drought stress (Specht *et al*., 2001). In citrus, water stress inhibits plant growth and height was reduced to 25 per cent in water stressed seedlings of citrus (Wu *et al*., 2008). A significant reduction in height in response with progressing drought stress was observed in five month old seedlingsoffivetreespeciesoftropicaldryforest*viz.*,*Albiziaprocera*,*Acacianilotica*, *Phyllanthusemblica*,*Terminaliaarjuna*and*Terminaliachebula*.Maximumheightwas displayed by *T. arjuna* and mean height of all the other four species showed decline due to water stress (Khurana and Singh, 2004). A study on argan seedlings from five different geographical provenances by Bezalla *et al*. (2017) indicated that height increment of seedlings was greatly reduced by water stress. A similar pattern was observed in olive trees (Roussos *et al*., 2010), *Acacia mangium* (Awang and Chavez, 1993), *Hopea odorata* and *Mimusops elengi* (Zainudin *et al*.,2003).

Water stress negatively affects collar diameter. Reduction in collar diameter was observed in seedlings of *Acacia mangium* (Awang and Chavez, 1993), *Hopea odorata* and *Mimusops elengi* (Zainudin *et al.*, 2003), *Dalbergia sisso* (Singh and Singh, 2009).

2.4.3 Drought stress and physiological response ofplants

2.4.3.1 Relative watercontent

Relative water content (RWC) indicates the water status in the plants and considered as an important criterion in selecting drought tolerant crops(Rachmilevitch *et al*., 2006). It shows the balance exhibited by plants in terms of water supplied to leaves and water transpired by leaves (Lugojan and Ciulca, 2011).According to Sánchez-Rodríguez *et al*. (2010), RWC is considered as an indicator of the sensitivity of plants towardsdehydration.

The normal value for RWC lies within a range of 98 per cent for completely transpiring leaves to 40 per cent for severely desiccated leaves. This decrease in RWC byexposingleavestowardshighermoisturestresswasstudiedinseveralplants(Nayyar andGupta,2006).Highrelativewatercontent isadroughttolerancemechanismwhich promotes recovery in plants exposed to severe drought (Lilley and Ludlow,1996).

Physiological responses in four populations of *Populus cathayana* under drought stress revealed that drought resistant genotype had lower RWC compared to drought sensitive species (Xiao *et al*., 2008). Experiments on four oilseed brassica species showed that plants with higher osmotic adjustment maintain higher RWC during moisture stress and those with higher RWC survive drought (Kumar and Singh, 1998). Chaudhary *et al*. (2017) reported that soybean cultivars that were resistant to drought had higher relative water content. Similar results were obtained with two teak clones differing in rejuvenation capacity after subjecting to drought stress. The clone which is tolerant to the imposed drought stress showed a lesser decrease in RWC compared with the susceptible clone (Husen, 2010).

2.4.3.2 Stomatalconductance

Stomatalconductanceplaysanessentialroleinmaintainingplantwaterbalance. Opening and closing of stomata were mainly controlled by turgor of guard cells, metabolic energy released from mesophyll photosynthesis and membrane stability. Closure of stomata inhibits cell expansion and growth rate and leads to a significant reduction in yield (Nemeskeri *et al.*,2015).

The first response of plants to severe moisture stress is stomatal closure. This processhelpstheplanttoreduceextensivewaterlossviatranspirationinawaterdeficit environment (Chaves, 1991). As drought progresses, stomatal closure also progresses following the severity of drought and is affected not only by the soil environment but also by several internal and external factors associated with leaves (Sharkey, 1990). Thedecreaseinstomatalconductshelpstheplantto remainhydratedduringtheperiod of drought (Berry *et al.,* 2010; Claw *et al.,* 2015; Nemeskeri *et al.,*2015).

Schurr *et al*. (1992) in their study on split root experiments, proposed that stomata close rapidly in response with drying soil environment while their shoot and leaf remain completely turgid. Dehydration of roots, transfer signals to stomata which in turn helps in stomatal closure. Reduction in stomatal conductance results in the decline of CO_2 uptake during drought and reduces photosynthesis (Sharkey, 1990). Miyashita *et al.* (2004) reported that leaf stomatal conductance declines in response to limited water availability in kidney bean.

2.4.3.3 Photosynthesis

Adaption of plants to a destabilized environment primarily relies on its ability to adjust photosynthesis, which has additional effects on various biochemical and physiologicalprocessesinvolvedinthegrowthanddevelopment(Chandra,2003).The decreaseintherateofphotosynthesisduringmoisturestressisduetostomatalandnon-stomatal limitations (Ni and Pallardy, 1992). Either the stomatal closure which decreases CO_2 diffusion from atmosphere to substomatal cavities or lack of mesophyll conductance which restricts CO_2 diffusion from substomatal cavities to chloroplast limits photosynthesis (Flexas *et al*., 2008). This has been studied by various scientists (Lawlor and Cornic, 2002, Flexas *et al.*,2007).

In plants, photosynthesis is more sensitive and dramatically than respiration varieddduringtheperiodofdroughtstress(Vassileva*etal.*,2009).Reductioningrowth during drought attributed to the decline in carbon balance which is due to an adverse relationship between respiration and photosynthesis (Flexas *et al.*, 2007). When the plants are dehydrated, percentage of respired carbon is comparatively higher than carbon fixed through photosynthesis due to inhibition ofphotosynthesis.

Boyer (1970) studied the relationship between leaf water potential and photosynthesis of corn, soybean and sunflower and found that photosynthesis declines with the reduction in leaf water potential and both are positively correlated. In contrast with this finding, Miyashita *et al.* (2004) proposed that in kidney bean, drought imposition leads to the rapid reduction in photosynthesis even before the leaf water potential drops. Gollan *et al.* (1985) stated that photosynthesis is more sensitive to stomatal closure than leaf relative water content and the decline in photosynthesis is triggered by a reduction in stomatal conductance. The same result was revealed by Mutava *et al.* (2015) during drought stress, decline in photosynthetic rate in soybean results from reduced stomatal conductance.

2.4.3.4 Transpiration

Role of stomata is to regulate water loss through transpiration and 90 per cent of water loss from plants occurs through stomatal openings via transpiration. During moisture stress, internal moisture preservation and quick stomatal closure are vital for plants to withstand water deficit condition. Under high transpiration, stomatal closure is the initial step to decrease water loss under drought stress (Fang *et al.*, 2015). In agreementwiththis,Miyashita*etal*.(2004),statedthatinkidneybeanthetranspiration rate decreases gradually along with the decrease of soil water content. This reduction in transpiration rate helps the plant to avoid dehydration duringdrought.

Study of Husen (2010) on two teak clones reported that withholding moisture for 20 days produced a significant reduction in the rate of transpiration. Teak clones FG1 and FG11 showed a decline of 72.17 per cent and 73.33 per cent in the rate of transpirationcomparedwiththecontrol.Teakclonewhichwasmoredroughtsensitive showed comparatively higher reduction in the rate oftranspiration.

2.4.3.5 Canopy air temperature difference(CATD)

Plant gas exchange is an important parameter which describes the intensity of drought stress. But measuring these gas exchange parameters are time consuming. However, plant canopy temperature forms an important qualitative index that can be usedtoeasilydeterminethewateravailabilityto plantsanddegreesofdrought (Idso*et al*., 1966). Plant canopy temperature is usually maintained at metabolically agreeable range until as long as the plants continuetranspiration.

Monteith and Szeicz (1962) were the firstto use infrared technology in measuring plant canopy temperature for quantifying the intensity of drought stress. Later, Jackson *et al*. (1981) and Idso *et al*. (1977) used canopy air temperature difference (CATD) or stress-degree-day index for determining the water status of the crop.CATDrelatescropcanopytemperaturetoambienttemperatureandisdetermined bythetemperaturedifferencebetweencanopies(T_c)andambientair(T_a).Thismeasure helps in understanding the evaporative cooling performed by plants. According toIdso *etal*.(1977),ifthedifferencebetweenT_c-$T_a$isnegative,itindicatesthattheplantsare well watered and a positive value indicates drought stress. The result of Sneha *et al.* (2017) revealed that CATD of teak seedlings under drought remains positive and for well watered plants, it remainsnegative.

Stomatal closure happens as a response to progressing drought stress, which causes a reduction in loss of latent energy; thereby increasing T_c. Plants with a cooler canopy temperature indicate efficient use of available moisture to cool the canopy for avoidingdehydrationduringtheperiodofdrought.CATDcanbealso usedasanindex to analyse the efficiency of root capacity in absorbing soil moisture and act as a proxy in determining root development and biomass partitioning in the root (Balota *et al*., 2008). Drought studies on wheat indicated that canopy temperature increased with progressingdroughtstressandahighnegativecorrelationexistedbetweentranspiration and canopy air temperature difference (Rashid *et al*.,1999).

2.4.3.6 Chlorophyllfluorescence

Light energy absorbed by chlorophyll molecules can undergo 3 processes: (i) drivephotosynthesis(ii)dissipatedasheator(iii)re-emittedaslight calledchlorophyll fluorescence.Thesethreeprocessesoccurincompetition,bywhich,inefficiencyinone increases the efficiency of the other (Maxwell and Johnson, 2000). The yield of fluorescencereflectsthequantumefficiencyofphotochemistryandheatdissipationand mostlyusedtostudythequantumyieldofPSII.Chlorophyllfluorescenceisconsidered as an important element in Eco physiological studies, along with other gas exchange parameters it is used for monitoring plants response towards environmental stresses (Kodru *et al.*,2015).

Kautsky *et al*. (1960) observed that by transferring a photosynthetic material from dark into light increases fluorescence yield, which is due to a reduction in the electron acceptor from PSII. When PSII is excited by an incident light radiation it transfers an excess electron to plastoquinone. This electron carrier is unable to accept another electron until it transferred the first electron to succeeding electron carrier. Duringthisperiodreactioncentresareconsideredasclosed.Atanytimeclosedreaction centres increase the fluorescence yield by decreasing efficiency in photochemistry (Stirbet and Govindjee,2011).

Nowadays, portable fluorometers are largely used in obtaining information about the rate of electron transport, PSII quantum efficiency (Fv/Fm), non-photochemicalquenching,photoinhibitioninresponsetomoisturestress(Schansker*et al.*,2014). Fv/Fm in previously dark-adapted leaves in non-stressed plants after exposingtolightvariedinbetween0.75-0.85andadecreaseinthisrangewasexhibited when plants were under stress. Earlier studies on the quantum efficiency of vascular plants by Schreiber *et al.* (1995) suggested that a reduction in Fv/Fm indicates photo inhibitory damage of PSII in response with drought stress. During the period of stress, photochemical quenching is minimum, which in turn increases the fluorescence and indicates the malfunctioning of PSII (Vazan,2000).

2.4.3.7 Chlorophyllcontent

Photosyntheticpigmentsareimportanttoplantsmainlyforharvesting lightand thereby carbon assimilation. Major photosynthetic pigments like chlorophyll a and b were very sensitive to environmental stresses (Farooq *et al*., 2009). During the period ofdrought,reductioninthephotosyntheticpigmentisthemajornonstomatallimitation which declines the rate of photosynthesis (Reddy *et al*., 2004; Din *et al*., 2011).This is duetotheclosureofstomata,whichresultsinloweringtheinfluxofCO_2,whichcauses an inequity between CO_2fixation and electron transport (Grassi and Magnani, 2005). This facilitates the transfer of excess electrons to ROS, which in turn damages chlorophyll pigment by excessive oxidation. Kaiser *et al*. (1981) reported that the loss of more chlorophyll pigment is from mesophyll than from bundle sheath cells during stress.

Reduction in chlorophyll content was reported in drought stressed cotton (Massacci *et al*., 2008). The chlorophyll content decreased to a significant level at higher water deficits in sunflower plants (Kiani *et al.,* 2008) and *Vaccinium myrtillus* (Tahkokorpi *et al*., 2007). Pandiyan *et al.* (2017) stated that the decline in the rate of photosynthesis attributed to a decrease in chlorophyll content in green gram and black gram. The susceptible genotypes of both the crops show reduced chlorophyll content than the tolerant one.

2.4.3.8 Chlorophyll stability index(CSI)

Chlorophyll stability index (CSI) is a measure of the integrity of membrane or heat stability of pigment under stress, which is widely used in the screening of stress resistant genotypes (Kaloyereas, 1958). Sairam *et al.* (1996) stated that in wheat cultivars,droughtstressimposesaconsiderablereductioninchlorophyllstability.High chlorophyllstabilityindexduringtheperiodofdroughtindicatestheabilityofplantsto withstand adverse environment by retaining more chlorophyll pigments and maintaining high productivity. In agreement with this, Pandiyan *et al.* (2017) reported that susceptible genotypes of both green gram and black gram under drought stress showed a decline in chlorophyll stabilityindex.

2.4.3.9 Membrane stabilityindex

Drought stress adversely affects plant cells by damaging the selective permeability of the plasma membrane, thereby causes an inability in maintaining the internal composition of the cell (Sairam *et al.,* 1998). This cellular membrane dysfunction increases the permeability and leakage of ions and it can be readily measured by efflux of electrolytes (Feller *et al*., 2017). Screening plant response to waterdeficitwasmainlyachievedthroughchemicaldesiccatorslikePEG.Thusseveral scientists used the effect of PEG on membrane stability as an early selection step to select the most promising drought tolerant strains (Quilambo and Scott,2004).

Increase in cell membrane stability indicates dehydration tolerance. Drought stress imposes a decline in membrane stability. In agreement with this, Juby, 2019 reported that drought tolerant hybrids of cocoa showed high membrane stability than susceptibleones.Ontheotherhand,anincreaseintheelectrolyteleakageindicatedcell membrane injury and less tolerance towards drought. In two clones of teak, electrolyte leakage showed a significant increase of 72.29per cent in FG1 and 89.05per cent in FG11 in comparison with control, after exposing to drought stress of twenty days (Husen,2010).

Materials and methods

3 MATERIALS AND METHODS

3.1 Location

The present study entitled “Selection for drought tolerance and wood quality traits from selected accessions of *Tectona grandis* Linn. f.” was carried out at College of Forestry, Kerala Agriculture University, Vellanikkara, Thrissur district, Kerala. The study was conducted during 2018-2020. As detailed below two experiments have been carried out in the study:

Experiment 1: Evaluation of teak accessions for wood properties, height, and girth

Experiment 2: Screening for droughttolerance.

3.2 Experimentalmaterial

Thirtyaccessionsofteakcollectedfromvariouspartsof SouthIndiaofuniform age maintained as provenance trial plantation in Livestock Research Station, Thiruvazhamkunnu in Palakkad District of Kerala formed the base material for study. This plantation was established under AICRP on Agroforestry in September 2001, for evaluating the growth and quality of selected accessions of teak from South India. The details of 30 accessions used in the study are presented inTable1.

Table 1. Details of accessions of teak used for the study

Sl No:	Accession No:	Accession name
1	A1	Cherupuzha
2	A2	Nedumkayam-1
3	A3	Nedumkayam-2
4	A4	Shankaramthode
5	A5	Tholpatti-1
6	A6	Tholpatti-2
7	A7	Tholpatti-3*
8	A8	Top slip-1*
9	A9	Top slip-2*

10	A10	Top slip-3*
11	A11	Top slip-4*
12	A12	Top slip-5*
13	A13	Top slip-6
14	A14	Top slip-7*
15	A15	Top slip-8*
16	A16	Top slip-9*
17	A17	Top slip-10
18	A18	Nellikutha-1
19	A19	Nellikutha-2
20	A20	Nellikutha-3
21	A21	Nellikutha-4
22	A22	Nellikutha-5
23	A23	Nellikutha-6
24	A24	Nellikutha-7
25	A25	Muthumala-1*
26	A26	Muthumala-2*
27	A27	Mananthavadi
28	A28	Aravallikkavu
29	A29	Karulai
30	A30	Thiruvazhamkunnu*

*****Discarded accessions due to lack of enough progenies or unsuccessful vegetative propagation

3.3 Experimentallocations

Teak trees from provenance trial plantation in Livestock Research Station, Thiruvazhamkunnu were used for measuring basic growth parameters and wood properties.Fieldviewofprovenancetrailplantationisgivenasplate1.Branchcuttings for vegetative propagation were also collected from the samelocation.

Plate 1 View of provenance trial plantation, Thiruvizhamkunnu

The planting materials of trees were multiplied using vegetative propagation which involves two vital steps, production of juvenile epicormic shoots from branch cuttings and rooting of these juvenile epicormic shoots. Vegetative propagation was done in mist chamber at KFRI, Peechi and ramets were used for further evaluation.

The experimental trial for imposing drought was performed in the field experimental shed of Department of Supportive and Allied Courses, College of Forestry, Kerala Agriculture University, Vellanikkara.

3.3.1 Short record on meteorological information of experimentallocations

Thiruvizhamkunnuissituatedatnorthlatitude11^{0}21ꞌ50ꞌꞌandeastlongitude76^0 21ꞌ 50ꞌꞌ. The maximum air temperature ranges from 24.4ºC (December) to 42.8ºC (March) and minimum air temperature ranges from 13.4ºC (January) to 27.0ºC (April).Relative humidity ranges from 9.11% to 100%. The climate is humid to subhumid and average annual rainfall recorded in this region was 2171mm (AICRP, 2018).

BranchcuttingswerepropagatedinthemistchamberofKSCSTE-KFRIPeechi campusinThrissurdistrict(northlatitude10^{0}31ꞌandeastlongitude76^{0}20ꞌ).Insidethe mist chamber, relative humidity and temperatures were artificially maintained by automated controlled mist installations that help in rooting of hardwood branch cuttings.Relativehumiditywasmaintainedbetween85-90%andthetemperaturerange was in between 28ºC-30ºC.

Drought tolerant studies were carried out at College of Forestry, Thrissur located at north latitude 10^0 31ꞌ and east longitude 76^0 13ꞌ. Study was performed from 28Juneto27Julyanddroughtstresswasimposedduring1Juneto5June.Forimposing droughtstressandtopreventexposuretorains,theclonesunderstudywerekeptinside the rain shelter. Since the temperature inside the rain shelter was higher than the temperature outside, it was essential to record the weather parameters to ensure there was no influence of heatstress.

The weather parameters collected during the period of drought are givenbelow (Table 2). Weather parameters like relative humidity, maximum and minimum temperature were recorded regularly using Testo cosmo basic datalogger.

Table 2. Weather parameters measured during days of drought

Date	Mean tempºC	RH (%)	Tmax ºC	Tmin ºC
28-06-2020	30.74	77.30	40.2	24.20
29-06-2020	30.35	77.34	41.5	25.1
30-06-2020	31.03	72.59	41.3	25.8
01-07-2020*	29.92	77.25	40	24.7
02-07-2020*	28.45	83.38	39.2	23.9
03-07-2020*	26.67	88.61	39.3	24.7
04-07-2020*	28.21	85.11	40.2	25.6
05-07-2020*	28.00	86.87	37.9	23.9
06-07-2020	28.25	85.61	39.2	22.1
07-07-2020	28.50	83.53	41.3	24.8
08-07-2020	28.51	82.24	38.7	24.2
09-07-2020	28.26	82.40	40.3	23.8
10-07-2020	25.78	90.60	39.2	23.1

***days of drought stress**

MeantempºC=Meantemperature,RH(%)=Relativehumidity,TmaxºC=Maximum temperature and Tmin ºC = Minimumtemperature

3.4 Outline ofexperiment

Two experiments were conducted in succession. In the first stage, thirty accessions from the provenance trail plantation were studied for wood properties. Evaluation of wood properties was conducted at Livestock Research Station, Thiruvazhamkunnu from March to July 2019. Out of 30 accessions, eight accessions were completely absent in the field and from the remaining 22 accessions three were discardedduetolackofenoughnumberofprogenies(minimum2peraccession).From the remaining 19 accessions branch cuttings were collected for vegetative propagation from October 2019 to March 2020. From the nineteen accessions, eighteen accessions were only successfullypropagated.

In the second phase, these eighteen accessions were subjected to drought tolerance studies in College of Forestry, Vellanikkara during June to July 2020.

3.5 Evaluation of wood properties, growthparameters

3.5.1 Measurement of growthcharacters

Growth characters such as total tree height and girth were measured using laser hypsometer and measuring tape.

3.5.1.1 Heightmeasurement

Height of teak trees was measured using HaglÖf Sweden AB vertex IV and it usestheultrasonictechniqueforheightmeasurement.Heightofeachtreewasmeasured from sight mark to top of the crown and expressed in*m.*

3.5.1.2 Girthmeasurement

The girth of each tree was measured using measuring tape at breast height and expressed in *cm*.

3.5.2 Evaluation of woodproperties

In this study pilodyn and tree sonic micro second timer were the two non-destructive instruments used for evaluation of wood properties.

3.5.2.1 Pilodynmeasurement

Pilodyn 6 J (FUJI TECK, Tokyo, Japan) a handheld instrument with pin diameter 2.5mm was used for obtaining pin penetration depth (PPD). Before taking measurements, outer bark from the area where the pin is to be penetrated was removed using a chisel. The PPD was taken from four diametrically opposite sides of standing teaktreesatthebreastheight.PPDforasingletreewascalculatedbytakingtheaverage of these four values obtained. Penetration depth was measured by pressing Pilodyn 6 J perpendicularly against the debarked area of standing trees. The penetration depth was readinmillimetresononesideofthe instrumentwithinarangeof0-40mm.Ponneth*et al*. (2014) proposed a regression equation which gives an estimate of relative density from pilodyn penetrationdepth.

$$y = -34.205x + 35.178$$

Where y = pilodyn penetration depth (mm) and x = relative density

3.5.2.2 Tree sonic microsecond timermeasurement

Tree sonic microsecond timer (Fakkopp, Hungary) non-destructively detects defectsinstandingtrees.Thetimerhastwotransducers,whicharelong, flatwithspike- like ends. The transducer with a red mark on one of its side is the start transducer and other is stop transducer. The spike of the transducer was inserted into the standing tree withstartendatbreastheightandthestopendatdiagonallyoppositesidekeepingboth transducers1mapart.Thespikeneedtopenetratethebark maintaininganangleof45^{0}between the spike and fibre. Hitting the start transducer with hammer displays “9999” in the timer, which shows that instrument is on. The time required for the sound wave totravelfromstarttostoptransducerwasdisplayedinmicrosecondsonthetimer.Three readings were taken from a single tree with spike re-inserted to opposite sides. These three readings were averaged to obtain the time. Velocity was calculated by dividing the distance travelled by stress wave with time taken. Dynamic modulus of elasticity obtained using equation: $E=\rho V^2$, where E is the modulus of elasticity, ρ is the density of the wood in Kg/m^{3}and V is the velocity inm/s.

Measurementofgirth

Measurement of height

MeasurementofSWV

Measurement ofppd

Plate 2 Evaluation of growth parameters and wood properties from field

3.6 Statisticalanalysis

Growth characters and non-destructive wood property measurements were subjected to statistical analysis using descriptive statistics and compact family block design, with nineteen accessions having two progenies with two replications each (19X2X2). R 3.6.1 package was used for analysis.

3.7 Vegetative propagation of selected plustrees

Teak was propagated by the production of rooted juvenile epicormic shoots obtainedfromthebranchcuttings.Treesfromwhichbranchcuttingsarecollectedwere selected through comparison method. 18 trees from 18 different accessions were selected and assigned with accession numbers. Branch cuttings of diameter 3 to 10 cm were collected from the middle and lower parts of the crown of plus trees of selected accessions. These cuttings were taken to KSCSTE-KFRI on the same day and kept overnight by spraying diluted carbendazim 50 % WP (15g L^{-1}). These branch cuttings weretheninsertedinto polybagsofsize(12"x10")filledwith2partsoil:1part FYM: 1 part sand with branchesremoved.

These were kept under mist chamber (20 seconds misting in every 20 minutes) was provided until they sprouted. Fungicide was sprayed with an interval of 5 daysfor thefirstfewweeks.Theidentityofaccessionwasretainedbylabellingwithaluminium foil. When the juvenile epicormic shoots produced on the branch cuttings attained a heightofabout8-10cm,withatleasttwoorthreepairsofleaves,theywere harvested. Immediately after harvesting, the cuttings were soaked in carbendazim 50 % WP solution (20%) for 20 minutes. The cuttings were then trimmed with a pruning scissor by removing the distal 2/3rd portion of the leaves, and retaining the apical bud and nearest 2 leaves completely intact. These cuttings then dipped into indole butyric acid (IBA) 5000 ppm prepared in talc. Cuttings were then planted into root trainers filled with vermiculite (soaked with carbendazim 50 % WP overnight). Root trainers were kept on mist bench and provided with intermittent misting. Temperature and relative humidityweremaintainedbyanautomatedsystemusingacoolingpadandexhaustfan. The temperature was always kept in between 28 ºC to 30ºC to avoidwilting.

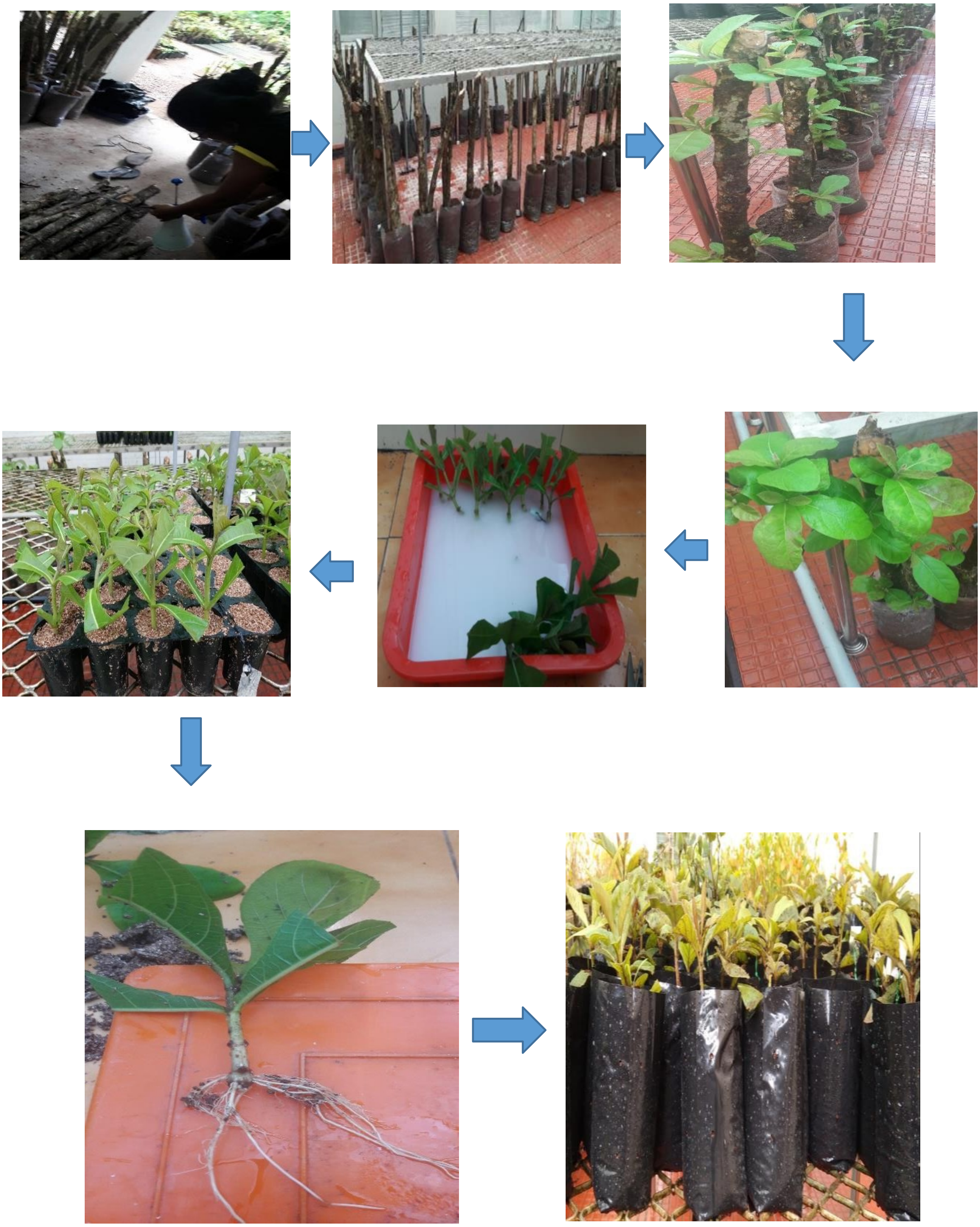


Plate 3 Stages of vegetative propagation on teak

Almost a month was needed for proper rooting. After this cuttings were removed from root trainer and transferred to polybag of size (6"x 4") with a potting mixture of 2 parts loam soil: 1 part FYM: 1 part sand. The plants were completely protected from pest and diseases. These plants were also maintained healthy by proper fertilization using 19:19:19 and watering. Rooted ramets were removed and subjected to hardening for 45 days (Plate 3).

3.8 Screening for drought tolerance

Five month old ramets of teak were kept under protected shade in controlled condition for imposing moisture stress. Moisture stress was imposed by withdrawing irrigation until plants show signs of wilting. During the drought imposition, soil moisture content was determined gravimetrically.

3.8.1 Determination of soil moisture content

Soil moisture content during the period of stress was determined by collecting the soil sample from polybags. The samples were collected from the root zone was transferredtoaPetridishandfreshweight(W_1)wasrecorded.Thesesampleswerethen kept in a hot air ovenat 105-110ºC for 24 hours until constant weight for obtaining dry weight (W_2). The soil moisture content was calculated as percent.

Soil moisture content = $[(W_1-W_2)/ W_2] \times 100$

3.8.2 Stages of moisture stressimposed

Physiological changes in response to imposed drought stress were studied in three stages *viz*. normal, stress and regain. Drought and rehydration studies were performed during the period of 26 June to 17 July 2020. For measuring physiological parameters under normal condition leaves from each accession were collected after irrigatingsoiltofieldcapacity.'Normal'stageobservationswererecordedatthisstage. Afterthisstresswasimposedbywithdrawing irrigationwhenplantsshowthefirstsign ofwilting.'Stress"stageobservationswererecordedatthisstage.Theplantswerethen irrigated to field capacity and maintained till plants were once again showing normal morphological growth. Observation of the "regain" stages was recorded at this time.

3.8.3 Determination of physiologicalparameters

Physiological parameters were studied on collected leaf samples. The samples were taken at solar noon $\pm$ 2 hours, as this is the most stable time of day concerning irradianceand temperature.Fully matured 3rdleaffromthetopoftheplantswastaken. After collection, leaves were rapidly transferred to an icebox and carried to the lab for furtheranalysis.

3.8.3.1 Determination of photosynthetic rate, stomatal conductance and transpirationrate

Observation on net photosynthetic rate, transpiration rate and stomatal conductance. These were done using a LI6400 portable photosynthetic system. From each replication 3rd fully expanded matured leaf of each accession were measured during morning hour between 10.00am to 11.00am providing a photosynthetic photon flux density of 2,000 μmol m^{-2} s^{-1}.

3.8.3.2 Estimation of relative water content(RWC)

Relative water content measures the water status of plants and used as anindex for screening drought-tolerant varieties. It is expressed as the percentage of the turgid watercontentofleafusingBarrs,(1968)methodwithslightmodifications.Twentyleaf discs from fresh leaf samples were taken for determining RWC. Fresh weight (FW) of the leaf discs was determined. The discs were soaked in deionized water in a Petri dish for4-5hoursatroomtemperatureuntilleafdiscswerecompletelysaturated.Leafdiscs were then taken out and surface water was wiped using a tissue paper. When they are completelydevoidofwater,turgidweight(TW)wasrecorded.Thentheleafdiscswere separately packed and labelled and kept for drying in a hot air oven at 75-80 ºC for 24 hours.Dryweight(DW)ofsampleswasrecordedwhenaconstantweightwasobtained after frequent drying. RWC was then calculated using Barrs, 1968formula:

$$RWC\ (\%) = \frac{(FW-DW)}{(TW-DW)} x\ 100$$

Where, FW = Fresh weight in grams, TW = Turgid weight in grams and DW = Dry weight in grams.

3.8.3.3 Estimation of membrane stability index(MSI)

MSI was determined using the method of Premachandran *et al.,* (1991) as modified by Sairam (1994). Hundred mg of fresh leaf samples were collected at 11 am and transferred in two test tubes. Ten ml of double distilled water was poured to both test tubes. One test tube was kept at 40 ºC for 30 minutes in a boiling water bath was taken as control. The later was kept at boiling water bath at 100 ºC for 15 minutes, was taken as treatment. After the stipulated time, both the test tubes were cooled down to roomtemperature.Theconductivityofcontrol(C_1)andtreatment(C_2)wasdetermined using a conductivity meter. MSI was determined using theformula:

$$MSI\ (\%) = 1- \frac{C1}{C2} x\ 100$$

Where C_1 = Conductivity of control in µS/cm and C_2 conductivity of treatment in µS/cm

3.8.3.4 Estimation of chlorophyllcontent

Chl a, Chl b and total chlorophyll were estimated using Hiscox and Israelstam (1979) method by using DMSO (Dimethyl sulphoxide). DMSO results in minimum damagetochlorophyllpigmentaschlorophyllremainsstableinthissolvent.Weighout 100 mg of fresh leaf sample from all accessions were cut into small pieces. This was transferred to a test tube containing 7 ml of DMSO and then incubated overnight. The extractedliquidfromthiswaspouredto agraduatedcylinderandvolumewasmadeup to 10 ml by addingDMSO.

The absorbance was then recorded using a visible spectrophotometer (Thermo Orion AquaMate 7000 Vis spectrophotometer) at 645nm, 663nm and 652nm. Total chlorophyll, chl a and chl b were measured using Arnon’s formula:

$$\text{Chl a} = \frac{(12.7 \text{ x A663} - 2.69 \text{ x A645}) \text{ x V}}{1000 \text{ x W}}$$

$$\text{Chl b} = \frac{(22.9 \text{ x A645} - 4.68 \text{ x A645}) \text{ x V}}{1000 \text{ x W}}$$

$$\text{Total chlorophyll} = \frac{\text{A652 x 1000 x V}}{\text{34.5 x 1000 x W}}$$

Where,A645=absorbanceat645nm,A663=absorbanceat663nm,A652=absorbance at 652nm, V = Final volume in ml and W = weight of leaf ingram.

3.8.3.5 Estimation of Chlorophyll stability index(CSI)

CSIwasestimatedbythemethodofMurthyandMajumdar,1962.Hundred mg offreshleafsamples,whichwerecutintofinepiecesweretakenintwotesttubeseach. 20ml of double distilled water (control) poured to one test tube and 20ml of hot water at 55 ºC (treatment) poured to the next test tube. Treatment tubes were then kept in a water bath for 30 minutes. After this, leaf bits were allowed to cool and they were transferredtotesttubecontaining7mlofDMSOandincubatedovernight at65ºC.The absorbance of control and treatment were measured using 652nm. CSI was expressed as a percentage of chlorophyll content in treatment to the chlorophyll content of the control.

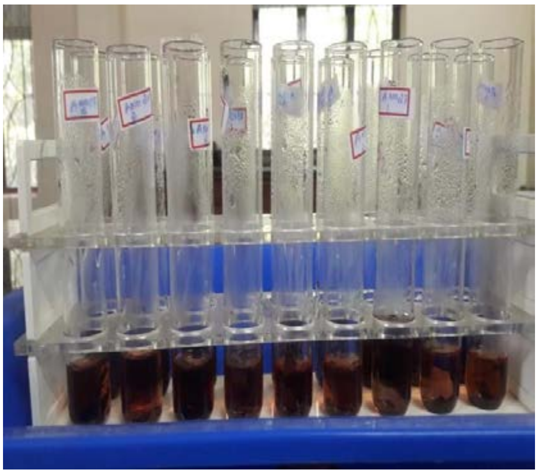
$$\text{CSI (\%)} = \frac{\text{A652 of treatment}}{\text{A652 of control}} \text{x } 100$$

Where, A 652 = Absorbance at 652nm.

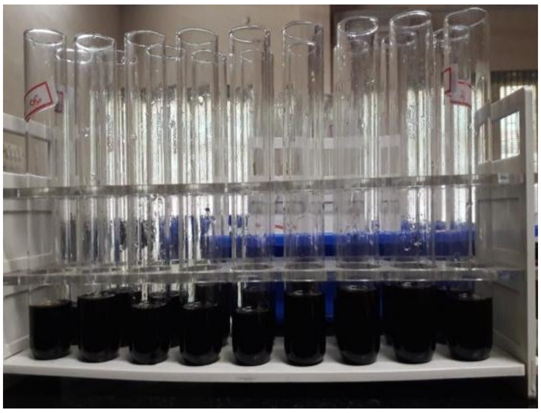
3.8.3.6 Estimation of Chlorophyllfluorescence

Chlorophyll fluorescence measurement was taken from 1000 to 1100h in the morning with the help of a portable Hansatech Plant Efficiency Analyser (Hansatech, King’s Linn, England). This plant efficiency analyser (PEA) has a sensor head which helps in the illumination of leaves and detection of resulting fluorescent signal, control box helps in obtaining measurement and white plastic clips for dark adaptation.

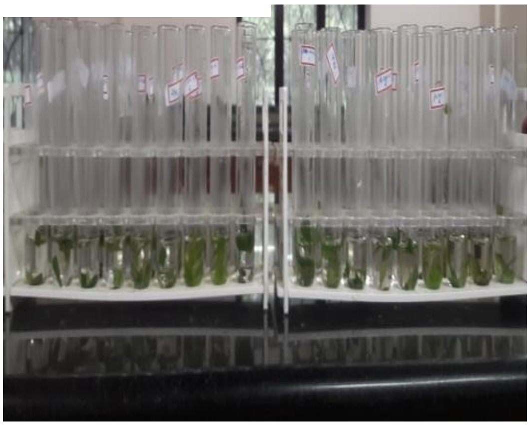

Estimation of Relative water content




Estimation of chlorophyll stability index



Estimation ofchlorophyllpigment



Estimation of Membrane stabilityindex

Plate 4 Determination of physiological observations

Leavesfromeachaccessionweredark-adaptedusingtheseclips.Sixclipswere pinned in single leaf for about 20 minutes for dark adaptation. After this, the sensor head was gently placed over clip, and the leaf was exposed for illumination by slid opening the shutter plate and fluorescence was recorded. The effective quantum yield of PSII was given by F_v/F_m (Genty *et al.*,1989). Fo and Fm were also recorded.

3.8.3.7 Canopy air temperature difference(CATD)

Effect of drought on canopy air temperature difference was observed by estimating CATD. Canopy temperature and the ambient air temperature was measured with a handheld infrared thermometer (Agri-Therm II). CATD Infrared thermometer was used to measure canopy air temperature difference.

3.9 Experimentaldesign

Physiological and growth parameter for drought tolerance were analysed using a completely randomized design (CRD). Three replications with two plants each were usedforeachclone.Forcomparisonofmeansofdifferentaccessions Duncansmultiple range test (DMRT) was used. Physiological observation during 3 stages of stress was separately analysed usingCRD.

In order to test the significance of various physiological parameters under 3 stages of moisture stress Kruskall Wallis test was used. Karl Pearson's correlation coefficient (r) was calculated among physiological observations. Hierarchical cluster analysis was carried out for grouping eighteen accessions under normal, drought and regain conditions. R 3.6.1 version and Minitab were used for performing analysis.

Measuring CATD using Infrared Thermometer

Measuring gas exchange parameter using portable photosynthetic system

Measuringchlorophyllfluorescence

Measuring membrane stability indexusing conductivitymeter

Plate 5 Instruments for measuring physiological parameters

Results

4. RESULTS

The present study entitled “Selection for drought tolerance and wood quality traits from selected accessions of *Tectona grandis* Linn. f.” was carried out at Department of Forest Biology and Tree Improvement, College of Forestry, Vellanikkara.

4.1 Screening of teak accessions on the basis of wood properties and growth characters

TeaktreesfromThiruvazhamkunnuprovenancetrialwasusedforscreeningon the basis of wood properties and growth parameters. In the plantation area only 19 accessions with enough number of progenies were present. Wood properties were measured non- destructively using pilodyn and tree sonic timer. Additionally height and diameter at breast height were also measured. Analysis was performed using compact family block design with nineteen accessions with two replicationeach.

4.1.1 Variations in wood properties and growthparameters

4.1.1.1 Height

Height was found to be significantly different (P<0.05) between 19 accessions of teak (Table 3). Highest value for height was observed in A2 (17.97m) which was on par with A29 (16.52m), A21 (15.72m), A20 (15.57m), A1 (15.54m), A3 (15.04m) and A22 (14.77m).

4.1.1.2 Girth

Girthbetween19accessionsofteakfoundtobesignificantlydifferent(P<0.05) and presented in the Table 3. Highest value for girth was observed in A29 (86.07cm) which was on par with A22 (72.51cm), A1 (70.87cm), A21(69.68cm), A2(66.50cm), A3(65.00cm), A18(64.91cm), A4(62.75cm), A17(61.62cm), A20(61.25cm), A23(59.00cm), A30(54.50cm), A24(54.20cm) andA28(52.25cm).

4.1.1.3 Pilodyn Penetration Depth(PPD)

Pilodyn penetration depth was found to be significantly different between 19 accessions at $P<0.05$ (Table 3). Lowest PPD was observed in A23 (20.25mm) which was on par with A1 (20.25mm), A17 (20.50mm), A5 (20.75mm), A28 (21.00mm), A2 (21.25mm), A19 (21.25mm), A27 (21.50mm), A13 (21.50mm), A3 (21.75mm), A21 (21.75mm), A18 (21.75mm) and A22 (22.00mm).

4.1.1.4 Specific gravity (Relativedensity)

Specificgravity(SG)showedsignificantvariationsamong19accessionsofteak and was presented in the Table 3. Highest SG registered for A1 (0.44) which was on parwithA23(0.44),A17(0.43),A5(0.42),A28(0.41),A19(0.41),A2(0.41),A13 (0.40), A27 (0.40), A18 (0.39), A3 (0.39), A21 (0.39) and A22 (0.38).

4.1.1.5 Stress wave velocity(SWV)

Stress wave velocity was found to be significantly different among the accessions (Table 3). Highest value for stress wave velocity was observed for A30 (4360.21 m s^{-1}), which is on par with A18 (4322.26 m s^{-1}), A21 (4319.80 m s^{-1}), A4 (4307.36 m s^{-1}), A17 (4264.06 m s^{-1}), A28 (4254.23 m s^{-1}), A24 (4219.73 m s^{-1}), A20 (4206.21ms^{-1}),A22(4205.81ms^{-1}),A6(4172.68ms^{-1}),A23(4162.18ms^{-1})andA19 (4150.70 ms^{-1}).

Table 3. Variations in height, girth, pilodyn penetration depth, specific gravity and stress wave velocity among accessions of *Tectona grandis*

Accessions	Height (m)	Girth(cm)	PPD(mm)	SWV (m/s)	Specific gravity
A1	15.54^{abcd}	70.87^{abc}	20.25^{f}	3875.3^{bc}	0.44^{a}
A2	17.97^{a}	66.50^{ab}	21.25^{cdef}	3810.2^{bc}	0.41^{abcd}
A3	15.04^{abcd}	65.00^{abc}	21.75^{bcdef}	3855.1^{bc}	0.39^{abcde}
A4	13.19^{bcdef}	62.75^{ab}	22.25^{abcde}	4307.3^{ab}	0.38^{bcdef}
A5	9.57^{g}	31.75^{c}	20.75^{def}	3929.1^{bc}	0.42^{abc}
A6	11.54^{efg}	44.75^{bc}	23.25^{ab}	4172.6^{ab}	0.35^{ef}
A13	13.24^{bcdef}	44.75^{bc}	21.50^{bcdef}	4001.9^{bc}	0.40^{abcde}
A17	12.32^{cdefg}	61.62^{abc}	20.50^{ef}	4264.1^{ab}	0.43^{ab}
A18	12.27^{defg}	64.90^{abc}	21.75^{bcdef}	4322.3^{ab}	0.39^{abcde}
A19	13.12^{bcdef}	49.25^{bc}	21.25^{cdef}	4150.7^{ab}	0.41^{abcd}
A20	15.57^{abcd}	61.25^{a}	24.25^{a}	4206.2^{ab}	0.32^{f}
A21	15.72^{abc}	69.68^{abc}	21.75^{bcdef}	4319.8^{ab}	0.39^{abcde}
A22	14.77^{abcde}	72.51^{ab}	22.00^{bcdef}	4205.8^{ab}	0.38^{abcde}
A23	12.94^{cdefg}	59.00^{abc}	20.25^{f}	4162.2^{ab}	0.44^{a}
A24	10.19^{fg}	54.2^{abc}	23.25^{ab}	4219.7^{ab}	0.35^{ef}
A27	11.24^{fg}	44.00^{bc}	21.50^{bcdef}	4004.0^{bc}	0.40^{abcde}
A28	13.29^{bcdef}	52.25^{ab}	21.00^{cdef}	4254.2^{ab}	0.41^{abcd}
A29	16.52^{ab}	86.07^{abc}	22.50^{abcd}	3535.0^{c}	0.37^{cdef}
A30	13.42^{bcdef}	54.50^{abc}	22.75^{abc}	4360.2^{a}	0.36^{def}
Mean	13.55	58.72	21.76	4102.9	0.39
CD	3.43	33.88	1.88	513.23	0.055

4.1.2 Correlation between wood quality traits and growth parameters among different accessions ofteak

Pearson correlation was used to understand relationship with various wood quality traits and growth parameters. High significant negative correlation was observed between PPD and SG. Along with that high significant positive correlation observed between height and girth among the 19 accessions of teak (Table 4).

Table 4 Correlation between growth parameters and wood properties among accessions of *Tectona grandis*

	Height	PPD	SWV	Girth	Specific gravity
Height	1				
PPD	0.04	1			
SWV	-0.38	0.18	1		
Girth	0.76**	0.07	-0.24	1	
Specific gravity	-0.03	-0.99**	-0.20	-0.08	1

**Correlation is significant at 0.01 level

4.2 Screening of teak accessions for droughttolerance

Vegetatively propagated plus tree accessions (ortets) of teak were subjected to drought stress. During the drought stress the soil moisture was measured gravimetrically. Variation of soil moisture content among the accessions were presented in the Table 5.

Table 5 Soil moisture content among accessions of *Tectona grandis* during normal condition of growth and drought stress

	Percentage soil moisture content during drought days (%)				
Accessions	day1	day2	day3	day4	day5
A1	16.63^{bcd}	13.76^{abcd}	10.18^{b}	7.80^{c}	6.00^{c}
A2	16.67^{bcd}	13.37^{efg}	10.26^{ab}	7.79^{c}	6.00^{cd}
A3	17.16^{a}	13.36^{fg}	10.38^{ab}	7.60^{f}	5.80^{f}
A4	16.67^{bcd}	13.02^{h}	10.49^{ab}	7.54^{g}	5.70^{g}
A5	16.74^{bc}	13.65^{abcde}	10.76^{ab}	7.29^{k}	5.40^{k}
A6	16.20^{f}	13.57^{bcdef}	10.89^{a}	7.23^{l}	5.30^{l}
A13	16.29^{ef}	13.90^{a}	10.72^{ab}	7.90^{b}	6.10^{b}
A17	16.22^{ef}	13.85^{ab}	10.38^{ab}	7.94^{a}	6.20^{a}
A18	16.27^{ef}	13.31^{fg}	10.68^{ab}	7.47^{h}	5.70^{hi}
A19	16.50^{cde}	13.49^{defg}	10.54^{ab}	7.74^{d}	5.90^{de}
A20	16.32^{ef}	13.54^{cdefg}	10.54^{ab}	7.69^{e}	5.90^{e}
A21	16.24^{ef}	13.51^{defg}	10.23^{ab}	7.19^{m}	5.30^{l}
A22	16.67^{bcd}	13.68^{abcd}	10.70^{ab}	7.43^{i}	5.60^{i}
A23	16.42^{def}	13.80^{abc}	10.62^{ab}	7.50^{h}	5.70^{gh}
A24	16.22^{ef}	13.28^{gh}	10.85^{ab}	7.36^{j}	5.50^{j}
A27	16.22^{ef}	13.33^{fg}	10.62^{ab}	7.74^{d}	5.90^{e}
A28	16.86^{b}	13.50^{defg}	10.12^{b}	7.62^{f}	5.80^{f}
A29	16.47^{cdef}	13.80^{abc}	10.57^{ab}	7.90^{b}	6.10^{b}
Mean	16.48	13.54	10.24	7.59	5.80
CD (5%)	0.29	0.28	3.01	0.03	0.05

Soil moisture content showed a significant variations among 18 accessions during five days of drought. In the first day of withholding water soil moisture content was observed highest in the A3 (17.16%). In the second day, soil moisture content declinedabout41.30%withhighestvalueobservedinA13(13.90%)whichwasonpar withA17(13.85%),A23(13.80%),A29(13.80%),A1(13.76%),A22(13.68%)and A5 (13.65%). Similarly in the third day of moisture stress a significant reduction in moisture content was observed with highest soil moisture in A6 (10.89%) which was on par with other accessions except A1 and A28. In the fourth day of moisture stress, soil moisture content declined again and highest percentage soil moisture content was observed in A17 (7.94%). In the last day of moisture stress, soil moisture content declined about 74.85% when compared with normal, with highest moisture content exhibited byaccessionA17(6.20%).Variationofsoilmoisturecontentduringdrought stress among the accessions were graphically represented by Figure1.

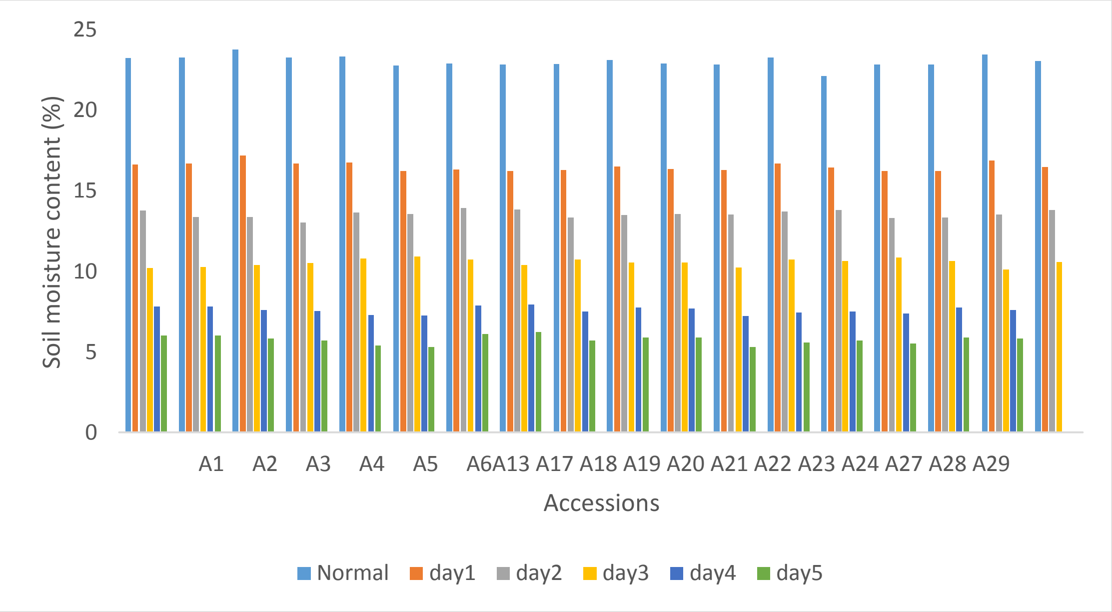


Figure 1 Variation of soil moisture content during drought stress among the accessions of *Tectona grandis*

Table 6 Number of leaves withered during drought among the accessions of *Tectona grandis*

Accessions	Total number of	Number of withered	Percentage leaf
A1	9.3	7.3^{a}	78.5^{c}
A2	9.0	7.0^{a}	77.8^{c}
A3	9.7	6.7^{ab}	69.4^{ef}
A4	8.3	6.0^{abc}	71.9^{de}
A5	7.7	4.0^{def}	52.4^{i}
A6	7.3	3.0^{fg}	41.0^{j}
A13	8.0	7.0^{a}	87.5^{b}
A17	7.3	7.0^{a}	96.3^{a}
A18	8.0	5.3^{bcd}	66.7^{f}
A19	8.0	6.0^{abc}	75.0^{cd}
A20	8.0	6.0^{abc}	75.0^{cd}
A21	9.0	2.3^{g}	25.7^{k}
A22	6.3	3.7^{efg}	58.1^{h}
A23	8.0	5.0^{cde}	62.5^{g}
A24	6.7	3.3^{fg}	50.0^{i}
A27	8.0	6.0^{abc}	75.0^{cd}
A28	7.0	5.0^{cde}	71.4^{de}
A29	7.0	6.0^{abc}	85.5^{b}
Mean	7.92	5.37	67.76
CD(P<0.05)	1.94	1.94	3.87

Leaf wilting on second dayofdrought

Leaf wilting on third day ofdrought

Leaf wilting on fourth dayofdrought

Leaf wilting on fifth day ofdrought

Plate 6 Variation in morphological character during period of drought

It was observed that under normal condition number of leaves didn't showed anysignificantdifferenceamongtheaccessions.Inordertounderstandinitialresponse amongtheaccessionsofteaktowardsdroughtpercentageofleafwitheredwasobserved (Table6).Atdroughtstress,percentageofwitheredleavesshowedsignificantvariation among the accessions of teak. Highest percentage of withered leaves was observed in A17. Lowest percentage of withered leaves was observed in A21 (Plate6).

4.2.1 Effect of physiological characters under three stages of droughtstress

For studying drought tolerance among 18 accessions of teak, physiological changes in response to imposed drought stress were studied in three stages *viz*. normal, stress and regain. Physiological observations during normal condition of growth was measuredafterirrigatingwholeplantstofieldcapacity.Afterthatdroughtwasimposed bywithholdingwaterfor5daysuntiltheplantsshowedsignsofwilting.Physiological observation during this period was observed. The plants were then irrigated and maintained till they again showed normal condition of growth. The observations for regain was recorded when plants showed two to three new leaf emergence. Prior to individual analysis for physiological parameters of teak accessions during three stages of drought it was essential to understand whether these parameters showed any significant variation among three stages ofdrought.

In order to test the significance of various physiological characters under three stages of drought *viz.*, normal, stress and regain, Kruskal Wallis test was used. Kruskal Wallis test is one of the important non parametric test, quite useful for the analysis of experimental data generated through a completely randomized block design. The post-hocpairwisecomparisonswasdonebyadjustingP valuesusingBonferronicorrection. The result obtained from Kruskal Wallis was given in Table7.

Photosynthetic rate showed a significant difference among the three stages of drought. Highest photosynthetic rate of 3.94 μmol CO_2 m^{-2} $s^{-1}$was observed at normal condition. During drought, photosynthetic rate showed a reduction of 77 percent compared to control. After re-watering photosynthetic rate showed a recovery of 37.56%.

Chlorophylla,chlorophyllbandtotalchlorophyllshowedasignificantdecrease when subjected to drought. After withholding water, chlorophyll a, chlorophyll b and total chlorophyll showed a decreased of 20.5%, 21.6% and 23.8% when compared to control. After rewatering they were recovered to 88.7%, 84.9% and 91.45% respectively.

RWC decreased with imposing drought stress. Drought stress decreased RWC in leaf by 52.8%. After rewatering a complete recovery of leaf RWC was observed.

When subjected to drought stress teak clones produced significant changes in stomatalconductance(gs),transpirationrate(E)andchlorophyllfluorescence(Fv/Fm). The decrease of gs, E and Fv/Fm were 33.5%, 31.65% and 15.1% respectively. After rewatering gs, E, Fv/Fm showed 93.7%, 77.8% and 97.4% recoveryrespectively.

Drought stress induced oxidative damage to membranes and was determined using membrane stability index (MSI). During drought MSI showed 12.4% reduction comparedtocontrolandafterrewatering93%recoveryofMSIwasobserved.Similarly chlorophyll stability index (CSI) also showed a significant decrease during drought. CSI was reduced to 24.9% compared to control and attained 97.3% recovery after rewatering.

Table 7 Effect of physiological characters under three stages of drought stress in *Tectona grandis*

Stages of drought	**Pn (μmol CO_2 m^{-2} s^{-1})**	**gs (mmol H_2O m^{-2} s^{-1})**	**E(μmol H_2O m^{-2} s^{-1})**	**leaf temp (^{o}C)**	**CATD (^{o}C)**	**Fv/Fm**	**RWC (%)**	**Chl a (μg g^{-1})**	**Chl b (μg g^{-1})**	**Total chl(μg g^{-1})**	**MSI (%)**	**CSI (%)**
Normal	3.94^{a}	0.063^{a}	1.58^{a}	35.67^{b}	-0.972^{c}	0.741^{a}	71.30^{a}	2.39^{a}	1.99^{a}	4.33^{a}	72.65^{a}	72.54^{a}
Stress	0.908^{b}	0.044^{b}	1.08^{b}	37.82^{a}	0.034^{a}	0.629^{b}	37.6^{b}	1.90^{b}	1.56^{ab}	3.30^{b}	63.62^{b}	54.48^{b}
Regain	1.48^{b}	0.062^{a}	1.23^{b}	32.06^{c}	-0.66^{b}	0.722^{ab}	77.94^{a}	2.12^{ab}	1.69^{b}	3.96^{ab}	67.70^{a}	70.64^{a}
Kruskal chi value	36.86	19.56	23.08	47.13	39.45	8.13	30.62	9.99	17.35	12.1	25.35	24.32
P	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

4.2.2 Physiological response of teak accessions under normal condition ofgrowth

4.2.2.1 Variations of physiological parameters during normalcondition

The observations of different physiological parameters among different plus tree accessions at normal condition are presented in the Table 8. Statistical analysis showedsignificant($P<0.05$)differencesinphotosynthesis,transpiration,conductance, canopy air temperature difference, leaf temperature, relative water content, cell membrane stability index, chlorophyll a, chlorophyll b, total chlorophyll and chlorophyll stability index among the eighteenaccessions.

Rate of photosynthesis was observed highest in A21 (4.24 μmol CO_2 $m^{-2}s^{-1}$) and showed a significant difference from other accessions. The A17 (3.64 μmol CO_2 $m^{-1}s^{-1}$)hadthelowestrateofphotosynthesis.Meanvalueofrateofphotosynthesiswas observed as 3.94 μmol CO_2 $m^{-2}s^{-1}$.

Under normal conditions, the highest rate of stomatal conductance was observedinA21(0.078mmol$H_2O$$m^{-2}s^{-1}$)whichwassignificantlydifferentfromother accessions. Minimum value was recorded in A17 (0.059 mmol H_2O $m^{-2}s^{-1}$), whereas the mean value for conductance was 0.063 mmol H_2O $m^{-2}s^{-1}$.

Rate of transpiration had the highest value in A21 (1.61 μmol H_2O m^{-2} s^{-1}). Lowest rate of transpiration was observed in A17 (1.57 μmol H_2O m^{-2} s^{-1}) followed by A29 (1.57 μmol H_2O m^{-2} s^{-1}) and A13 (1.57 μmol H_2O m^{-2} s^{-1}) and all the three accessions were on par with each other. Mean value of rate of transpiration was 1.58 μmol H_2O m^{-2} s^{-1}.

The Relative Water Content (RWC) ranged from 89.42 % in A22 to 53.50% in A17 with the mean value being at 71.20%. Among these, A22 was significantly different from other accessions.

ThehighestvaluesforChlorophylla(Chla)contentwereobservedinA21(3.05 μg g^{-1}), A24 (2.90 μg g^{-1}) and A5 (2.83 μg g^{-1}), in that order, with A21 significantly differing from all other accessions. The lowest value for chl a was observed in A17 (1.60 μg g^{-1}). Mean value for chl a content was 2.39 μgg^{-1}.

The highest and lowest Chlorophyll b (Chl b) content were recorded in accessionsA21(2.50μgg^{-1})andA17(1.46μgg^{-1}),respectively,andtheformershowed a significant difference from the other accessions. Mean value for chl b contentwas 1.99 μg g^{-1}.

Totalchlorophyllcontentwasrecordedhighestfor A22(4.76μgg^{-1}),A13(4.73 μg g^{-1}), A24 (4.70 μg g^{-1}), A19 (4.69 μg g^{-1}), A21 (4.61 μg g^{-1}), A17 (4.57 μg g^{-1}),A3 (4.57μgg^{-1}),A6(4.54μgg^{-1}),A28(4.45μgg^{-1}),A4(4.34μgg^{-1}),A23(4.31μgg^{-1}) andA29(4.27μgg^{-1})andtheywereonpar.TheaccessionsA18(3.24μgg^{-1}),A1(3.60 μg g^{-1}) and A2 (3.62 μg g^{-1}) which were on par with each other showed the lowest set of values for total chlorophyll content. Mean value for total chlorophyll contentwas 4.33 μg g^{-1}.

Chlorophyll Stability Index (CSI) was recorded highest in A21 (86.76%) and A24 (85.64%), they were on par. Lowest value was observed in A17 (51.70%). Mean value obtained for chlorophyll stability index was 72.54%.

Membrane Stability Index (MSI) was recorded highest in A21 (80.71%) and showed significant difference from other accessions, followed by A24 (79.63%) and A5 (79.21%). Lowest value was observed in A17 (61.82%). Mean value obtained for chlorophyll stability index was 72.65%.

Maximum potential quantum efficiency of PSII (Fv/Fm) was observed highest in A21 (0.790) showed significant difference from other accessions. Lowest value was observedinA17(0.678).Meanvalueforchlorophyllfluorescenceobservedwas0.741.

The leaf temperature values ranged from 36.52°C (A17) to 34.42°C (A21) and the former was significantly different from other accessions. Mean value of leaf temperature under normal condition was observed as 35.66°C.

The Canopy air temperature difference (CATD) wasobserved lowest in in A21 (-1.08°C) and A24 (-1.06°C) which were on par. The highest value for CATD was observed in accession A17 (-0.75°C) and showed significant difference from other accessions. Mean value observed for CATD was-0.972°C.

Table 8 Physiological response of *Tectona grandis* accessions under normal condition of growth

Acc	**Pn**(µmol CO_2 $m^{-2}\ s^{-1}$)	**gs** (mmol $m^{-2}\ s^{-1}$)	**E (**µmol H_2O $m^{-2}\ s^{-1}$)	**Leaf temp** (°C)	**CATD** (°C)	**Fv/Fm**	**RWC** (%)	**Chl a** (µg g^{-1})	**Chl b** (µg g^{-1})	**Total chl** (µg g^{-1})	**MSI** (%)	**CSI** (%)
A1	3.83^{j}	0.062^{jk}	1.58^{d}	36.22^{cd}	-0.95^{e}	0.722^{jk}	63.44^{j}	2.08^{jk}	1.80^{j}	3.60^{e}	67.38^{k}	62.43^{l}
A2	3.79^{k}	0.061^{kl}	1.58^{d}	36.30^{bc}	-0.92^{d}	0.715^{kl}	61.10^{k}	2.01^{kl}	1.66^{l}	3.62^{e}	65.99^{l}	61.54^{lm}
A3	3.95^{gh}	0.066^{h}	1.59^{c}	35.61^{f}	-1.00^{gh}	0.747^{fg}	71.46^{g}	2.48^{fg}	2.12^{e}	4.57^{ab}	73.15^{g}	75.79^{gh}
A4	3.94^{gh}	0.064^{i}	1.59^{c}	35.85^{e}	-1.00^{gh}	0.743^{gh}	69.40^{h}	2.43^{gh}	1.97^{g}	4.34^{abcd}	74.81^{f}	75.35^{h}
A5	4.10^{c}	0.072^{c}	1.60^{b}	34.93^{k}	-1.04^{jk}	0.773^{bc}	84.36^{c}	2.83^{bc}	2.29^{c}	4.05^{cde}	79.21^{b}	84.9b^{c}
A6	4.09^{cd}	0.070^{d}	1.59^{c}	35.08^{j}	-1.03^{ij}	0.769^{bcd}	82.69^{d}	2.74^{cd}	2.26^{c}	4.54^{abc}	78.38^{c}	84.13^{c}
A13	3.72^{l}	0.061^{l}	1.57^{e}	36.35^{b}	-0.81^{b}	0.702^{m}	58.43^{l}	1.85^{m}	1.60^{m}	4.73^{a}	64.36^{n}	54.36^{n}
A17	3.64^{m}	0.059^{m}	1.57^{e}	36.52^{a}	-0.75^{a}	0.678^{n}	53.50^{m}	1.60^{n}	1.46^{n}	4.57^{ab}	61.82^{o}	51.70^{o}
A18	4.02^{e}	0.069^{e}	1.59^{c}	35.21^{i}	-1.02^{ij}	0.762^{de}	75.47^{f}	2.58^{ef}	2.15^{de}	4.08^{cde}	76.78^{e}	79.23^{e}
A19	3.90^{i}	0.063^{j}	1.58^{d}	36.16^{d}	-0.97^{f}	0.729^{ij}	67.21^{i}	2.23^{i}	1.87^{i}	4.69^{a}	69.08^{j}	70.00^{j}
A20	3.99^{ef}	0.068^{fg}	1.59^{c}	35.35^{gh}	-1.02^{ghi}	0.757^{ef}	64.64^{j}	2.54^{f}	2.07^{f}	4.04^{cde}	76.20^{e}	77.06^{f}
A21	4.24^{a}	0.078^{a}	1.61^{a}	34.42^{m}	-1.08^{l}	0.790^{a}	75.08^{f}	3.05^{a}	2.50^{a}	4.61^{a}	80.71^{a}	86.76^{a}
A22	4.06^{d}	0.069^{ef}	1.59^{c}	35.27^{hi}	-1.02^{hi}	0.766^{cde}	89.42^{a}	2.65^{de}	2.17^{d}	4.76^{a}	77.64^{d}	82.20^{d}
A23	3.96^{fg}	0.068^{g}	1.59^{c}	35.45^{g}	-1.01^{ghi}	0.749^{fg}	80.10^{e}	2.50^{fg}	2.05^{f}	4.31^{abcd}	75.43^{f}	76.54^{fg}

Table 8 Physiological response of *Tectona grandis* accessions under normal condition of growth (Contd.)

A24	4.15^{b}	0.075^{b}	1.60^{b}	34.71^{l}	-1.06^{kl}	0.780^{b}	72.91^{g}	2.90^{b}	2.38^{b}	4.70^{a}	79.63^{b}	85.64^{ab}
A27	3.86^{j}	0.061^{jkl}	1.58^{d}	36.25^{bcd}	-0.94^{de}	0.723^{jk}	86.13^{b}	2.16^{ij}	1.90^{hi}	3.97^{de}	70.22^{i}	63.61^{k}
A28	$3.92h^{i}$	0.064^{i}	1.58^{d}	35.95^{e}	-0.99^{fg}	0.735^{hi}	68.20^{hi}	2.36^{h}	1.92^{h}	4.45^{abcd}	71.71^{h}	73.95^{i}
A29	3.76^{k}	0.061^{kl}	1.57^{e}	36.34^{b}	-0.89^{c}	0.706^{lm}	59.96^{kl}	1.95^{lm}	1.70^{k}	4.27^{abcd}	65.25^{m}	60.48^{m}
Mean	3.94	0.063	1.58	35.67	-0.972	0.741	71.30	2.39	1.99	4.33	72.65	72.54
CD (5%)	0.034	0.001	0.005	0.112	0.228	0.011	1.66	0.105	0.037	0.516	0.69	1.15

Acc=accessions,RWC=Relativewater,CATD=Canopyairtemperaturedifferences,Pn=Photosyntheticrate,gs=Stomatalconductance, E = Transpiration rate, Chl a = Chlorophyll a, Chl b = Chlorophyll b, CSI = Chlorophyll stability index, Total Chl. = Total chlorophyll, MSI = Membrane stabilityindex

4.2.2.2 Correlation study on physiological characters at normalcondition

Pearson correlations were done to determine the relationship among various physiological parameters under normal growth condition. The results are given in the Table 9.

There was a significant positive correlation between photosynthetic rate and Fv/Fm, transpiration rate, stomatal conductance, RWC, Chl a, Chl b, MSI and CSI. Highestpositivecorrelationof0.99wasshowedbyphotosyntheticrateandFv/Fm,Chl a and Chl b. Photosynthetic rate showed significant negative correlation with CATD and leaftemperature.

Stomatal conductance showed a significant positive correlation with transpiration rate, Fv/Fm, chl A, Chl b, MSI, RWC and CSI. It also showed significant negative correlation with leaf temperature and CATD.

Transpiration rate showed a significant positive correlation with Fv/Fm, Chl a, Chl b, MSI, RWC and CSI. Significant negative correlation exist between rate of transpiration and CATDand leaf temperature.

LeaftemperatureandCATDshowedasignificantnegativecorrelationwithchl a,Chlb,Fv/Fm,MSI,RWCandCSI.Fv/Fmwasfoundtobepositivelycorrelatedwith Chl a, Chl b, MSI, RWC and CSI. RWC showed a significant positive correlation between Chl a, Chl b, MSI and CSI. Chl a and Chl b showed a significant positive correlationwithMSIandCSI.MSIshowedahighsignificantpositivecorrelationwith CSI.

Table 9 Correlation between physiological parameters of *Tectona grandis* under normal condition of growth

	Pn	gs	E	tleaf	CATD	Fv/Fm	RWC	Chl a	Chl b	MSI	CSI
Pn	1										
gs	0.96**	1									
E	0.95**	0.94**	1								
tleaf	-0.96**	-0.99**	-0.94**	1							
CATD	-0.94**	-0.83**	-0.88**	0.84**	1						
Fv/Fm	0.99**	0.94**	0.94**	-0.96**	-0.95	1					
RWC	0.67**	0.53	0.58*	-0.58*	-0.68**	0.69**	1				
Chl a	0.99**	0.95**	0.95**	-0.96**	-0.95**	0.99**	0.68	1			
Chl b	0.99**	0.95**	0.95**	-0.96**	-0.93**	0.98**	0.69**	0.99**	1		
MSI	0.97**	0.92**	0.93**	-0.95**	-0.93**	0.98**	0.73**	0.98**	0.97**	1	
CSI	0.97**	0.91**	0.91**	-0.93**	-0.95**	0.98**	0.69**	0.98**	0.97**	0.98**	1

RWC = Relative water, CATD = Canopy air temperature differences, Pn = Photosynthetic rate, gs = Stomatal conductance, E = Transpiration rate, Chl a = Chlorophyll a, Chl b = Chlorophyll b, CSI = Chlorophyll stability index, MSI = Membrane stability index

4.2.2.3 Clusteranalysis

A hierarchical cluster analysis was carried out for the 18 accessions based on the Euclidian squared distance. The 18 accessions were grouped into five clusters. Details of the five clusters are given in the Table 10. The accessions comes in a cluster havesimilarphysiologicalcharacterswhereasitdiffersbetweentwoclusters.Fromthe table, the cluster II possess maximum number of accessions whereas the least number observed for the clusterIII.

Table 10 Clusters for physiological parameters among *Tectona grandis* accessions during normal condition of growth

Clusters	I	II	III	IV	V
Accessions	A1 A2 A13 A29	A3, A4, A20, A18, A23, A5, A6, A22	A17	A19 A28 A27	A21 A24

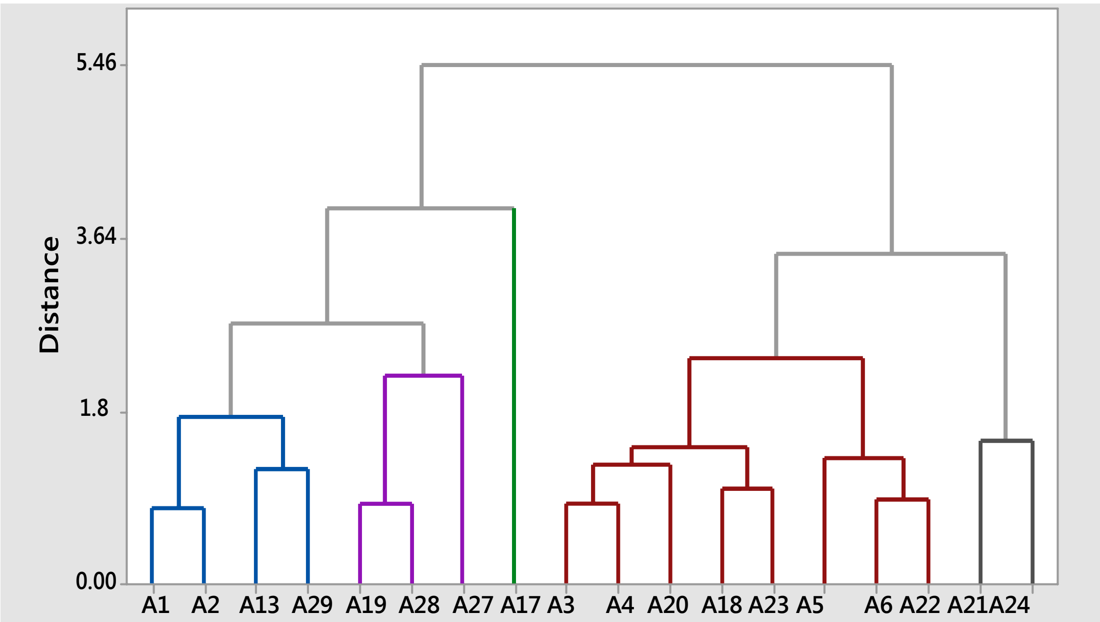


Figure 2. Dendrogram of cluster analysis among accessions of *Tectona grandis* during normal condition of growth

Adendrogramisthediagrammaticrepresentationoftheclusteranalysis.Figure 2 represents the dendrogram of the cluster analysis of 18 accessions of teak during normal condition ofgrowth.

Table 11 Distance between cluster centroids among accessions of *Tectona grandis* under normal condition of growth

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Cluster 1	0.92				
Cluster 2	5.21	1.25			
Cluster 3	2.88	7.92	0.00		
Cluster 4	2.47	3.00	5.23	1.02	
Cluster 5	8.20	3.32	10.80	6.22	0.76

Table 11 gives the inter and intra cluster distances. Intra cluster distances gives the average distance between the elements within a cluster whereas the distance betweentwoclustersgivestheinterclusterdistances.Thediagonalelementsshowsthe intra cluster distances and the off diagonal elements shows the inter cluster distances. It is observed from the table that highest intra cluster distance shown by the II cluster (1.25) and the highest inter cluster distance shown by clusters III and V(10.80).

4.2.3 Physiological response of teak accessions under droughtstress

4.2.3.1 Variations of physiological parameters of teak accessions atdrought stress

Subjectingtheteakaccessionstodroughtstressproducedsignificantdifferences ($P < 0.05$) in the photosynthetic rate, stomatal conductance, transpiration rate, Fv/Fm, CATD, leaf temperature, total chlorophyll content, RWC, MSI, chlorophyll a, chlorophyll b and CSI (Table 12). Rate of photosynthesis was significantly highest in A21 (1.35 µmolCO_2 $m^{-2}s^{-1}$). Other accessions with highest rate of photosynthesis are A6(1.29µmol$CO_2$$m^{-2}s^{-1}$),A5(1.27µmol$CO_2$$m^{-2}s^{-1}$)andA24(1.18µmol$CO_2$$m^{-2}s^{-1}$). Lowest rate of photosynthesis was observed in A17 (0.51 µmol$CO_2$$m^{-2}$ s^{-1}). The mean value of photosynthetic rate was 0.908 µmolCO_2 $m^{-2}s^{-1}$.

Stomatal conductance was highest in A21 (0.067 mmolH_2O m^{-2} s^{-1}) which was on par with A6 (0.065 mmolH_2O m^{-2} s^{-1}). Minimum value was recorded in A17 (0.018 mmolH_2O m^{-2} s^{-1}). Mean value for conductance was 0.044 mmolH_2O $m^{-2}s^{-1}$. Rate of transpiration was highest in A21 (1.210 μmolH_2O m^{-2} s^{-1}) which was on par with A6 (1.207 μmolH_2O m^{-2} s^{-1}.). Lowest rate of transpiration was observed in A17 (0.953 μmolH_2O m^{-2} s^{-1}). Mean value of rate of transpiration was 1.08μmolH_2O m^{-2} s^{-1}.

Fv/Fm was found to be highest in A21 (0.790) which was statistically similar withA24(0.780),A5(0.773)andA6(0.769).LowestvaluewasobservedinA17(0.35) and A13 (0.35). Mean value for Fv/Fm observed was 0.629. Among the 18 accessions, A17(38.72°C)recordedhighestleaftemperaturewhichwasonparwithA13(38.62°C). Significantly lowest leaf temperature was observed in A21 (36.56°C). Mean value for leaf temperature was37.82°C.

CATD was lowest in A21 (-0.720°C). Highest value for CATD was obtained for A17 (0.780°C). Mean value obtained for CATD recorded was 0.034°C. RWC was recorded highest in A21 (74.20%) which showed significant difference from other accessions. Lowest RWC was observed in A29 (18.01%) which was on par with A2 (20.20%) and A1 (20.55%). Mean value for RWC was 37.60%.

Chl a content was found to be significantly highest in accession A21 (2.74 μg g^{-1}). Lowest chl a content was observed in A17 (1.31 μg g^{-1}) which was on par with A13 (1.34 μg g^{-1}). Mean value for chl a content was 1.90 μg g^{-1}. Chl b content was recorded highest in A21 (1.91 μg g^{-1}) and it showed significant difference from other accessions.LowestchlbcontentwasobservedinA17(1.08μgg^{-1}).Meanvalueforchl bcontentwas1.56μgg^{-1}.Totalchlorophyllcontentwasrecordedhighestfor A21(3.86 μg g^{-1}) and minimum value was recorded in A17 (2.65 μg g^{-1}). Mean value for total chlorophyll content observed was 3.30 μgg^{-1}

CSI was recorded significantly highest in A21 (70.35%). Lowest value was observed in A17 (36.11%). Mean value obtained for CSI was 54.48%.Among the accessions, A21 and A17 recorded highest (78.43%) and lowest (24.06%) MSI respectively. Mean value obtained for MSI was 63.62%.

Table 12 Physiological response of *Tectona grandis* accessions during drought stress

Acc	Pn (μmol CO_2 m^{-2} s^{-1})	Gs (mmol H_2O m^{-2} s^{-1})	E (μmol H_2O m^{-2} s^{-1})	leaf temp (^oC)	CATD (^oC)	Fv/Fm	RWC (%)	Chl a (μg g^{-1})	Chl b (μg g^{-1})	Total chl(μg g^{-1})	MSI (%)	CSI (%)
A1	0.64^{m}	0.029^{l}	1.029^{fg}	38.34^{cd}	$.031^{cd}$	0.47^{ij}	20.55^{jk}	1.47^{m}	1.38^{i}	2.84^{m}	57.44^{g}	42.70^{l}
A2	0.67^{l}	0.030^{l}	1.021^{g}	38.18^{de}	0.26^{de}	0.51^{i}	20.20^{jk}	1.58^{k}	1.45^{h}	3.11^{k}	64.27^{e}	43.49^{l}
A3	0.92^{h}	0.048^{g}	1.079^{cd}	37.84^{ghij}	0.77^{hi}	0.70^{def}	34.40^{f}	1.94^{h}	1.64^{e}	3.49^{g}	62.18^{f}	57.23^{g}
A4	0.94^{gh}	0.050^{f}	1.089^{c}	37.77^{hij}	0.03^{i}	0.71^{def}	32.66^{fg}	1.73^{j}	1.54^{fg}	3.36^{i}	72.11^{bc}	58.17^{g}
A5	1.27^{c}	0.064^{b}	1.670^{b}	37.11^{lm}	-0.37^{l}	0.77^{ab}	63.69^{b}	2.47^{c}	1.78^{bc}	3.71^{c}	63.16^{ef}	67.47^{c}
A6	1.29^{b}	0.065^{ab}	1.207^{a}	36.97^{m}	-0.53^{m}	0.77^{ab}	57.28^{c}	2.65^{b}	1.81^{b}	3.75^{b}	61.26^{f}	69.01^{b}
A13	0.52^{o}	0.021^{n}	0.978^{h}	38.62^{ab}	0.47^{b}	0.35^{k}	24.78^{i}	1.34^{n}	1.19^{k}	2.74^{o}	45.41^{i}	38.78^{m}
A17	0.51^{o}	0.018^{o}	0.953^{i}	38.72^{a}	0.78^{a}	0.35^{k}	23.61^{ij}	1.31^{n}	1.08^{l}	2.65^{p}	24.06^{j}	36.11^{n}
A18	1.01^{f}	0.052^{f}	1.100^{c}	37.70^{j}	-0.11^{j}	0.72^{cde}	45.35^{d}	2.08^{f}	1.71^{d}	3.56^{ef}	72.71^{b}	62.36^{e}
A19	0.74^{k}	0.033^{k}	1.030^{fg}	38.09^{ef}	0.22^{ef}	0.57^{h}	23.42^{ij}	1.53^{l}	1.40^{i}	3.02^{l}	62.63^{ef}	46.84^{k}
A20	0.87^{i}	0.042^{i}	1.060^{de}	37.98^{efgh}	0.17^{fg}	0.67^{f}	34.93^{f}	1.71^{j}	1.50^{g}	3.27^{j}	70.24^{cd}	52.35^{i}
A21	1.35^{a}	0.067^{a}	1.210^{a}	36.56^{n}	-0.72^{n}	0.78^{a}	74.20^{a}	2.74^{a}	1.91^{a}	3.86^{a}	78.43^{a}	70.35^{a}
A22	1.13^{e}	0.058^{d}	1.163^{b}	37.45^{k}	-0.24^{k}	0.74^{bcd}	43.92^{de}	2.29^{e}	1.74^{cd}	3.58^{e}	74.00^{b}	64.56^{d}
A23	0.96^{g}	0.055^{e}	1.083^{c}	37.72^{ij}	-0.12^{j}	0.71^{de}	40.84^{e}	2.04^{g}	1.65^{e}	3.53^{f}	73.00^{b}	60.27^{f}

A24	1.18^{d}	0.061^{c}	1.170^{b}	37.27^{kl}	-0.31^{kl}	0.75^{abc}	64.10^{b}	2.39^{d}	1.76^{c}	3.67^{d}	73.97^{b}	66.79^{c}
A27	0.83^{j}	0.036^{j}	1.050^{ef}	38.00^{efg}	0.20^{efg}	0.62^{g}	25.89^{hi}	1.61^{k}	1.57^{f}	3.13^{k}	69.10^{d}	50.06^{j}
A28	0.92^{h}	0.045^{h}	1.060^{de}	37.93^{fghi}	0.13^{gh}	0.69^{ef}	29.12^{gh}	1.87^{i}	1.63^{e}	3.42^{h}	70.23^{cd}	54.48^{h}
A29	0.59^{n}	0.025^{m}	0.994^{h}	38.44^{bc}	0.36^{c}	0.44^{j}	18.01^{k}	1.45^{m}	1.26^{j}	2.80^{n}	50.10^{h}	39.65^{m}
Mean	0.908	0.044	1.08	37.82	0.034	0.629	37.6	1.90	1.56	3.30	63.62	54.48
CD	0.024	0.018	0.023	0.233	0.079	0.04	3.58	0.039	0.04	0.065	2.07	1.19

Acc=accessions,RWC=Relativewater,CATD=Canopyairtemperaturedifferences,Pn=Photosyntheticrate,gs=Stomatalconductance, E = Transpiration rate, Chl a = Chlorophyll a, Chl b = Chlorophyll b, CSI = Chlorophyll stability index, Total Chl. = Total chlorophyll, MSI = Membrane stabilityindex

4.2.3.2 Correlation study on physiological characters at stresscondition

Relationship among various physiological parameters under stress condition were done using Karl Pearson correlations. The results has been given in the Table 13. Duringstressasignificantpositivecorrelationbetweenphotosyntheticrateandfv/Fm, transpiration rate, stomatal conductance, RWC, Chl a, Chl b, MSI and CSI was observed. Photosynthetic rate showed significant negative correlation with CATD and leaftemperature.

Thereexistsahighsignificantpositivecorrelationofstomatalconductancewith CSI followed by chlorophyll content a and b, Fv/Fm, RWC, transpiration and MSI. Negative correlation was found between stomatal conductance and leaf temperature followed byCATD.

Transpiration rate showed a high significant positive correlation with RWC followedbyChla,Chlb,Fv/Fm,CSIandMSI.Significantnegativecorrelationexisted between rate of transpiration and canopy air temperature difference and leaf temperature.

Leaf temperature and CATD was found to be negatively correlated with Chl a, Chl b, Fv/Fm, RWC, MSI and CSI.

Fv/Fmshowedahighsignificantpositivecorrelationwith CSI followedbyChl a, Chl b, MSI andRWC.

RWC showed a significant positive correlation between Chl a, Chl b, CSI and MSI. Chlorophyll a and b showed high significant positive correlation with CSI.

Table 13 Correlation between physiological parameters of *Tectona grandis* accessions under stress

	Pn	Gs	E	tleaf	CATD	Fv/Fm	RWC	Chl a	Chl b	MSI	CSI
Pn	1										
gs	0.99**	1									
E	0.73**	0.7**	1								
tleaf	-0.98**	-0.96**	-0.7**	1							
CATD	-0.87**	-0.84**	-0.63**	0.9**	1						
Fv/Fm	0.93**	0.95**	0.62**	-0.89**	-0.75**	1					
RWC	0.93**	0.9**	0.73**	-0.93**	-0.84**	0.77**	1				
Chl a	0.98**	0.96**	0.71**	-0.97**	-0.87**	0.86**	0.95**	1			
Chl b	0.99**	0.96**	0.71**	-0.99**	-0.89**	0.89**	0.95**	0.99**	1		
MSI	0.69**	0.71**	0.32	-0.68**	-0.67**	0.83**	0.5*	0.6**	0.64**	1	
CSI	0.99**	1.00**	0.69**	-0.96**	-0.84**	0.96**	0.9**	0.96**	0.96**	0.73**	1

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

RWC = Relative water, CATD = Canopy air temperature differences, Pn = Photosynthetic rate, gs = Stomatal conductance, E = Transpiration rate, Chl a = Chlorophyll a, Chl b = Chlorophyll b, CSI = Chlorophyll stability index, MSI = Membrane stability index

4.2.3.3 Clusteranalysis

The 18 accessions of teak were grouped into five clusters according to their performanceduringdrought.Detailsofthe fiveclustersaregiven inthetable14.From the table, the cluster II possess maximum number of accessions whereas the least number observed for the cluster III and clusterV.

Table 14 Clusters for physiological parameters during stress condition among the accessions of *Tectona grandis*

Clusters	I	II	III	IV	V
Accessions	A1, A19, A27, A2, A13, A29	A3, A4, A20, A18, A23, A5, A28, A22	A5	A6 A21 A24	A17

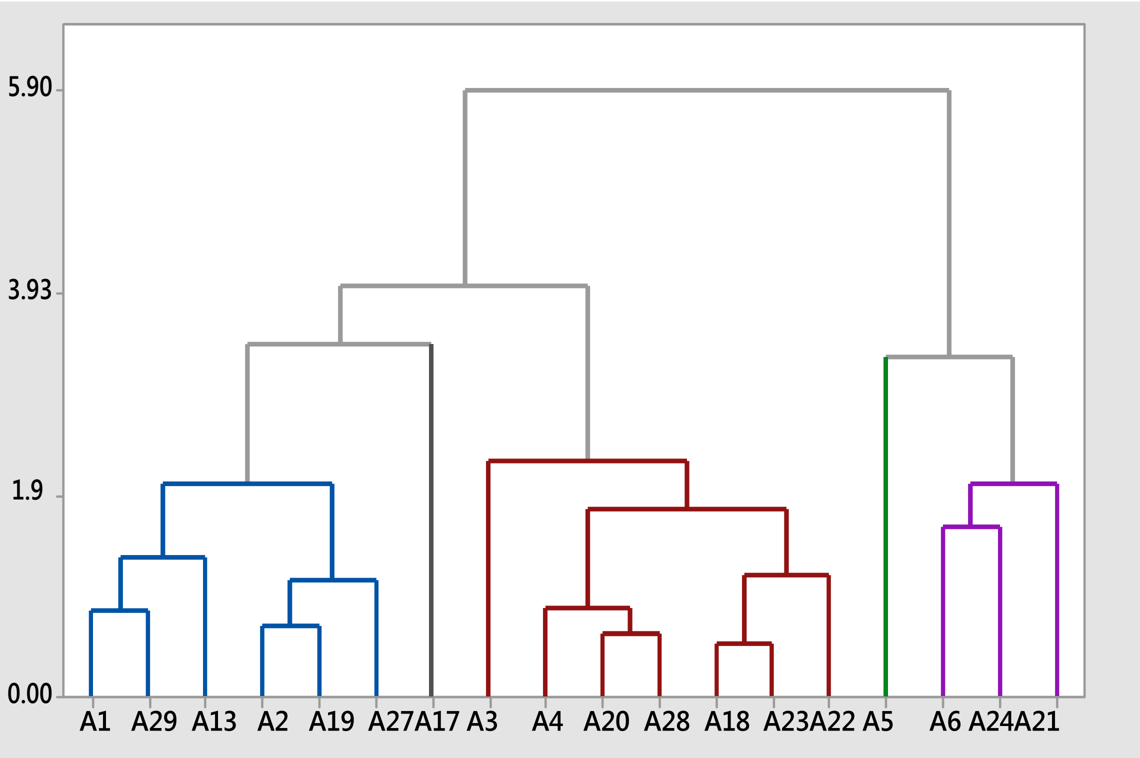


Figure 3. Dendrogram of cluster analysis among accessions of *Tectona grandis* during drought stress

The above figure 3 is the graphical representation of the cluster analysis.

Table 15 Distance between cluster centroids during drought stress among accessions of *Tectona grandis*

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Cluster 1	1.06				
Cluster 2	3.45	1.11			
Cluster 3	7.57	4.92	0.00		
Cluster 4	6.99	3.84	3.12	1.12	
Cluster 5	3.39	6.38	9.85	9.56	0.00

The above Table 15 gives the inter and intra cluster distances among different accessions of teak during drought stress. It was observed from the table that duringthe period of stress highest intra cluster distance was seen in cluster IV (1.12) and the highest inter cluster distance was observed in clusters III and V(9.85).

4.2.4 Physiological response of teak afterregain

4.2.4.1 Variation of physiological parameters of teak accessions afterregain

Physiological parameters viz. photosynthesis, transpiration, conductance, CATD, leaf temperature, total chlorophyll content, Fv/Fm, RWC, CSI, Chl a, and chl b among different plus trees accessions at regain showed significant ($P < 0.05$) differences among the eighteen accessions (Table16).

Highest rate of photosynthesis was observed in A21 (2.75 µmol CO_2 $m^{-2}s^{-1}$) whichwasonparwithA6(2.70µmol$CO_2$$m^{-2}s^{-1}$),A5(2.58µmol$CO_2$$m^{-2}s^{-1}$)andA24 (2.53µmol$CO_2$$m^{-2}s^{-1}$).LowestrateofphotosynthesiswasobservedinA17(0.63µmol CO_2 $m^{-2}s^{-1}$) which was on par with A13 (0.64 µmol CO_2 $m^{-2}s^{-1}$) and A29 (0.67 µmol CO_2 $m^{-2}s^{-1}$). Mean value was observed as 1.48µmol CO_2 $m^{-2}s^{-1}$.

Atregain,higheststomatalconductancewasobservedinA21(0.080mmolH_2O $m^{-2}s^{-1}$)whichshowedsignificantdifferencefromotheraccessions.Minimumvaluewas recorded in A17 (0.038 mmol H_2O $m^{-2}s^{-1}$) followed by A13 (0.046 mmol H_2O $m^{-2}s^{-1}$). Mean value of conductance was observed as 0.062 mmol H_2O $m^{-2}s^{-1}$. Fv/Fm was observedhighestinA21(0.771)whichwasonparwithA24(0.769).Lowestvaluewas observed in A17 (0.620). Mean value for Fv/Fm observed was 0.722. Rate of transpiration was observed highest in A21 (1.98 μmol H_2O $m^{-2}s^{-1}$) which showed significant difference from other accessions. Lowest rate was observed in A29 (0.99 μmolH_2Om^{-2}s^{-1}).Meanvalue ofrateoftranspirationwas1.23μmolH_2Om^{-2}s^{-1}.

The lowest leaf temperature was observed in A21 (29.47°C). It was recorded highest in A13 (34.30°C) which showed significant difference from other accessions. Mean value observed for leaf temperature was 32.06°C. Canopy air temperature difference(CATD)wasobservedlowestinA21(-1.33°C).HighestCATDwasrecorded inA17(-0.38°C),A13(-0.47°C),A29(-0.44°C)andA1(-0.50°C),theseaccessionswere on par. Mean value for CATD was0.722°C.

Highest value for relative water content (RWC) was recorded in A22 (89.79%) whichwasonparwithA6 (89.70%)andA21(89.34%).LowestRWCwasobservedin A17 (59.33%). Mean value for RWC was77.94%.

Chlacontentwasrecordedhighest inA21(2.76μgg^{-1})whichwassignificantly different from other accessions. Lowest chl a content was observed in accession A13 (1.47μgg^{-1}).Meanvaluewasobservedas2.12μgg^{-1}.TheChlbcontentwasrecorded highestinA21(2.07μgg^{-1})whichshowedsignificantdifferencefromotheraccession. Lowest chl b content was observed in A13 (1.28 μg g^{-1}). Mean value for chl b content was 1.69 μg g^{-1}. Total chlorophyll content was recorded highest for A21 (4.58 μg g^{-1}) which was significantly different from other accessions. Lowest value for total chlorophyllcontentwasobservedinA13(2.93μgg^{-1}).Meanvaluefortotalchlorophyll content was 3.96 μgg^{-1}.

CSI was recorded highest in A21 (74.43%). Lowest value was observed in A13 (68.14%).MeanvalueobtainedforCSIwas70.64%.MSIwasrecordedhighest inA21 (72.77%) which was significantly different from other accessions. Lowest value was observed in A17 (60.94%). Mean value obtained for MSI was67.70%.

Table 16. Physiological response of *Tectona grandis* accessions after regain

Acc	Pn (μmol CO_2 m^{-2} s^{-1})	gs (mmol H_2O m^{-2} s^{-1})	E(μmol H_2O m^{-2} s^{-1})	leaf temp (^oC)	CATD (^oC)	Fv/Fm	RWC (%)	Chl a (μg g^{-1})	Chl b (μg g^{-1})	Total chl(μgg^{-1})	MSI (%)	CSI (%)
A1	0.77^{gh}	0.052^{m}	1.04^{hi}	33.26^{d}	-0.50^{abc}	0.695^{jk}	68.84^{l}	1.77^{l}	1.52^{i}	3.64^{j}	63.21^{l}	69.28^{mn}
A2	0.83^{fgh}	0.053^{l}	1.06^{gh}	32.83^{e}	-0.56^{bcd}	0.692^{k}	75.68^{i}	1.83^{k}	1.61^{h}	3.76^{i}	65.52^{j}	70.10^{jk}
A3	1.07^{ef}	0.065^{g}	1.15^{e}	31.99^{ij}	-0.63^{def}	0.736^{gh}	77.30^{h}	2.24^{fg}	1.72^{e}	4.08^{fg}	68.51^{f}	70.23^{ij}
A4	1.11^{e}	0.066^{fg}	1.17^{de}	32.15^{hi}	-0.64^{def}	0.730^{h}	81.43^{f}	2.22^{gh}	1.70^{ef}	4.04^{g}	68.92^{f}	71.19^{e}
A5	2.58^{abc}	0.074^{c}	1.76^{c}	30.34^{n}	-0.84^{g}	0.762^{bc}	88.22^{b}	2.58^{c}	1.91^{b}	4.43^{b}	71.73^{b}	71.91^{c}
A6	2.70^{ab}	0.077^{b}	1.87^{b}	29.78^{o}	-1.08^{h}	0.757^{cd}	89.70^{a}	2.67^{b}	1.95^{b}	4.49^{b}	71.22^{c}	73.36^{b}
A13	0.64^{h}	0.046^{o}	1.02^{i}	34.40^{a}	-0.41^{a}	0.670^{m}	61.84^{n}	1.47^{o}	1.28^{k}	$2\ .93^{l}$	61.81^{m}	68.14^{p}
A17	0.63^{h}	0.038^{p}	0.99^{i}	33.77^{b}	-0.38^{a}	0.620^{n}	59.33^{o}	1.60^{n}	1.43^{j}	3.46^{k}	60.94^{n}	68.72^{o}
A18	2.43^{c}	0.069^{e}	1.20^{d}	31.84^{j}	-0.67^{def}	0.743^{efg}	84.79^{d}	2.27^{fg}	1.77^{d}	4.13^{ef}	69.42^{e}	71.03^{ef}
A19	0.88^{efgh}	0.056^{k}	1.07^{fgh}	33.10^{d}	-0.57^{cde}	0.721^{i}	73.54^{j}	1.80^{kl}	1.55^{i}	3.68^{ij}	66.34^{i}	69.84^{kl}
A20	1.01^{efg}	0.062^{i}	1.08^{fg}	32.39^{fg}	-0.60^{cdef}	0.746^{ef}	64.13^{m}	2.08^{i}	1.66^{fg}	3.92^{h}	67.06^{h}	70.45^{hi}
A21	2.75^{a}	0.08^{a}	1.98^{a}	29.47^{p}	-1.33^{i}	0.771^{a}	89.34^{a}	2.76^{a}	2.07^{a}	4.58^{a}	72.77^{a}	74.43^{a}

A22	2.48^{bc}	0.070^{e}	1.20^{d}	30.73^{m}	-0.69^{ef}	0.749^{de}	89.79^{a}	2.49^{d}	1.86^{c}	4.31^{c}	70.23^{d}	71.27^{de}
A23	1.62^{d}	0.067^{f}	1.19^{de}	31.59^{k}	-0.65^{def}	0.739^{fg}	86.61^{c}	2.29^{f}	1.79^{d}	4.18^{de}	69.74^{de}	70.83^{fg}
A24	2.53^{abc}	0.072^{d}	1.21^{d}	31.09^{l}	-0.71^{f}	0.769^{ab}	83.27^{e}	2.38^{e}	1.81^{d}	4.26^{cd}	81.80^{c}	71.57^{d}
A27	0.95^{efg}	0.059^{j}	1.08^{fg}	32.57^{f}	-0.59^{cdef}	0.703^{j}	88.18^{b}	1.93^{j}	1.65^{gh}	3.85^{h}	67.39^{h}	69.58^{lm}
A28	1.04^{ef}	0.064^{h}	1.11^{f}	32.25^{gh}	-0.61^{cdef}	0.713^{i}	71.25^{k}	2.17^{h}	1.68^{fg}	3.94^{h}	68.02^{g}	70.65^{gh}
A29	0.67^{h}	0.050^{n}	0.90^{j}	33.55^{c}	-0.44^{ab}	0.679^{l}	79.59^{g}	1.70^{m}	1.51^{i}	3.53^{k}	65.00^{k}	69.01^{no}
Mean	1.48	0.062	1.23	32.06	-0.66	0.722	77.94	2.12	1.69	3.96	67.70	70.64
CD	0.251	0.015	0.042	0.187	0.124	0.068	0.856	0.054	0.045	0.084	0.492	0.307

RWC = Relative water, CATD = Canopy air temperature differences, Pn = Photosynthetic rate, gs = Stomatal conductance, E = Transpirationrate,Chla= Chlorophylla,Chlb=Chlorophyllb,CSI=Chlorophyllstabilityindex,TotalChl.= Totalchlorophyll,MSI= Membrane stabilityindex

4.2.4.2 Correlation study on physiological characters afterregain

Relationship among various physiological parameters after regain was studied using pearson correlation. The result is given in the Table 17.

After regain photosynthetic rate exhibited high positive correlation with total chlorophyll content, stomatal conductance, transpiration rate, CSI, MSI, RWC, Fv/Fm withhighestpositivecorrelationwithchlorophyllcontent.Highestnegativecorrelation of -0.91 exist between photosynthetic rate and leaf temperature,CATD.

Stomatal conductance showed high positive correlation of 0.98 with MSI and low positive correlation of 0.73 with RWC. In addition to this, it also showed positive correlation with transpiration rate, Fv/Fm, chlorophyll content, CSI and MSI. High negative correlation was showed between stomatal conductance and CATD.

At regain, transpiration showed highest positive correlation with CSI, followed by chl a, chl b, RWC, MSI and Fv/Fm. It was also found to be negatively correlated with CATD.

It was observed that, canopy air temperature difference and leaf temperature were positively correlated with each other, whereas both these showed a negative correlation with all other physiologicalparameters.

Chlorophyll fluorescence showed a positive correlation with chl a and chl b, CSI,RWCandMSI.Itwasalsoobservedthatrelativewatercontentshowedapositive correlation with chlorophyll content, MSI andCSI.

Table 17 Correlation analysis between physiological parameters among Tectona grandis accessions after regain

	Pn	gs	E	tleaf	CATD	Fv/Fm	RWC	Chl a	Chl b	MSI	CSI
Pn	1										
Gs	0.87**	1									
E	0.80**	0.77**	1								
tleaf	-0.91**	-0.94**	-0.87**	1							
CATD	-0.80**	-0.85**	-0.95**	0.91**	1						
Fv/Fm	0.80**	0.95**	0.65**	-0.85**	-0.75**	1					
RWC	0.69**	0.73**	0.48*	-0.70**	-0.52*	0.65**	1				
Chl a	0.90**	0.97**	0.82**	-0.99**	-0.87**	0.89**	0.70**	1			
Chl b	0.88**	0.95**	0.82**	-0.98**	-0.89**	0.86**	0.73**	0.98**	1		
MSI	0.85**	0.98**	0.73**	-0.94**	-0.82**	0.93**	0.79**	0.96**	0.96**	1	
CSI	0.86**	0.92**	0.90**	-0.96**	-0.96**	0.82**	0.58*	0.94**	0.95**	0.89**	1

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Pn = Photosynthetic rate, E = Transpiration rate, Chl a = Chlorophyll a, Chl b = Chlorophyll b, CSI = Chlorophyll stability index, MSI = Membrane stability index, gs = Stomatal conductance, RWC = Relative water, CATD = Canopy air temperature differences

4.2.4.3 Clusteranalysis

The 18 accessions of teak were grouped into five clusters according to their performanceafterregain.Detailsofthefiveclustersaregiveninthetable18.Fromthe table, the cluster I possess maximum number of accessions whereas the least number observed for the clusterV.

Table 18 Clusters for physiological parameters among accessions of *Tectona grandis* during regain

Clusters	I	II	III	IV	V
Accessions	A1, A19, A3, A27, A2, A4, A29, A28, A20	A5, A6	A13, A17	A18, A23, A22, A24	A21

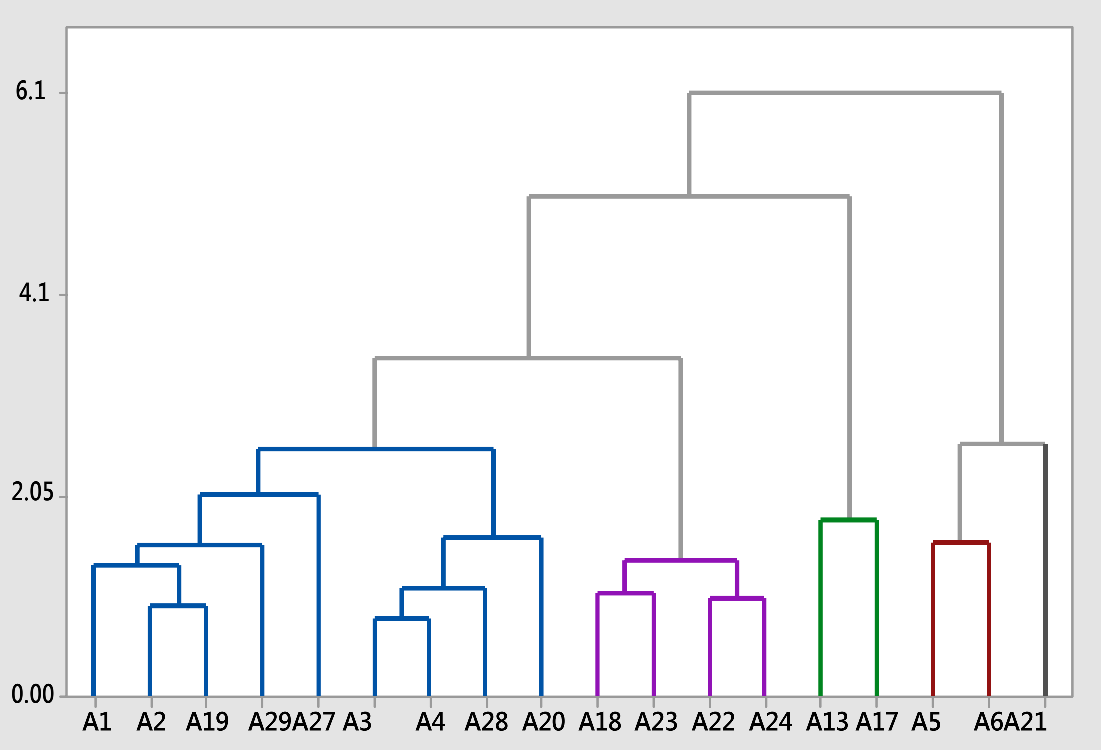


Figure 4. Dendrogram of cluster analysis among accessions of Tectona grandis during regain

The above figure 4 represent the dendrogram of the cluster analysis of 18 accessions after regain.

Table 19 Distance between cluster centroids among accessions of *Tectona grandis* during regain

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Cluster 1	1.42				
Cluster 2	5.68	0.79			
Cluster 3	3.10	9.28	0.91		
Cluster 4	3.23	2.97	7.03	0.78	
Cluster 5	7.51	2.52	10.92	5.10	0.00

The above Table 19 gives the inter and intra cluster distances. It is observed from the table that highest intra cluster distance shown by cluster I (1.42) and the highest inter cluster distance shown by clusters III and V (10.92).

Discussion

5. DISCUSSION

In forest trees, variation exists in different categories which can be broadly grouped as variability within species, provenances, stands, sites and individual trees (Zobel*etal.*,1960).Evenwhilegrowinginthesamestand,individualtreesofaspecies often vary a great deal from one another in terms of their wood properties and ability in growing and reproducing under severe environmental conditions. This is the major type of genetic variation used in selection and breeding programs (Zobel and Talbert, 1984).

Thepresentinvestigationattemptedadetailedevaluationofwoodpropertiesof teak (*Tectona grandis* L.f) using non-destructive method and screening for physiological plasticity to droughtstress.

5.1 SCREENING OF TEAK ACCESSIONS BASED ON WOOD PROPERTIES AND GROWTHCHARACTERS

To improve the productivity and rotation period of teak several scientists performed provenance trials of growth characteristics. These studies revealed that the growth characters and stem quality varied significantly among the provenances. Later on, studies revealed that along with growth characters, wood properties can also be improved using appropriate tree breeding techniques.

In the current study, teak accessions maintained as part of a provenance study located at Thiruvazhamkunnu was screened for both growth characters and wood properties. Growth parameters like height and girth were studied. Non-destructive methods were used for studying wood properties. Pilodyn penetration depth was used toanalysetherelativedensityoftree.Treesonictimerwasusedtocalculatestresswave velocity which gives an estimate for defects and decay in standing trees ofteak.

5.1.1 Variation in tree growth characters among the accessions ofteak

Growth characters like height (h) and girth (g) showed significant variation among the 19 accessions. In the present study, the highest value for h was observed in

A2 (17.97m) which was on par with A29 (16.52m), A21 (15.72m), A20 (15.57m), A1 (15.54m), A3 (15.04m) and A22 (14.77m). Among the accessions, highest value for g wasobserved inA29(86.07cm)whichwasonparwithA22(72.51cm), A1(70.87cm), A21 (69.68cm), A2 (66.50cm), A3 (65.00cm), A18 (64.91cm), A4 (62.75cm), A17 (61.62cm), A20 (61.25cm), A23 (59.00cm), A30 (54.50cm), A24 (54.20cm) andA28 (52.25cm). This variation in h and g might be due to the ability of individual trees in resource utilization. Kempes *et al.*, (2011) suggested that height determines the resource use among various trees in the same site. Individuals with higher resource utilization attain higher growth parameters as compared with other individuals of the same site. Among the accessions, A29, A20, A21 showed better growth characters in terms of h and dbh as compared to other accessions.

Similarly, a significant difference for growth characteristics was observed among teak trees from 42 different genetic origins which were planted in Malaysia (Monteuuis *et al.*, 2011). According to Hidayati *et al*., (2013) significant variation in h and dbh were observed among 21 seed provenance of teak in a provenance trial plantation in Indonesia.

In the current study accessions A2, A29, A21, A20, A1, A3 and A22 showed better growth parameters.

5.1.2 Variation in tree wood quality traits among the accessions ofteak

Wood relative density or specific gravity is considered as the best index in determining timber quality because of its ability in predicting timber strength. Along with that its high heritability and economic importance make it highly desirable to include in tree improvement programmes. In the present study for understanding the variation among individual accessions for wood properties and to avoid unnecessary sacrificeofvaluabletimbernon-destructiveevaluationwasperformed.Non-destructive evaluation is the science of identifying the mechanical properties of a material without altering its end-utility (Wang *et al*.,2007).

Amongthenon-destrutiveevaluationofwoodpropertiespilodynisextensively usedworldwideinassessingthewooddensityofbothhardwoodandsoftwood.Pilodyn providesanestimateofrelativewooddensity,whichcanbeusedtorankvariousgenetic units about wood density (Hansen, 2000). Studies also showed a high negative correlation between pilodyn estimates and wood density estimates. Tree sonic timer is another instrument used in non-destructive evaluation of wood properties (Todoroki, 2010). This instrument uses a non-destructive technique to determine stiffness and modulus of elasticity of trees by measuring stress wave velocity (SWV). Speed/SWV withwhichsoundwavespassthroughlogswassufficientlyhighlycorrelatedwithwood stiffness.

In the present study, pilodyn penetration depth (PPD) showed significant variation among 19 accessions with lowest PPD observed in A23 (20.25mm) which was on par with A1 (20.25mm), A17 (20.50mm), A5 (20.75mm), A28 (21.00mm), A2 (21.25mm),A19(21.25mm),A27(21.50mm),A13(21.50mm),A3(21.75mm),A21 (21.75mm), A18 (21.75mm) and A22 (22.00mm). Similarly, Jilijith (2016) observed significantvariationinPPDamongdifferentclonesof35yearoldteak.Specificgravity determined from the regression equation proposed by Ponneth *et al*. (2014) showed a significant variation among 19 accessions of teak with highest value observed in A1 (0.44)whichwasonparwithA23(0.44),A17(0.43),A5(0.42),A28(0.41),A19 (0.41), A2 (0.41), A13 (0.40), A27 (0.40), A18 (0.39), A3 (0.39), A21 (0.39) andA22 (0.38). Relationship between PPD and SG was studied using pearson correlation and observed a high significant negative correlation of -0.99. This was in agreement with Ponneth *et al.* (2014) with highest negative correlation of -0.91 was observed in teak followed by Jackwood (-0.88) and Mahogany (-0.87). This indicates that accessions withlesserPPDhavehigherrelativedensityorspecificgravity.Higherspecificgravity observed in certain accessions might be due to increased cellwall thickness, proportion ofdifferenttissues,andpercentageofcellulose,ligninsandextractives.Severalstudies suggested the genetic control and higher heritability of specific gravity (Wei and Borralho, 1997; Lan, 2011). So in the current study variation of individual accessions of teak in terms of specific gravity attributed to its geneticdifference.

Stress wave velocity (SWV) also showed significant variations among 19 accessions of teak. Highest value for stress wave velocity was observed for A30 (4360.21 m s^{-1}), which was on par with A18 (4322.26 m s^{-1}), A21 (4319.80 m s^{-1}), A4

(4307.36 m s^{-1}), A17 (4264.06 m s^{-1}), A28 (4254.23 m s^{-1}), A24 (4219.73 m s^{-1}), A20 (4206.21ms^{-1}),A22(4205.81ms^{-1}),A6(4172.68ms^{-1}),A23(4162.18ms^{-1})andA19 (4150.70 m s^{-1}). SWV acts as a surrogate measure for stiffness and defects present in standingtree.ManyscientistsstudiedthepotentialuseofSWVinstudyingdefectsand decay (Wang *et al*., 2004). The concept behind the study was that stress wave propagated by transducers was sensitive to the presence of defects, hollow spaces or other degradation in wood. The stress wave propagated faster in sound wood than in deterioratedwood.SotheaccessionswithhighervalueforSWVindicatelessincidence of decay and defects compared to other accessions. Variation of individual trees for SWV also attributed to its genetic origin. Studies stated that SWV were moderately genetic controlled with a broad sense heritability of 0.27 (Moya and Marin, 2011). Hidayati *et al*. (2013) also studied significant variation for SWV for 24 year old teak treesfrom21seedprovenancesinIndonesia.InthepresentstudyaccessionsA23,A17, A28, A19, A18, A21 and A22 showed better wood qualitytraits.

5.2 SCREENING OF TEAK ACCESSIONS UNDER MOISTURESTRESS

Availability of water is considered as one of the major constraints that limit plantgrowthanddevelopment.Plantsthataregrowninatropicalclimatearefrequently subjectedtoacertainamountofdroughtstress.Wateraffectsplantgrowthbyaffecting cell division, differentiation, cell enlargement and genetic composition (Patel and Golakia, 1988). Trees vary largely in their response towards drought stress. These includemodificationin visiblemorphologicalcharactersorinvisiblephysiologicaland biochemicalcharacters.

The present study was performed to understand the physiological plasticity of teak accessions to water stress. These included physiological parameters like photosynthesis, stomatal conductance, transpiration, chlorophyll content, membrane stability index, chlorophyll stability index, relative water content, leaf temperature, canopy air temperature difference and chlorophyll fluorescence.

5.2.1 Variation of soil moisture content among accessions ofteak

The soil moisture content of the containers of each accession during normal growthconditionandfivedaysofstresswasdeterminedusingthegravimetric method. The determination of soil moisture content helps in quantifying the reduction in soil moisture content under days of progressing moisture stress due to withholding water. The observations showed a significant decline in soil moisture content during stress across the genotypes and a significant difference in the reduction in moisture content among accessions. On the fifth day of moisture stress accession A21 registered lowest soilmoisturecontentandA17wasobservedwiththehighestmoisturecontent. Among theaccessions,thelowestnumberofwitheredleaveswerealsoobservedinA21which indicatedtheaccessionsabilitytoextracthighersoilmoistureandremainhydratedeven after the onset ofdrought.

5.3 EFFECT OF DROUGHT STRESS AND RECOVERY ON PLUS TREE ACCESSIONS OFTEAK

In the present experiment, the physiological response of 18 accessions of teak was evaluated at three stages of moisture *viz.*, normal, stress and regain. The comparison of their physiological responses under the three stages of moisture stress determines the tolerant accessions to drought stress.

5.3.1 Stomatal conductance(gs)

Stomatal conductance gives an estimate of gas (CO_2) and water exchange in plants and it has a strong influence on the rate of photosynthesis and transpiration. Regulation of stomatal conductance helps in maintaining temperature and water use efficiency in plants and considered a vital process for the existence of plants. It is observed that stomatal closure is more sensitive to soil dehydration than drought stress signalsarisingfromleaves(Hoshika*etal.*,2013).This isduetoincreasedbiosynthesis of abscisic acid in roots during water stressed condition. The abscisic acid would then get transported to guard cells which help in activating signalling pathway for stomatal closure.

Inthepresentstudy,exposingdroughtstressonteakclonesshowedasignificant reduction in gs compared to normal (Fig 6). Drought stress imposed a 33% reduction inthemeanvalueofgswhencomparedwithcontrol.Manyscientistsbelievedthatfirst reaction exhibited by plants during drought stress is stomatal closure to prevent water loss via transpiration. A reduction in the mean value of gs by 76% was registered in blackpepperaccessionsafterexposingtomoisturestressforfivedays(Prakash,2019).

Thestudyalsorevealedthatasignificantvariationinstomatalconductancewas observed among the accessions. The maximum value for stomatal conductance was exhibited by accessions A21 (0.067 mmol m^{-2} s^{-1}) and A6 (0.065 mmol m^{-2} s^{-1}) with a percentagereductionof14%and7%respectivelyascomparedwithnormal.Thelower value for stomatal conductance was observed in A17 (0.018 mmol m^{-2} s^{-1}) with a percentage reduction of 69% compared to normal. Reduction of gs under water stress is an adaptive mechanism to reduce water loss in plants (Karimi *et al*., 2015). Drought studies on *Populus* population revealed that the tolerant triploid population, compared tothediploidpopulationshowedalesserreductioninstomatalconductanceunderwater stress compared to well-watered condition (Liao *et al.*,2018).

Relationshipbetweenstomatalconductanceandotherphysiologicalparameters during drought were studied using correlation analysis. It was observed that positive correlation exists between stomatal conductance and other physiological parameters like RWC, photosynthetic rate and transpirationrate.

During the period of rewatering, stomatal conductance showed no significant variation when compared with control with a recovery of 93%. In regain, highest stomatal conductance was observed in A21 followed by A6, A5 and A24 and they showedcompleterecoverytothatofcontrol.ThisindicatesthestresstoleranceofA21. Lowest stomatal conductance was observed in A17 and A13 and they showed a recoveryof64%and75%respectively.Similarlyinyoungappletreesafterrehydration stomatal conductance of all stressed plants increased and recovered to levels of control with the highest recovery percentage observed among tolerant genotypes (Wang *et al*., 2018).

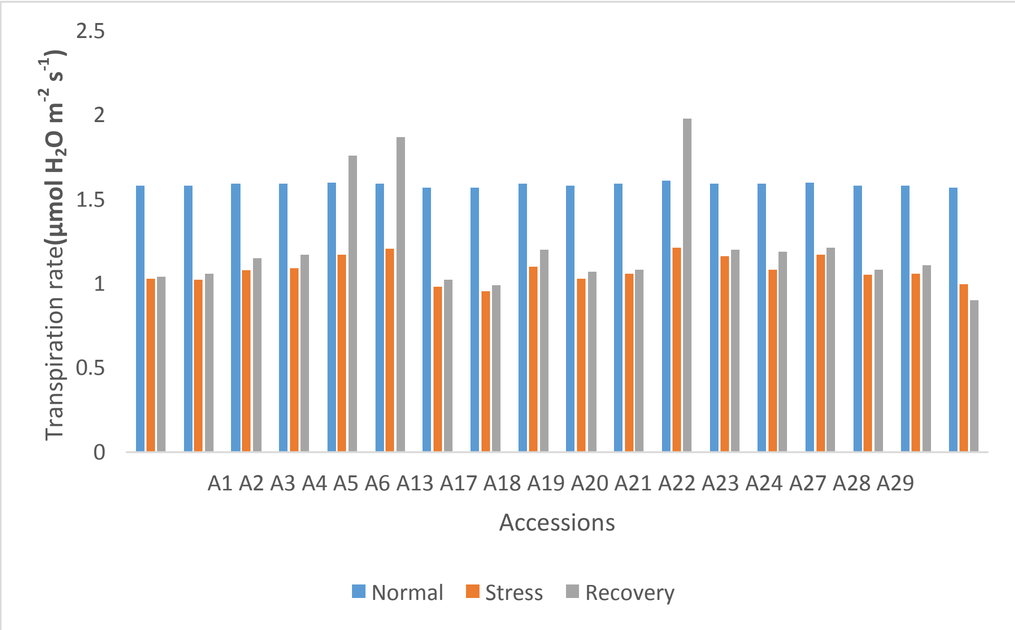


Figure 5 Variations in rate of transpiration among the accessions of *Tectona grandis* during normal, stress andrecovery

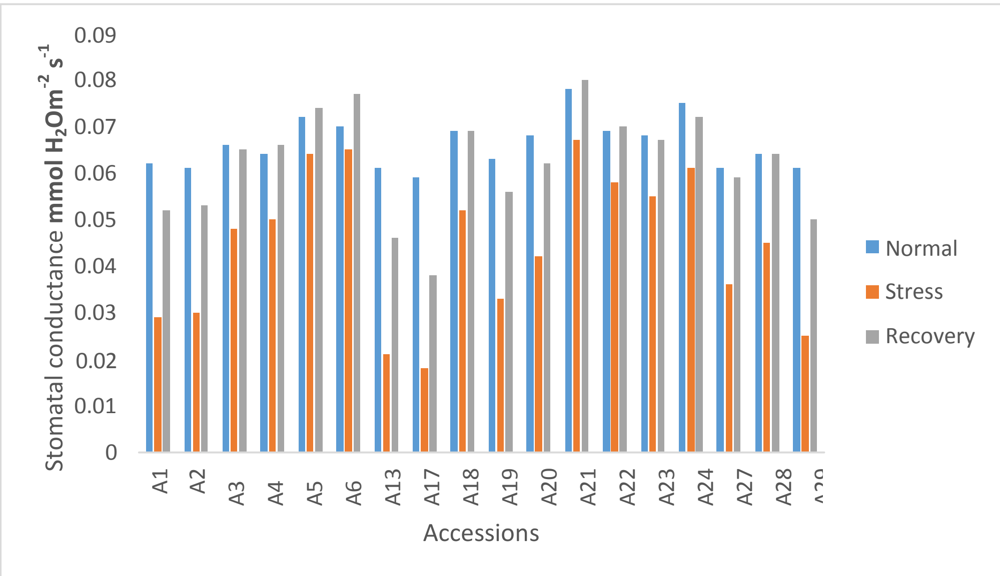


Figure 6 Variations in stomatal conductance among the accessions of *Tectona grandis* during normal, stress andrecovery

5.3.2 Transpirationrate

The mean value for transpiration registered a significant reduction of 31.6% during moisture stress as compared to normal (Fig 5). Along with that, a significant difference was observed among the accessions during drought. Highest transpiration rate was observed for A21 followed by A6 with a percentage reduction of 24.8% and 24.1% compared to normal.

The decrease in stomatal conductance during drought reduces transpiration which helps in maintaining water balance in plants. Lowest transpiration rate was observed in A17 and A13 with a percentage reduction of 39% and 38% respectively compared to normal. A similar reduction in transpiration rate was observed in teak clones when subjected to drought stress (Husen, 2010).

During drought relationship between transpiration and stomatal conductance were studied and a positive linear relation between stomatal conductance and transpiration was observed. This indicates as stomatal conductance increases transpiration also increases.

After resuming irrigation, transpiration rate showed a significant recovery of 77.8% compared to control. Among the accessions, the highest transpiration rate was observed by A21. Recovery in transpiration rate was least in A17 and A13 with percentage recovery of 63% and 65%, respectively.

5.3.3 Photosynthetic rate

In the current study, among the teak accessions, the photosynthetic rate was observed highest under normal condition of growth (Fig 7). Exposure to drought resulted in a significant reduction of the photosynthetic rate to 77% compared to normal. In plants, a reduction in the photosynthetic rate can be attributed to stomatal andnon-stomatallimitations(AliandAshraf,2011).Theformermeanstheregulations in stomatal conductance and the latter indicates the metabolic impairment. Ni and Pallardy(1992)statedthatundermoisturestress,stomatallimitationonphotosynthesis accountedfor50%reductionincarbonfixation.Thisisbecausethedroughtinduced closureofstomatawhichinturnreducesthediffusionofCO_2tothesiteofcarboxylation that leads to a decline in photosynthetic rate (Grassi and Magnani, 2005; Erismann *et al.*, 2008 and Peeva and Cornic, 2009). In *A. lebbek, D. sisso, L. leucocephala* photosynthetic rate showed a significant reduction during moisture stress (Rao *et al.*, 2008). A similar reduction in the rate of photosynthesis was observed in teak (Rajendrudu and Naidu, 1998) and different woody species (Ramanjulu *et al*., 1998; Moringa and Sykes,2001).

In the present study, the reduction of photosynthesis during drought varied significantly within accessions. Among the accessions, the highest rate of photosynthesis was observed in accession A21 with a percentage reduction of 68% as compared to normal. The lowest rate of photosynthesis was observed in the accessions A17andA13with86%reductionascomparedtonormal. TheabilityofaccessionA21 in maintaining high photosynthetic rate during drought indicates its tolerance. During water stress, higher stomatal conductance was probably one reason for the higher photosynthetic rate. This is in agreement with Cornic (2000) who observed that that triploid population which was more tolerant than the diploid population of *Populus* showed higher photosynthetic rate during the period of drought stress attributed to its higher stomatal conductance. The tolerant genotype found to have higher photosynthetic rate than the susceptible genotype. In cocoa tolerant hybrids showed a higher rate of photosynthetic rate compared to susceptible hybrids (Juby, 2019). The relationship between photosynthetic rate and stomatal conductance showed a high positive correlation during drought indicates stomatal conductance induced decline in photosynthetic rate.

During regain, the highest photosynthetic rate was observed in A21 with percentage recovery of 65% compared to control. Among the accessions after regain lower photosynthetic rate was observed in A17 and A13 with percentage recovery of 17.3% and 17.2% respectively. This indicates prolonged damage to the photosynthetic apparatus to these two accessions after drought imposition.

5.3.4 Relative watercontent

Relative water content (RWC) is considered as an important parameter which indicates water status in plants than other water potential parameters (Lugojan and Ciulca, 2011). According to Lima *et al.* (1999), measuring RWC is thought to be a key feature in assessing plant-water relation during drought.

RWC shows the balance between water supplied to the leaves and water loss via transpiration. It is estimated as the percentage of water present in the leaf to maximumwaterthatcanbereservedatturgidity.RWCactasanimportantdeterminant of metabolic activity and survival ofleaf.

In the current study, the mean value of RWC registered a significant reduction of 47.3% during drought as compared to normal (Fig 8). Drought stress-induced reduction in RWC was reported by several scientists (Duan *et al*., 2005; Xiao *et al*., 2008).

According to Serraj and Sinclair (2002), the higher value of RWC indicates the ability of plants to maintain leaf turgidity even under drought stress. Rao *et al.* (2008), after a study on the effects of drought on five important woody timber species, viz. *A. lebbek*, *D. sisso, L. leucocephala*, *S. robusta* and *T. grandis* found that the RWC tends to decrease after exposure to drought as compared to normal. Among the species studied,higherRWCof64%wasmaintainedby*L.leucocephala*underseveremoisture stress indicating its drought tolerance compared to otherspecies.

The current study also indicates a significant reduction of RWC among accessions. Maximum RWC of 64.2% was shown by accession A21 with a percentage reduction of 14%. The accessions with low values for RWC were A19 and A17 with a percentagereductionof65.15%and55.8%respectivelywhencomparedtocontrol.The higher RWC exhibited by A21 during drought helps in maintaining favourablecellular turgorpotentialunderwater-limitedconditionstherebyretainingstomatalopening,CO_2 assimilation,cellexpansionanddevelopmentinplants,henceRWCisconsideredasan important parameter in determining drought tolerance amongplants.

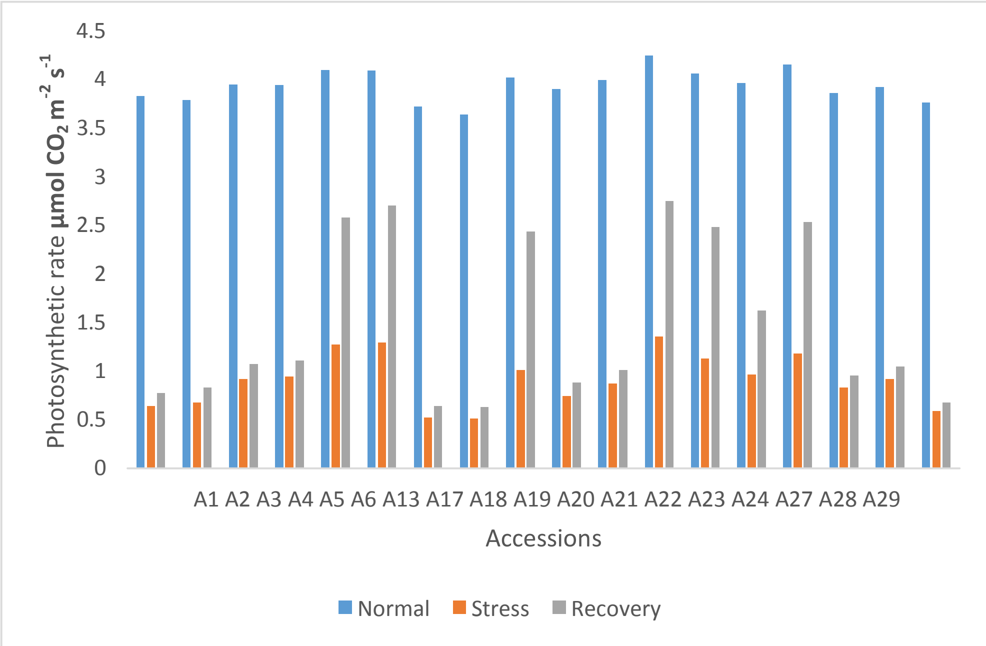


Figure 7 Variations in rate of photosynthesis among the accessions of *Tectona grandis* during normal, stress and recovery

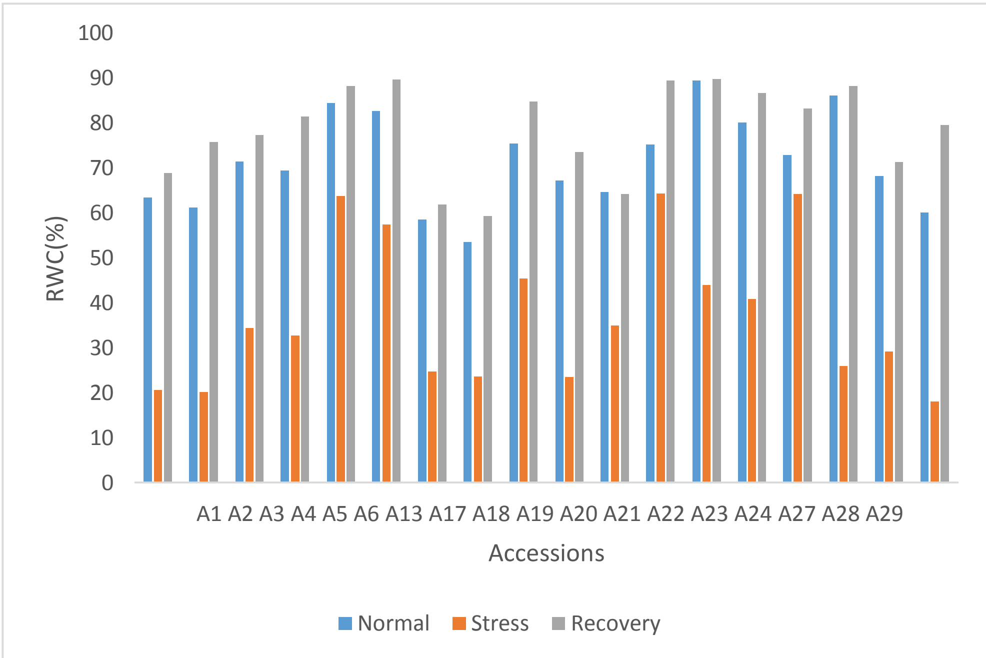


Figure 8 Variations in rate of relative water content among the accessions of *Tectona grandis* during normal, stress and recovery

The correlation studies of teak accessions during drought stress also showed a significant positive correlation between RWC and other physiological parameters like photosynthetic rate, stomatal conductance and transpiration rate.

Experiment on four oilseed brassica species found out that plants with higher osmoticadjustmentmaintainhigherRWCduringmoisturestressandthosewithhigher RWC survive drought (Kumar and Singh,1998).

Physiological responses in four populations of *Populus cathayana* under drought stress revealed that drought resistant genotype had higher RWC compared to drought sensitive species (Xiao *et al*., 2008).

Husen (2010) observed a significant reduction in relative water content in two teakclonesafterimposingdrought,inwhichtolerantteakcloneretainedhigherrelative watercontent.AfterregainRWCwasobservedhighestinA22andA21withacomplete recover as compared to control. The lower value for RWC during regain was observed in A17. Higher RWC values in A22 and A21 indicates its fast recovery after drought imposition.

5.3.5 Membrane stabilityindex

Membrane stability index (MSI) is used to assess the effect of various stresses on the physiology of plants. A major impact of environmental stress was cellular membrane dysfunction that reduced membrane stability which caused an increased permeability and leakage of ions. It is considered as an indirect measurement of integrity and stability of cell membrane (Zarei *et al*., 2007).

Estimating MSI helps in assessing the severity of water stress. A high MSI indicates a high tolerance of crops towards stress (Sairam *et al.*, 1998).

Inthepresentstudy,MSIshowedasignificantdeclineinmeanvalueby12.42% during drought compared to that of normal (Fig 9). Drought stress-induced damage on thecellularmembraneshasbeenreportedbymanyscientists(Yin*etal*.,2005;Duan*et* *al*., 2005). According to Abid *et al* (2018), the magnitude of the decline in MSI for wheat plants was greater under severe stress than moderate stress.

Significant variation in MSI within accessions of teak were also observed during drought. The maximum value of 78.4% was observed for accession A21 and a minimum of 24.06% was observed for accession A17 with a percentage reduction of 2%and61%respectively.HigherMSIindicateslessdamagetothecellularmembrane. The accession A21 is capable of retaining higher MSI during the period of drought indicating its tolerance. Chowdary *et al.* (2017) found out that tolerant genotype of soybean during drought retained MSI of63%.

Prakash (2019) also observed that drought tolerant pepper maintained higher membrane stability index than susceptible ones, with tolerant species retaining 74% membrane stability even after exposure to drought. A similar result was showed by Juby (2019), who observed that the drought tolerant cocoa showed high MSI under stress compared to normal.

After regain, MSI values was observed highest in A21 with complete recovery compared to control. Lower MSI value was observed in A17. This indicates speedy recovery of A21 after drought imposition compared with other accessions.

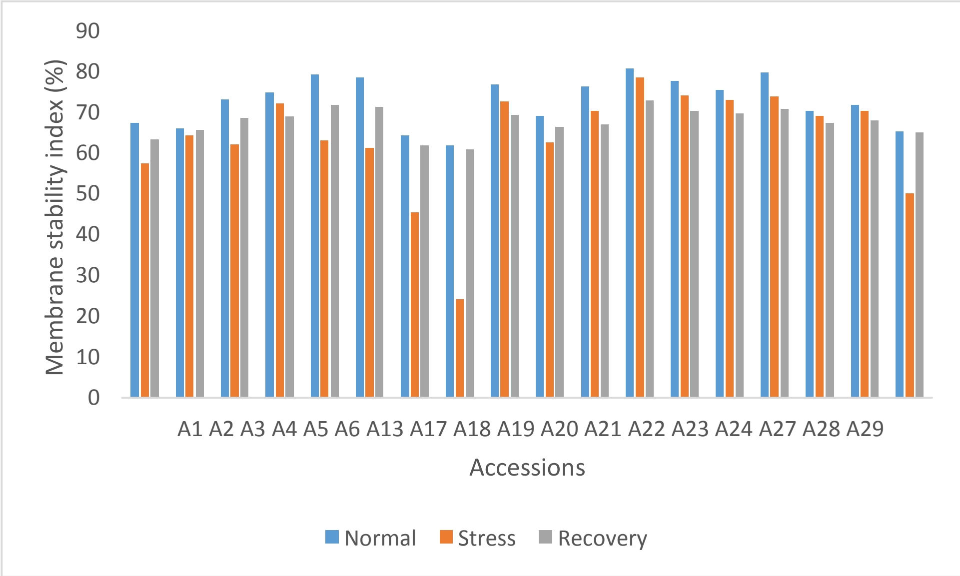


Figure 9 Variations in Membrane stability index among the accessions of *Tectona grandis* during normal, stress and recovery

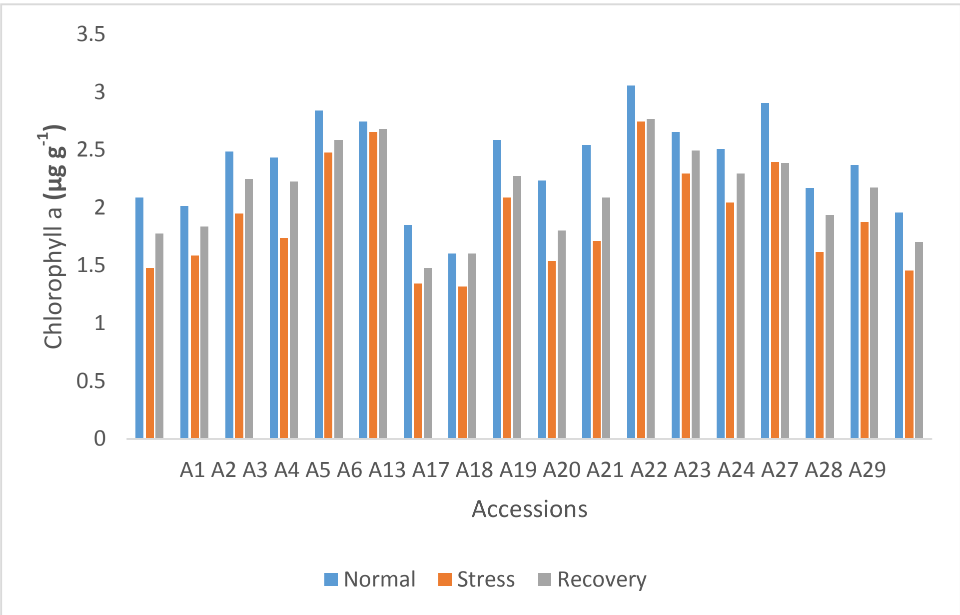


Figure 10 Variations in chlorophyll a content among the accessions of *Tectona grandis* during normal, stress and recovery

5.3.6 Chlorophyll a (chl a), chlorophyll b (chl b) and total chlorophyllcontent

The photosynthetic pigments act as major drivers of the photosynthetic process in plants due to their role in the absorption of light (by chlorophyll) and dissipation. Drought adversely affects chlorophyll content in plant leaves. According to Farooq *et al.* (2009) both chl a and chl b content declined due to soil drying. Reduction in chlorophyll content during stress is an adaptive strategy performed by the plant which helps in minimizing absorption of excess light energy and thereby photoinhibition (Powles, 1984). However, Elvira *et al.* (1998) stated that reduction in chlorophyll content is attributed to photo-oxidative damage.

In the present study, drought stress caused a reduction in the mean value of chl a and chl b by 20.5% and 21.6% respectively, in which significant reduction was observed only in chl a content when compared to normal. Along with that a significant reductionintotalchlorophyllcontentwasalsoobservedwithapercentagereductionof 23.8% when compared to control. Mafakheri *et al.* (2010) while studying drought on soybeanassertedthatchlawasmoresensitivetodroughtthanchlb.Severalhypotheses suggested that the effect of drought stress on chlorophyll content was species-specific. Drought stress caused a significant reduction in chlorophyll content in peach trees (Dhindsa *et al.*, 1981), cotton (Massacci *et al.*, 2008), sunflower (Kiani *et al.*, 2008) and in *Vaccinium myrtillus* (Tahkokorpi *et al.*,2007).

Inthecurrentstudy,accessionsexhibitedasignificantreductioninchlaandchl b content during drought. Higher chl a was observed in A21 (2.7 μg g^{-1}) and a lower value was observed in accession A17 (1.3) with a percentage reduction of 10.2% and 18.1%, respectively, with that of normal (Fig 10). The maximum value for chl b was observed in accession A21 (1.99μg g^{-1}) with a percentage reduction of 20.4% and the minimum value in A17 (1.08μg g^{-1}) with a percentage reduction of 26% compared to thatofnormal(Fig11).ThemaximumvaluefortotalchlorophyllwasobservedinA21 (3.86 μg g^{-1}) and minimum was observed in A17 (2.65 μg g^{-1}) (Fig 12). In the present study accession A21 retained the highest chl a, chl b and total chlorophyll content. Higher chlorophyll content helps the plant to sustain better photosynthetic rate even during a period of drought which made them tolerant compared with otheraccessions.

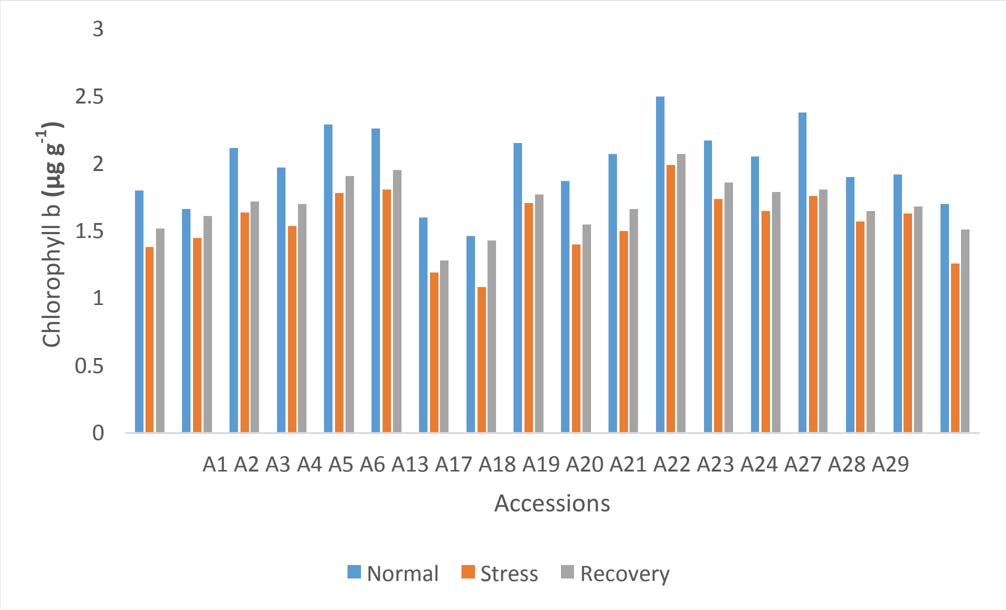


Figure 11 Variations in chlorophyll b content among the accessions of *Tectona grandis* during normal, stress and recovery

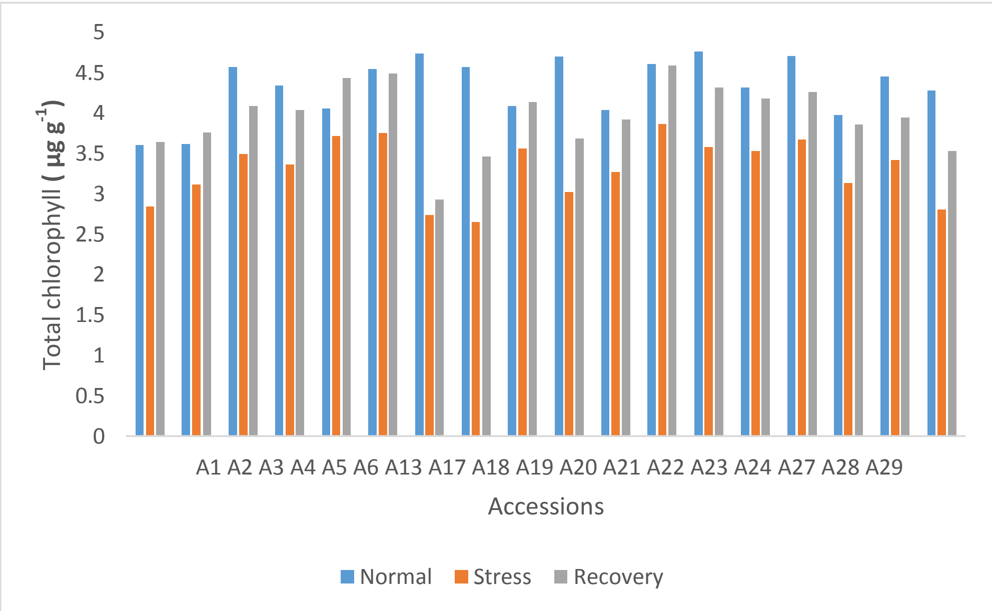


Figure 12 Variations in total chlorophyll content among the accessionsof *Tectona grandis* during normal, stress and recovery

The correlation study during drought showed a significant positive correlation between photosynthetic rate and chl a and chlb content this indicates a reduction in the rate of photosynthetic rate attributed to damage or decline in chlorophyll content.

Abraham *et al* (2008) stated that higher retention in chlorophyll content during drought was observed in tolerant genotypes than in susceptible genotypes of *Sesamum indicum*.Similarresultswerereportedinsoybeanunderdrought stressbyMakbul*etal* (2011). Husen (2010) also reported that drought stress reduced chlorophyll content in teak clones and it might be due to reduction in lamellar content of light harvesting chl aandchlband/ordamagescausedbychloroplastduetoreactiveoxygenspecies(ROS). Healso foundthatmoretolerant teakcloneretainedhigherchlaandchlbcontentthan susceptible one.

After regain, chl a and chl b content was observed highest in A21 with percentage recovery of 90.5% and 82.8%, respectively. Lowest recovery in chl a and chlbwasobserved inA17.Inadditiontothatduringrecoverytotalchlorophyllcontent recovered to 91% compared with control. Stressed plants after rehydration recovered total chlorophyll content in different degree. A21 registered higher total chlorophyll content and A17 was observed with lower total chlorophyll content. A similar result wasfoundafterregaininteakclonessubjectedtodroughtstress,withtolerantaccession showed higher recovery in chl a, chl b and total chlorophyll content compared with susceptible accessions (Husen,2010).

5.3.7 Chlorophyll stability index(CSI)

Chlorophyll stability index (CSI) is an indicator of stress tolerance in plants. A higher CSI helps plants to withstand stress with better availability of chlorophyll by maintaining more dry matter production and productivity (Mohan *et al*., 2000). According to Baroowa and Gogai (2012), a drop in CSI value was observed during drought stress in green gram and black gram, with a higher decline in CSI value, was observed in green gram indicating a low drought tolerance.

In the present study, CSI showed a significant decline by 24.9% in the mean value after exposing to drought compared to that of normal (Fig 13). The accessions showed a significant reduction in CSI with maximum value observed in A21 (70%) with a percentage reduction of 18% as compared to normal. The minimum value of 36.11% was observed for accession A17 with a percentage reduction of 30.2%. Juby (2019) stated that tolerant genotypes retained more than 70% of CSI when exposed to drought and susceptible genotypes of cocoa showed CSI lower than 40%.

Duringregain,97%recoveryinCSIwasobservedwithhighestCSIinA21with a percentage recovery of 85.8% compared with control. Lowest CSI was observed in A17. Correlation analysis during regain revealed high positive correlation between chl a and chl b and CSI which indicates recovery of chlorophyll membrane from damage. This might be due to decrease in canopy temperature afterregain.

5.3.8 Chlorophyllfluorescence

Chlorophyll fluorescence is widely used in studying plants performance duringstress.Whenaplantleafisilluminatedwithlightitcanserveforthreefunctions: it can be used in photosynthesis (Photochemistry), it can be dissipated as heat, and it can be re-emitted as a light which is termed as chlorophyll fluorescence (Maxwell and Johnson, 2000). These three processes compete with each other and efficiency in one will decrease the efficiency in the other two. Therefore a measure in chlorophyll fluorescence will give the information regarding the efficiency of photochemistry and heatdissipation.

Chlorophyll fluorescence mainly determines the efficiency in photosynthetic energyconversionorphotochemistryofPSII.ThestateofPSIIisanindicatorofoverall photosynthetic performance in plants. So this parameter can be studied during the drought to understand the plant's photosynthetic efficiency and its physiological state. (Maxwell and Johnson,2000).

Among the fluorescence parameters, Fv/Fm is the most useful one. It studies the potential quantum efficiency of PSII with the optimal value of 0.83 (Zhu *et al*., 2005). Studies by Epron *et al*. (1992) revealed that during water stress there is an increased maximal fluorescence which in turn cause a sustained reduction in dark adaptedFv/Fm(ameasureoftheefficiencyofPSII).Asthereductionofphotosynthetic activity is prominent during the stress period, the light energy perceived by the chloroplasts is in excess than utilized by photosynthesis which in turn damages PSII. This excess light energy is then re-emitted in the form of fluorescence and this is the reason why maximal fluorescence increases under drought.

In the present study, drought stress reported to cause a significant reduction in the potential quantum efficiency (Fv/Fm) and the mean value of Fv/Fm registered a reduction of 15.11% as compared to normal (Fig 14). Yao *et al*. (2018) suggested that reduction in Fv/Fm during drought stress indicates damage to PSII reaction centre thereby weakening photosynthetic efficiency or photochemical quenching. In agreement with this Wang *et al* (2018) stated that in young apple trees, the photochemical efficiency of PSII decreased significantly by 24% with increased intensityofwaterstressascomparedtocontrol.Droughtstress inbarleyalsoexhibited a significant decline in the mean value of Fv/Fm by 18% compared to control (Rong-hua *et al*.,2006).

During drought, Fv/Fm was registered maximum for the accession A21 (0.78) followed by A5 (0.77), A6 (0.77) and A24 (0.75) with a percentage reduction of 1%, 4.7%, 0.4% and 3.8%, respectively as compared to normal. This indicates its ability to maintain the comparatively higher value of Fv/Fm which in turn helps in better photosyntheticrateevenafterexposuretodroughtwhichmadethemtolerantcompared to other accessions. In agreement with this, correlation showed a significant positive correlation between Fv/Fm and photosyntheticrate.

The reduction in Fv/Fmduring drought was also observed on four genotypes of barley, in which tolerant genotype maintained higher Fv/Fm value of 0.78 (Rong-hua *et al.*, 2006). Colom and Vazzana (2002) used chlorophyll fluorescence to identify drought tolerant cultivars from *Eragrostis sp.* and stated that tolerant cultivar showed the least reduction in Fv/Fm compared to susceptible one. The minimum value for chlorophyll fluorescence was registered for A13 (0.35) and A17 (0.35) with a percentagereductionof50%and48%,respectivelythanthatofnormal.Thisreduction in Fv/Fm is due to reduction in photochemical quenching, which in turn increases the fluorescence and indicates the malfunctioning of PSII (Vazan,2000).

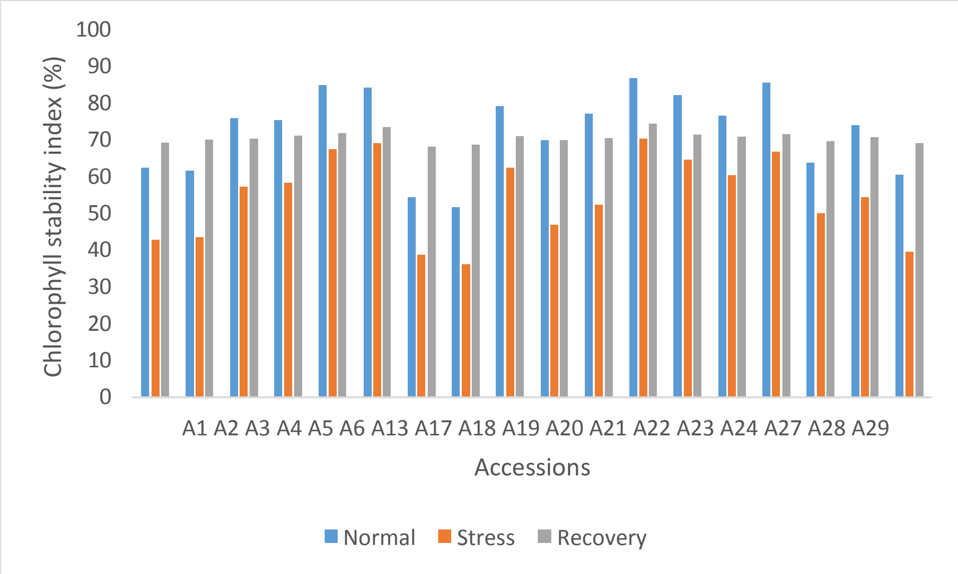


Figure 13 Variations in chlorophyll stability index among the accessions of *Tectona grandis* during normal, stress and recovery

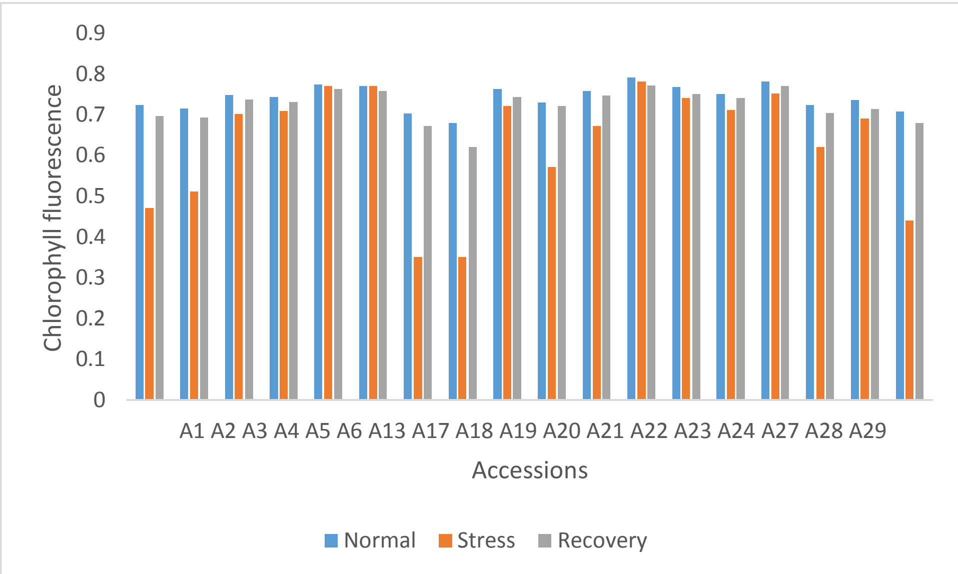


Figure 14 Variations in chlorophyll fluorescence among the accessions of *Tectona grandis* during normal, stress and recovery

During regain, Fv/Fm showed 97% recovery compared with control. Fv/Fm of stressed plants recovered in different degrees. Highest Fv/Fm during regain was observed in A21 indicates least damage to photosynthetic apparatus and its speedy recoveryaftertheonsetofdrought.LowestFv/FmvalueswereobservedforA17.After rehydration RWC recovered to pre drought levels and it was not enough for complete recovery of Fv/Fm. It might be due to permanent damage inphotosystem.

5.3.9 Canopy air temperaturedifference

Canopy air temperature difference (CATD) is one of the important physiological traits that help in identifying drought tolerant cultivars. CATD indicates the difference between canopy temperature (T_c) and ambient air temperature (T_a). It measures the plant water balance which is considered as a direct measure of drought response of crops. In the present study, the CATD registered a significant increase of 103%afterexposingtodroughtstressascomparedtonormal.Transpirationisthemain cause of change in T_c. Transpiration alters the canopy temperature in a way that as transpiration increase T_c decreases. Transpiration helps in maintaining T_c in a metabolically active range until the plants continue to transpire. Under drought stress, the gs decline due to insufficient soil moisture to meet evaporative demand which increases the canopy temperature by reducing transpiration rate (Mahan *et al.,* 2012). In this study, the correlation between transpiration rate and CATD during drought among the teak accessions showed a significant negative correlation. Teak accessions also exhibited significant variations in CATD under drought stress (Fig 15). Relatively low CATD was showed by accession A21 (-0.72 ^oC) accounts for its higher transpiration rate. A higher value of CATD was observed in accession A13 (0.47 ^oC). Lower CATD under drought stress indicates the ability of the accessions to use more available moisture to cool the canopy by transpiration and avoid a drought stress. Drought studies on wheat proved that the tolerant genotypes maintained a cooler canopy temperature along with a negative CATD than susceptible ones (Reynolds *et al*., 2009) because they use more available soil moisture to cool the canopy by transpiration to avoiddehydration.

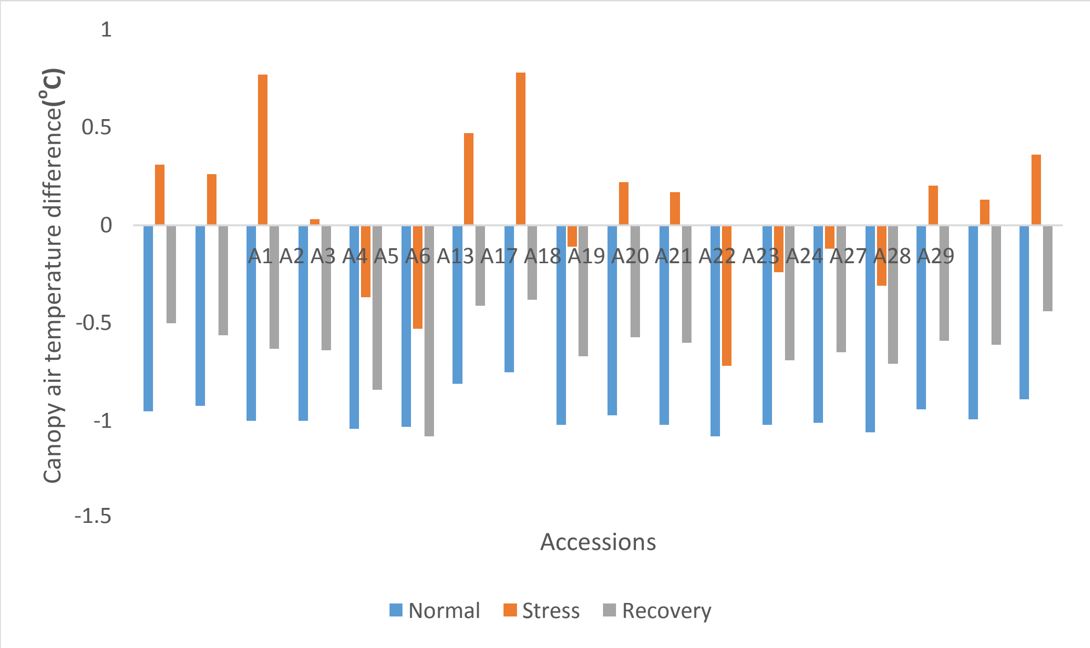


Figure 15 Variations in canopy air temperature difference among the accessions of *Tectona grandis* during normal, stress and recovery

The result of Sneha *et al* (2017) revealed that CATD of teak seedlings remain negative for irrigated plants. Biju *et al*. (2018) reported that drought tolerant lentil genotypes showed lower values of canopy temperature than susceptible ones.

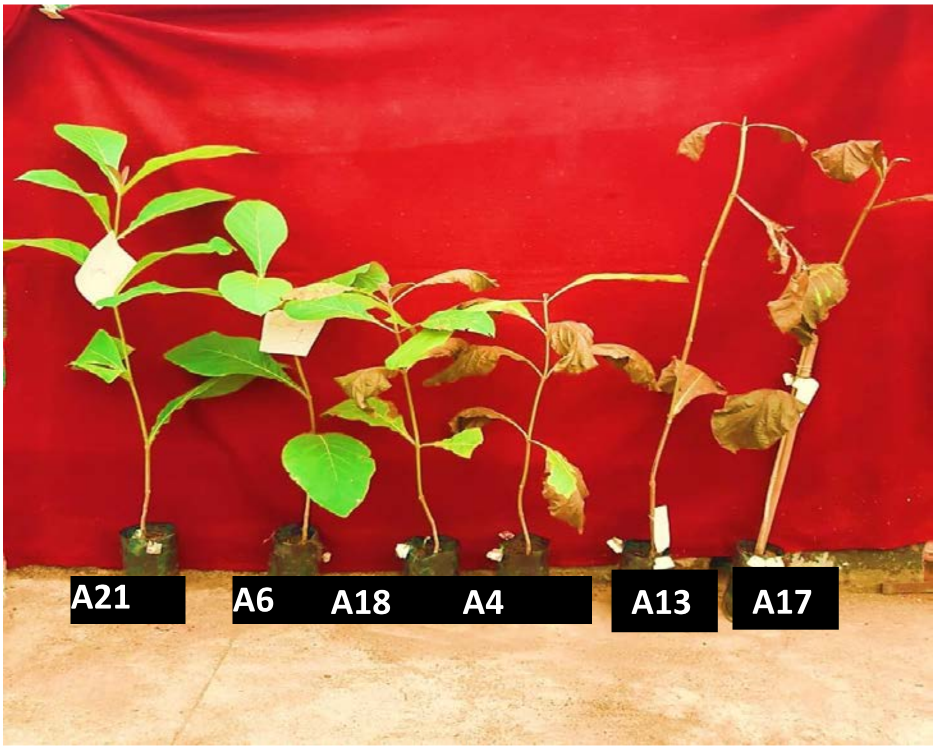
Duringregain,leastCATDwasobservedinA21whichmaybeduetoitshighest transpiration rate. Highest CATD was registered for A17 and this accounts for its reduced transpiration. The relationship between transpiration rate and CATD during regainwasstudiedusingcorrelationand identifiedasignificantnegativecorrelationof 0.87 between transpiration rate and CATD. Studies stated that tolerant genotype immediately attains cooler canopy than susceptible genotypes by increasing its transpiration rate (Biju *et al*., 2018).

5.4 Clusteranalysis

In this study, hierarchical cluster analysis was carried out for the 18 accessions during drought and regain. During the period of drought 18 accessions of teak were grouped in to five clusters according to their performance during drought. ClusterII possess the maximum number of accessions whereas the least number of accessions were found in the cluster III. The clustering pattern revealed that A21, A6 and A24 weregroupedintosamecluster(ClusterIV).Duringtheperiodofdrought,highvalues for CSI, MSI, RWC, Chl a, Chl b, total chlorophyll content and lower CATD was observed foraccessionA21.AhighervalueforFv/Fmandthephotosyntheticratewas observed in the accessions A21, A24, A5 and A6. A higher value for transpiration rate and stomatal conductance were observed in A21 and A6. This is the reason why A6, A21 and A24 were grouped in the sameclusters.

Clustering was also performed during regain stage. The 18 accessions of teak were grouped to five clusters with maximum number of accessions observed in cluster Iandminimumnumberofaccessionswereobservedinclusterv.Clusterwithonlyone accessionindicatesitssuperiorityinphysiologicalparameters.Inthepresentstudyafter rehydration A21 recovered faster than other accessions. This is why cluster V only contains A21 indicates its superiority than other accessions. Cluster III possess accession A13 and A17 which recovered theleast.

In general, a reduction in the mean value of physiological parameters was observed during drought stress except in CATD which showed an increase in mean value as compared to normal. Among the accessions, high values for CSI, MSI, RWC, Chl a, Chl b, total chlorophyll content and lower CATD was observed for accession A21. A higher value for Fv/Fm and the photosynthetic rate was observed in the accessions A21, A24, A5 and A6. A higher value for transpiration rate and stomatal conductance were observed in A21 and A6. This is the reason why A6, A21 and A24 were grouped in the same clusters. A21 attains higher value in all physiological parameters during stress and regain indicates its higher drought tolerance compared with other accessions.



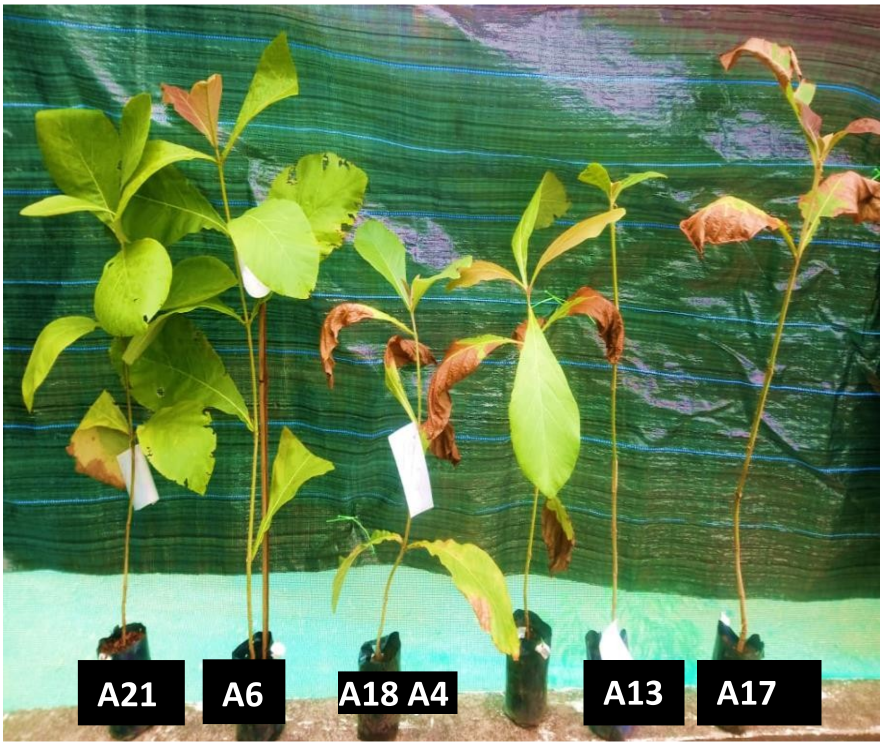


Plate 7 Response of different accessions during stress and regain

Summary

6. SUMMARY

A study was conducted to evaluate selected accessions of *Tectona grandis* Linn f.fromThiruvazhamkunnuplantation intermsofwoodpropertiesanddrought stressand attempt to select plus trees for the future breeding program. Teak trees from a provenance trial plantations were used to evaluate growth characters and wood properties. For stress evaluation studies, branch cuttings were collected from the accessions and vegetatively propagated. The experimental trial for imposing drought wasperformedinthefieldexperimentalshedatCollegeofForestry,KeralaAgriculture University,Vellanikkara.

The important findings of the study are given below.

1. Variation of wood properties and growth characters among the 19 accessions were studied. For evaluating wood properties NDE techniques were used. Relative density or specific gravity calculated from pilodyn penetration depth (PPD) and stress wave velocity (SWV) were the two wood quality traits evaluated. Height and girth at breast height were studied for estimating growth characters.

2. Growth parameters like height, girth showed significant variations among 19 provenances. Variation of height was in the range of 9.57m (A5) to 17.97m (A2). The variation in the girth at breast height was in the range of 31.75cm (A5) to 86.07cm (A29). Accessions A2, A29, A21, A20, A1, A3 and A22 showed better growthparameters.

3. PPDandSWVshowedsignificantvariationsamong19provenances.Thevalue forPPDrangefrom20.25mm(A1,A23)to24.25mm(A20).ThevalueforSWV ranged from 3535 ms^{-1} (A29) to 4360 ms^{-1} (A30). Specific gravity for the different accessions was calculated from the regression equation using PPD. Specific gravity range from 0.32 (A20) to 0.44 (A1, A23). Among the accessions, A23, A17, A28, A19, A18, A21 and A22 showed better wood qualitytraits.

4. The correlation matrix between wood quality traits and growthcharacters

showed a highly significant positive correlation between height and girth. A high negative correlation was observed between PPD and specific gravity.

5. Selection through comparison method was conducted among the trees in the provenance trial and 18 trees belonging to 18 accessions were selected. These trees were then vegetatively propagated through stem cuttings for further studies.

6. For studying drought tolerance among these accessions of teak, physiological changes in response to imposed drought stress were studied in three stages *viz*. normal, stress and regain. Moisture stress was imposed by withdrawing irrigation until plants show signs of wilting. After taking observations during stress the plants were then irrigated to field capacity and maintained till plants were once again showing normal morphological growth. Observation of the "regain" stages was recorded at thistime.

7. Physiological responses like stomatal conductance (gs), transpiration rate (E), photosynthetic rate (Pn), relative water content (RWC), chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophyll, canopy air temperature difference (CATD),chlorophyllstabilityindex(CSI),membranestabilityindex(MSI)and chlorophyll fluorescence (Fv/Fm) were determined during three stages of moisture stress.

8. Kruskal Wallis test was used to test the significance of above mentioned physiological characters under three stages of drought *viz.*, normal, stress and regain. A significant variation of physiological parameters during these three stages wasobserved.

9. Physiological responses of 18 accessions of teak were recorded highest under normal condition ofgrowth.

10. Soil moisture content during the period of stress was evaluated using the gravimetrictechniqueandobservedsignificantvariationsamongtheaccession. In the last day of moisture stress, soil moisture content declined about74.85%

when compared with normal, with the highest moisture content exhibited by accession A17 (6.20%).

11. The number of leaves withered during the period of drought was determined and it showed significant variation among the accessions of teak. The lowest percentage of withered leaves was observed in A21. The highest percentage of withered leaves was observed inA17.

12. After drought imposition, the accessions showed significant reduction in stomatal conductance, transpiration rate, photosynthetic rate, relative water content, chlorophyll a and chlorophyll b content, total chlorophyll content, membrane stability index, chlorophyll stability index as compared to normal growing conditions. A significant increase was observed in the canopy air temperature difference among theaccession.

13. Correlation analysis was done to study the relationship between various physiological parameters during drought among the accession. A significant positive correlation between photosynthetic rate and chlorophyll fluorescence, transpiration rate, stomatal conductance, chlorophyll a and b, chlorophyll stability index and membrane stability index was observed. Stomatal conductance showed a significant positive correlation with relative water content and transpiration. Transpiration showed a positive correlation with relative water content. Chlorophyll fluorescence showed a significant positive correlation with chlorophyll a and b, chlorophyll stability index. Canopy air temperaturedifferenceandleaftemperaturefoundtohaveasignificantnegative correlation with all other physiologicalparameters.

14. A hierarchical cluster analysis was carried out for physiological parameters of the accessions using Euclidean square distance. The accessions were grouped into five clusters according to their performance during drought. Least number of accessions were found in the cluster III and V whereas the Cluster II possessesthemaximumnumberofaccessions.Theaccessionswhichperformed well during drought were grouped in cluster IV. The accessions belongingto

this cluster was A21, A6 and A24. This is due to high values for chlorophyll stability index, membrane stability index, chlorophyll a and chlorophyll b content,totalchlorophyllcontent,relativewatercontentandthephotosynthetic rate was observed for A21 during drought. In addition to that highest value for stomatal conductance and transpiration was recorded in A21 and A6. Chlorophyll fluorescence was observed highest in A21, A24, A5 and A6. Among the accessions, the lowest value for the canopy air temperature difference was observed inA21.

15. After regain, the physiological parameters *viz.* photosynthesis, transpiration, stomatalconductance,canopyairtemperaturedifference,leaftemperature,total chlorophyll content, relative water content, membrane stability index, Chlorophyll a and b content and chlorophyll fluorescence among different plus trees accessions showed significant ($P < 0.05$) differences among them. Completerecoveryinrelativewatercontentwasobservedwhencomparedwith control.Otherphysiologicalparametersshowedsignificantincreasescompared to drought stress. Canopy air temperature difference showed a decline as compared to drought which indicates cooler canopy. Correlation analysis performed during regain followed the same trend as stressedconditions.
16. During regain A21 showed higher values for physiological parameters like chlorophyll stability index, membrane stability index, chlorophyll a and b content, total chlorophyll content, chlorophyll fluorescence, relative water conductance, transpiration and stomatal conductance. The photosynthetic rate was observed highest in A21, A6, A5 and A24. Canopy air temperature difference showed a minimum value compared with otheraccessions.
17. Hierarchical cluster analysis was performed to group accessions into different clusters.Duringregain,theaccessionsofteakweregroupedtofiveclusterswith the maximum number of accessions observed in cluster I and the minimum number of accessions were observed in cluster V. Cluster with only one accession indicates its superiority in physiological parameters. In the present study after rehydration A21 recovered faster than other accessions andwas

clustered alone in cluster V. Cluster III possess accession A13 and A17 which recovered the least.

18. It can be concluded from the above results that considerable variation existed among the teak provenances for wood properties, growthcharacters.
19. Variation in response in terms of drought tolerance was significant among the accessions tested.
20. These findings could be useful in future breeding programs ofteak.

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Selection for drought tolerance and wood quality traits from selected accessions of *Tectona grandis* Linn. f.

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ABSTRACT OF THESIS

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ABSTRACT

Teak (*Tectona grandis* Linn. f.) is an important hardwood timber in the tropic. Most teak-growing countries are now performing tree improvement programs. It mainly aimed at achieving superior growth characteristics. These may have indirect effect on wood properties. So it is essential to include wood quality traits in breeding of teak. As teak requires long nursery period which extends to almost one year and any decline in moisture during this period may cause decline in initial growth and may eventually lead to death of teak.Asstated,mostofthebreedingactivitiesthathavebeendoneonteakinvolvedselecting plustreesbasedonlyonquantitativeandqualitativetraits.Tillnow,veryfewworkwasdone on screening teak for drought tolerance.

The study is being conducted at the teak provenance trial plantation established in Livestockresearchstation,Thiruvizhamkunnu.30accessionsofteakwereplantedincompact family block design with 3 progenies each, replicated five times. Out of 30 accessions, eight were completely absent in the field. From the remaining 22 accessions, three were discarded due to the lack of enough number of progenies (minimum 2) per accession. So the 19 accessions were used for the further studies. Growth characters and wood quality traits were observed among these accessions from thefield.

Growth parameters like height and girth showed significant variations among 19 provenances.Variationofheightwasintherangeof9.57m(A5)to17.97m(A2).Thevariation in the girth at breast height was in the range of 31.75cm (A5) to 86.07(A29). PPD and SWV showedsignificantvariationsamong19provenances.AccessionsA2,A29,A21,A20,A1,A3 andA22showedbettergrowthparameters.ThevalueforPPDrangefrom20.25mm(A1,A23) to 24.25mm (A20). The value for SWV ranged from 3535 ms^{-1} (A29) to 4360 ms^{-1}(A30). Specific gravity for the different accessions was calculated from the regression equationusing PPD. Specific gravity range from 0.32 (A20) to 0.44 (A1, A23). Among the accessions, A23, A17, A28, A19, A18, A21 and A22 showed better wood qualitytraits.

Eighteen trees belonging to eighteen accessions were then selected using comparison method. These trees were then vegetatively propagated through stem cuttings for further studies. These accessions were then screened for drought tolerance by studying physiological changes in response to imposed drought stress in three stages *viz*. normal, stress and regain. Kruskal Wallis test showed significant variation among physiological parameters during these three stages of drought. A significant reduction in stomatal conductance, transpirationrate,

photosynthetic rate, relative water content, chlorophyll a and chlorophyll b content, total chlorophyll content, membrane stability index, chlorophyll stability index as compared to normal growing conditions among the accessions of teak. A significant increase was observed in the canopy air temperature difference among the accession.

A hierarchical cluster analysis was carried out for physiological parameters of the accessionsduringdrought.Theaccessionswhichperformedwellduringdroughtweregrouped in cluster IV. The accessions belonging to this cluster was A21, A6 and A24. During drought, higher values for chlorophyll stability index, membrane stability index, chlorophyll a and chlorophyll b content, total chlorophyll content, relative water content and the photosynthetic rate was observed for A21. In addition to that highest value for stomatal conductance and transpiration was recorded in A21 and A6. Chlorophyll fluorescence was observed highest in A21, A24, A5 and A6. Among the accessions, the lowest value for the canopy air temperature difference was observed inA21.

Duringregainrecoveryinphysiologicalcharacterswasobservedamongtheaccessions. A21 showed higher values for physiological parameters like chlorophyll stability index, membrane stability index, chlorophyll a and b content, total chlorophyll content, chlorophyll fluorescence, relative water conductance, transpiration and stomatal conductance. The photosynthetic rate was observed highest in A21, A6, A5 and A24. A13 and A17 found to be least recovered during drought because of prolonged damage to physiological process after imposeddrought.Itcanbeconcludedfromtheaboveresultsthatconsiderablevariationexisted among the teak accessions for wood properties and growth characters. In drought tolerance studies significant variation among the accessions were also observed. A21 is found to be drought tolerant compared with otheraccessions.