VARIATION IN WOOD PHYSICAL AND ANATOMICAL PROPERTIES OF ANJILY (*Artocarpus hirsutus* LAM.) GROWN IN DIFFERENT AGRO-CLIMATIC ZONES OF THRISSUR DISTRICT, KERALA

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled "**VARIATION IN WOOD PHYSICAL AND ANATOMICAL PROPERTIES OF ANJILY (*Artocarpus hirsutus* Lam.) GROWN IN DIFFERENT AGRO-CLIMATIC ZONES OF THRISSUR DISTRICT, KERALA**" is a bonafide record of research done by me during the course of research and and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"VARIATION IN WOOD PHYSICAL AND ANATOMICAL PROPERTIES OF ANJILY (*Artocarpus hirsutus* Lam.) GROWN IN DIFFERENT AGRO-CLIMATIC ZONES OF THRISSUR DISTRICT, KERALA"** is a record of research work done independently by Ms. Swagatika Sahoo (2015-17-012) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Introduction

INTRODUCTION

The pioneering attempt in scots pine (*Pinus sylvestris*) by Sanio (1872) in the area of wood anatomy drove special attention to wood anatomical variation in forest trees. Thereafter, the succeeding works by Dinwoodie (1961), Panshin and de Zeeuw (1980), Zobel and van Buijtenen, (1989) led to a deeper understanding of variation in length of hardwoods fibres and vessel elements. In hardwoods, most of the studies were focused on radial variation including variation in fibre length and vessel elements and specific gravity (Panshim and de Zeeuw, 1980; Zobel and Sprague, 1998).

Good understanding of wood anatomical variation is quite useful since internal structure of wood profoundly influences the properties of wood (Dadswell, 1957; Burley and Palmer, 1979). Different features of interest in this scenario include cell size, arrangements of different elements, cell proportion and most importantly specific gravity. The usual pattern of variation in wood element dimensions can be seen not only within a species but also within a tree (Dinowoodie, 1961; Rao and Rao, 1978; Pande *et al.*, 1995). The understanding of variation within tree as well as between trees is needed for efficient end use of the wood (Zobel and van Buijtenen, 1989). According to Baas (1973), the structure of secondary xylem can be influenced by environmental factors which can result in variation in anatomical characteristics and it can influence the functional performance of xylem in various environmental conditions and under different ecological conditions (Carlquist, 2001).

Even though teak (*Tectona grandis* L.f.), is the most popular and costly timber species in Kerala, its distribution in the TOF (Trees Outside Forests) sector is relatively limited to around 23,461 ha. Rubber wood (*Hevea brasiliensis)* forms a major share of timber tree species in Kerala sprawling over an area of 5,49,955 ha. Yet another tree species with large increase in area is jack with an estimated extent of 92,203 ha across the state. Estimated volume of standing stock of jack

(*Artocarpus heterophyllus* Lam.) in the country is 38, 885 m. m^3 while the corresponding value for wild jack or anjily or ainy (*Artocarpus hirsutus*) was 10,527 m. m^3 (FSI, 2015).

Western Ghats have been endowed with a rich diversity of flora and fauna in its wet evergreen forests. These forests generally occur throughout the tropical parts of Southern India and Andamans. The vegetation consists of tree species like *Artocarpus hirsutus* Lam. commonly known as the wild jack tree (Khanna, 2009). The tree is one of the important endemic timbers of Southern Western Ghats and also popular along the Malabar Coast (Mathew *et al*., 2006). The name *Artocarpus* has been derived from the Greek words *artos* (bread) and *carpos* (fruit). The family of the genus *Artocarpus* is Moraceae a part of the tribe Urticales. Around 50 genera and over 800 tropical and sub-tropical species are found in the family Moraceae. Peculiar feature of this family is the exudation of latex by all its members (Haq, 2006).

Artocarpus hirsutus or Ainy forms one of the major woody components of homegardens in Southern India especially in Kerala. The timber obtained from this species comes next to teak in economic value. The most common use is in boat making (Manilal, 2003). Wood obtained from the tree is having high calorific value and hence, it can be used for fuel wood purposes also (Gopikumar, 2009). But with the technological advances and changing societal status, these traditional uses have now been neglected (Mathew *et al*., 2006). However, no studies have been reported yet on the physical and anatomical properties of the wood of this important timber species, pertaining to homestead grown trees.

The timber is very durable and resistant to white ants and fungal attack. The high durability of its timber, comparable with teak, often justifies the high price paid for its wood. It is also resistant to termite and fungus (Pearson and Brown, 1932). Despite its immense popularity, little is known about the variation in wood properties of anjily, particularly due to geographic and site related factors. Therefore, a thorough knowledge about the wood property variation existing in its natural range of distribution is essential. Unlike teak, no advanced research seems to have been carried out on *A. hirsutus* as a crop. Quality improvement of wood by any agency is desperately in need. Unfortunately, the species has not become popularized beyond the southern Western Ghats region. Advanced research and forestry experiments on this species and its popularization in tropical habitats would certainly be rewarding and lead toward prevention of its local loss. This would also potentially enable retention of the traditional knowledge associated with the trees. Hence, the present study entitled "Variation in wood physical and anatomical properties of anjily (*Artocarpus hirsutus* Lam.) grown in different agro climatic zones of Thrissur district, Kerala" was conducted with the following objectives:

- To assess the variation in wood anatomical and physical properties of anjily (*Artocarpus hirsutus* Lam.) grown in different agro climatic zones of Thrissur district, Kerala.

- It is also intended to compare anatomical and physical property of wood between plantations and homesteads.

Review of Literature

REVIEW OF LITERATURE

Wood is an important part of forestry. Wood is the most valuable product that used as raw material for various industries. Due to its immense contribution, wide range of studies have been made relative to wood properties and its variation. There are so many literatures available related to these subjects, but all are confusing and contradictory in nature (Downes and Raymond, 1977). So it is very difficult to utilize the available information.

Genus *Artocarpus* belongs to the family Moraceae, a part of the tribe Urticales. The genus consists of approximate 50 species of small to large evergreen trees and is native to South and South-east Asia (Rajendran, 1992 and Soepadmo, 1992). Jackfruit (*Artocarpus heterophyllus*), breadfruit (*Artocarpus altilis*) and champedak (*Artocarpus integer*) are grown mainly for their fruits but some species are economically important as timber trees (Purseglove, 1968). *Artocarpus* species are distributed from Sri Lanka and India to South China and through Malaysia to Solomon Islands (CSIR, 1985). According to Troup and Bor (2009) this genus includes eight Indian species, of which some are important timber trees or fruit trees. The trees are found mostly in tropical forest. They bear fleshy fruits that ripen early in the rainy season. Some of the species are *Artocarpus hirsutus*, *A. heterophyllus*, *A. chaplasha*, *A. altilis*, *A. lakoocha* etc.

Artocarpus is a unique genus, which on account of its peculiar characteristics and edible fruits has attracted attention from the very past. This genus covers up about 50 species of evergreen and deciduous forests. The genus is also has remarkable importance economically as it provides edible fruit, good quality timber and is widely used raw material in folk medicines. Species are also rich in phenolic compounds and Jacalin, a lectin (Jagtap and Bapat, 2010).

2.1. *Artocarpus hirsutus*: AN OVERVIEW

Artocarpus hirsutus is a tall evergreen tree, generally 70-80' in height and up to 15' in girth, with a straight clean bole and dense foliage. The tree is common in Western Ghats from North Canara to Malabar, Coorg and Travancore. The tree requires heavy rainfall and thrives well in any soil, both at the foot of the Ghats and on the slopes (CSIR, 1985). Various uses have been reported from different parts of the tree. Most common is in boat making (Manilal, 2003). Wood obtained from the tree is having high calorific value and hence, it can be used for fuel wood purpose (Gopikumar, 2009). Apart from uses of its wood, the fruit and roasted seeds are eaten by villagers (Mathew *et al.*, 2006). Furthermore, it is also used locally in medicines and is edible (CSIR, 1985). Its bark is used for treating ulcers, diarrhoea and pimples (Dibinlal *et al.*, 2010). An analysis on diameter increment of *A. hirsutus* in mixed deciduous forests of Waynaad revealed that annual d.b.h. increment for the tree was 0.48 cm concluding that it would take at least 137 years for this species to reach a d.b.h. of 60 cm in these forests (Rai and Sarma, 1993). Nagaraja *et al.* (2001) proved the potentiality of *A. hirsutus* for afforesting the wastelands of Western Ghats, Karnataka on the basis of its survival percentage and growth. Prakash *et al.* (2007) were the first to report *Macrophomina* leaf spot disease on older (lower) leaves of *Artocarpus hirsutus* in India and elsewhere.

2.2 SOURCES OF WOOD VARIATION

Wood is a highly variable material which can vary among species and genera as well as among geographical source within a species and among trees within geographical source as well as within each individual tree (Zobel and Van Bujitenen, 1989). The highest degree of variation has been found among trees i.e. genetically influenced including internal and external factors. Internal factors include apical or cambial ageing and positional effects of the crown. External factors such as environment, site condition and silvicultural operations also have significant effect on wood variation and these are called extrinsic (Perera *et al.*, 2012).

Different locality also imposes variation between species as well as within a species range (Callaham, 1964; Burley and Wood, 1976). But the actuality is that all wood properties are the result of interaction of both genetic and environment in which the tree grows. Its wide variation in different properties gives it a pleasing aesthetic appearance. The variability in its structure makes it more attractive and distinctive for different uses. Quality variation i.e. caused due to variation in wood properties influences the production efficiency as a major need in wood industries is uniformity in wood (Zobel *et al.*, 1983). Larson (1969) states that, lack of uniformity has been a hindrance for all wood industries as it causes quality problems.

These problems can be solved through various researches in the area of wood variation and its control. All these information should be spread from tree grower to those people who convert the wood into saleable products (Zobel and Van Bujitenen, 1989). Such studies been carried out in species like on loblolly pine (Thor, 1961), on Virginia pine (Lamb, 1973; Barnes *et al.*, 1977), on jack pine (Yeatman, 1967).

2.2.1. Wood Variation in Plantation grown Hardwood

Butterfield *et al.* (1993) compared the radial variation of wood properties like basic density, fibre length and vessel area from pith to bark in *Hyeronima alchorneiodes* and *Vochysia gutamelanensis* in natural condition and in plantation. Gonzalez and Fisher (1998) studied the wood physical properties viz. specific gravity and also some anatomical properties like fibre length, vessel density and vessel radial diameter in *V. gutemalensis* from pith to bark in Costa Rica.

Plantation species has been gaining attraction from industrial people for various end uses. The choice of material may be based upon single property or a combination of different properties. Among the wood properties, specific gravity of the wood is usually preferred as it is a strong indicator of end use. There are other wood properties not related to specific gravity of the wood that can also effect end use requirements (Zobel and Van Bujitenen, 1989). There is wide range of wood properties that have significant influence on wood processing and wood product. However, first requisite is to identify the main characteristics that determine the quality of wood products (Laurila, 1995).

Various factors like latitude, altitude, soil, rainfall differences etc. influence the wood of natural stands within the species range. The variation in wood occurs both within the native range and in new environment where it is introduced. Talbert and Jett (1981) suggested that, the average difference in plantation wood grown from different geographic seed sources are not strongly genetically determined but usually a result of differing environment into which trees have been moved. For example, loblolly pine (*Pinus taeda*) has a low specific gravity in northern range compared to the southern part of its range. Exotic woods show much variation due to extreme environment in their growing area.

2.2.2. Tree to Tree Variability

Generally high difference in wood properties can be found within a species or within a provenance. This difference is much higher than that between species both in hardwood and soft wood. For example, Harris (1961) suggested that differences in specific gravity can be ranged to 60 percent among trees of same age grown at any one site. Chudnoff (1961) reported that, variation among trees is dominant over the site difference in *Eucalyptus camaldulensis.*

McKimmy (1959) stated that the huge variation between tree to tree often hides the other causes of wood variability. So the variation between trees should be thoroughly studied for better utilization of wood.

2.2.3. Variation within Trees

All trees have tendency to show variation in wood quality from centre to bark, from the base to top of the tree and also within an annual ring, and sometimes even on different sides of the tree in relation to sun and temperature (Sluder, 1972). Anoop *et al.* (2016) have studied within tree variation in Nedun (*Pericopsis mooniana*) which is an introduced species in south India and found that there is a variation from centre to bark. The important pattern of variability within trees generally includes within ring variation, changes from pith to bark of the tree and also the differences from base to top of the tree. Larson (1967) stated that more variability in wood characteristics exists within a single tree, than among trees growing on the same site or between trees growing in different sites.

2.2.3.1. Wood Variability within Annual Ring

Wood variation within an annual ring generally means difference between early wood and late wood. Specific gravity and chemical constitution shows difference between early wood and late wood within an annual ring than between sapwood and heartwood of same Douglas fir tree (Andrews, 1986).The transition zone between early wood and late wood is the reason behind the variation in wood properties in juvenile wood. There are so many variations in cellular level can be seen within annual ring and it mostly found in hard woods than soft woods. Within ring variation is determined by the growth pattern within the plant and one method of modifying the within ring variability is through fertilization (Isebrands and Hunt, 1975).

2.2.3.2. Radial Variation

Most of the studies pertaining to hardwoods were to find variation related to radial direction and confined to fibre length and vessel element length and occasionally specific gravity (Panshin and de Zeeuw, 1980; Zobel and Sprague, 1998). Radial variation in wood is the most studied aspect in wood variation. It includes change in wood properties in radial pattern of juvenile wood as well as mature wood. There are immense studies have done on radial variation which includes five Mississippi Delta hardwood, black willow, willow oak, sycamore, pecan and sugarberry (Taylor and Wooten, 1973), on *Eucalyptus grandis* (Malam and Gerischer, 1987) and on *E. camaldulensis* (Ohshima *et al.*, 2003).

2.2.3.3. Variation from the Base to the Top of the Tree

Height can be an impact factor on wood properties variation in the tree for many species and it may leads to the increase in proportion of juvenile wood in the stem from the base to the top. For depth understanding in longitudinal pattern of variation in juvenile and mature wood separate study is needed in changing pattern of wood properties with the height of the tree (Zobel and Van Buijtenen, 1989).

2.3. PHYSICAL PROPERTIES

Wood quality can be accessed through various available methods by taking timber samples in large number of technical tests. However, specific gravity is related to many mechanical properties of wood, such as strength and elasticity. Hence specific gravity is widely used parameter for determining wood quality (Panshin and de Zeeuw, 1980). Both genetic and ecological factors are having significant effect on variation in specific gravity (Brazier and Brazier, 1956; Butterfield *et al.*, 1993; Omolodun *et al.*, 1991).

2.3.1. Basic Density

Basic density can be considered as a reliable index of wood quality which reflect the amount of wood substances deposited per volume of a tree trunk, thus is a factor influencing the amount of forest biomass (Wiemann and Williamso, 1988; Woodcock, 2000).

The specific gravity of wood showed considerable difference between species within each region and between regions. The effect of growth rate on wood properties, especially on wood density has been intensively studied (Spurr and Hsiung, 1954; Megraw, 1985). Negative correlation between density and mean growth rate per species has been observed in a number of tropical forests (Enquist *et al.,* 1999; Landau, 2004). Wood specific gravity is one of the important factors that determine the economic utility of wood. Specific gravity in hardwood species influenced mainly stiffness and strength property of wood

(Huang *et al.*, 2003), as well as by cellulose microfibril angle, the proportion of lignin, extractives and interlocked grain and the extent of spiral grain (Chafe, 1990; Aggarwal *et al.*, 2002 and Huang *et al.*, 2003). Wood density and ring width are the most commonly used indicators of wood material, quantity and quality. Wood density is considered the best single index for pulp yield and quality and also overall wood quality (Bendtsen, 1978). Overall wood density typically increases with tree age as the proportion of lower-density material formed early in a tree's life is reduced by the formation of higher-density material in older trees (Silva *et al.*, 2004).

Due to high valued structural and medicinal properties, wood specific gravity and other physical and anatomical characters were studied (MacLachlan and Gasson, 2010). Vessel diameter and frequency tend to be inversely proportional to wood density, particularly in ring porous species having large early wood vessels. Thus wood having relatively high fibre; vessel ratios yield more dense wood than those with lower ratio (Barnett and Jeronimidis, 2003).

Specific gravity and mechanical properties were affected by species provenance and site, revealed by study conducted in *Acacia auriculiformis* and *Acacia mangium* (Sahri *et al.,* 1998). Wood density is the best single description for wood which correlates with numerous, mechanical, physiological and ecological properties (Chave *et al.*, 2006). Variation within tree of wood anatomical properties and basic density of I-214 poplar in Beijing area were examined by Jiang *et al.* (2003). Their results indicated an initial rapid and then gentle increase in fibre length and width, fibre wall thickness from pith to outwards, while the tissue ratio of fibre and fibre wall ratio gradually decreased and then tended to stable.

2.3.2. Moisture Content

Moisture content in wood is measured by finding the amount of water present in a piece of wood relative to wood itself. It has direct effect on weight, strength, physical behaviour and processing characteristics that influence its utilization. The amount of water present in a given piece of wood is expressed as the percentage of weight of water to the oven dry weight (Simpson and Tenwolde, 1999). Moisture content in trees can range from 30% to more than 200% of weight of wood substances. In soft woods, moisture content of sapwood is higher than that of heartwood.

Moisture content and specific gravity are negatively related within a species; higher the specific gravity, lower the moisture content (Zobel *et al.*, 1968). It is found that moisture content differ significantly with respect to species. Different species and different specimen of the same species shows varied responses to percentages change in strength, due to given changes in moisture content for clear wood. Sindhumati (2012) observed an increase in moisture content towards periphery region, but it doesn't show any definite radial pattern of variation in *Pericopsis mooniana* and *Pterocarpus dalbergoides*. Mechanical properties of wood alter with moisture content (Gerhards, 1980). He has found that mechanical properties of wood increases as moisture content decreases below fibre saturation point, at least down to about 5% moisture content.

2.3.3. Colour

Colour is a unique feature of wood which has a profound impact on aesthetic value of wood. Consumer always wants a good quality product with attractive appearance and wood is the only natural material which loaded with its own colour of beauty. Thulasidas and Bhatt (2004) have analysed the colour of the wood by using Munsell colour chart in which they considered hue, value and chroma value for identification of colour. The colour was then identified by its hue, value and chroma. Hue value ranged from 9.9R to 1.0Y, from red to yellow. In-significant variation in wood properties is attributed to genetic factors as wood colour within species varies due to genetic factors (Rink and Phelps, 1989; Mosedale *et al.*, 1996). Knust (2009) also explained that soil properties are associated with wood colour of teak independent from effects of tree age as observed by Nelson *et al.* (1969) for walnut wood.

2.4. ANATOMICAL PROPERTIES

Anatomical properties of wood can be influenced by environmental as well as genetic factors. Variation of anatomical features of wood within the main stem of a tree is often quite large, and has been shown to be strongly related to proximity of crown during wood formation (Larson, 1960, 1962, 1964; Isebrands, 1972). In general all anatomical properties will vary significantly from pith to outwards within a tree. Mature wood and juvenile wood can be distinguished by anatomical properties (Bhat *et al*., 2001). The variability in wood anatomical characteristics has remarkable influence on the various properties of wood (Dadswell, 1957; Burley and Palmer, 1979). Features of interest in this connection include cell size, proportion and arrangements of different elements and specific gravity. Morphological and anatomical studies in *Artocarpus* species has investigated by Sharma (1962). Achari and Rao (2006) explained the additory effect of extractives in heartwood of *Artocarpus heterophyllus* on strength properties.

2.4.1. Vessel Morphology

Vessel morphology is sustainably influenced by wide range of factors includes environmental factors, silviculture, breeding technique and treatment with plant growth substances. Schmitz *et al.* (2006) studied the effect of salinity factor on the vessel characters of mangrove species and found that there is a positive correlation between vessel characters and salinity for the early wood of mangrove species. Gartner *et al.* (1997) concluded that radial variation was minimum, in *Alnus rubra* and also shown that variation is significant for vessel frequency and vessel diameter. Fitchtler and Worbes (2012) studied the variation in anatomical properties of wood within all groups and analysed that veseel diameter significantly varied both in families and sites. MacLachlan and Gasson (2010) made a comparative study between *Pterocarpus santalinus*, *Pterocarpus osun* and *Pterocarpus erinaceus* with a greater mean tangential vessel diameter than Pterocarpus santalinus. Mean vessel frequency was substantially lower in *P. osun* (1-2 vessels mm^{-2}) than in *P. santalinus* (5-9 vessels mm^{-2}).

Naidoo *et al.* (2006) have got a result showed a strong relationship between mean annual rainfall and mean vessel frequency, mean vessel percentage in *Eucalyptus grandis* in warm temperate region of south.

Studies by Carlquist (1966) and Zhang *et al.* (1988) showed that vessel diameter and vessel element length declines with increase in aridity. Vessel lumen diameter greatly shows a juvenile to mature pattern of variation from pith to the bark (radial variation), where vessel lumen diameter is smaller in the inner part of stem, and gradually increase in size outward before levelling off in the outer part of the stem (Furukawa and Hashizume, 1987; Ohbayasi and Shiokura, 1990, Raczkowska,1994; Peszlen, 1994; Gartner *et al.*, Raczkowska and Fabisiak, 1999; Bhat *et al.*, 2011). Singh *et al.* (2017) studied the vessel length in *Artocarpus nitidus* and observed that the vessel length was 284.4 μm grown in Assam and Mizoram.

2.4.2. Ray Morphology

Ray morphology has significant contribution to various wood properties. Variation in wood structure associated with difference in growth rate concerns the development of rays. In fast-grown timber the rays tend to become more numerous, wider, or higher, than in slow grown wood; there are marked increases in total number of the ray cells per unit tangential area of the wood. Varying differences of this nature have been described in softwood (Bannan, 1954; Cami *et al.*, 1972; Gregory, 1977).

Ray width is considered as useful tool for wood identification of species group in maple (Dakkak *et al.*, 1999). Krib's classification provides a concise system of describing the rays of hardwoods and has been generally used in relation to the description and identification of timber (Brazier and Franklin, 1961; Barefoot and Hankins, 1982). Trees with a lesser amount of ray cells are of more interest due to adverse effects upon specific gravity and wide variability (Zobel, 1989).

2.4.3. Fibre Morphology

Fibres are narrow elongated cells with tapering end that give mechanical support to wood. It is one of the most significant features that influence the strength and shrinkage properties.

Studies has been conducted to analyse the morphological features of wood fibres in two provenance of *Eucalyptus dunnii* by timber segregation method (Qiang *et al.*, 2014) showed the linear correlation between DBH and fibre length and linear correlation between DBH and fibres width is remarkable. Raymond (1995) while reviewing published estimates for fibre traits and genetic parameters of wood in eucalyptus indicated existence of negative relationship between tree diameter, basic density and fibre length. The external factors bring out the physiological changes in trees by affecting the cambial activity. The fast grown timber showed higher values for fibre parameters viz. fibre length, fibre diameter, fibre lumen diameter, double wall thickness of fibre than the slow grown timber. Interestingly, the intra tree variation revealed that the outer region of wood in both types of trees had longer and wider vessels. Though variation between trees and among trees is non significant, numerically superior values are recorded in fast grown tree than slow grown tree (Swaminathan *et al.*, 2012).

The mean value of lumen diameter appeared to be larger in the wavy grained trees (red sanders) as compared to that of normal grained trees and difference between the mean values were found to be very highly significant. This is likely to be a useful character for screening the saplings if it is confirmed after an examination of a large number of trees (Kedharnath and Rawat, 1976).

In diffuse porous wood, density is known to be almost totally controlled by fibre characteristics. A significant positive correlation was observed among density fibre length and fibre diameter and other fibre properties in *Michelia champaca* Linn. (Purkayastha, 1974).

Bhat *et al.* (1989) also included branches for investigating the fibre length variation in eleven tropical Indian hardwoods growing in Kerala in which branch fibres were significantly shorter then stem fibres. Rao *et al.* (2003a) studied radial variation in anatomical properties of plantation grown *Tecomella undulata*. Significant pith-to-periphery variations in fibre length, fibre diameter, fibre lumen diameter were reported. All fibre characters were found inter-related. The radial wood variation patterns were determined for quebrancho blanco (*Aspidosperma quebranchoblanco*). Patterns of variation of fibre diameter, lumen diameter, and fibre cell wall thickness were examined in different locations. Along the radius, the tissue proportion of fibre diameter and fibre cell wall thickness increased more rapidly up to a distance of 10.5 cm (Moglia and Lopez, 2001). Intra-tree radial variations in fibre morphology were studied by Pande *et al.* (2007) in 12 years old tree of *Leucanea leucocephala*. They observed that the variations were nonsignificant except for fibre-diameter from pith to outwards. They also observed significant variations among main bole, first and second branch of the tree. Dimensional variation was investigated in fibre along vertical and horizontal axes of a 40-year-old tree of *Afzelia africana* felled in Gerei forest Nigeria by Idu and Ijomah (1996). Mean dimensional values were: fibre length 1116.23 μm, fibre diameter 21.94 μm, lumen diameter 11.8 μm, fibre wall thickness 5.55 μm, Runkel Ratio 0.98, flexibility coefficient 0.5, relative fibre length 50.56, vessel length 194.02 μm and fibre length varied significantly on both axes investigated (showing patterns of alternate increase and decrease with increasing height and distance to pith), while fibre diameter and lumen diameter varied significantly only along vertical axis. Other traits analyzed showed considerable variation but were not significantly related to distance along either axis.

Materials and Methods

MATERIALS AND METHODS

3.1. MATERIALS

The present study was carried out to understand the variation in wood anatomical and physical properties of anjily (*Artocarpus hirsutus* Lam.) from three different girth classes grown in different agro-climatic zones of Thrissur district, Kerala. The study was conducted in the department of Wood Science of the College of Forestry, Kerala Agricultural University, Vellanikkara.

3.1.1. Species Studied

Artocarpus hirsutus Lam., which is also called anjily is found in most of the homegardens in Southern India, especially in Kerala. The timber value is very high which is comparable to teak. In addition to the wood, the other parts like fruits and roasted seeds were the basic source of food until the latter half of the 20^{th} century. According to Ramesh and Pascal (1997), *Artocarpus hirsutus* or the wild jack tree is one of the endemic timber species of southern Western Ghats, extending geographically from Kalinadi river of Maharashtra in the north to Agasthyamala in Thiruvananthapuram district of Kerala in south.

3.1.2. Location

The present study was carried out in Thrissur district (between N 10° 11' 8.16" and N 10° 41' 2.76" latitude, and E 75° 58' 2.64" and E 76° 53' 29.04" longitude) of central Kerala, India. Wood samples were also collected from three plantations located in Thalassery taluk of Kannur revenue district. The tract dealt with falls between $12^{0}14'$ to $11^{0}\ 50'$ north latitude and $75^{0}10'$ to $75^{0}50'$ which was established in 1949, 1950 and 1951 respectively.

Plate 1. Map showing sample collection sites of Thrissur district, Kerala

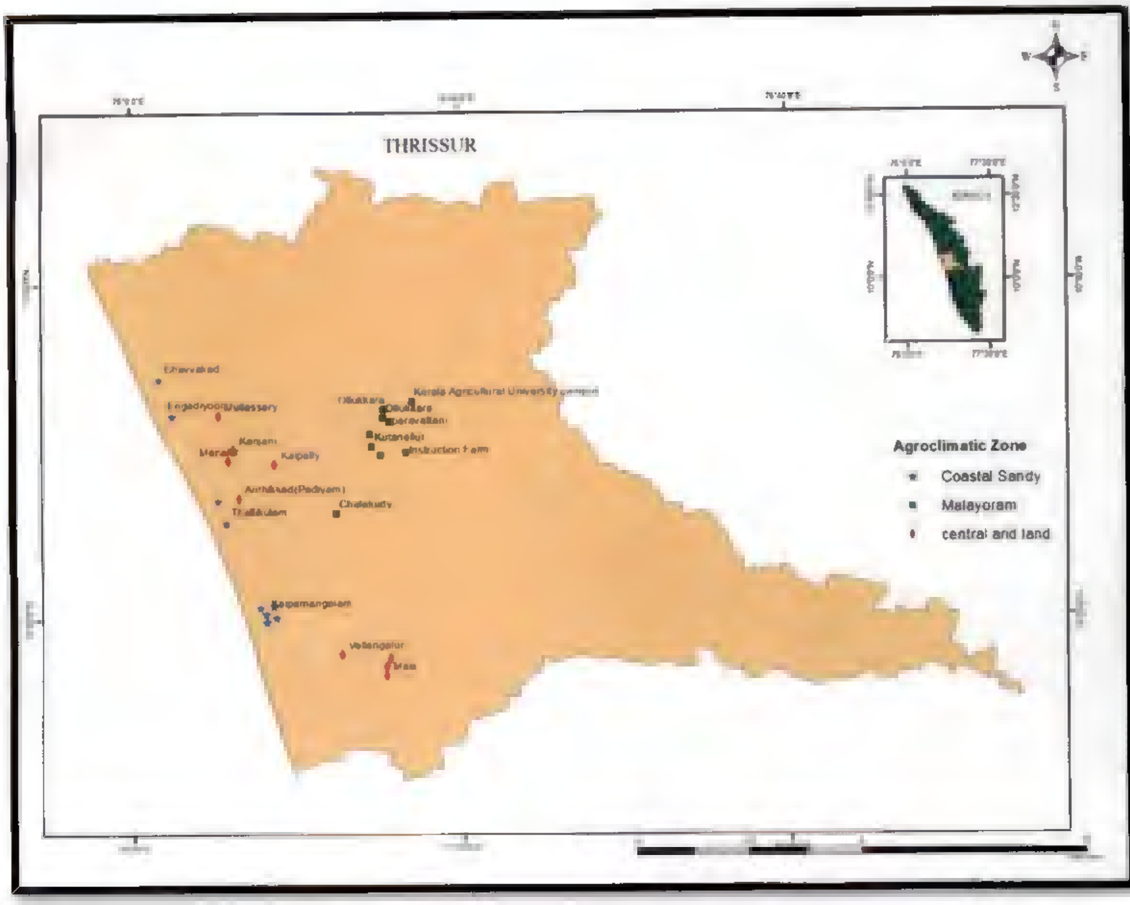


Plate 2. Map showing sample collection sites of Thallasery taluk, Kannur

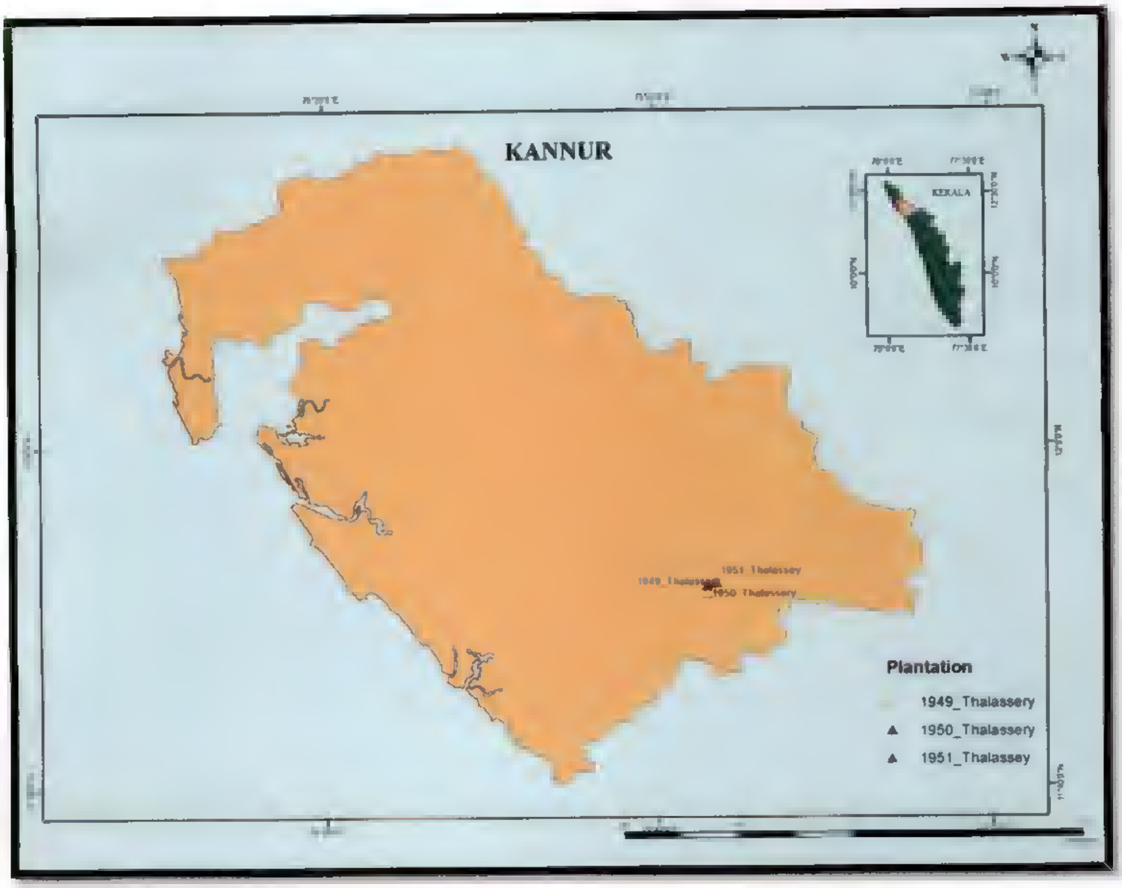


Table 1. Details of wood samples collected from homesteads in three agro-climatic zones of Thrissur district, Kerala

Agroclmatic zones	Place	DBH (cm)	Latitude(N)	Longitude(E)
COASTAL SANDY	Thallikulam (Nattika)	90	10°27'04"	76°5'15.30"
	Kaipamangalam	90	10°20'12"	76°8'11.12"
	Kaipamangalam	75	10°20'15.70"	76°8'08"
	Kaipamangalam	134	10°20'15.59"	76°8'07"
	Chavvakad	145	10°34'24.42"	76°01'34.18"
	Engadiyoor	115	10°32'08"	76°02'28.34"
	Kaipamangalam	152.4	10°20'20.23"	76°08'06"
	Kaipamangalam	155	10°20'19.56"	76°5'15.30"
	Thallikulam	187	10°25'41.95"	76°5'44.84"
CENTRAL ARID LAND	Anthikkad(Padiyam)	80	10°27'30.68"	76°06'32.4"
	Manalur	60.75	10°29'31.33"	76°6'00"
	Kanjani	90	10°29'44.99"	76°06'07"
	Mala	139.7	10°17'04"	76°15'27.20"
	Mala	142.24	10°17'034"	76°15'27.99"
	Vellangalur	130	10°17'54.43"	76°12'43.57"
	Kaipally	175	10°29'07"	76°8'35.18"
	Mullassery	190.25	10°32'12.74"	76°5'18.33"
	Mala	177.8	10°17'04"	76°15' 27.40"

	Chalakudy	60	10°26'10.46"	76°12' 24.16"
	Ollukkara	80.75	10°27'30.68"	76°06'42.32"
	Paravattani	95	10°31'00"	76°14' 28"
	Paravattani	130	10°27'30.66"	76°06'42.37"
MALAYORAM	Ollukkara	143.20	10°31'58.28"	76°15'16.88"
	Kutanellur	150.76	10°30'17"	76°14'55.62"
	Kerala Agricultural University campus	175	10°32'56.13"	76°17'03"
	Kutanellur	187	10°30'14.28"	76°15'08"
	Instruction Farm	284	10°30'00"	76°16'34.93"

Table 2. Details of wood samples collected from plantations in Thallasery taluk of Kannur district, Kerala

Thallasery, Kannur plantation	**Plantations**	**Year of establishment**	**Latitude(N)**	**Longitude(E)**
	1	1949	11°51'47.41"	75°42'55.44"
	2	1950	11°51'58.52"	75°43'10.02"
	3	1951	11°51'21.37"	75°42'55.44"

Plate 3. Images of collection and preparation of samples

Collection of wood samples using increment borer

Collection of sample from Kannur

Measurement of girth of the trees using a measuring tape

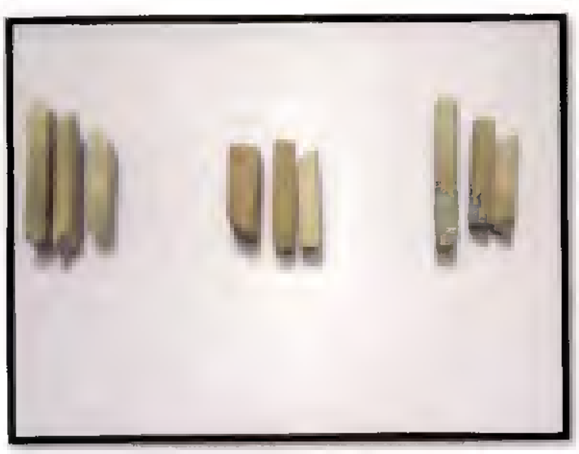
Sample taken out using the increment borer

Slides prepared for anatomical studies

Observations taken under image analyser

Preparation of sample for colour estimation

Sanding of wood surface for colour estimation



Samples prepared for colour estimation

Taking measurements of colour parameters

3.1.2.1. Agro-Climatic Zones

Four parameters (altitude, rainfall pattern, soil type and topography) together creates a distinct agronomic environment which leads to distinct cropping patterns. Using a matrix built upon these parameters at its different levels, Kerala has been delineated into 13 agro-climatic zones with block panchayaths as the unit of delineation. The study site, Thrissur district encompasses three agro-climatic zones namely Coastal sandy, Central midlands and Malayoram (KAU, 2011).

3.1.2.1.1. Coastal Sandy

Coastal sandy zone includes Kodungallur, Thalikkulam, Mathilakom and Chavakkad block panchayats. The zone has the altitude Type I i.e., up to 500 m above mean sea level (low altitude-humid tropics); rainfall (Pattern I) where both the south west and north east monsoon are active and moderately distributed, south-west monsoon with June maximum (south of 11^{0}N latitude); topography (Model I) of extensive valleys with level but raised garden lands and sandy loam soil.

3.1.2.1.2. Central Midlands

Mala, Vellangallur, Irinjalakuda, Cherpu, Anthikad, Puzhakkal, Mullassery, Kunnamkulam and Chowannur block panchayats were delineated to Central midlands. The zone has an altitude (Type I) up to 500m above mean sea level (low altitude-humid tropics); rainfall pattern I i.e., both the south west and north east monsoon are active and moderately distributed, south-west monsoon with June maximum (south of 11^{0}N latitude); topography (Model IIa) where valleys are less extensive, hills with moderate gradients, slopes having mild gradients and laterite soil with well-defined B-horizon.

3.1.2.1.3. Malayoram

Malayoram includes Chalakudy, Kodakara, Ollukkara and Pazhayannur block panchayats. The zone has the altitude type I i.e., up to 500 m above mean sea level (low altitude-humid tropics); rainfall pattern I i.e., both the south west and north east monsoon are active and moderately distributed, south-west monsoon with June maximum (south of 11^0N latitude); topography model III i.e., narrow valleys, hills with steep gradients, steep slopes and laterite soil without B-horizon.

3.1.2.2. Thallasery Taluk of Kannur District

The altitude of this division varies from 35 m to 1,230 m above mean sea level. The climate is tropical maritime and monsoon in character. During the south-west monsoon, from June to August the wind blows all through the day and night. The atmosphere is predominantly saturated throughout the year. The tracts have many rivers and backwaters. Vegetation in such climate supports luxuriant growth of tree and shrubs. Humidity varies from 60-90 percent. The district receives a total annual rainfall of around 3438 mm. Soil is a heterogeneous collection of mineral fragments. Physically, the area is divisible into low land, mid land and high land.

3.2. METHODS

The methods adopted to carry out the study are discussed below.

3.2.1. Selection of Samples

Study samples from anjily trees were selected from the three agro-climatic zones of Thrissur district following stratified random sampling technique. The experimental materials were collected from three agro-climatic zones (9 Costal sandy + 9 Central midlands + 9 Malayoram) which also include trees from girth classes 50-100 cm, 100-150 cm. and more than 150 cm. Wood samples of three trees were collected from each girth class. For comparing the wood properties between homesteads and plantations wood samples were collected from homesteads of Thrissur and three plantations in Thallasery taluk of Kannur district. From each plantation, we have selected three girth classes and from each girth class samples were collected from three trees. The same was also done for homesteads in Thrissur.

3.2.2. Physical Properties

Wood specimens of size 2.0 cm^3 were made out from each sample assessing wood basic density, moisture content and heartwood colour.

3.2.2.1. Basic Density

Green volume of the sample was estimated using the immersion method. The samples were oven dried at $103^0C \pm 2^0C$ until the weight became constant for the determination of oven dry weight using a precision electronic balance (Shimadzu AUY 220) and were weighed correct to 0.001g.

Basic density (standard specific gravity) of wood specimens were calculated by the following formula,

Basic density ($kg\ m^{-3}$) = (Oven dry weight)/(Green volume)

3.2.2.2. Moisture Content

In order to determine moisture content, the samples were weighed to an accuracy of 0.001gm in a weighing balance (Shimadzu AUY 220) and then dried in a hot air oven at a temperature of $103^0C \pm 2^0C$ till a constant weight. The final weight has been taken as oven dry weight. The moisture content of each specimen was calculated using the formula,

Moisture content (%) = (Green weight-Oven dry weight)/(Oven dry weight)×100

3.2.2.3. Colour

Colour of the heartwood has been investigated by C.I.E Lab colour system. Heartwood colour variation was quantitatively measured in reflectance mode as CIELAB colour co-ordinates (10^o standard observer, D65 standard illuminant) using Hunter Lab Scan XE colorimeter (IWST, Bangalore). CEILAB L^*, a^*, b^* and ΔE^* parameters were measured on each specimen and average value was calculated. In the CIELAB system, the L^*axis represents lightness and a^* and b^* are the chromaticity coordinates (+a* is for red, -a* for green, +b* for yellow, -b* for blue).

3.2.3. Wood Anatomical Properties

Wood anatomical properties were studied with the help of two techniques: wood microtomy and maceration. Anatomical feature studied included vessel length, vessel frequency, vessel area, ray frequency, ray height, ray width, fibre length, fibre wall thickness and fibre lumen diameter.

3.2.3.1. Microtomy

Wood core samples size of 3 cm were taken out from each tree by using Haglöf Increment Borer and anatomical properties were studied. The specimens were then softened by keeping in water bath (Rotex water bath) at 100^0C depending on the nature of specimen. Transverse sections (TS) and longitudinal sections (TLS) of 10-15 μm thickness were prepared using a Leica sliding wood microtome (Leica SM 2000R). The sections were stained using saffranin and later washed through a series of alcohol solutions at different concentrations (70 %, 90 % and 95 %) to ensure complete dehydration. They were subsequently dipped in acetone followed by xylene and finally mounted in DPX mountant to prepare permanent slides (Johansen, 1940).

3.2.3.2 Maceration

Maceration of the wood samples was done using Jeffrey's method (Jeffrey, 1917). For maceration, Jeffrey's solution was prepared by mixing equal volumes of 10 per cent potassium dichromate and 10 per cent nitric acid. Radial chips of wood shavings were taken from the 2 cm^3 wood blocks. These chips were taken in test tubes and boiled in the maceration fluid for 15-20 minutes so that the individual fibres were separated. These test tubes were then kept for 5-10 minutes so that the fibres settled at the bottom. The solution was discarded and the resultant material was thoroughly washed in distilled water until traces of acid were removed. The samples were stained using saffranin and mounted on temporary slides using glycerol as the mountant.

3.2.3.3 Image Analysis

Microscopic examination and quantification of sections was undertaken using an Image Analyzer (Labomed-Digi 4). It consists of a microscope, digital camera and PC (Personal computer). The image analyzer provides quick and accurate data replacing the more laborious traditional methods. The digital camera provides digitized images which are analysed by the computer software (Labomed DigiPro-4). The software provides several classes of measurements like length, diameter, area and frequency of the sections.

3.3 ECOANATOMICAL PROPERTIES

Ecoanatomical wood features of the collected samples were also calculated. Wood anatomical indices of vulnerability (mean vessel member diameter divided by mean vessel frequency) and mesomorphy (vulnerability multiplied by mean vessel member length) were calculated by using the formulae of Carlquist (1977).

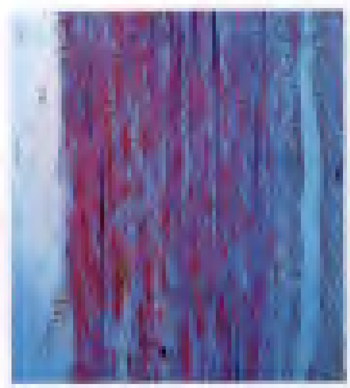
4a

4b

4c

4d

4e



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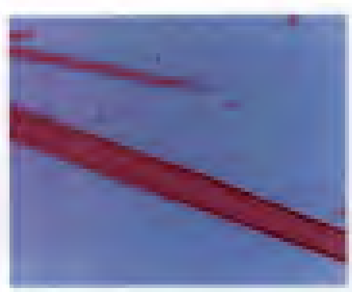


4i

Plate 4. Wood anatomical features of *Artocarpus hirsutus* Lam. a. TS 4X b. TS 10X c. Full vessel (Maceration 40X) d. TLS 10X e. TLS 10X f. TLS 4X g. Fibre (Maceration 4X)) h. Fibre (Maceration 10X) i. Fibre (Maceration 40X)

3.4 OBSERVATIONS

Different wood anatomical parameters were observed from the two planes of sections includes TS, TLS. Both quantitative and qualitative observations were recorded. The transverse sections (T.S.) of the species were used for determining different wood features like vessel frequency (vessel per mm^2), vessel diameter, vessel area. Vessel frequency was calculated by counting the number of pores in randomly selected fields of the section with the help of image analysis software, Labomed-Digi 4 and was expressed as number per millimetre (mm).

The ray parameters viz. ray frequency, ray width and ray height were taken from the tangential section. The observations like fibre length, fibre wall thickness, fibre lumen diameter and vessel length were taken through maceration.

3.5 STATISTICAL ANALYSIS

Samples were collected from three zones and within these zones, from three girth classes. Hence, the sampling and subsampling gives rise to nested or hierarchical classification. Therefore, the statistical method used for the analysis of present investigation for comparing different wood anatomical and physical properties of *Artocarpus hirsutus* Lam. from three different agro-climatic zones of Thrissur and between girth classes within zone was NESTED ANOVA by using MINITAB (Ver. 17). For comparing wood anatomical and physical properties between homestead and plantation, independent t-test was performed using IBM SPSS (Ver. 20) software. Pearson's correlation coefficient among wood properties were determined using the above software.

Results

RESULTS

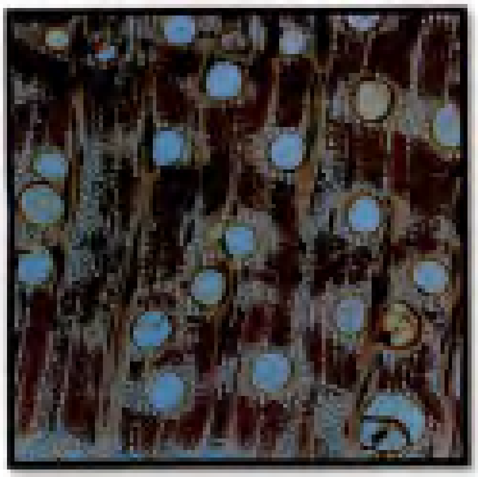
This chapter deals with the results of the various tests conducted to analyse the wood physical, anatomical properties of anjily, across three different girth classes grown in three agro-climatic zones of Thrissur district, Kerala. The results are presented in this chapter under the following headings:

- General features and gross anatomical features of anjily wood
- Physical property variation between three zones and between girth classes within zones
- Variation in anatomical properties between three zones and between girth classes within each zone
- Ecoanatomical features of anjily wood
- Relationship between different wood properties
- Variation in wood physical and anatomical properties between homesteads and plantations

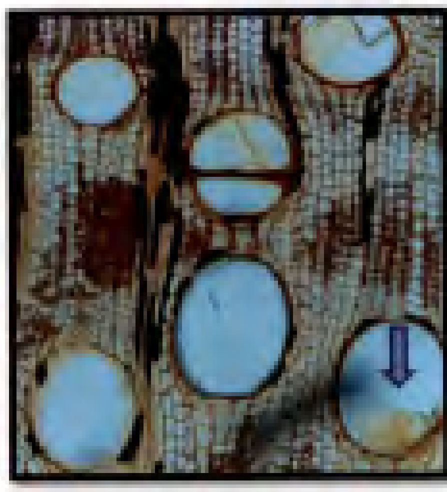
4.1. GENERAL FEATURES AND GROSS ANATOMICAL FEATURES OF ANJILY WOOD

The sap wood was found to be distinct from heartwood as the heartwood had dark yellowish brown colour with white chalky deposits. Parenchyma arrangement was found to be paratracheal i.e. aliform confluent. Tyloses were found in vessels. Vessels were having simple perforation plates with alternate polygonal pits. Rays were multiseriated and heterogenous in nature (Kribb's Type 2) having 1 or 2 row of procumbent body ray cells with upright cells. Fibres were non-septate; thick to thin walled.

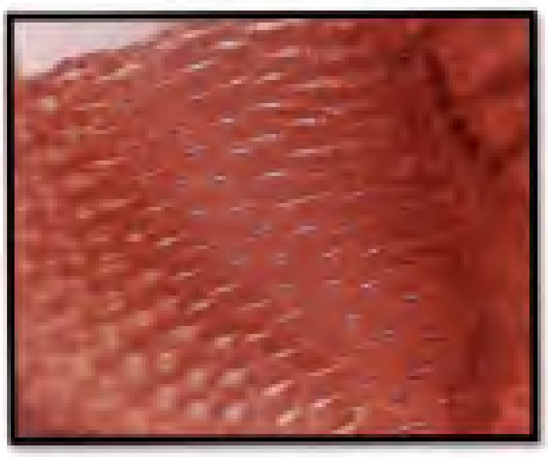
Plate 5. Profiling of anatomical properties of anjily wood



5a



5b



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5d

Plate 5. Anatomy of (*Artocarpus hirsutus* Lam.) wood a. Diffuse porous wood (TS 4X) b. Vessel with tyloses (arrow head) TS 10X c. Vessel with alternate polygonal pits (Macerated 100X) d. Vessel with polygonal pits (Macerated 40X)

5e

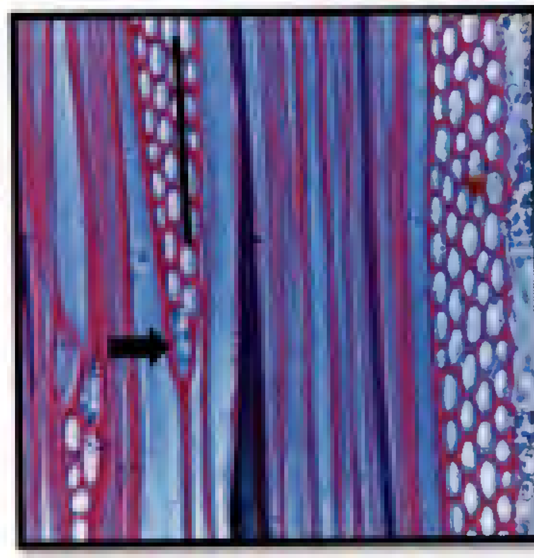

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Plate 5. Anatomy of anjily (*Artocarpus hirsutus* Lam.) wood e. Multiseriated ray cells (TLS 4X) f. Procumbent body ray cells and upright cells (arrow head) TLS 40X g. Non-septate fibres (TLS 40X) h. Fibre with wide lumen (Macerated 40X)

4.2 PHYSICAL PROPERTIES

The results obtained from the analysis of physical properties (basic density, moisture content and colour) of wild jack wood are discussed below.

4.2.1 Basic Density

The basic density of anjily wood ranged from 475.27 kg m^{-3} to 530 kg m^{-3} for Coastal sandy, 560.40 kg m^{-3} to 589.15 kg m^{-3} for Central mid land and 435.66 kg m^{-3} to 565.41 kg m^{-3} for Malayoram. There was no significant variation in basic density between zones and also there was no significant difference between girth classes within zones.

Table 3. Wood Basic density (kg/m^3) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Wood Basic density (kg/m^3)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	530.66 (113.77)	475.27 (71.60)	488 (56.66)	497.67 (29.01)	2.43^{ns} (Zones)
Central mid land	560.40 (56.03)	582.38 (60.94)	589.15 (21.19)	577.31 (15.03)	0.88^{ns} (Girth classes within zone)
Malayoram	435.66 (24.00)	565.41 (171.83)	555.00 (73.99)	518.69 (72.09)	

- *Values within parentheses is standard deviation (SD); ns-non significant at 0.05 level*

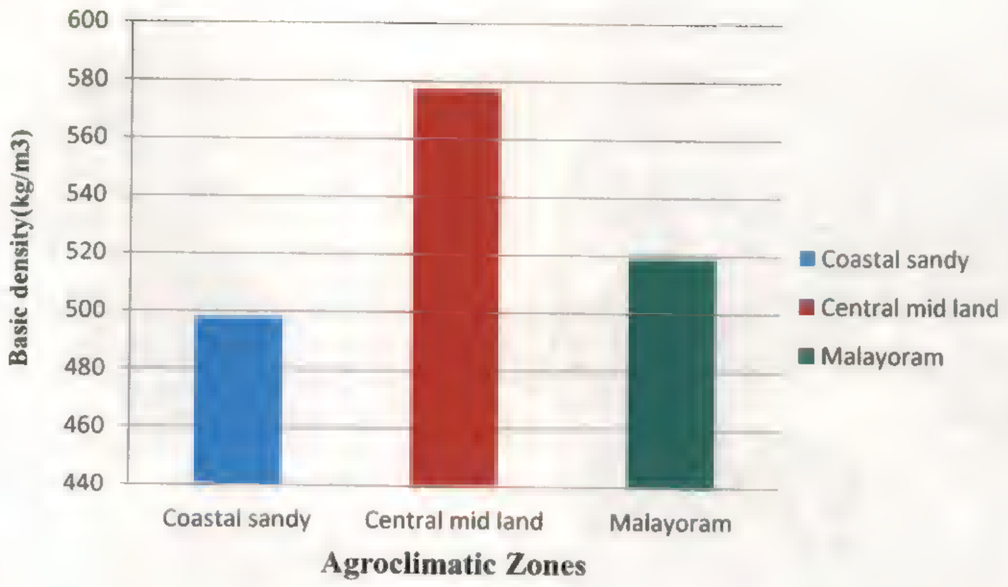

Figure 1. Wood Basic density of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

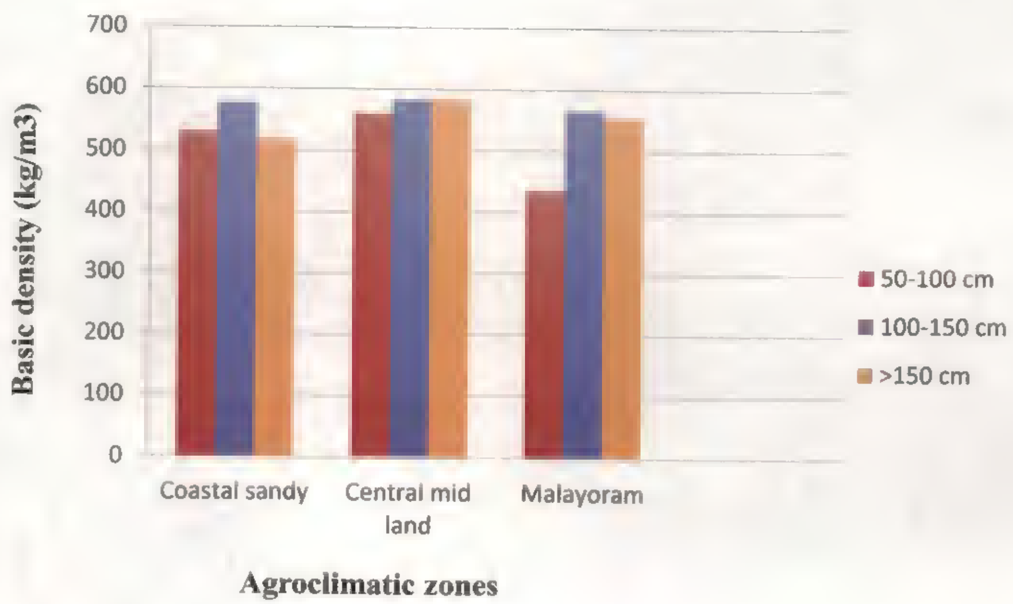

Figure 2. Wood Basic density of *Artocarpus hirsutus* Lam. wood between different girth classes from different agro-climatic zones

4.2.2. Moisture Content

The moisture content of samples in green to oven dry condition ranged from 46.30% to 63.66% for coastal sandy, 63.85% to 67.60% for Central mid land and 58.60% to 62.72% for Malayoram. Analysis revealed that there was no significant variation in moisture content between zones as well as between girth classes within zones.

Table 4. Green to oven dry moisture content (%) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Green to oven dry moisture content (%)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	63.66 (16.65)	56.09 (11.06)	46.30 (14.52)	54.35 (10.29)	2.89^{ns} (Zones)
Central mid land	65.68 (10.91)	67.60 (10.10)	63.85 (8.03)	65.71 (1.87)	0.35^{ns} (Girth classes within zone)
Malayoram	60.61 (16.78)	62.72 (26.93)	58.60 (16.26)	60.64 (2.06)	

- *Values within parentheses is standard deviation (SD);ns-non significant at 0.05 level*

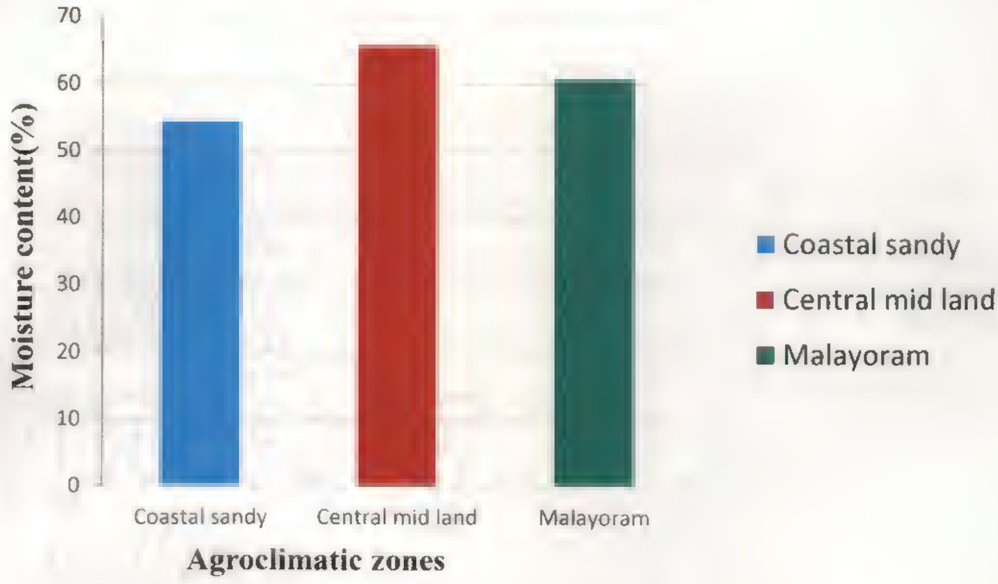

Figure 3. Green to oven dry moisture content of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

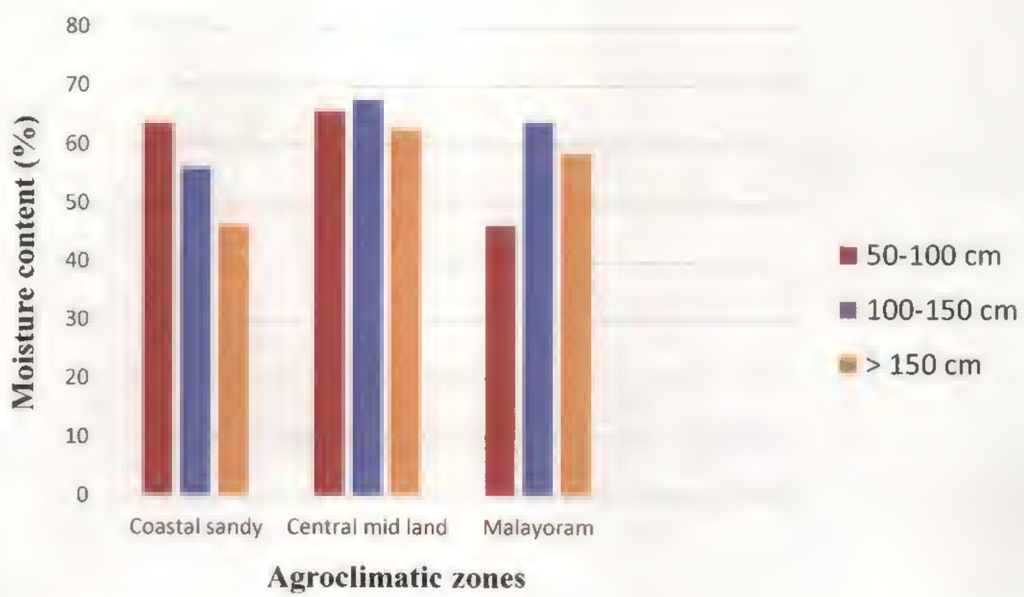

Figure 4. Green to oven dry moisture content of *Artocarpus hirsutus* Lam. wood between girth classes from different agro-climatic zones

4.2.3 Heartwood Colour

Analysis of variance revealed that there was no significant difference of colour parameters among zones. The lightness index (L^*) ranged from 62.38 to 67.59, a^* value varied from 6.35 to 8.90 and b^* value ranged from 22.31 to 24.97 across three agro-climatic zones of Thrisssur.

Table 5. Colour parameter (L^*) of *Artocarpus hirsutus* Lam. wood in three agro-climatic zones of Thrissur, Kerala observed under CIE Lab system

	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	60.50 (1.56)	73.97 (1.52)	68.32 (1.39)	67.59 (6.76)	0.44^{ns} (Zones)
Central mid land	62.56 (2.01)	50.80 (1.03)	68.42 (1.22)	60.59 (8.97)	43.44^* (Girth classes within zone)
Malayoram	62.36 (1.53)	61.91 (2.00)	62.87 (2.52)	62.38 (0.48)	

- *Values within parentheses is standard deviation (SD);*- significant at 0.05 level; ns-non significant at 0.05 level*

Table 6. Colour parameter (a^*) of *Artocarpus hirsutus* Lam. wood in three agro-climatic zones of Thrissur, Kerala observed under CIE Lab system

	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	7.55 (0.34)	4.91 (0.35)	6.60 (0.37)	6.35 (1.33)	3.96^{ns} (Zones)
Central mid land	7.36 (0.27)	9.43 (0.15)	9.92 (0.11)	8.90 (1.35)	32.84^* (Girth classes within zone)
Malayoram	7.27 (0.19)	7.11 (0.55)	5.76 (0.59)	6.71 (0.83)	

- *Values within parentheses is standard deviation (SD);*- significant at 0.05 level; ns-non significant at 0.05 level*

Table 7. Colour parameter (b^*) of *Artocarpus hirsutus* Lam. wood in three agro-climatic zones of Thrissur, Kerala observed under CIE Lab system

	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	22.36 (0.88)	24.51 (0.78)	28.04 (1.09)	24.97 (2.86)	1.38^{ns} (Zones)
Central mid land	24.64 (0.61)	21.48 (0.38)	24.07 (0.33)	23.39 (1.68)	30.31^* (Girth classes within zone)
Malayoram	23.01 (0.19)	22.45 (0.18)	21.48 (0.38)	22.31 (0.77)	

- *Values within parentheses is standard deviation (SD);*- significant at 0.05 level; ns-non significant at 0.05 level*

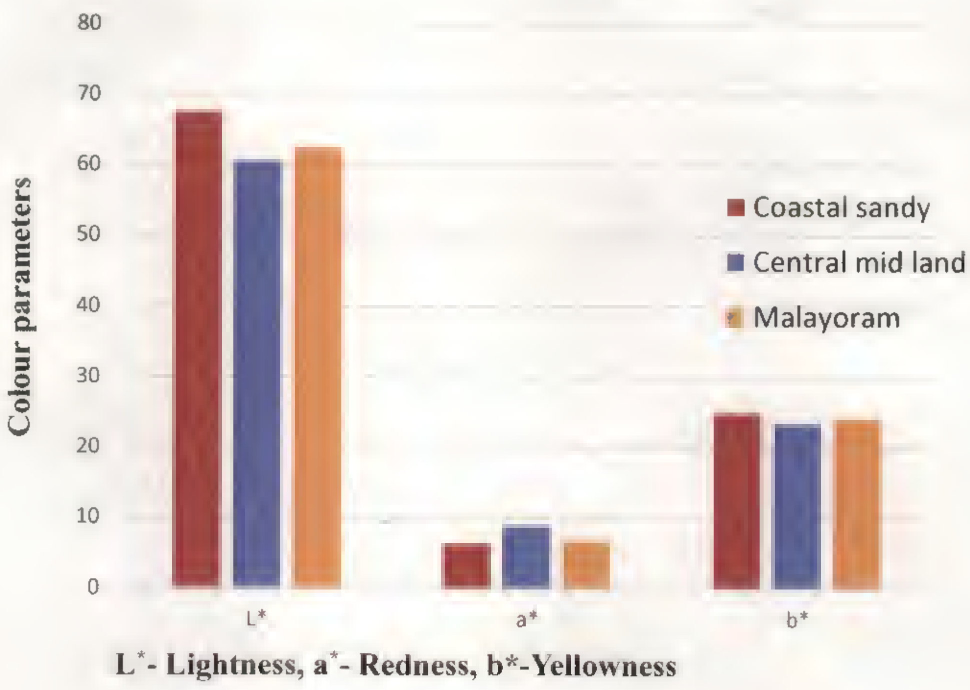

Figure 5. Colour parameters of *Artocarpus hirsutus* Lam. in three agro-climatic zones of Thrissur, Kerala observed by CIE Lab system

4.3 ANATOMICAL PROPERTIES

The results obtained from analysis of anatomical properties (vessel length, vessel frequency, vessel area, ray frequency, ray height, ray width, fibre length, fibre wall thickness and fibre lumen diameter) of *Artocarpus hirsutus* Lam. wood are discussed below.

4.3.1 Vessel Frequency

Vessel frequency ranged from 3 to 2 per mm^2 for all the three zones. There was no significant variation in vessel frequency between zones. The vessel frequency was 3 or 2 per mm^2 for all the girth classes also. There was no significant difference of vessel frequency between girth classes within zones.

Table 8. Vessel frequency (no./mm^2) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Vessel frequency (no./mm^2)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	2 (0.58)	3 (0.58)	2 (0.00)	2 (0.58)	1.75^{ns} (zones)
Central mid land	2 (0.00)	2 (0.00)	2 (0.00)	2 (0.00)	1.33^{ns}
Malayoram	2 (0.58)	2 (0.00)	2 (0.00)	2 (0.00)	(Girth classes within zones)

- *Values within parentheses is standard deviation (SD);ns-non significant at 0.05 level*

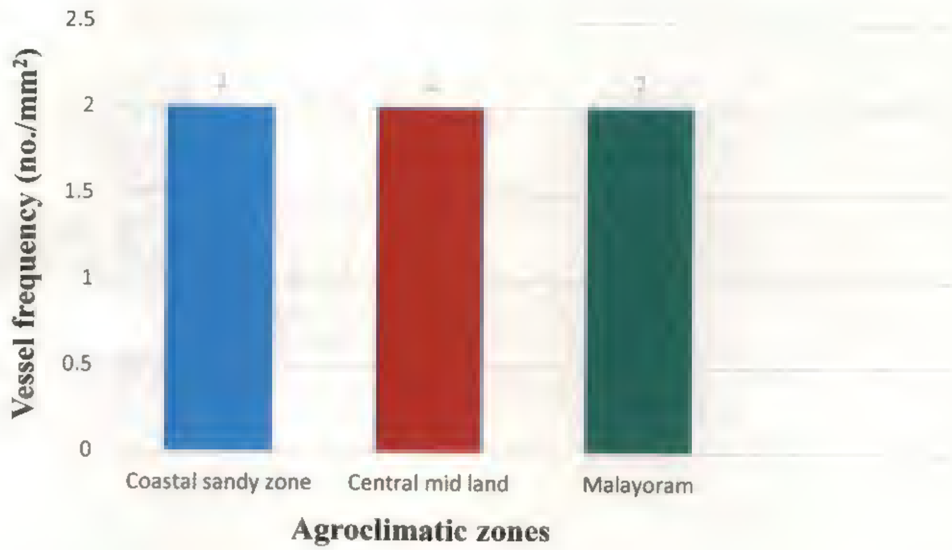

Figure 6. Vessel frequency of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

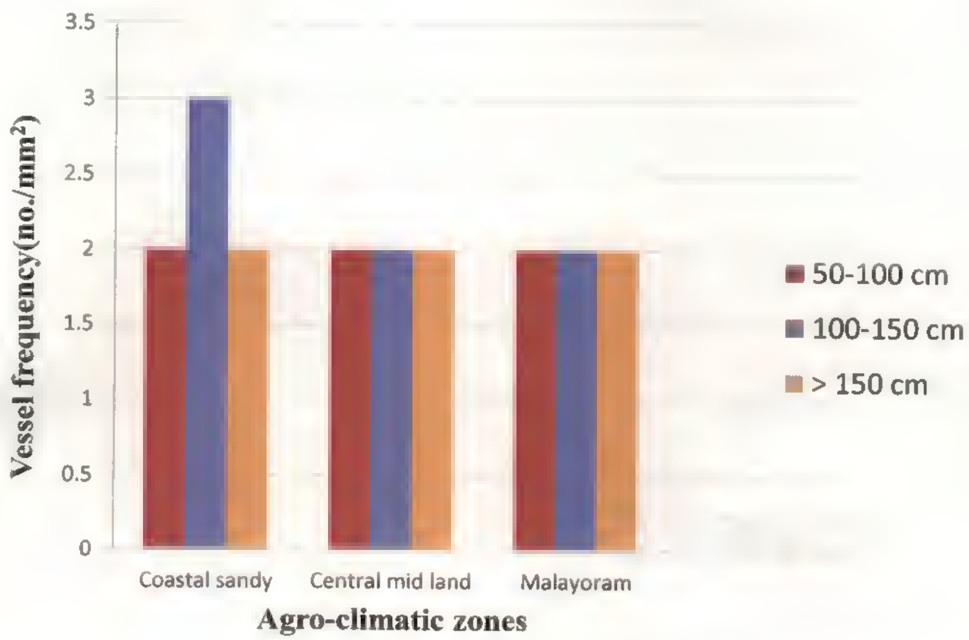

Figure 7. Vessel frequency of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

4.3.2 Vessel Diameter

Vessel diameter ranged from 194.93 µm to 236.49 µm for coastal sandy, 245.47 µm to 291.52 µm for Central mid land and 222.85 µm to 261.22 µm for Malayoram. There was no significant variation in vessel diameter between zones as well as between girth classes within zones.

Table 9. Vessel diameter (µm) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Vessel diameter (µm)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	236.49 (41.19)	223.08 (22.09)	194.93 (67.37)	218.26 (21.21)	4.65^{ns} (Zones)
Central mid land	245.47 (18.99)	283.18 (15.12)	291.52 (17.27)	273.39 (24.53)	1.63^{ns} (Girth classes within zones)
Malayoram	261.22 (4.33)	222.85 (23.25)	255.66 (9.02)	246.57 (20.73)	

- *Values within parentheses is standard deviation (SD); ns-non significant at 0.05 level*

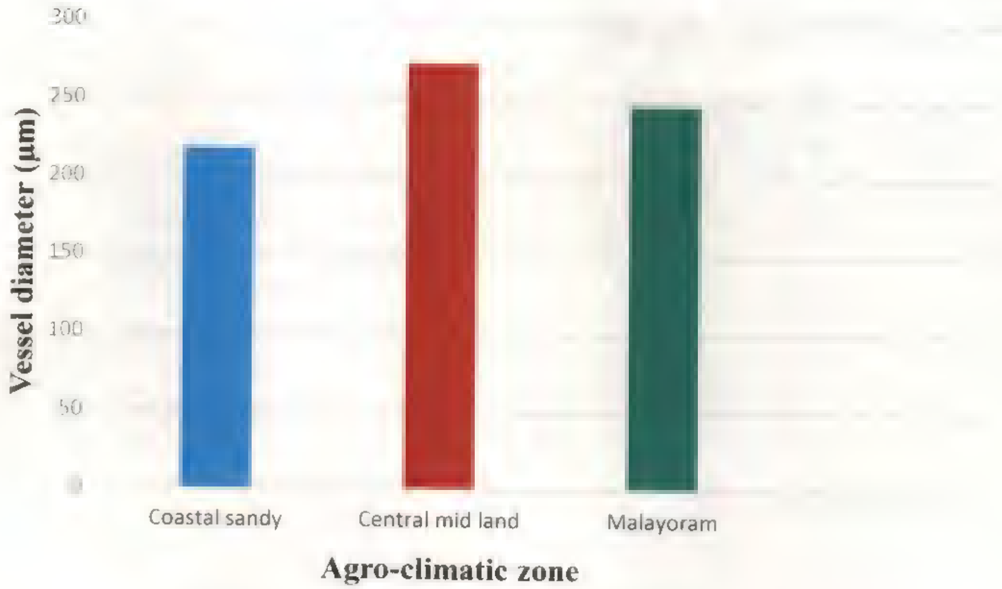

Figure 8. Vessel diameter of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

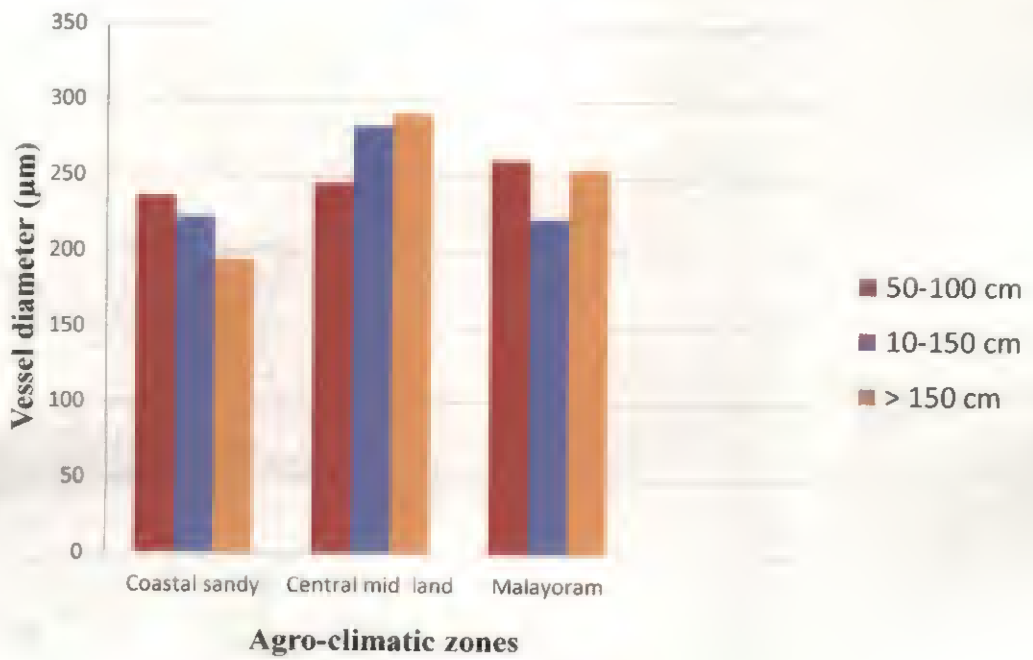

Figure 9. Vessel diameter of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

4.3.3 Vessel Area

Vessel area ranged from 49432.03 μm^2 to 78869.70 μm^2 for coastal sandy, 70159.32 μm^2 to 93481.86 μm^2 for Central mid land and 69449.11μm^2 to 127585.48 μm^2 for Malayoram. There was no significant variation in vessel area between zones. There was no significant difference in vessel area between girth classes within zones.

Table 10. Vessel area (μm^2) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Vessel area (μm^2)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	78869.7 (55949.60)	61746.08 (8289.14)	49432.03 (25416.11)	63349.27 (14784.17)	1.12^{ns} (zones) 1.11^{ns} (Girth classes within zones)
Central mid land	70159.32 (14588.22)	93481.86 (16933.03)	72912.51 (15952.51)	78851.23 (12705.45)	
Malayoram	127585.48 (83357.50)	69449.11 (12551.09)	73216.4613 (5007.35)	90083.68 (32532.08)	

- *Values within parentheses is standard deviation (SD);ns-non significant at 0.05 level*

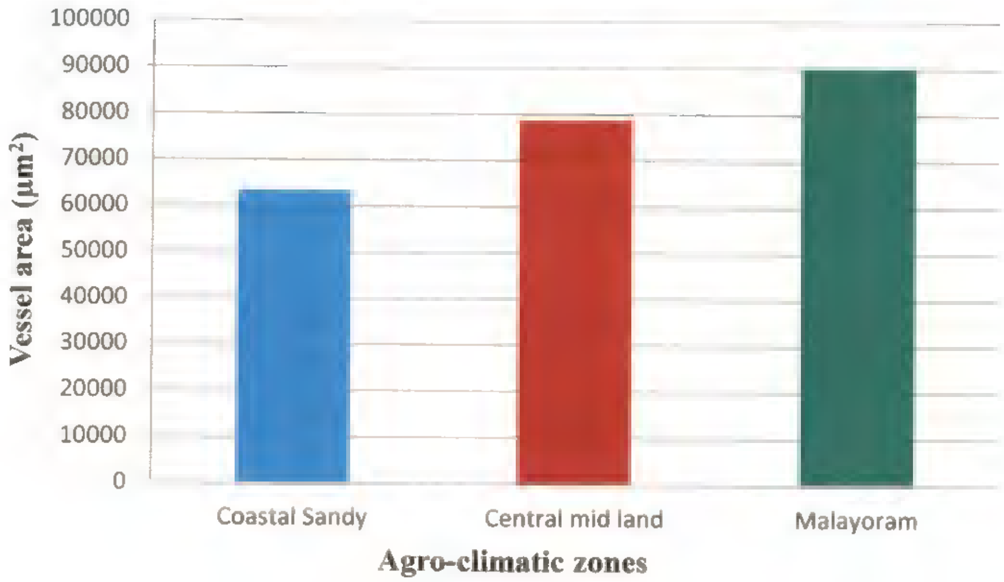

Figure 10. Vessel area of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

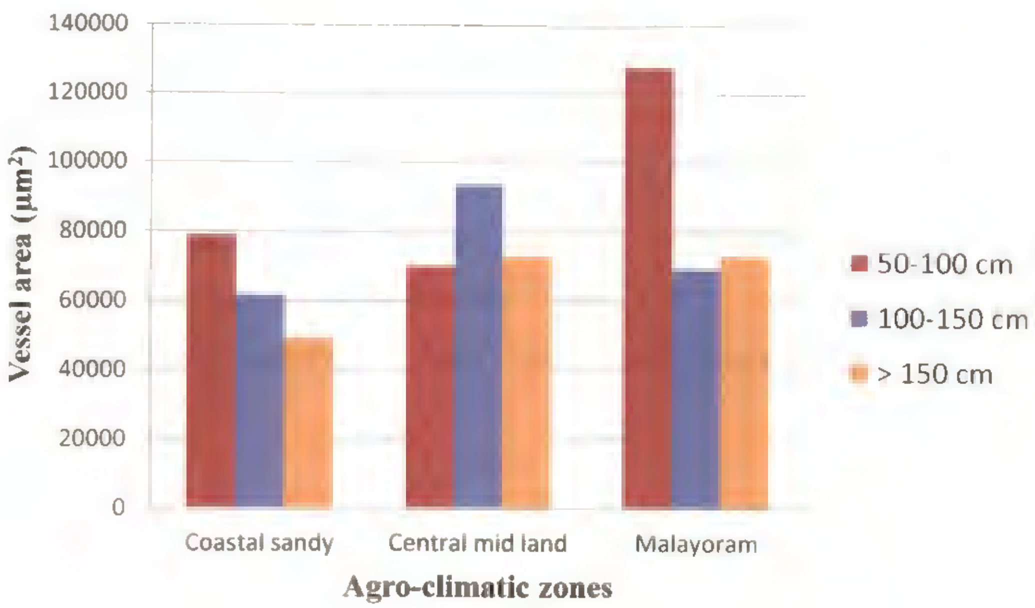

Figure 11. Vessel area of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

4.3.4 Vessel Length

Vessel length ranged from 248.47 µm to 289.43 µm for coastal sandy, 126.86µm to 171.31 µm for Central mid land and 192.71 µm to 330.27 µm for Malayoram. There was a significant difference in vessel length between zones. There was no significant difference in vessel length between girth classes within zones.

Table 11. Vessel length (µm) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Vessel length (µm)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	271.24 (46.64)	289.43 (74.70)	248.47 (35.22)	269.71^{B} (20.522)	6.47^{*} (zones) 1.11^{ns} (Girth classes within zones)
Central mid land	126.86 (2.36)	160.35 (25.50)	171.31 (19.74)	152.84^{A} (23.15)	
Malayoram	330.27 (86.65)	329.02 (62.84)	192.71 (58.14)	284^{B} (79.06)	

- *Values within parentheses is standard deviation (SD); *- Significant at 0.05 level; ns-non significant at 0.05 level*
- *Means with same letter as superscript indicates homogeneous group*

Vessel length in anjily wood showed significant variation among three zones at 5% level. Vessel length was found to be superior in Malayaram(284 µm) followed by Coastal sandy (269.71 µm) and Central mid land (152.84 µm).

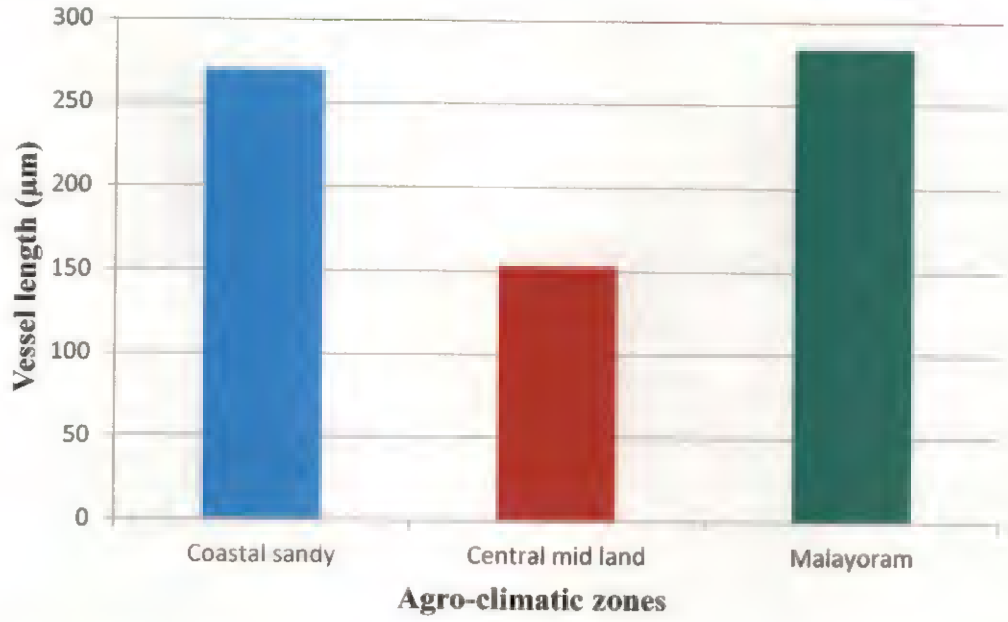

Figure 12. Vessel length of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

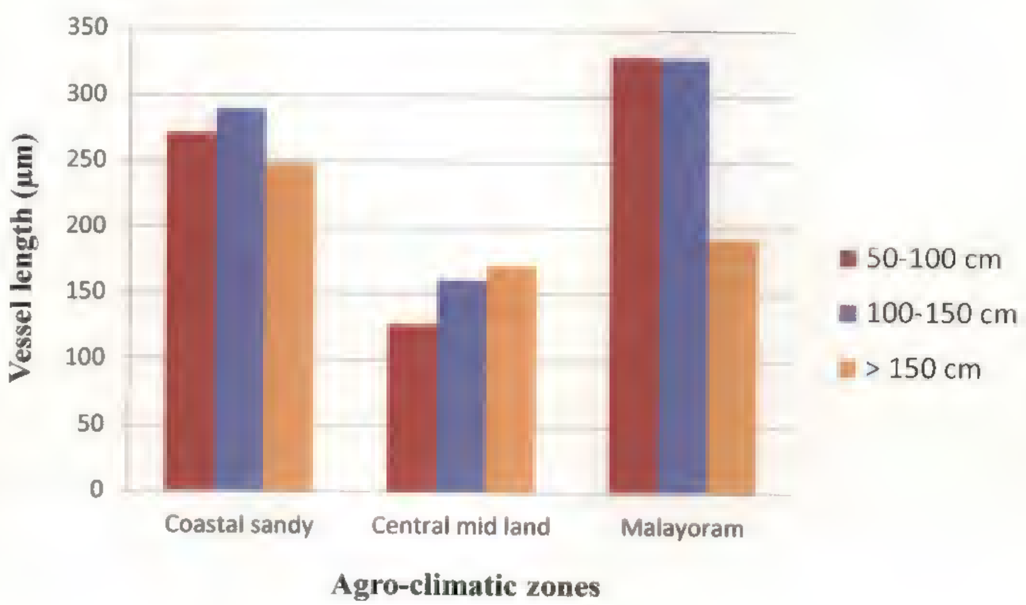

Figure 13. Vessel length of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

4.3.5 Ray Frequency

Ray frequency ranged from 4 to 5 per mm^2 for all the three zones viz. coastal sandy, Central mid land and Malayoram. There was no significant variation in ray frequency between zones. The ray frequency in different girth classes also ranged from 4 to 5 per mm^2 for all three zones. There was a significant difference of ray frequency between girth classes within zones.

Table 12. Ray frequency (no./mm^2) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Ray frequency (no./mm^2)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	4 (0.00)	4 (1.00)	5 (0.00)	4 (0.58)	0.21^{ns} (Zones)
Central mid land	5 (0.00)	4 (0.58)	3 (0.00)	4 (1.00)	8.86^{*} (Girth classes within zone)
Malayoram	5 (0.58)	4 (0.58)	4 (0.58)	4 (0.58)	

- *Values within parentheses is standard deviation (SD); *-Significant at 0.05 level; ns-non significant at 0.05 level*

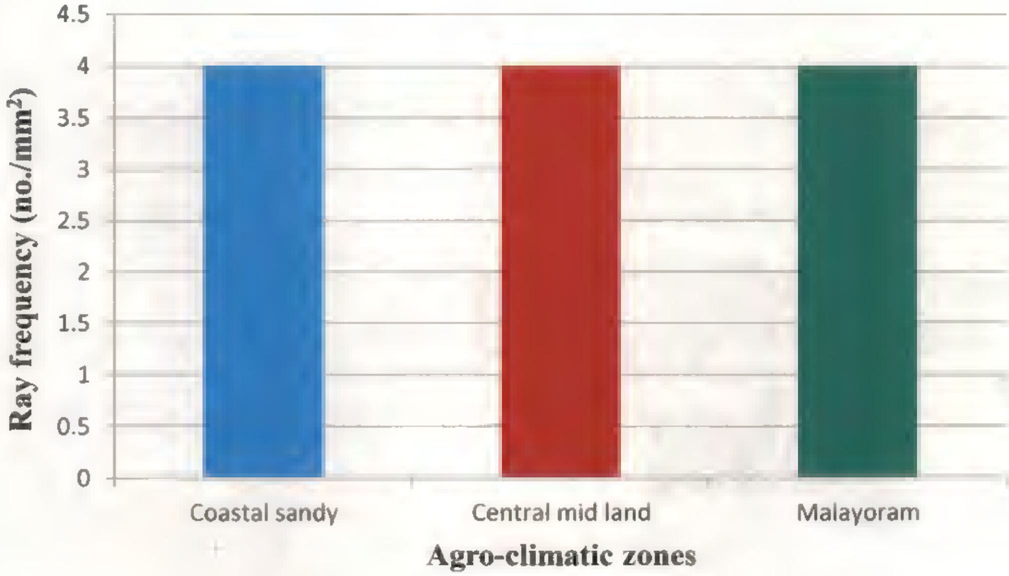

Figure 14. Ray frequency of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

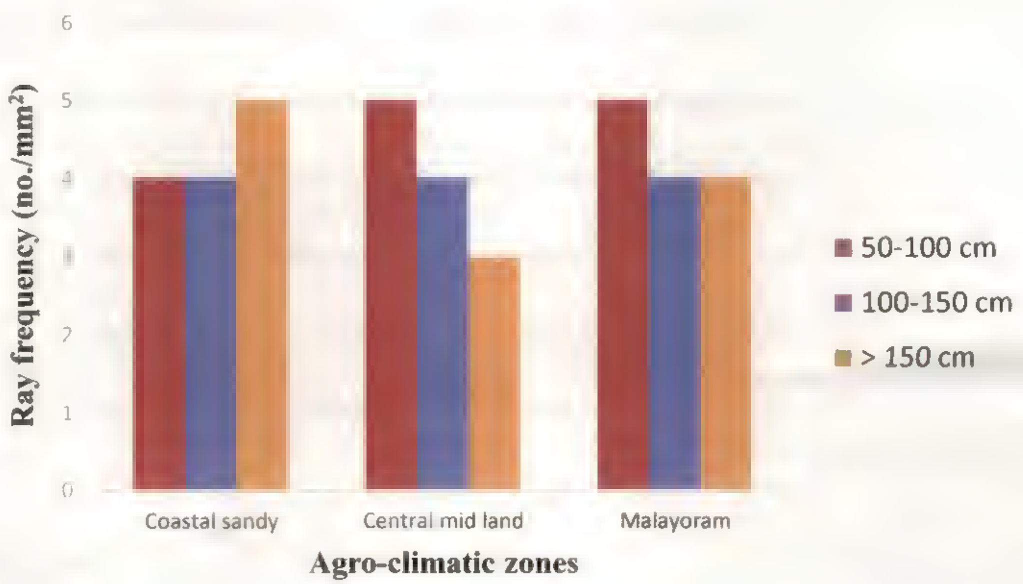

Figure 15. Ray frequency of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

4.3.6 Ray Height

Ray height ranged from 704.56 µm to 867.97 µm for coastal sandy, 775.13 µm to 1015.08 µm for Central mid land and 710.70 µm to 1038.31 µm for Malayoram. There was no significant variation in ray height among zones but there was significant variation between girth classes within zones.

Table 13. Ray height (µm) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Ray height (µm)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	867.97 (26.70)	775.13 (161.97)	710.70 (44.15)	804.62 (87.67)	0.36^{ns} (Zones)
Central mid land	841.34 (81.94)	1015.08 (8.727)	1038.31 (192.59)	873.44 (125.70)	4.87^{*} (Girth classes within zone)
Malayoram	704.56 (86.58)	830.13 (66.16)	917.46 (97.20)	888.82 (165.67)	

- *Values within parentheses is standard deviation (SD); *- Significant at 0.05 level; ns-non significant at 0.05 level*

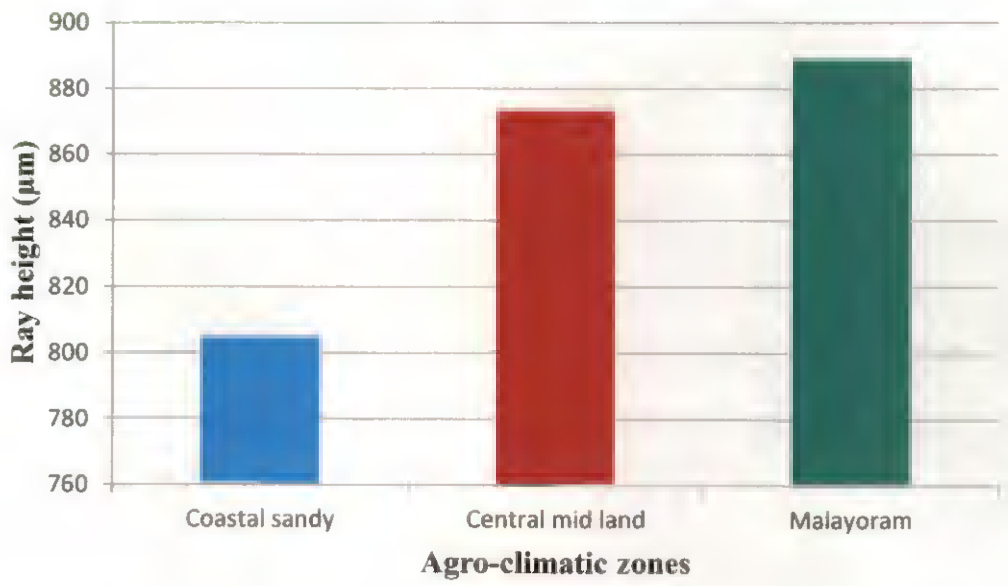

Figure 16. Ray height of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

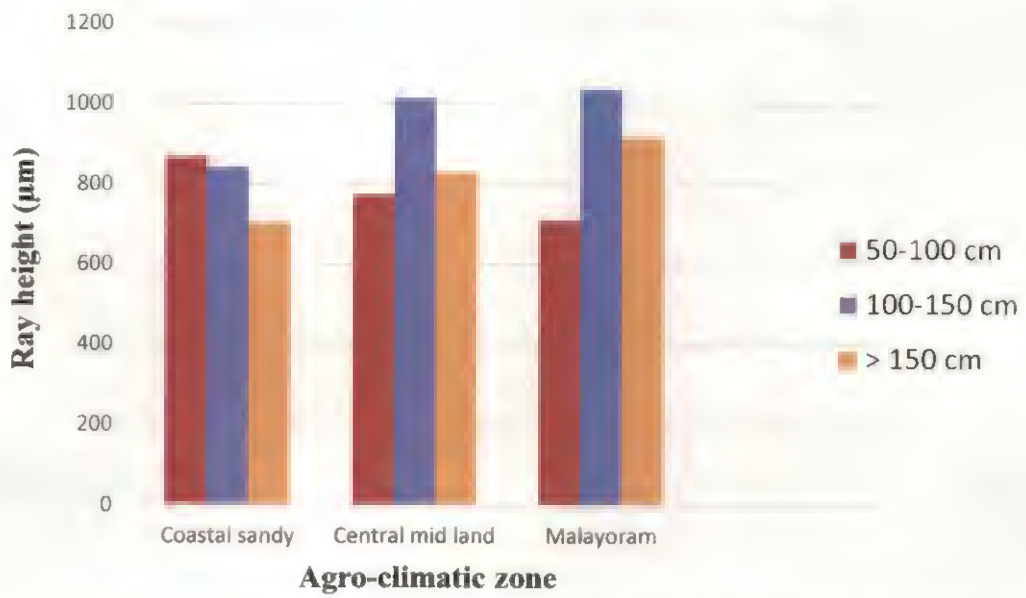

Figure 17. Ray height of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

4.3.6 Ray Width

Ray width ranged from 85.92 µm to 93.14 µm for coastal sandy, 93.44 µm to 139.67 µm for Central mid land and 115.08 µm to 156.31 µm for Malayoram. There was no significant variation in ray width among zones but there was a significant difference of ray width between girth classes within zones.

Table 14. Ray width (µm) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Ray width (µm)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	85.92 (7.21)	88.23 (14.12)	93.14 (39.34)	89.09 (3.68)	4.72^{ns} (Zones)
Central mid land	93.44 (22.11)	131.64 (9.18)	139.67 (13.44)	121.58 (24.70)	3.05^{*} (Girth classes within zone)
Malayoram	132.72 (5.72)	115.08 (12.17)	156.31 (19.24)	134.70 (20.68)	

- *Value within parentheses is standard deviation (SD);*
- **-Significant between girth at 5% level; ns-non significant at 0.05 level*

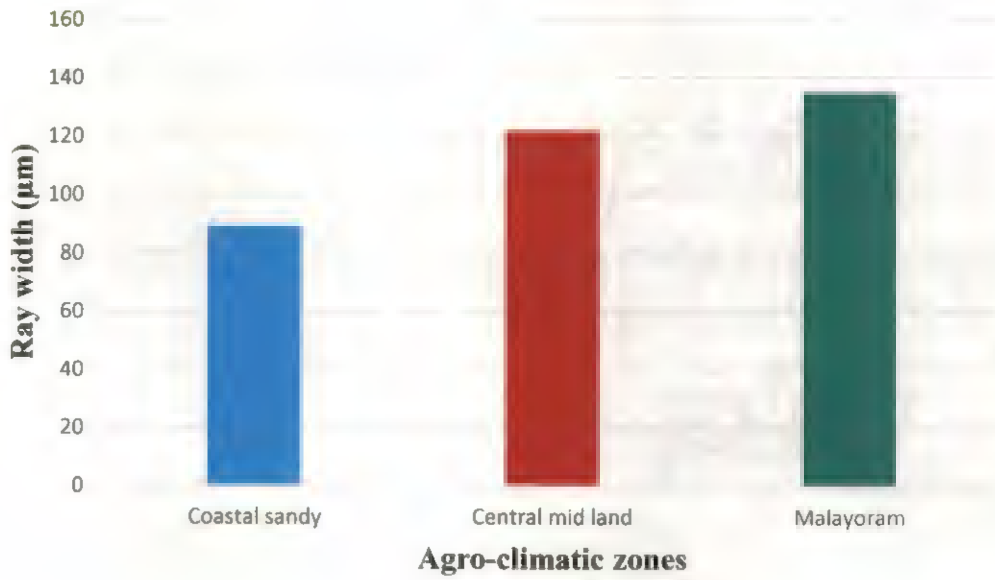

Figure 18. Ray width of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

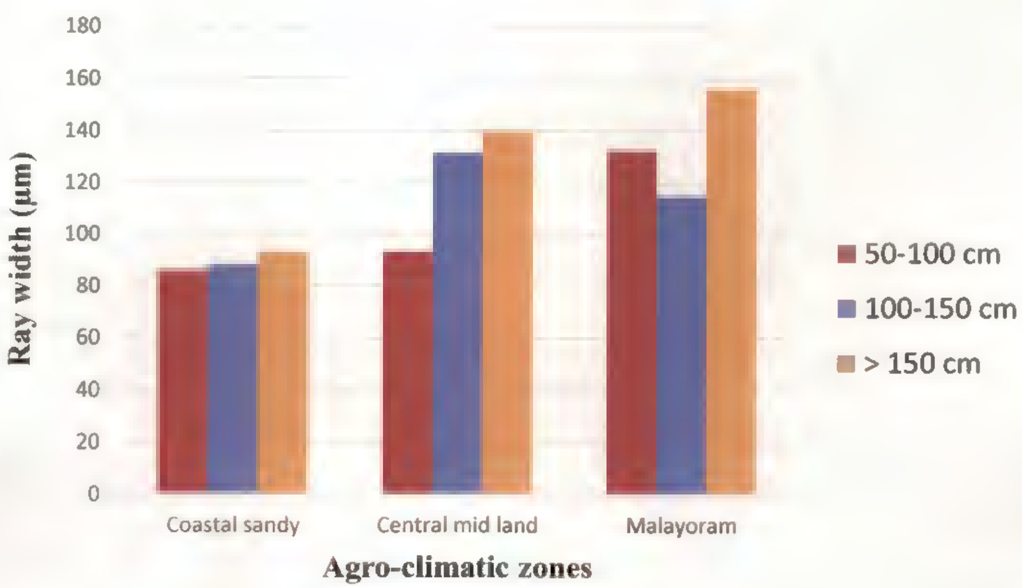

Figure 19. Ray width of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

4.3.6 Fibre Length

Fibre length ranged from 1032.95 μm to 1071.53 μm for coastal sandy, 1581.51 μm to 2046.80 μm for Central mid land and 1105.71 μm to 1919.48 μm for Malayoram. Analysis revealed that there was a significant variation in fibre length among zones but no significant difference between girth classes within zones. The fibre length was found to be highest in Central mid land followed by Malayoram and Coastal sandy.

Table 15. Fibre length (μm) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Fibre length (μm)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	1032.95 (92.34)	1071.53 (47.13)	1057.93 (61.52)	1054.13^{A} (19.56)	5.52^{*} (Zones)
Central mid land	1581.51 (553.54)	1816.53 (611.38)	2046.80 (147.74)	1814.94^{B} (232.64)	1.75^{ns} (Girth classes within zone)
Malayoram	1105.71 (137.49)	1834.75 (658.043)	1919.48 (372.64)	1619.98^{B} (447.38)	

- *Value within parentheses is standard deviation (SD); *-Significant between zone at 5% level; ns-non significant at 5% level*
- *Means with same letter as superscript indicates homogeneous groups*

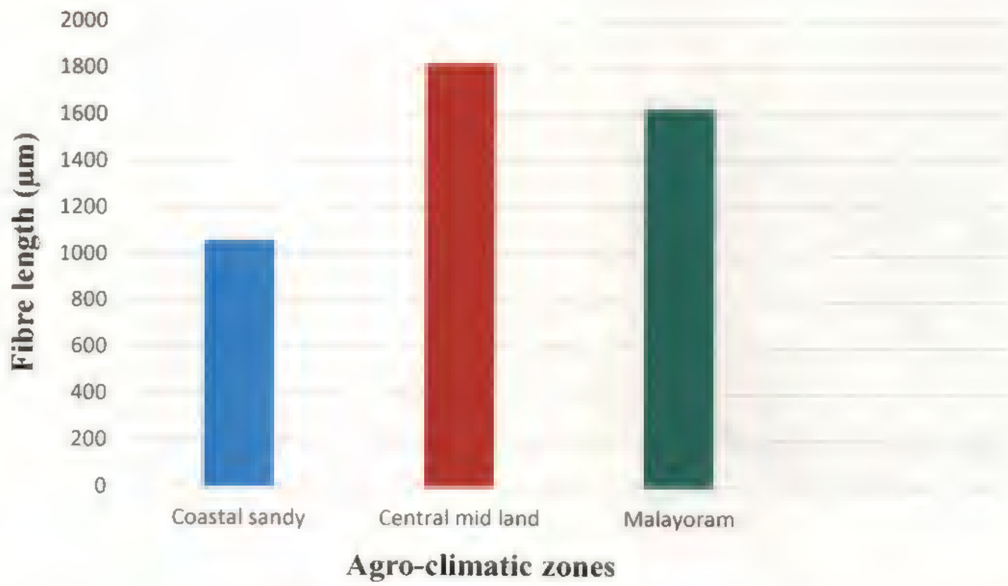

Figure 20. Fibre length of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

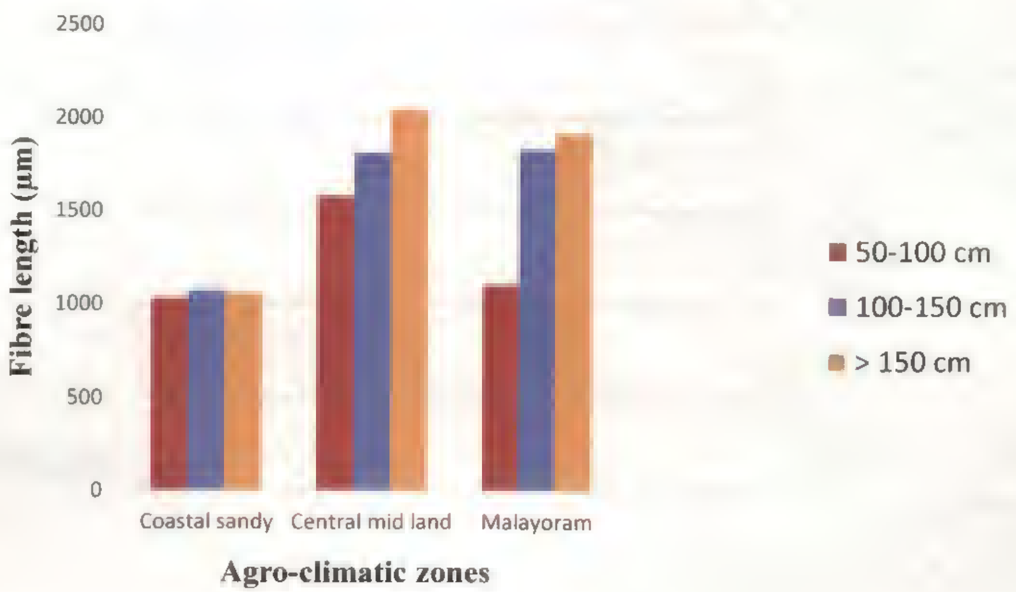

Figure 21. Fibre length of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

4.3.6. Fibre Wall Thickness

Fibre wall thickness ranged from 5.72 µm to 4.8 µm for coastal sandy, 6.21 µm to 5.84 µm for Central mid land and 5.86 µm to 5.0 µm for Malayoram. Analysis revealed that there was no significant variation in fibre wall thickness among zones as well as between girth classes within zones.

Table 16. Fibre wall thickness (µm) of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones and girth classes

	Fibre wall thickness (µm)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	5.72 (0.97)	4.8 (0.25)	4.85 (0.56)	5.12 (0.52)	3.21^{ns} (Zones)
Central mid land	5.84 (0.88)	6.21 (1.02)	5.82 (0.27)	5.95 (0.22)	1.03^{ns} (Girth classes within zone)
Malayoram	5.00 (0.35)	5.86 (0.97)	5.39 (0.33)	5.41 (0.43)	

- *Values within parentheses is standard deviation (SD); ns-non significant at 0.05 level*

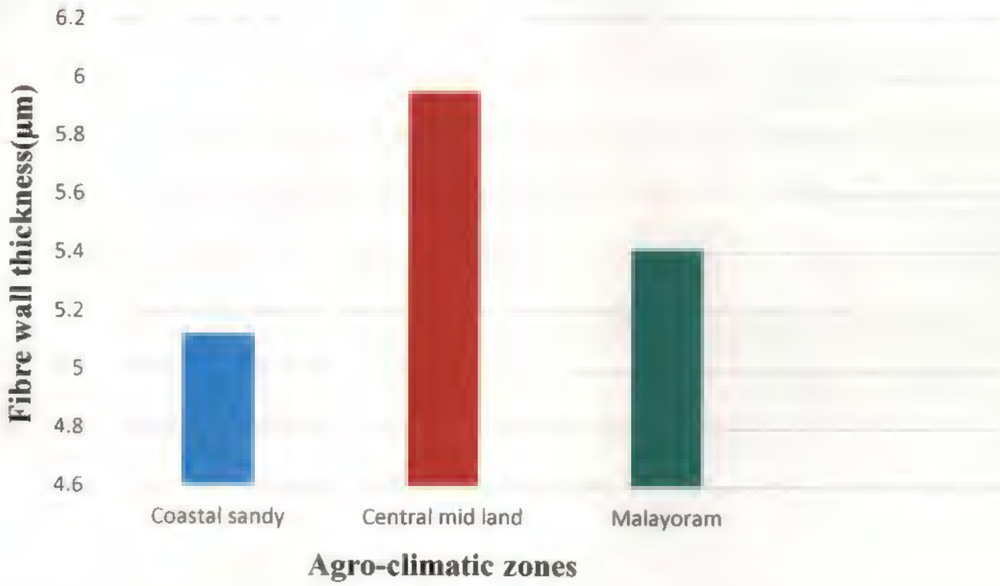

Figure 22. Fibre wall thickness of *Artocarpus hirsutus* Lam. wood from different agro-climatic zones

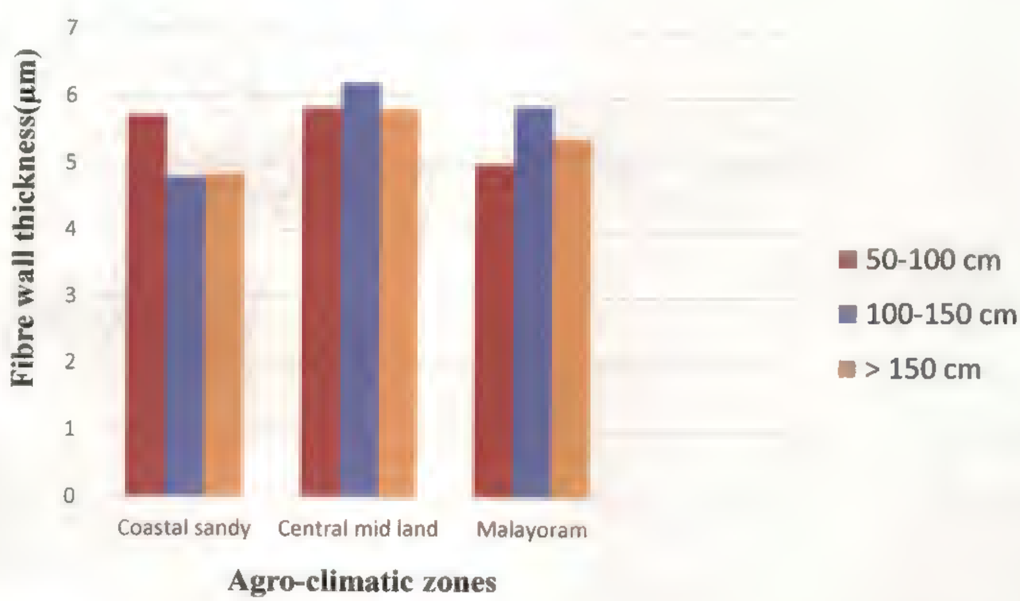

Figure 23. Fibre wall thickness of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

4.3.6 Fibre Lumen Diameter

Fibre lumen diameter ranged from 11.77 µm to 16.37 µm for coastal sandy, 9.82 µm to 15.39 µm for Central mid land and 12.37 µm to 18.07 µm for Malayoram. Analysis revealed that there was no significant variation in fibre lumen diameter among zones but there was a significant difference between girth classes within zones.

Table 17. Fibre lumen diameter (µm) of *Artocarpus hirsutus* Lam. wood from different agro climatic zones and girth classes

	Fibre lumen diameter (µm)				
	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	11.77 (1.53)	13.39 (0.17)	16.37 (2.21)	13.84 (2.33)	0.95^{ns} (Zones)
Central mid land	9.82 (1.08)	15.39 (2.03)	13.81 (1.28)	12.86 (2.82)	5.20^{*} (Girth classes within zone)
Malayoram	18.07 (3.95)	17.82 (1.57)	12.37 (3.04)	16.08 (3.22)	

- *Value within parentheses is standard deviation (SD)*
- **- Significant between girth at 5% level; ns-non significant at 5% level*

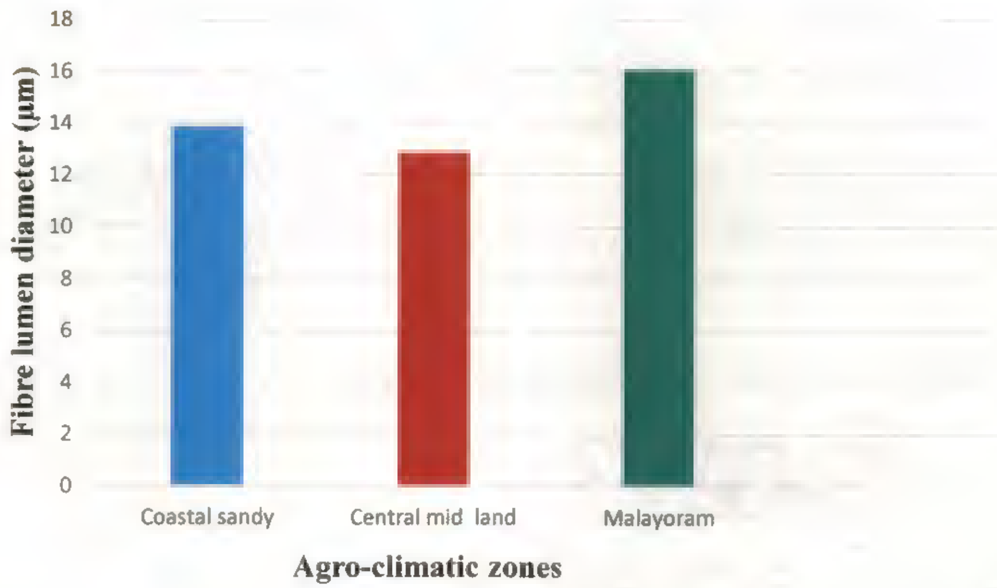

Figure 24. Fibre lumen diameter of *Artocarpus hirsutus* Lam. wood from different agro climatic zones

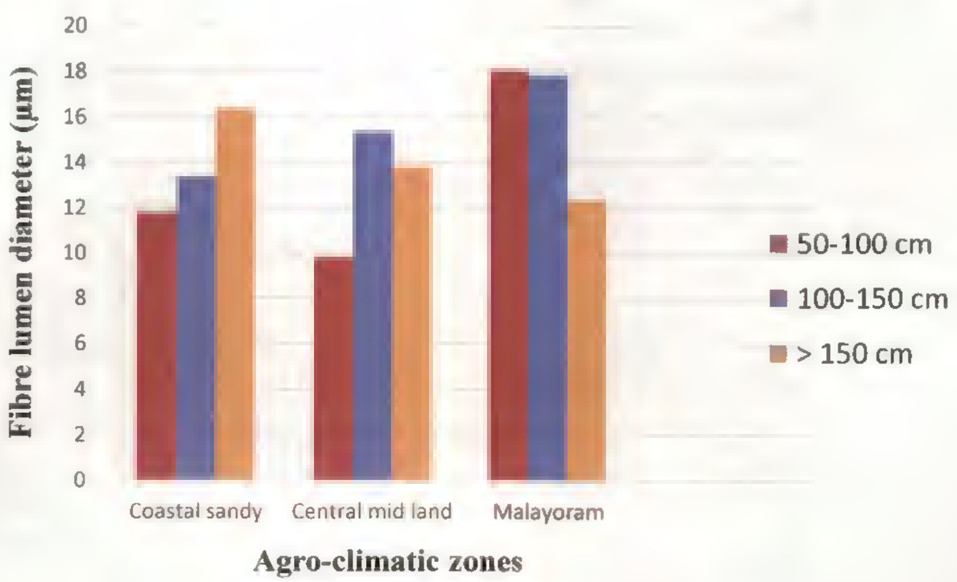

Figure 25. Fibre lumen diameter of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

4.4 ECOANATOMICAL PROPERTIES (VULNERABILITY INDEX AND MESOMORPHY)

Vulnerability index was found to be highest in central mid land zone (136.82) and lowest in coastal sandy zone (96.24). Analysis revealed that there was significant variation in vulnerability index among zones but there was no significant difference between girth classes within zones.

Table 18. Vulnerability index of *Artocarpus hirsutus* Lam. wood from different agro climatic zones and girth classes

	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	105.85 (33.69)	85.41 (12.45)	97.46 (33.68)	96.24^{A} (10.27)	11.26^{*} (zones) 0.88^{ns} (girth classes within zones)
Central mid land	122.73 (9.49)	141.99 (7.56)	145.76 (8.63)	136.82^{B} (12.35)	
Malayoram	97.46 (33.68)	145.76 (8.63)	127.83 (4.51)	118.39^{AB} (8.47)	

- *Values within parentheses is standard deviation (SD); *- Significant between zone at 5% level; ns-non significant at 0.05 level*
- *Means with same letter as superscript indicates homogeneous group*

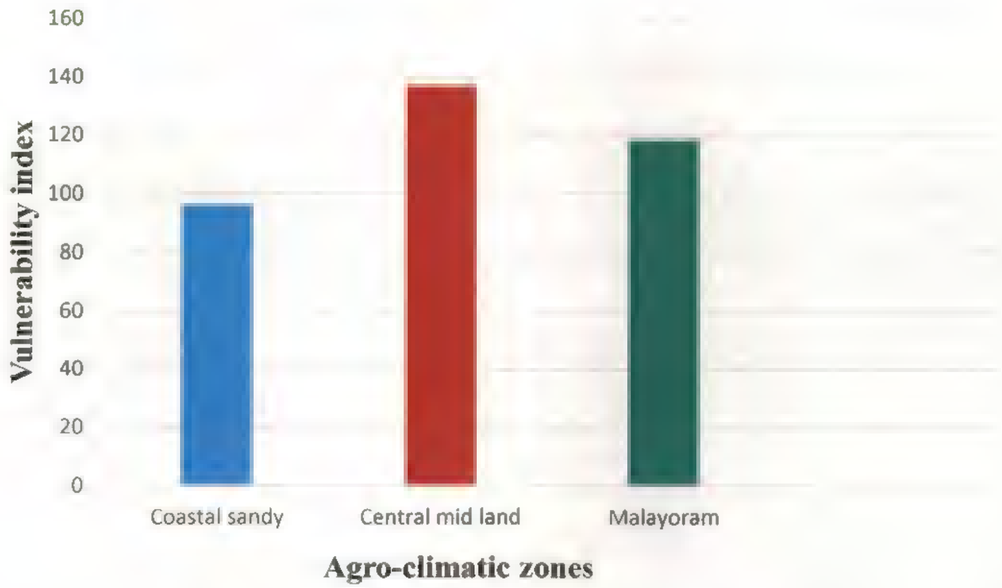

Figure 26. Vulnerability index of *Artocarpus hirsutus* Lam. wood from different agro climatic zones

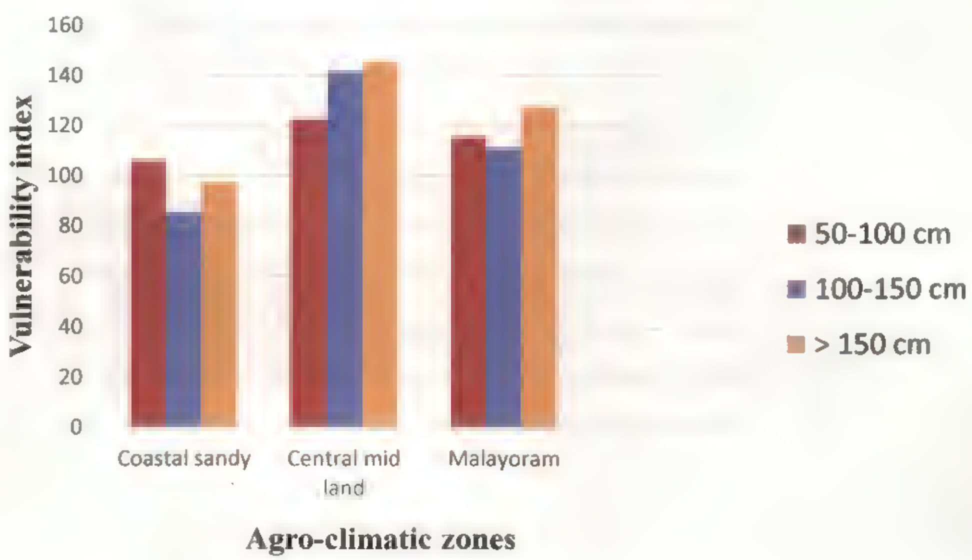

Figure 27. Vulnerability index of *Artocarpus hirsutus* Lam. wood in different girth classes across three agro-climatic zones

Table 19. Vessel mesomorphy of *Artocarpus hirsutus* Lam.wood from different agro climatic zones and girth classes

	Girth classes				
Agro-climatic zones	50-100 cm	100-150 cm	>150 cm	Zone Mean	F-value
Coastal sandy	29317.70 (13557.07)	24226.26 (3716.67)	24937.41 (10903.85)	26160.45 (2757.27)	3.76^{ns} (zones)
Central mid land	15556.60 (912.06)	22833.02 (4423.26)	24862.36 (1427.36)	21083.99 (4893.22)	1.33^{ns}
Malayoram	37485.71 (9669.53)	36844.75 (9474.96)	24536.51 (7088.06)	32955.65 (7298.43)	(girth classes within zones)

Values within parentheses is standard deviation (SD); ns-non significant at 0.05 level

The vessel mesomorphy was found to be ranged from 21083.99 to 32955.65 among three zones. Analysis revealed that there was no significant variation in mesomorphy among zones as well as between girth classes within zones.

4.5. INTER-RELATIONSHIP BETWEEN WOOD PROPERTIES

Table 14 shows correlation coefficient values between different wood properties of *Artocarpus hirsutus* Lam. wood from three different agro-climatic zones of Thrissur district, Kerala. Basic density was positively correlated with moisture content, ray height, fibre length, fibre wall thickness and negatively correlated with vessel length. Moisture content was positively correlated ray height, fibre length and fibre wall thickness.

Table 20. Correlation coefficient between different wood properties

	VF	VD	VA	VL	RF	RH	RW	FL	FWT	LD	MC	BD
VF	1											
VD	-0.073	1										
VA	-0.108	0.415*	1									
VL	0.438*	-0.212	0.280	1								
RF	0.050	-0.244	0.007	0.110	1							
RH	-0.098	0.266	0.066	0.074	0.555**	1						
RW	-0.273	0.316	0.091	-0.152	-0.240	0.227	1					
FL	-0.304	0.448*	0.079	-0.370	-0.476*	0.553**	0.523**	1				
FWT	-0.052	-0.272	-0.132	-0.271	-0.258	0.575**	0.268	0.631*	1			
LD	-0.210	-0.087	0.167	0.330	0.108	0.072	0.242	0.086	-0.005	1		
MC	-0.084	0.152	0.131	-0.087	-0.192	0.435**	0.155	0.502**	0.588**	0.050	1	
BD	-0.218	0.139	0.348	-0.439*	-0.302	0.476*	0.240	0.772**	0.686**	-0.032	0.729*	1

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

VF- Vessel frequency, VD- Vessel diameter, VA- Vessel area, RF- Ray frequency, RH- Ray height, RW- Ray Width, FL- Fibre length, FWT- Fibre wall thickness, LD- Lumen diameter

4.6 REGRESSION ANALYSIS

4.6.1 Dependence of Basic density on Anatomical Properties

Linear models were developed to show the dependence of basic density on wood anatomical properties. Table 15 illustrates the regression equation developed to show the dependence of basic density on various anatomical properties in *Artocarpus hirsutus* Lam. wood. Analysis revealed that there was very weak relationship between basic density with anatomical properties.

Table 21. Results of regression analysis of basic density (Y) with anatomical properties(X)

Species	Independent Variable(X)	Name of fitted equation	Fitted equation	R^2 square
Artocarpus hirsutus Lam.	Vessel length	Linear	Y= 637.38-0.450X	0.193
	Ray height	Linear	Y=283.07+0.290X	0.227
	Fibre length	Linear	Y=337.29+0.130X	0.595
	Fibre wall thickness	Linear	Y= 100.54+78.28X	0.470

4.7 WOOD PROPERTIES VARIATION BETWEEN HOMESTEADS AND PLANTATION

For comparing the wood properties between homesteads and plantations wood samples were collected from homesteads of Thrissur and three plantations in Thallasery taluk of Kannur district. From each plantation, three girth classes were selected and from each girth class samples were collected from three trees. The same was also done for homesteads in Thrissur. Analysis revealed that there was significant difference of vessel frequency, vessel diameter, vessel length, ray width, fibre length, fibre lumen diameter, moisture content and basic density between homesteads and plantation. Highest mean value for vessel diameter (286.97 μm), vessel area (95815.81 μm), vessel length (316.51 μm), fibre lumen diameter (17.76 µm) and moisture content (74.16%) were found in plantation. Basic density was found highest for homesteads i.e. 533.70 kg/ $m^{3.}$ a*- value of the colour parameters also showed significant difference between homesteads and plantations i.e yellowness of heartwood colour.

Table 22. Results of t-test for physical and anatomical properties of homesteads and plantation grown *Artocarpus hirsutus* Lam. wood

		Mean	Std. Deviation	t-value
Vessel frequency (no./mm^2)	1	2.15	0.362	1.62^{ns}
	2	2.41	0.747	
Vessel diameter (µm)	1	246.14	38.88	3.19^{**}
	2	286.97	53.82	
Vessel area (µm^2)	1	77383.67	36873.62	1.76^{ns}
	2	95815.81	40056.98	
Vessel length (µm)	1	235.52	84.65	3.84^{**}
	2	316.51	69.61	
Ray frequency (no./mm^2)	1	4.15	0.864	1.11^{ns}
	2	3.89	0.801	
Ray height (µm)	1	855.64	142.76	0.70^{ns}
	2	797.51	106.075	
Ray width (µm)	1	115.13	29.38	5.03^{**}
	2	84.07	12.96	

Fibre length (µm)	1	1496.35	517.11	2.98^{**}
	2	1191.71	118.29	
Fibre wall thickness (µm)	1	5.50	0.761	1.40^{ns}
	2	5.202	0.825	
Fibre lumen diameter (µm)	1	14.31	3.24	3.25^{**}
	2	17.76	4.45	
Moisture content (%)	1	60.57	14.30	3.74^{**}
	2	74.16	12.32	
Basic density (kg/m^3)	1	533.70	90.39	2.84^{**}
	2	468.56	75.14	
L^* Value	1	63.53	6.34	0.33^{ns}
	2	63.07	3.78	
a^* Value	1	7.32	1.55	1.73^{ns}
	2	6.58	1.60	
b^* Value	1	23.56	2.04	2.64^{*}
	2	21.81	2.76	

*- significant at 5% level

**- significant at 1% level

ns-non significant at 5% level

Discussion

DISCUSSION

Wood physical, anatomical and mechanical properties of a timber species decide the quality of end product of that wood. Therefore, wood quality evaluation is essential for determining the quality of wood products. Even though Anjili (*Artocarpus hirsutus* Lam.) is popular timber species, but information on its wood property is scarce. Considering the increasing demand of timber species for various end uses and also for developing a database of various wood properties for this species, a study was conducted to evaluate and compare wood properties between three agro-climatic zones of Thrissur district in Kerala.

Data generated on the various physical and anatomical properties of Anjili grown in three different agro-climatic zones (Coastal sandy, Central mid-land, Malayoram) across three different girth classes (50-100 cm, 100-150 cm, > 150 cm) of Thrissur, Kerala are discussed here under.

5.1 ANJILY OR AINY WOOD

Artocarpus hirsutus is a diffuse porous wood with various diagnostic features and is commonly known as anjily or aini wood. This wood was found containing vessels with alternate polygonal pits. Alternate polygonal pitting in vessel is a good diagnostic feature. Paratracheal arrangement (aliform confluent) of parenchyma was found in anjily wood. In the past it was suggested that abundant paratracheal parenchyma could help to refill air-filled vessels in the recovery from embolism (Salleo *et al.*, 2009). Beeckman (2016) addressed that a high amount of paratracheal axial parenchyma is found in various tropical wood. He also suggested that this tissue plays an important role in water balance. Anjily wood is enriched with vessel occlusion like tyloses. Vessel occlusions like tyloses or gums prevent the spread of embolism. Both biotic and abiotic stresses have significant effect on vessel occlusion (Stevenson *et al.*, 2004; Sun *et al.*, 2011; Davidson, 2014).

Ray cells were found multiseriated with one to two rows of procumbent body cell and upright cell. The same pattern was found in *Populus deltoides* by

Pandey (2012). Homogeneous procumbent cells were common in *Sonneratia* spp. which are more efficient at radial translocation of ions and storage of photosynthates (Anju *et al.*, 2017). Thin to thick walled fibres were found in this species which were mostly non-septate. Singh *et al.* (2017) also showed that septate fibres were absent in *Artocarpus heterophyllus* Lam., a related species. Ogata *et al.* (2008) has also shown that non-septate fibres are also found in *Tectona grandis* which is an important diagnostic feature.

5.2. PHYSICAL PROPERTIES

The present work focused on some important physical properties viz. basic density, moisture content and heartwood colour of anjily wood and variation of these characteristics across three agro-climatic zones of Thrissur, Kerala.

5.2.1 Basic Density

Basic density is one of the important characteristics for wood quality evaluation. It has a tremendous effect on different wood physiological, ecological as well as morphological characteristics of the wood (Jerome *et al.*, 2006). Density can be taken as a crucial property and has a great effect on both solid and fibrous wood products (Bhat, 1985).

Analysis of data revealed that there was no significant difference present across three agro-climatic zones as well as between diameter classes within zones of Thrissur district of Kerala. Our finding is in line with the findings by George (2017) who showed that there was no significant variation of basic density of coconut palm across agro-climatic zones of Thrissur. Wanneng *et al.* (2014) also observed similar results in 10, 15, 20 and, 25 years old teak of different diameter classes. However, Bhat (1998) showed that mean specific gravity varied significantly between juvenile wood and mature wood of 65-years old teak trees grown in three locations in Kerala which is contrary to our findings. The different result obtained in the present study attributed to indistinct climatic variation and age effect of the sampled trees across three agro-climatic zones of Thrissur district, Kerala. As density is one of the most heritable characters in wood, genotypic effect may be one of the reasons for this.

5.2.2 Moisture Content

Moisture content is also an important feature of the wood which influences the durability and workability of the wood. Sindhumati (2012) also showed that moisture content was associated with large vessel area and vessel lumen diameter. In this study, moisture content analysis showed that there was no significant difference across agro-climatic zones as well as across the girth classes. Mean moisture content of the *Eucalyptus regnans* wood also didn't show any significant variation between northern and southern island of New Zealand (Frederic, 1982). This might be due to water availability of the area.

5.2.3 Heartwood Colour

Colour is a crucial factor in hardwood appearance. It is often considered important in assessing aesthetic value of the wood product. Hon and Minemura (2001) have shown that the interaction of chemical components with light is responsible for colour characteristics of wood. They have also obtained that lignin is the chromophore binding molecules in wood along with phenolic extractives such as tannin, flavonoids, quinines etc. In the present study, heartwood colour showed no significant variation across the agro-climatic zones of Thrissur. This can be comparable to the findings by Thulasidas *et al.* (2006) who observed that no significant difference existed between teak samples collected from dry and moist area. But our finding is contrary to information given by Knust (2009) that there was significant difference of L^*, a^* and b^* value across the agro-ecological regions of Ghana. This difference can be attributed to geographical locations and soil properties of the two research sites. In-significant variation in wood properties is attributed to genetic factors as wood colour within species varies due to genetic factors (Rink and Phelps, 1989; Mosedale *et al.*, 1996). Tadashi *et al.* (2000) showed that teak wood colour is darker in wetter region than drier area. Knust (2009) also explained that soil properties are associated with wood colour of teak independent from effects of tree age as observed by Nelson *et al.* (1969) for walnut wood. The fact behind this was explained by Knust (2009) that availability of more soil minerals to wood that eventually interact with its (wood) chromophores in such a way as to absorb more light, thus reflecting less light and hence the wood appearing darker.

5.3 ANATOMICAL PROPERTIES

5.3.1 Vessel Morphology

Vessel frequency in *Artocarpus hirsutus* was found to be 2-3/mm^2 across all the zones. Most of the vessels were found to be solitary. This may be due to the higher frequency of vessels; smaller the diameter, and greater the chance for grouping of vessels (Vijayan, 2017). The same frequency has been found in teak by Cardoso *et al.* (2015) from East Timor. Analysis revealed that no significant differences existed between zones or girth classes as all the three zones were experiencing more or less similar rainfall pattern and also since vessel frequency is mostly related to water conductivity. Vessel diameter was also did not vary significantly varied between zones or girth classes. Vessel diameter of anjily wood ranged from 218.26 μm to 273.29 μm (Table 9). Singh *et al.* (2017) also found the same range for *Artocarpus nitidus* i.e. 277.92 μm. Vessel diameter is negatively correlated with vessel frequency. As vessel frequency was very less for *Artocarpus hirsutus*, hence vessel diameter was large. Vessel diameter is also related to water conductivity and water availability of the site. But from the safety point of view Zimmerman (1983) showed that short vessel elements were more resistant to collapse and deformation. In *Artocarpus hirsutus* Lam., smaller vessel length was observed (Table 11) which was also found in teak under particulate pollution stress (Anoob *et al.*, 2017). Here the vessel length was short as per the classification given by Metcalfe and chalk (1950) i.e. when the mean length of vessel member is less than 350μm, it is described as short and when the mean length is over 800 μm, it is described as long. Hence, we can infer that anjily is having good resistance to deformation. As all the three zones get similar pattern of rainfall there won't be much variation in water availability. Thus, vessel diameter variation was non significant for all the three zones. Vessel area was also found to be non significant between zones. It is obvious that if vessel diameter is more, then vessel area will be more. Vessel area ranged from 63349.27 μm^2 to 90083.68 μm^2 among the zones. Zhang *et al.* (1988) have observed that vessel diameter and vessel element length decreased with increasing aridity and that vessel numbers increase. This finding was supported by Tyree and Alexander (1993) who showed that safety of transpiration system increases with decrease in vessel diameter and increase in vessel frequency. Vessel length (284 μm) was found to be highest in Malayoram. Singh *et al.* (2017) also found to be vessel length 284.4 μm in *Artocarpus nitidus* collected from Assam and Mizoram. The vessel length of teak was also found to be 279 μm (Ahmed and Chun, 2011).

A significant difference was found in vessel length across the agro-climatic zones of Thrissur. Carlquist (2001) noted that along with moisture availability and freezing effect on xylem anatomy, geographical location of a wood sample also affects structure, or phenology, e.g., slope exposure, rainfall, deciduous nature of plant, leaf size, or seasonal stem dieback. Therefore, it can be inferred that the above difference can be attributed to slope and exposure as all the three zones have different topographical features. Nevertheless, environmental factors clearly do affect some aspects of xylem structure, as shown for soil fertility and wood density (Muller-Landau, 2004), soil water and vessel diameter (Stevenson and Mauseth, 2004), climate and growth rings (Wang *et al.*, 2005), and temperature and vessel diameter (Thomas *et al.*, 2007).

5.3.2 Ray Morphology

Ray frequency was found to be 4 to 5 per mm^2 across the three zones of Thrissur which can be comparable to findings given by Meena and Gupta (2014) in *Albizia procera* in range of 4-10 per mm^2 in different geographical zones of the Indian Subcontinent. Singh *et al.* (2017) also observed the same frequency for *Artocarpus chaplasa* (4) and in *Artocarpus heterophyllus* (6) in north east India. Ray frequency was found to be non significant among agro-climatic zones that can be comparable to the observations of Rehman *et al.* (2003) on teak. They found that there was little effect of ring width on ray frequency. Ray height variation was also non significant among agro-ecological zones but had variation among girth classes. This may be due to variation in cambial growth in different girth classes (Larson, 1994). He also observed that environment had a great effect on ray height as environmental stress reduces the growth of cambium. Ray height was found for *A. hirsutus* was 804.62 µm to 888.82 µm which is comparable to the findings by Anoop *et al.* (2014) who found that ray height of *Artocarpus hirsutus* was 711.94 µm from research trials at LRS Thiruvazhamkunnu, Palakkad, Kerala. Ray width also found significantly varied between girth classes not between zones which ranged from 89 µm to 134 µm which is higher than the values obtained by Anoop *et al.* (2014) who found that ray width was 41.3 µm which might be due to location difference.

5.3.3 Fibre Morphology

Fibre length is a vital property studied for determining the end use of wood. Fibre dimensions are presented by two things i.e. dimension of cambial fusiform cells from which they are derived and cell differentiation processes (Ridoutt and Sands, 1993). Ghouse and Siddiqui (1976) also gave the information that phloem fibre resulted from combined effect of intrusive growth and fusiform cells present in aging of the cambium. Fibre length was found to be highest in central mid land i.e. 1814.94 µm and lowest in coastal sandy i.e. 1054.13 µm (Table 15); this range was also found in *Artocarpus nitidus* (1193.73 µm) and *A. lakoocha* (1425 µm).

Anoop *et al.* (2014) found that fibre length of *A. hirsutus* was more than *Artocarpus heterophyllus* i.e 1803.45 µm which is comparable to our finding. We found a significant difference in fibre length across three agro-climatic zones where fibre wall thickness, fibre lumen diameter didn't show had any significant difference across zones. This can be explained by the information provided by Moya *et al.* (2009) that among fibre parameters only fibre length was affected by the climate and type of the growing site. Verghese *et al.* (2000) reported there was no significant difference in fibre characters of 60 years old teak among nine different locations in Peninsular India. Fibre wall thickness for Aini ranged between 5.12 µm to 5.95 µm which can be comparable to the findings by Singh et al.(2017) who found fibre wall thickness of 4.90 µm in *Artocarpus nitidus*. Naji *et al.* (2011) informed that fibre wall thickness in *Hevea brasiliensis* was 3.98 µm to 4.88 µm in Tok Dor from Rubber Research Institute Mini Station (RRIMINIS) in Malaysia.

5.4 INTER-RELATIONSHIP BETWEEN WOOD PROPERTIES AND REGRESSION ANALYSIS

Correlation analysis revealed that various anatomical properties were correlated negatively and positively with physical properties and also among themselves also (Table 20). Fibre characteristics are highly correlated with specific gravity which influences the quality of the wood and wood products (Zobel and Buijtenen, 1989). In the present study the mean fibre parameters of Anjili wood showed a significant positive correlation between fibre wall thickness and basic density. Moya and Tomazelo (2008) demonstrated the same fact in *Gmelina arborea*. Anoop *et al.* (2014) also observed the same results in *Switenia macrophylla* trees from Kerala. The information provided by Purkayastha and Rao (1969) gave the impression that specific gravity couldn't predict only from fibre characteristics of wood. Only about 56% of variation in specific gravity can be contributed to fibre characteristics and cell wall proportion. Purkayastha *et al.* (1972) observed that fibre characteristics of wood were highly correlated with specific gravity in teak trees from different localities.

Rays are parenchymatous cells which have thin wall can give a good indication of density of the wood. Tylor (1969) provided the fact that species that possesses high specific gravity often possesses a high amount of ray tissues. There is very little literature available on the relation of basic density with ray morphology. Results of the present study showed that there was significant positive relation between ray height and basic density. A significant positive correlation between ray height and ray frequency was found in anjily wood. Rahman *et al.* (2005) revealed that increased ray volume resulted in higher specific gravity in *Tectona grandis* trees from two different locations in Bangladesh. Similar results were also showed by Taylor (1969) in four different species.

Vessel frequency was found to be negatively correlated with vessel area and vessel diameter (Table 20). Alla and Camarero (2012) also stated that there was a negative correlation between vessel frequency and mean vessel area across the species. Regression analysis showed that some of the anatomical properties of *Artocarpus hirsutus* were linearly related to basic density of the wood. Regression equations were developed for basic density, vessel length, ray height, fibre length, fibre wall thickness to show the dependence of basic density on anatomical properties.

5.5 ECOANATOMICAL PROPERTIES OF WOOD

A vast area has been covered related to ecological effects on wood anatomy in woody perennials and also in entire floras (Carlquist, 2001; Baas *et al.*, 2004). Vulnerability and Mesomorphy are two indices determined by Carlquist (1977) for determining the role of ecological factors in variation in wood anatomy. The values of Vulnerability and Mesomorphy vary according to different climatic conditions. A low value for vulnerability (1.0) and mesomorphy (75) indicate adaptation to xeric condition i.e it can withstand the low water availability while high value of vulnerability and mesomorphy indicate the adaptation of species to mesic according to Meena *et al.* (2014) who studied these parameters in *Albizia* *procera* which also possessed large vessels with low frequency. They demonstrated that vulnerability of *A.procera* in tropical condition was 85.10 in Bangladesh and Mesomorphy in tropical area varied from 31999.10 to 10970. This finding is similar to our study in which we found that vulnerability ratio was highest in central mid land zone of Thrissur i.e.136.82 (Table 18) and *Artocarpus hirsutus* proved efficient enough in conductivity due to its large vessel area and few numbers. Nooshin *et al.* (2012) who studied the vulnerability and mesomorphy in *Haloxylon ammodendron* also found that it was resistant to drought condition. Vessel diameter is inversely proportional to vessel density and is a good indicator of determination of vulnerability and mesomorphy (Carlquist, 1988). According to Carlquist (1977) the vessel parameters is controlled by length of fusiform initials. In this study, we also observed that some of the anatomical features varied across the ecological zones. Vessel diameter and vessel area were found higher in Central mid-land and Malayoram than coastal sandy. This can be explained by the finding that long and wide vessels are adaptable to mesic condition where soil moisture and relative humidity is high. So sandy soil in coastal area can be the reason for small diameter vessels. High vulnerabiltity value of *Artocarpus hirsutus* indicates the efficient conduction of water with wide diameter vessels.

Mesomorphy is considered as the measure of availability of water to the species (Carlquist, 2009). Mesomorphy of three zones ranged from 21083.99 to 32955.65 (Table 19). The mesomorphic ratio of *Artocarpus hirsutus* the wood inferred that it was more mesic in nature. Poorter (2008) observed that wider vessels leads to higher flow rate due to increased cross-sectional area of lumen. Anfodilo *et al.* (2006) also showed that conduit dimensions were influenced by environmental factors like water deficit.

5.6 WOOD PROPERTY VARIATION IN *ARTOCARPUS HIRSUTUS* LAM. BETWEEN HOMESTEADS AND PLANTATIONS

In the present study, significant difference in various wood properties between homesteads and plantation were observed. Basic density of *Artocarpus hirsutus* showed significant difference between homesteads and plantation which is contrary to the results found by Sharmin *et al.* (2015) in *Switenea macrophylla*. This variation in our study might be due site of the sample collection site differences. The topographic variation between Thrissur and Kannur resulted in variation in basic density and also in some other anatomical features. Sanwo (1986) reported that the rate of growth had no significant influence on specific gravity of plantation grown teak in Nigeria. We also found significant difference in yellowness between homesteads and plantation which was also found in teak samples from homesteads and plantation by Bhat and Thulasidas, (2004). They also found that there was no significant difference of lightness and redness of teak samples. Similar results were also found in the present study.

5.7 COMPARISON OF WOOD PROPERTIES OF *ARTOCARPUS HIRSUTUS* LAM. WITH TEAK (*TECTONA GRANDIS*).

Some of the anatomical properties of *Artocarpus hirsutus* obtained in this study were compared to *Swietenia macrophylla* Roxb. (Anoop *et al.*, 2014) and *Tectona grandis* (Tulasida and Bhat, 2012). Basic density of *A. hirsutus* in the present study was more than in *Swietenia macrophylla* Roxb. as reported by Anoop *et al.* (2014) but less than teak from wet site and dry site homesteads in Kerala given by Thulasidas and Bhat (2012). Some of the anatomical properties of *Artocarpus hirsutus* Lam. wood were found to be similar to the results by Thulasidas and Bhat (2012). for wood samples of teak from homegardens of Kerala viz. vessel diameter, fibre length, fibre wall thickness and fibre lumen diameter.

Table 24. Comparison of wood properties of *Artocarpus hirsutus* Lam., *Swietenia macrophylla* Roxb. grown in research plot of the Kerala Forest Department and *Tectona grandis* from homegarden of Kerala.

Wood properties	***Artocarpus hirsutus* Lam.** (Homesteads of Thrissur, Kerala)	***Swietenia macrophylla* Roxb.** (Anoop *et al.*, 2014) (Research plot of the Kerala Forest Department)	**Teak (*Tectona grandis* L.)** Thulasidas and Bhat (2012) (Homegarden of Kerala)	
			Wet site	**Dry site**
Basic density(kg/m^3)	531.22	526	649	691
Vessel frequency (no./mm^2)	2-3	6	6	5.7
Vessel diameter(μm)	246.07	167.6	217.1	198.7
Fibre length (*μm*)	1496.3	1311.1	1160	1240
Fibre lumen diameter (μm)	14.26	12.8	19.35	17.4
Fibre wall thickness (μm)	5.49	1.9	5.87	5.76

Based on the results of the present study, the following conclusions can be drawn:

Artocarpus hirsutus is one of the endemic timber species of the southern Western Ghats. Nayar (1996) also considered the tree as one of the "key tone" species of the Western Ghats. *Artoccarpus hirsutus* attains its rotation age at 25-40 years (Mathew *et al.*, 2006). From our study, we observed that the sap wood was white in colour and distinct from heartwood. Heartwood was golden yellow colour with indistinct growth ring. Different analysis revealed that basic density and moisture content didn't show any significant variation across three agro-climatic zones as well as between girth classes. Vessel frequency, vessel area, vessel diameter, ray width, fibre wall thickness and fibre lumen diameter didn't show significant difference across three agro-climatic zones. Ray frequency, ray height, ray width and fibre lumen diameter showed significant difference between three girth classes across the zones. Analysis revealed that there was significant difference of vessel frequency, vessel diameter, vessel length, ray width, fibre length, fibre lumen diameter, moisture content and basic density between homesteads and plantation. Correlation analysis also showed basic density was positively correlated with moisture content, ray height, fibre length, fibre wall thickness. The wood properties of *Artocarpus hirsutus* are also comparable to teak wood in various aspects.

Ecoanatomical characters like vulnerability index and vessel mesomorphy were also analysed and vulnerability index was found to be highest in central mid land. The result of the present study can be used as a baseline data for future tree improvement programme of this species for different end uses. As information on wood properties of *Artocarpus hirsutus* is very scarce, this study can provide more details regarding wood properties of this species.

Summary

SUMMARY

Wood samples of *Artocarpus hirsutus* Lam. were collected to understand the variation in wood anatomical and physical properties of Anjily (*Artocarpus hirsutus* Lam.) from three different girth classes grown in different agro-climatic zones of Thrissur district, Kerala. The study was conducted in the department of Wood Science of the College of Forestry, Kerala Agricultural University, Vellanikkara. The study area was located in Thrissur district (between N 10° 11' 8.16" and N 10° 41' 2.76" latitude, and E 75° 58' 2.64" and E 76° 53' 29.04" longitude) of central Kerala, India. Wood samples were also collected from three plantations located in Thalassery taluk of Kannur revenue district. The tract dealt with falls between $12^{0}14'$ to $11^{0}50'$ north latitude and $75^{0}10'$ to $75^{0}50'$ and plantation from which samples were collected were established during 1949, 1950 and 1951 respectively.

The experimental materials collected from Thrissur district belonged to three agro-climatic zones (9 Costal sandy + 9 Central midlands + 9 Malayoram) which also included trees from girth classes 50-100 cm, 100-150 cm. and more than 150 cm. Wood samples of three trees were collected from each girth class for the determination of wood physical and anatomical properties of *Artocarpus hirsutus* Lam. the summary of the investigations are provided below.

- The basic density ranged from 475.27 kg m^{-3} to 530 kg m^{-3} for Coastal sandy, 560.40 kg m^{-3} to 589.15 kg m^{-3} for Central mid land and 435.66 kg m^{-3} to 565.41 kg m^{-3} for Malayoram. There was no significant variation in basic density among zones and also there was no significant difference between girth classes within zones.
- The moisture content of samples in green to oven dry condition ranged from 46.30% to 63.66% for coastal sandy, 63.85% to

67.60% for Central mid land and 58.60% to 62.72% for Malayoram. Analysis revealed that there was no significant variation in moisture content among zones as well as between girth classes within zones.

- Analysis of variance revealed that there was no significant difference in colour parameters among zones. Lightness index (L^*) ranged from 60.59 to 67.59 whereas redness index (a∗) ranged from 6.35 to 8.9 yellowness (b∗) was varied from 22.31 to 24.97.
- Vessel frequency ranged from 3 to 2 for all the three zones. There was no significant variation in vessel frequency among zones. The vessel frequency was 3 or 2 for all the girth classes also. There was no significant difference of vessel frequency between girth classes within zones.
- Vessel diameter ranged from 194.93 µm to 236.49 µm for coastal sandy, 245.47 µm to 291.52 µm for Central mid land and 222.85 µm to 261.22 µm for Malayoram. There was no significant variation in vessel diameter among zones as well as between girth classes within zones.
- Vessel area ranged from 49432.03 μm^2 to 78869.70 μm^2 for coastal sandy, 70159.32 μm^2 to 93481.86 μm^2 for Central mid land and 69449.11 μm^2 to 127585.48 μm^2 for Malayoram. There was no significant variation in vessel area among zones. There was no significant difference in vessel area between girth classes within zones.
- Vessel length ranged from 248.47 µm to 289.43 µm for coastal sandy, 126.86µm to 171.31 µm for Central mid land and 192.71 µm to 330.27 µm for Malayoram. There was a significant

difference in vessel length among zones. There was no significant difference in vessel length between girth classes within zones.

- Ray frequency ranged from 4 to 5 per mm^2 for all the three zones viz. coastal sandy, Central mid land and Malayoram. There was no significant variation in ray frequency among zones. The ray frequency in different girth classes also ranged from 4 to 5 per mm^2 for all three zones. There was a significant difference of ray frequency between girth classes within zones.

- Ray height ranged from 704.56 µm to 867.97 µm for coastal sandy, 775.13 µm to 1015.08 µm for Central mid land and 710.70 µm to 1038.31 µm for Malayoram. There was significant variation in ray height among zones and also between girth classes within zones.

- Ray width ranged from 85.92 µm to 93.14 µm for coastal sandy, 93.44 µm to 139.67 µm for Central mid land and 115.08 µm to 156.31 µm for Malayoram. There was no significant variation in ray width among zones but there was significant difference of ray width between girth classes within zones.

- Fibre length ranged from 1032.95 µm to 1071.53 µm for coastal sandy, 1581.51 µm to 2046.80 µm for Central mid land and 1105.71 µm to 1919.48 µm for Malayoram. Analysis revealed that there was a significant variation in fibre length among zones but no significant difference between girth classes within zones.

- Fibre wall thickness ranged from 5.72 µm to 4.8 µm for coastal sandy, 6.21 µm to 5.84 µm for Central mid land and 5.86 µm to 5.0 µm for Malayoram. Analysis revealed that there was no significant variation in fibre wall thickness among zones as well as between girth classes within zones.
- Fibre lumen diameter ranged from 11.77 µm to 16.37 µm for coastal sandy, 9.82 µm to 15.39 µm for Central mid land and 12.37 µm to 18.07 µm for Malayoram. Analysis revealed that there was no significant variation in fibre lumen diameter among zones but there was a significant difference between girth classes within zones.
- Vulnerability index was found to be highest in central mid land zone (136.82) and lowest in coastal sandy zone (96.24). Analysis revealed that there was significant variation in vulnerability index among zones but there was no significant difference between girth classes within zones.
- Vessel mesomorphy ranged from 21083.99 to 32955.65 across the three zones. Analysis revealed that there was no significant variation in mesomorphy among zones as well as between girth classes within zones.
- Correlation coefficient values between different wood properties of *Artocarpus hirsutus* Lam. wood from three different agro-climatic zones of Thrissur district, Kerala showed that basic density was positively correlated with moisture content, ray height, fibre length, fibre wall thickness and negatively correlated with vessel length. Moisture content was positively correlated ray height, fibre length and fibre wall thickness.

- Analysis revealed that there was significant difference in vessel frequency, vessel diameter, vessel length, ray width, fibre length, fibre lumen diameter, moisture content and basic density between homesteads and plantation. Highest mean value for vessel diameter (286.97 μm), vessel area (95815.81 μm), vessel length (316.51 μm), fibre lumen diameter (17.76 μm) and moisture content (74.16%) were found in the plantation source. Basic density was found highest for homesteads i.e. 533.70 kg/ m^3. a*- value of the colour parameters also showed significant difference between homesteads and plantations i.e yellowness of heartwood colour.

- Linear models were developed to show the dependence of basic density on different anatomical properties. In the present study, linear equations were developed between basic density and anatomical properties like fibre length, fibre wall thickness, vessel length, ray height etc.

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VARIATION IN WOOD PHYSICAL AND ANATOMICAL PROPERTIES OF ANJILY (*Artocarpus hirsutus* LAM.) GROWN IN DIFFERENT AGRO-CLIMATIC ZONES OF THRISSUR DISTRICT, KERALA

by

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ABSTRACT

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ABSTRACT

A study entitled "Variation in wood physical and anatomical properties of anjily (*Artocarpus hirsutus* Lam.) grown in different agro-climatic zones of Thrissur district, Kerala" was conducted in the College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur during the period 2015-2017. The present investigation was conducted with the objective to assess the variation in wood anatomical and physical properties of anjily (*Artocarpus hirsutus* Lam.) grown in different agro-climatic zones (Coastal sandy, Central mid land and Malayoram) of Thrissur district, Kerala and to compare the anatomical and physical property of wood between plantations and homesteads.

Samples from anjily trees were selected from the three agro-climatic zones of Thrissur district following stratified random sampling technique. The experimental materials were collected from three agro-climatic zones (9 Costal sandy + 9 Central midlands + 9 Malayoram) which also include trees from three girth classes viz., 50-100 cm, 100-150 cm. and more than 150 cm. Wood samples of three trees were collected from each girth class. Wood samples were also collected from three plantations in Thalassery taluk of Kannur district. Analysis revealed that some of the anatomical properties were significantly different between girth classes across three agro-climatic zones. Basic density, moisture content, heartwood colour, vessel frequency, vessel area, vessel diameter, ray width, fibre wall thickness and fibre lumen diameter did not show significant difference across three agro-climatic zones. Ray frequency, ray height, ray width and fibre lumen diameter showed significant difference between three girth classes across the zones. Analysis revealed that there was significant differences in vessel frequency, vessel diameter, vessel length, ray width, fibre length, fibre lumen diameter, moisture content and basic density between homesteads and plantation.

Ecoanatomical characters like vulnerability index and vessel mesomorphy were also analysed and vulnerability index was found to be highest in central mid land. Mesomorphy values of anjily wood indicated that it was mesic in nature. Correlation analysis also showed that basic density was positively correlated with moisture content, ray height, fibre length and fibre wall thickness. The wood properties of anjily was also found to be comparable to teak wood in various aspects.

Appendices

APPENDICES

1. Analysis of Variance of basic density (kg/m^3) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	30476	15238	2.43^{ns}	0.168
Girth(zone)	6	37590	6265	0.88^{ns}	0.530
Error	18	128329	7129		
Total	26	196395			

ns-non-significant at 0.05 level

2. Analysis of Variance of green to oven dry moisture content (%) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	482.9	241.43	2.89^{ns}	0.132
Girth(zone)	6	501.1	83.52	0.35^{ns}	0.903
Error	18	4336.5	240.92		
Total	26	5320.5			

ns-non-significant at 0.05 level

3. Analysis of Variance of L^*- value versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	240.54	120.27	0.44^{ns}	0.44
Girth(zone)	6	755.34	125.88	43.44*	0.00
Error	18	52.16	2.90		
Total	26	1048.04			

**- significant at 0.05 level, ns-non-significant at 0.05 level*

4. Analysis of Variance of a^*- value versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	34.27	17.14	3.96^{ns}	0.08
Girth(zone)	6	25.93	4.32	32.84^{*}	0.00
Error	18	2.37	0.13		
Total	26	62.58			

**- significant at 0.05 level, ns-non-significant at 0.05 level*

5. Analysis of Variance of b^*- value versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	32.14	16.07	1.38^{ns}	0.32
Girth(zone)	6	69.85	11.64	30.31^{*}	0.00
Error	18	6.91	0.38		
Total	26	108.91			

**- significant at 0.05 level, ns-non-significant at 0.05 level*

6. Analysis of Variance of vessel frequency (no./mm^2) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	0.5185	0.2593	1.75^{ns}	0.252
Girth(zone)	6	0.8889	0.1481	1.33^{ns}	0.293
Error	18	2.000	0.1111		
Total	26	3.4074			

ns-non-significant at 0.05 level

7. Analysis of Variance of vessel diameter (μm^2) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	13860	6930.0	4.65^{ns}	0.060
Girth(zone)	6	8943	1490.4	1.63^{ns}	0.197
Error	18	16508	917.1		
Total	26	39311			

ns-non-significant at 0.05 level

8. Analysis of Variance of vessel area (μm^2) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	3240310032	162015516	1.12^{ns}	0.385
Girth(zone)	6	8650635313	1441772552	1.11^{ns}	0.397
Error	18	23460329702	1303351650		
Total	26	35351275047			

ns-non-significant at 0.05 level

9. Analysis of Variance of vessel length (μm) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	93200	46600	6.47*	0.032
Girth(zone)	6	43247	7208	2.60^{ns}	0.054
Error	18	49862	2770		
Total	26	186309			

**- significant at 0.05 level, ns-non-significant at 0.05 level*

10. Analysis of Variance of ray frequency (no./mm^2) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	0.9630	0.4815	0.21^{ns}	0.817
Girth(zone)	6	13.7778	2.2963	8.86^{*}	0.000
Error	18	4.6667	0.2593		
Total	26	19.4074			

**- significant at 0.05 level, ns-non-significant at 0.05 level*

11. Analysis of Variance of ray height (no./mm^2) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	36205	18103	0.36^{ns}	0.715
Girth(zone)	6	305512	50919	4.87^{*}	0.004
Error	18	188214	10456		
Total	26	529931			

**- significant at 0.05 level, ns-non-significant at 0.05 level*

12. Analysis of Variance of ray width (µm) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	9923	4961.3	4.72^{ns}	0.059
Girth(zone)	6	6311	1051.8	3.05^{*}	0.031
Error	18	6214	345.2		
Total	26	22448			

**- significant at 0.05 level, ns-non-significant at 0.05 level*

13. Analysis of Variance of fibre length (μm) versus zones, girth classes

Source	DF	Adj ss	Adj MS	F-value	P-value
Zone	2	2811072	1405536	5.52*	0.044
Girth(zone)	6	1527961	254660	1.75ns	0.166
Error	18	2613551	145197		
Total	26	6952583			

**- significant at 0.05 level, ns-non-significant at 0.05 level*

14. Analysis of Variance of fibre wall thickness (μm) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	3.22	1.61	3.21ns	0.113
Girth(zone)	6	3.02	0.50	1.03ns	0.440
Error	18	8.82	0.48		
Total	26	15.06			

ns-non-significant at 0.05 level

15. Analysis of Variance of fibre lumen diameter (μm) versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	45.62	22.81	0.95ns	0.439
Girth(zone)	6	144.36	24.06	5.20*	0.003
Error	18	83.35	4.63		
Total	26	273.33			

**- significant at 0.05 level, ns-non-significant at 0.05 level*

16. Analysis of Variance for vulnerability index versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	7432	3716.2	11.26^{*}	0.009
Girth(zone)	6	1979	329.9	0.88^{ns}	0.530
Error	18	6762	375.7		
Total	26	16174			

**- significant at 0.05 level, ns-non-significant at 0.05 level*

17. Analysis of Variance for vessel mesomorphy versus zones, girth classes

Source	DF	Adj SS	Adj MS	F-value	P-value
Zone	2	638682010	319341005	3.76^{ns}	0.087
Girth(zone)	6	508922573	84820429	1.33^{ns}	0.293
Error	18	1144903781	63605766		
Total	26	229508364			

ns-non-significant at 0.05 level