Geographical Indications status for Nilambur Teak (*Tectona grandis* L.f.)

By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Geographical Indications status for Nilambur Teak (*Tectona grandis* L. f.)"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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SWATHY M. HARIDAS

Dedicated to my Parents, Sisters

and My beloved Teachers

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INTRODUCTION

INTRODUCTION

A Geographical Indications (GI) is a sign used on products that have a specific geographical origin and possess qualities or a reputation that are due to that origin. It acts as a mechanism that helps producers differentiate their products from competing products in the market and enables producers to build a reputation and good will around their products that will fetch a premium price (WTO, 2004).

The concept of Geographical Indications has its origin in 19th century Europe and has considerably evolved since then. The current international framework is laid down in Article 22 of the Trade Related Aspects of Intellectual Property Rights (TRIPS) agreement which mandates member countries to provide for protection of all GIs, where the obligation is for members to provide the 'legal means for interested parties' to secure protection of their GIs. As a party to the TRIPS agreement, India is required to protect GI and hence in order to fulfill that obligation, the Geographical Indications of Goods (Registration and Protection) Act, 1999 was enacted (GI Registry, 2010).

Darjeeling tea was the first product in India registered under GI registry in 2004. After that 172 GIs have been registered with the GI Registry of India. Of these, more than half (64 %) are handicrafts, agricultural products constitutes more than 26 percent and the remaining are food and manufacturing products (Nanda *et al.*, 2013). According to latest report, India has 272 GI registered products (India Today, 2016).

Nilambur Teak is destined to be one of the first forest resources from India to get GI registration. The superiority of Nilambur teak for ship building and structural purpose due to its large size, tree form, colour and workability has been documented during the last two centuries. Thus, centuries of glorious tradition associated with tree form and colour of Nilambur Teak and the separate genetic identity suggest the possibility of considering GI registration for Nilambur Teak under IPR and TRIPS (Balasundaran, 2010).

Teak (*Tectona grandis* L. f.) which belongs to the family Verbenaceae is predominantly tropical and subtropical in distribution. Teak occurs in natural forest between 9^0 to 26^0 North latitude and 73^0 to 104^0 East longitudes, which includes India, Myanmar, Laos Peoples Democratic Republic, and Northern Thailand (Kjaer, 1996). Teak exhibits wide geographic/ provenance variation in India with regard to wood figure and strength (Chundamannil, 1998). Habitat destruction and fragmentation have restricted the distribution of species to small and isolated populations (Kjaer, 1996). Expanding teak cultivation to new areas, increasing the productivity of existing plantations and devising better marketing strategies including a good market intelligence system are some of the proposed solutions. The superior quality of Nilambur teak with respect to the tree form and fast growth shown in international provenance trial in Africa, Latin America, Indonesia and in India itself recognised by silviculturists and tree breeders (Varghese *et al.,* 2000).

Studies conducted by Balasundaran *et al.* (2010) on genetic diversity of teak growing in the natural forest of the Western Ghats, Eastern Ghats and Central India using AFLP and micro satellite markers had revealed the genetic identity and uniqueness of Nilambur Teak.

The uniqueness of Nilambur Teak with respect to growth and wood quality is world famous. Malabar teak (Nilambur, Kerala) from the Western Ghats region in India, generally displaying good growth and log dimensions with desired wood figure (golden yellowish brown colour), has a wide reputation in the world trade for ship-building (Bhat and Priya, 2004). Thulasidas and Bhat (2006) compared sapwood-heartwood percentages in home garden teak and forest plantation teak in Nilambur. They observed no significant differences between the heartwood- sapwood ratio of home garden and forest plantation teak. A study conducted by Anish (2013) on the effect of growth rate on wood quality of teak grown under differing site quality conditions revealed that wood quality parameters such as specific gravity resistance to deformation, heartwood colour and total extractive content were found to be higher for Nilambur Teak irrespective of their growth rate. This also highlights the superiority of Nilambur Teak over teak grown in other countries.

Chundamannil (1997) found that site quality was better in Nilambur than other forest divisions of the state. He also found that even with a higher rotation age, the mean yield in other Divisions was lower than that in Nilambur. This indicates that on an average, Nilambur Teak plantations have higher productivity may be due to higher site quality.

Technologies using wave propagations have been well established as material evaluation tools, and their use has become widely accepted in the forest products industry for on-line quality control and products grading (Pellerin and Ross, 2002; Wang *et al.*, 2007). These technologies provide strategic information that could be used to sort and grade trees and logs, according to their aptness for structural applications and for a range of other desirable properties. For rapid, onsite evaluation of wood quality, particularly for teak in Kerala, non- destructive evaluation (NDE) has been reported to be useful (Ponneth *et al.*, 2014).

According to Varghese *et al.* (2000) the edaphic characters, mainly parent material or nature of the underlying rocks from which soils are formed influence the quality and distribution of natural teak. In plantations, the physical and chemical properties of the soil influence to a large extent tree growth and cell characteristics.

The consistent superiority of teak originated from the specific territory of Nilambur valley located at 11^0 North latitude and between 75^0 and 76^0 East longitude in North Kerala, India render it a product for consideration for Geographic Indications registration under IPR and TRIPS (Balasundaran, 2010).

This GI registration will give growers and users of Nilambur Teak the legal rights to exclusive use. This is expected to encourage more people to take up teak planting and improve the prosperity of the region through export of teak timber and further helps to increase demand in national and international timber markets for Nilambur teak. Non- destructive technique (NDT) of timber properties evaluation helps assess wood quality without sacrificing logs, compared to destructive methods. So in order to ensure GI tag for wood products manufactured using Nilambur Teak wood, an analysis of wood quality and the influence of site factors on it will be critical.

The objectives of the present study was to analyse the potential of securing Geographical indications status for Nilambur teak by (a) Exploring the historical importance of Nilambur teak, (b) Comparing its wood quality with other national and international provenances, (c) Analyzing the potential agro-ecological and biophysical factors responsible for the uniqueness of Nilambur teak.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Geographical indications are a unique expression of local agro-ecological and cultural characteristics that have come to be valued and protected in many countries throughout the world. Darjeeling tea, Parmigiano cheese, Bordeaux wine, Kobe beef, Idaho potatoes, Jamaica Blue Mountain coffee, and Tequila are just some of the more popular Geographical Indications (GIs). According to TRIPS agreement Geographical indications are, indications which identify a good as originating in the territory of a Member, or a region or locality in that territory, where a given quality, reputation or other characteristic of the good is essentially attributable to its geographic origin (Giovannucci *et al.*, 2009).

A GI acts as a link not only between a product and a specific geographic region, but usually also with unique production methods, characteristics or qualities that are known to exist in the region. Geographical indications can be used as differentiation tools in marketing strategies: from mere source indicators to brands. Now a day, consumers pay increasing attention to the geographical origin of products, and care about specific characteristics present in the products they buy. In some cases, the "place of origin" suggests to consumers that the product will have a particular quality or characteristic that they may value. Often, consumers are prepared to pay more for such products. This has favored the development of specific markets for products with certain characteristics linked to their place of origin (WIPO, 2014).

According to Moschini *et al.* (2008) GI act as an effective certification tool for high quality products that attempts to overcome the credibility problem that consumers face when quality cannot be readily ascertained prior to purchasing. Berard and Marchenay (2006) remarked that Protected Geographical Indications (PGI) label was mainly based on product's reputation, its history, related its place of origin and its particular characteristics or qualities.

According to Sahai and Barpujari (2007) GIs may especially facilitate protection of the collective rights of the rural and indigenous communities in their indigenous knowledge, ensuring that the entire community which has preserved the knowledge and has passed it on with incremental refinement over generations, stand to benefit from the knowledge and that this is not locked up as the private property of one individual. Chethana *et al.* (2010) remarked that the GIs are designed to defend valuable intellectual property rights belonging to the community in a specific geographic boundary.

Major advantage of GI's are that the knowledge remains in the public domain, the scope of protection is limited to controlling the class and/ or location of people who may use the protected indication and the rights can potentially be held in perpetuity as long as the product-place link is maintained (CIPR, 2004).

Teuber (2007) reported that GI is used as a tool of product differentiation in the coffee sector in the international market. The price and demand of GI registered single-origin coffees increased. The study also found that the country and the region of origin is an important determinant of prices paid by importers and roasters.

Arief (2016) reported that after the implementation of GI system in Indonesia the Indonesian craft got a bigger opportunity to survive in the global market as a cultural product. The study also found the the implementation GI for Indonesian craft has benefited the stakeholders and the professionals in Indonesian craft Industries.

Dwi *et al.* (2006) reported that Javenese teak GI created a form of monopoly among the Javenese people in the trade of Javanese teak. The study also found that GI for Javenese teak provides advantages to the small and large wood processors in Java. The GI tag for Javanese teak helped to reduce the competition in the market with China and Vietnam in wood products.

According to Dattawadkar and Mohan (2012) had a total of 157 products has been registered under GI registry of India, of which most of them are for handicrafts (99) followed by agriculture products (42). Karnataka showed a leading trend in GI registration with 30 GI followed by Andhra pradesh, Kerala and Tamilnadu. The lowest number of registrations was observed in Goa, Nagaland and Punjab, only a single GI was registered so far from each of these states. They also observed an increasing trend in GI registration in India. Their study also stated that in India there were 3000 potential GIs, which need to be protected, but till now only 238 applications have been filed for registration.

2.1. History of Nilambur Teak

From the time immemorial, Malabar had been famous as the principal source of spices and timbers. Teak is the major plantation species in Nilambur. Nilambur teak has a long history and it began with Zamorin of Kozhikode who gifted the teak forests of Nilambur to local property owners of Nilambur (Zainulabdeen, 2011).

In the medieval period, with the rise of brahminical supremacy in Malabar, there arose a strong tradition which prohibited strictly the non-brahmins from using the timbers like teak for their house construction. According to this tradition, the teak was to be used only to construct temples, Nambutiri houses and a few of the aristocratic houses of the privileged classes (Thanumalayan, 2007). From ancient times onwards Arabs used "Uru" (Dhow) as their major trading vessels. Arabs discovered Kerala, wealthy for her solid timber, skilled craftmen and native technology. They shifted their dhow construction unit to Beypore in Malabar. Uru is built of several types of wood, the main one being teak from Nilambur forests in earlier times. Even now Uru's are being manufactured and exported to Arab nations from Beypore. Uru is a remainder of the trade ties Malabar had established with the Chinese, Arabs, Jews, Romans and many others who came in search of rich products of the land, long before the Portugese navigator Vasco da gama had landed on the Malabar (Lushington, 1896).

As per the Sriranga Pattanam treaty, 1792, complete Malabar Area, except Wayanad, came under the British rule. Later, Wayanad was also brought under their control. In contrast to the practices followed in Travancore and Cochin, the forests in Malabar Area were considered as private property under the British rule. But some areas for which, there were no claimants were kept under the control of government. After identifying the forests and the teak in India, Britain was interested in administering forests in India especially in Malabar region. Nilambur in Malabar Coast became the major source of teak wood required for the construction of navy and mercantile vessels of Britain. British domination gifted a new era to the history of teak forests of Malabar and this made India to integrate with international trade network even when it was administered by the West (Lushington, 1896).

British colonial forces were attracted to the wood resources of Kerala, on account of their superior qualities and vast export potential (Tucker, 1988). During the medieval period, Malabar region was a leading trading centre of spices on the west coast of India. Kozhikode (formerly Calicut), the most important city of Malabar enjoyed a prominent place in the international wood trade in the subcontinent. The village Kallai in Kozhikode along the bank of Kallai river was once the 'hub of timber market' in south Asia which dictated the international timber prices for several decades. Under the management of A. Brown the first organized wood processing (sawmilling) unit in Kerala was set up at Kallai in 1893 (Muraleedharan and Bhat, 1989). Nilambur in the eastern part of Malabar is yet another internationally acclaimed centre often known as the 'Mecca of teak' that helped Kallai in carving its own wood legacy. The primary reason for the glorious legacy of Kozhikode (Kallai) was attributed to the luxuriant supply of quality teak which grabbed a unique niche for Nilambur teak in the international market. The Chaliyar River and its tributaries played a prominent role in spreading the glory of Nilambur teak by cheaper mode of transporting teak through rafts. International wood trade was mainly focused on quality saw logs for ship building and for furniture making. The demand for specific wood products such as long teakwood planks for the manufacture and repair of large country boats (used in royal navy) was a major international wood trade sector.

Lengthy teak wood planks of size 35" to 40" were easily transported from the Nilambur forests in huge rafts through the Chaliyar river. Also, the major source of wood for railway sleeper making in southern India was delivered through Kallai (Kunhamu, 2011)

The British administered and managed the Indian forests predominantly for the requirements of the military particularly its navy. British used teak as an admirable substitute for the oak that they were using in navy and mercantile marines. The teakwood, required for Naval Dockyard, Bombay, was collected from Kanara, and Malabar areas during those days. With a perpetual aim of steady supply of first class timber, mainly teak, for the British Navy, Mr. Machnochie of the medical services established a timber syndicate in Malabar in 1796. Through the Chaliyar river, big logs of teak wood from Nilambur forests reached the ports at Calicut. After a short period, different agencies opened outlets for the supply of Teak to the Britain Navy and they plundered the natural forest resources of India including teak from Nilambur. The teak forests of Malabar were highly affected by this supply. To meet their requirement, even immature trees were felled. The massive destruction of Nilambur forests led to the evolution of the concept of conservation of teak forests in the Malabar region. An order was issued in 1792 by the Bengal Bombay Joint Commission, prohibiting the felling of teak below 21 cm of girth in Malabar forests. In 1806, Captain Watson was appointed as the Conservator of Teak (Lushington, 1896).

Mr. Sheffield, who came to India, as the Principal Collector of Malabar in 1828 was highly disturbed at the wanton destruction of teak forests in Nilambur and brought it to the attention of the then government and suggested a total ban on felling of teak trees. However, the proposal did not materialize. Later, Mr. Smith was entrusted with the work to increase the forest land by regenerating teak artificially during 1841. The over exploited area in the western side of Nilambur was selected for the work. In 1842, teak seeds were broadcasted and natural seedlings were transplanted in the degraded areas. Since the attempt of Mr. Smith had failed, Mr. Graham, was appointed in 1842 October in his place to continue the artificial regeneration (Srinivasan, 2004).

In 1842, Sir H.V. Connolly was, appointed as the Collector of Malabar. Considering the extent of forest under government ownership and its potential to grow more trees, he had prepared a note and brought to the notice of the government the immediate need for raising plantations considering the projected needs. He assessed the timber requirements as 2230 cu.m / year for the construction of one ship each year. According to him 2000 teak trees were to be felled annually to meet the projected need. Considering 60 years as the minimum rotation for teak, he anticipated to plant 1,20,000 trees in a phased manner. For this, 670 sq.km of forest land from private owners had to be purchased. His suggestions were promptly accepted by the Government and Connolly made history by raising the first ever teak plantation in the world with the assistance of Shri Chathu Menon, the then sub conservator, on the northern bank of Chaliyar river in Nilambur (KFRI, 1991). A part of this plantation, the 'Conolly 's Plot', as it is now known, is still preserved and venerated as the oldest teak plantation in Asia and even now has some of the trees planted by the two pioneers, Mr. H.V. Conolly and Mr. Chathu Menon. The Conolly's plot occupies an area of 2.31 hectares. Accordingly the forest land under Thrikalayur Devasom was taken on lease. Later forest area of Nilambur Thirumulpad, and Zamorin of Kozhikode were also taken on lease in 1841 and 1843. When large teak areas were identified in Kanara, further leasing of forest land was stopped in 1843. Between 1844 and 1862, about 1512.71 acres of land were raised with teak (Zainulabdeen, 2011).

In 1882, Madras Forest Act came into force. During 1883-87, the forests of Karimpuzha New Amarambalam, Silent Valley, Valayar and Chennath Nair Reserve were declared as Reserved Forests. Later, more areas became Reserved Forests. In 1894, the first working plan for Nilambur division (1896 – 1905) was prepared. This indicates that management of forests guided by Working Plans started in Malabar area much before the practice started in Travancore. Mr. Ribbon Troup, the Inspector General of Forests visited the Teak plantations of Nilambur in 1898. Mr. Rodez Morgan, District Forest Officer had made a study of Flora & Fauna of Malabar and included in the book of Mr. Willian Logan in 1887 (Srinivasan, 2004).

During 'Mappila Lahala', in 1921-22, forest officials were harassed and many of the forest buildings were burned and destroyed. One of the oldest collection of books and other authoritative records of forestry in Malabar kept in the Divisional Forest Office in Nilambur, were also destroyed during the 'Mappila Lahala'. Many of the teak plantations were affected by flood in 1924. In 1927 Nilambur-Shornur railway line was laid for the economic and swift transportation of wood from Nilambur. The private forests were over exploited and mismanaged during early 1900. Lot of people from Central Travancore colonized Malabar and large areas were brought under cultivation destroying the forest cover. The Madras Preservation of Private Forest Act, 1949 came into force and all private holdings of forests exceeding 40 ha came under the purview of the Act. Nevertheless, the Act could not fully control the destruction of forests (Srinivasan, 2004).

Among the timbers of India, teak has the realm of supreme quality and in olden days, Indian teak was formerly known by the name of 'Malabar teak'. Historically, Nilambur was the major source of Malabar teak. Currently, the forests and plantations in Nilambur are the major source of quality teak in India. Additionally, the homesteads and farmlands in Nilambur also supply substantial quantity of teak quality teakwood particularly to the domestic local market. This agrees with the observation that homesteads and farm lands contribute almost 60% of the domestic timber requirements in Kerala (Krishnankutty *et al.*, 2005). Nilambur teak acquired worldwide reputation due to its superior qualities. The superiority of teak from Nilambur and surrounding regions for shipbuilding and structural purpose were due to the large size and form of the tree, the color and workability of the wood and its ability to withstand termite attack. This unique quality of Nilambur teak was the major factor that helped gain the worldwide attention for it in the ship and yacht building dockyards. This is true even today. Sail boats and small ships (Dhow or 'Uru' as it is called locally) made entirely out of teak wood from Nilambur continue to be built at Beypore in Kozhikode district and the yacht industry in Europe still prefers the beautifully figured and very durable teak wood from Nilambur, reminiscent of the olden days. Nilambur teak has unique qualities such as it is world renowned golden yellow color and attractive figure. No wonder, most of the well known palaces and other historical monuments in Kerala have immense wood work of teak from Nilambur. The Kerala legislative assembly hall and the building contain considerable quantities of wooden furnitures and fixtures out of Nilambur teak.

The Nilambur region is traversed by a major river, the Chaliyar, which flows westward and drains into the Arabian Sea at Beypore. The major tributaries are Chaliyarpuzha, Karimpuzha and Punnapuzha. The rich alluvial deposit in the river banks of Chaliyar enhance the soil fertility and thus enhance the quality of Nilambur teak. Local belief, which is not yet scientifically validated, is that the unique golden brown color of Nilambur teak is due to the presence of gold ore in the soils of Nilambur. The Nilambur valley was famous for artisanal gold mining. Gold prospecting in the Nilambur belt by the Geological Survey of India (GSI) and the Department of Mining and Geology, Kerala, had revealed presence of deposits estimated to be worth Rs 600 crores at current gold prices. (Business Line, 2005). Scientific studies have also revealed the presence of placer gold grains in the Nilambur Valley (Santhosh *et al.*, 1992).

2.2. WOOD QUALITY VARIATION IN TEAK

Teak is known to display wide variations in the wood characteristics among different growing conditions and regions in India (Bhat and Indira, 1997). Several provenances of teak have also been recognized based on the geographical location and the morphological characteristics of stem and leaves and timber properties. It exhibits wide geographic/ provenance variations in India with regard to wood figure and strength properties (Tewari, 1992). The Malabar teak (Nilambur, Kerala) from the Western Ghats region in India, generally displays good growth and log dimension with desired wood figure (golden yellowish brown colour) (Balasundaran and Gnanaharan, 1997). Teak of different origin is considered to vary in height, growth rate, and stem form and in physical properties of the timber. Central Indian teak is reputed to possess a better form and deeper colour than the teak from the West Coast, which closely resembles Myanmar teak in its properties. Limaye (1942) found Central Indian teak to have slow growth and 7-8 % lighter wood than Myanmar or South Indian teak. There are various studies reported on variations in percentage heart wood, colour, durability and mechanical properties depending on ecological conditions.

2.3. PHYSICAL PROPERTIES OF WOOD

Physical properties like heartwood colour, heartwood- sapwood ratio are important factors that affects the price variation of teak in the International teak market.

2.3.1. Heartwood Colour

The colour and markings of the heartwood also vary considerably with locality (Tewari, 1992). The colour of wood differs widely among species and also within a tree. It is an important factor for end user to consider and price of wood is often dependant on its colour parameters. Generally, the colour prescription is of interest to industries in the context of better marketability of wood products especially furniture, decorative veneer, etc. For example, a slight change in heartwood colour would yield product of different value.

Thulasidas *et al.* (2006) reported that wood colour along with other quality parameters such as poor log form visual defects such as bends and sound knots and low sawn timber output from dry site might influence the price of the teak from homegarden forestry.

Hillis (1978) observed that wood produced from drier areas with darker coloured heartwood in teak is similar to fast growing eucalypts in areas of high rainfall which produced lighter coloured heartwood. The teak wood from dry locality displayed characteristic darker heartwood with decorative black streaks, probably due to slower growth and higher amount of extractive as related to the site or edaphic factors (Bhat, 2003; Thulasidas and Bhat, 2003).

Derkyi *et al.* (2009) studied colour variation in teak (*Tectona grandis*) wood from plantations across the 4 ecological zones (moist semi-deciduous forest, MSDF; dry semi-deciduous forest, DSDF; transition savanna forest; and savanna forest) of Ghana. They investigated effect of environmental and tree age on the colour of teak heartwood and found that environmental factors had a stronger effect on the colour of teak heartwood than the stand age. The study also observed variation in wood colour parameters with change in soil chemical properties.

2.3.2. Heartwood- Sapwood ratio

Proportion of heartwood in a tree is an important factor for wood quality. Heartwood is the non-functional central part of a tree trunk and no living cells exist in this wood (Hillis, 1987). Higuchi (1997) found that in the process of heartwood formation, certain chemical processes take place, which helps to improve durability and change the colour of wood. The estimation of heartwood content helps to define differences in durability and other wood characteristics (Weimann and Williamson, 1989).

Thulasidas *et al.* (2007) studied on wood quality of planted teak outside the forest, revealed that timber from homesteads of wet sites is more susceptible to brown-rot fungi although no significant differences exists with respect to white-rot fungi among the home garden and plantation grown timbers. Natural durability and dimensional stability of teak wood was determined by the extractive content of the wood. They also observed that natural durability was higher for teak wood from drier home gardens and forest plantations is reflected in higher extractive contents with darker colour than wet site teak, which has faster growth.

Morais and Pereira (2012) studied the variation in extractives content in sapwood and heartwood among 12 trees in each of four commercial plantations of *Eucalyptus globulus* in central Portugal. The study was carried out at 15 % height level and observed that for all sites, heartwood had significantly more extractives than sapwood, on average 3.8 and 2.4 respectively.

Bhat (1998) found that increased tree growth rate does not retard the formation of heartwood. However the amount of heartwood in teak is related to tree age (Okuyama *et al.*, 2000; Simatupang and Yamamoto, 2000; Bhat, 2000)

Okuyama *et al.* (2000) observed that compared to other plantation species, heartwood formation begins relatively early in teak trees, at about 7 years of age. Bhat (2000) found that no evolution in heartwood volume occurred in trees aged 55-65 years old.

Kjaer *et al.* (1999) reported that volume of heartwood in teak originating from Asia is greater than that in African teak. Heartwood volume in teak therefore appears to be influenced by tree age, silvicultural practices and genetic provenances.

Searle and Owen (2005) studied species, provenances and within tree variation in heartwood percentage for different Acacia species (40 provenances) and *Eucalyptus nitens* (one provenance) from southern Australia. He observed some association between percentage heartwood and basic density at species level but no association was found between provenances.

Perez and Kanninen (2003) observed that heartwood volume increases with increasing age and diameter on planted *Tectona grandis* trees in Costa Rica. They also observed that wide spacing plantations (150-800 trees/ha) present a significant higher proportion of heartwood than those in narrow spacings (1600 trees/ ha).

Miranda *et al.* (2009) studied variation of heartwood and sapwood in 18 year old *Eucalyptus globulus* trees grown with different spacing and suggested that, the tree possess a considerable proportion of heartwood at breast height which was very highly and positively correlated with stem diameter. Several studies report on heartwood content and variations in wood dry density, from pith to bark, with stem height, with age, with stand density, and with climatic conditions for teak in different countries (Nair and Chavan, 1985; Bhat, 1995; Brennan and Radomiljac, 1998; Priya and Bhat, 1999)

The amount of sapwood may influence wood properties and utilization and it can be used as an important selection criterion to forest industries involved in timber drying, wood pulping, preservation and furniture manufacturing (Yang *et al.*, 1985; Miranda *et al.*, 2009).

2.4. NON DESTRUCTIVE EVALUATION

Non-destructive evaluation (NDE) of a material is, by definition, the science of analysing the physical as well as mechanical properties of a piece of material without altering or changing its end-use capabilities.

2.4.1. Pilodyn

Pilodyn is an important instrument for indirect non-destructive assessment of basic density of logs (Greaves *et al.*, 1996; Raymond and Donald, 1998). Pilodyn have been successfully used for indirect estimation of wood density in tree breeding programmes of many softwoods and hardwoods (Warrier and Venkataramanan, 2014). Wu *et al.* (2010) tested the effectiveness of Pilodyn in evaluating wood basic density, outer wood density, heartwood density and modulus of elasticity (MOE) in four year old eucalyptus clones in Guangxi, China. There found to have significant differences (1% level) in Pilodyn pin penetration depth between the different treatments, along different directions and between the various clones. They also observed strong negative correlations between Pilodyn pin penetration depth and wood properties. The results confirmed that Pilodyn is an effective and efficient means of estimating wood properties.

Warrier and Venkataramanan (2014) observed strong significant negative correlation between the Pilodyn pin penetration depth and wood basic density (-0.847) in the four year old clones of *Casuarina equisetifolia.* Hansen (2000) also observed that the penetration depth was inversely proportional to the density of the wood. Ponneth *et al.* (2014) observed that significant negative correlation (1% level) between specific gravity (oven dry) and Pilodyn pin penetration depth in all the seven tropical hardwood species in the study. The highest correlation was observed in *Tectona grandis* and the lowest in *Hevea brasiliensis*. They also noticed a negative correlation between specific gravity at pith, middle and periphery regions and Pilodyn penetration depth at these positions. Significant negative correlation was found for pin penetration depth with modulus of rupture, horizontal shear stress at maximum load and dynamic MOE. A linear relationship was also noticed between the penetration depth and specific gravity (air dry). Similar findings were reported by Greaves *et al.* (1996) and Muneri and Raymond (2000).

2.4.2. Tree sonic timer

Treesonic Microsecond Timer (TMT, Fakopp Enterprises, Sopron, Hungary) is an acoustic tool for rapid prediction of wood stiffness (MOE) of standing trees from stress wave velocity (Lindstorm *et al.*, 2002; Wang *et al.*, 2007)

Ishiguri *et al.* (2006) studied the relationship between stress wave velocity of standing tree and wood quality in 27 year old Hinoki (*Chamaecyparis obtusa* Endl.) and found that stress wave velocity of standing trees appeared to be affected by wood quality, especially by basic density and Young's modulus in juvenile wood. They also observed a significant relationship between stress wave velocity of standing trees and dynamic young's modulus or modulus of elasticity in static bending of square timber.

Wang *et al.* (2001) found that by using stress wave propagation method MOE can be computed using the equation MOE = $\rho * v^2$, where, v is the velocity and ρ is the mass density of the material. They also observed that round and straight logs produced better correlation between dynamic MOE and static MOE than the logs that were of inconsistent dimensions. The diameter- length ratio (D/L) also had a decisive effect contributing significantly when used in the analysis of dynamic MOE.

Ross and Pellerin (1988) found that longitudinal stress wave non-destructive evaluation techniques were useful in assessing the modulus of elasticity of green material. Searles and Moore (2009) observed that, portable stress- wave based tools deliver a cost effective means of forecasting the stiffness or elastic properties in standing tree or in logs. In the application of stress –wave based tools to the Sitka spruce supply chain in the UK, there was a strong relationship exhibited between the mean modulus of elasticity of the timber cut from a particular site and the mean modulus of elasticity of the timber cut from a particular site and the mean stress wave velocity measured for trees at the same site.

Mochan *et al.* (2009) observed that there exist a strong relationship between stress wave velocity measured using the two different methods. The results of resonance measurements and the time-of-flight measurements taken on standing trees taken on logs cut from same trees. The correlation between the readings of the two instruments indicates that it is possible to make reliable estimates of wood stiffness in a plantation before a tree is felled.

Wang *et al.* (2001) observed a strong relationship between SWV in trees and in small, clear specimens (Correlation coefficient, r= 0.83). The stress wave based non-destructive evaluation technique used in their study provided reliably accurate stress wave information, there by strengthening the argument for using such instruments in the prediction of wood properties in standing trees.

Ponneth *et al.* (2014) found that Treesonic Microsecond Timer (TMT, Fakopp) can be used in the field to predict mechanical strength properties. Dynamic modulus of elasticity obtained by TMT correlates well with barring shearing stress, bending MOE and MOR. Regression equations related to dynamic MOE and static MOE demonstrate that the stiffness of logs can also be determined by TMT. The study also concluded that the species-specific responses to acoustics show the necessity to calibrate NDT instruments to the needs of local resources and local markets.

Ross and Pellerin (1988) studied various wood materials like clear wood, lumber and veneer and found a correlation coefficient (R=0.9) between stress wave modulus of elasticity (dynamic MOE) values obtained from time- of-flight-type measurements and static MOE.

Chauhan and Walker (2006) observed that within the same stand acoustic velocity was found more variable than the peripheral wood basic density; it signifies the prominence of acoustic velocity as a better parameter in the screening based on the outer wood modulus of elasticity (MOE). They also observed a strong positive relationship between the acoustic velocity measured on standing trees using the instruments, Fakopp and Hitman ST 300 on butt logs of the corresponding logs obtained from same trees. The Fakopp instrument gave higher velocity on an average by 9% in the 8 and 16 year old trees and up to 17% higher in the 25 year old trees. Though a justifiably good correlation was observed between the velocities obtained, the strength of comparison was poorer in the 25 year old stand. Some trees exhibited huge differences (25-30%) in the two velocities obtained. They point out this difference to be due to the tree diameter, stand age and the bark proportion on the trees and also to be due to presence of a knot or any such defects in the area through which the wave propagate. Though the relationship between log basic density and acoustic velocity was very weak for young stands, it was found to be improved in the older stands.

2.5. PROPERTIES OF PLANTATION SOIL

Influence of physical properties like soil texture, bulk density and chemical properties like soil organic carbon content, pH, mineral nutrient content etc in the growth of plantation grown trees were discussed below.

2.5.1. Physical properties of soil

Balagopalan (1995) studied the soil characteristics in natural forests (evergreen and moist deciduous forests), grassland, plantations of teak and cashew in the Malayattoor Forest Division, Kerala. The study found that excluding gravel and silt, most of the soil properties differed significantly due to vegetation types. Compared to the natural forest soils in the plantations were found to be deteriorated.

Alexander *et al.* (1987) studied the soil properties in different site qualities of teak plantations and observed that variation in site quality of teak plantations and observed that variation in site quality of teak plantations is influenced by soil parameters such as gravel, sand, pH and exchange acidity.

Okoro *et al.* (2000) compared the soil properties of monoculture plantations of teak (*Tectona grandis*), opepe (*Nauclea diderrichii*), idigbo (*Tectona ivorensis)* and gmelina (*Gmelina arborea*) in the lowland rain forest belt of South-western Nigeria with that of natural forest found that the texture of the soils were not affected by the respective plantation species. Rathod and Dewar (2003) studied morphological and physical properties of soils of teak plantations of different ages, noticed an increased compaction of soil in older plantations than the younger plantations. They also observed a change in texture from loamy sand to sandy loam in young plantations.

After summarizing the earlier studies on soils in teak plantations and adjacent natural forests, Champion, (1932) concludes that soil samples showed no significant difference in the distribution of particle –size seperates. However soils in plantations were found to be much harder due to exposure. Jose and Koshy (1972) found that when the morphological and physical properties of soils of teak plantations of different age were studied an increase in compaction was reported in the older teak plantations.

Mishra *et al.* (1997) studied the soil physical properties under *Acacia auriculiformis* and *Tectona grandis* plantations with barren land. The study observed that clay and silt content increased and sand content decreased in soils under plantations as compared to barren land.

Bulk density is a dynamic property of soil that varies with the soil structural conditions. It was also noticed that due to changes in organic matter content, porosity and compaction, bulk density increased with profile depth (Chaudhari *et al.*, 2013).

Amponash and Meyer (2000) studied soils of natural forests converted to teak plantations in the Offinso and Juaso Forest Districts in the Ashanti region, Ghana observed that, bulk density increased in the 0-20 cm and 20-40 cm depth. Teak plantations of Nilambur attribute good site quality due to high silica-sesquioxide ratio, alluvial soils, moisture availability, drainage, sandy loam texture and higher level of bases (Davis, 1940; Laurie and Griffith, 1942).

Jose and Koshy (1972) studied on the morphological, physical and chemical characteristics of soils under 1, 15, 30, 60, and 120 years of teak growth. They observed that the natural forest and 120- year teak plantation have similarity in surface horizons rich in organic matter. The study also observed higher values for bulk density and particle density and relatively lower values for pore space and water-holding capacity than those of natural forests. However, it was also noticed that physical properties of soils from 120 year plantation were similar to those of natural forest although there is considerable compaction in second rotation plantations.

Balagopalan and Rugmini (2006) studied the soils under different teak growing regions of Kerala (Achencoil, Konni, Ranni, Thenmala, Nilambur and Wynad). Soils from Nilambur region were loamy and medium acidic in all site quality classes.

Sharma (2015) studied physic-chemical properties of soils under different land use systems (bamboo grooves, teak plantation, rubber plantation, orange orchard, lowland rice field and natural forest) in Dimoria tribal belt of Assam. The study found that average bulk density of soil ranged from 1.07 to 1.41 for different land use systems. Teak plantation had higher value for bulk density while bamboo grooves had the lowest. They also observed that soil in the bamboo plantation was fine textured, clay or silty clay soil whereas in teak plantation coarse or sandy textured soil was found.

2.5.2. Chemical properties of soil

Balagopalan and Alexander (1984) reported a decline in soil organic carbon distribution in teak plantations when compared to natural forests. Balagopalan *et al.* (1992) studied the chemical properties of soils under monocultures of teak (Tectona grandis), eucalyptus (*Eucalyptus terticornis*, coppiced and uncoppiced) and mixed stands of teak and bombax (*Bombax ceiba*) in Kerala. They found that the chemical properties varied between the plantations. Relatively low values were observed for pH, organic carbon, exchangeable bases and exchange acidity in monoculture plantations of both teak and eucalyptus compared to those in mixed plantations.

Aborisade and Aweto (1990) investigated the effects of exotic plantations of teak and gmelina on forest soil in South-western Nigeria and observed that the concentrations of total nitrogen, exchangeable calcium, magnesium and potassium were greater under forest soil, but for available phosphorous concentrations were similar under all ecosystems.

Krishnakumar *et al.* (1991) studied the ecological impacts of plantations of *Hevea brasiliensis* and *Tectona grandis* and natural forest on soil properties, nutrient enrichment, understorey vegetation and biomass recycling. The study observed that all stand types retained high organic matter input that helped to enrich the soils. Teak had the highest organic matter content in the surface layer and depletion of organic matter with depth was also highest for teak and less for natural forests.

Mongia and Bandayopadhyay (1994) observed that under teak, rubber, oil palm and padauk plantations N, P, K, organic carbon and pH were found to be low than natural forests soil. Dagar *et al.* (1995) found a significant decrease in soil pH, organic matter, extractable phosphorous and exchangeable potassium contents in areas cleared for commercial plantation in the Andaman and Nicobar Islands. The study concluded that nutrient cycling was negatively affected by the monoculture of commercial plantations.

Salifu and Meyer (1998) studied the physico-chemical properties of soils associated with logged forest and areas converted to teak in Ghana. They observed significantly higher nitrogen and magnesium concentrations and organic matter contents in the surface soil horizons under logged forest than in teak plantations. They also found that phosphorous and potassium concentrations were higher in logged forest.

Amponsah and Meyer (2000) studied soils of natural forests converted to teak plantations (21.3 ± 5.1 years) and significant decrease in soil organic matter content, total nitrogen, available phosphorous was observed in the 0-20 cm depths, where natural forests were replaced with teak plantations. Similar trend was also observed for 20-40 cm soil depths.

Geetha and Balagopalan (2005) studied soil fertility variations within a rotation period in teak plantations in Kerala. They observed that organic carbon in teak plantations varied from 0.9 to 2.3 % and mean values of nitrogen varied from 0.21 to 0.27 %. In all, organic carbon and nitrogen were significantly lower than that in the natural forest.

Sharma (2015) studied physic-chemical properties of soils under different land use systems (bamboo grooves, teak plantation, rubber plantation, orange orchard, lowland rice field and natural forest) in Dimoria tribal belt of Assam. Most of the soil samples revealed organic matter above 3 percent, of which highest organic matter content was observed in bamboo grooves followed by orange orchard and natural forest and lowest amount was found in teak plantation. They also conclude that lower value of organic matter content may be due to low under vegetation and sandy soil, whereas others experience regular falling of leaves which may increase soil organic carbon and thus the total organic matter. Also the pH of soil samples was found acidic in almost all the samples. Compared to other land use systems soil from teak plantation had relatively lower value of nitrogen, phosphorous and potassium.

2.6. RELATION BETWEEN TEAK GROWTH AND SOIL PROPERTIES

Hardly *et al.* (1935) stated that the relationship that existed between the plant and its environment was not simple and factors other than nutrient supply might affect the growth and composition of the plant. Teak can grow on a variety of soils. The quality of its growth depends on the depth, structure, porosity, drainage and moisture holding capacity of the soil. The best teak growth is obtained in well-drained deep alluvial soils (Seth and Yadav, 1957)

Kadambi (1972) suggested that high SiO2/ R2O3 ratio in the soil, alluvial site, high content of bases, especially Ca and Mg, good moisture availability, sandy loam texture and good drainage are the factors helpful for high quality of teak.

Singh *et al.* (1990) studied the characteristic of teak soils in the Tarai region of West Bengal revealed that there was a significant correlation existed between height and certain chemical properties of surface soils. Chongsuksantikun (1991) studied the relationship between some soil properties and growth of teak revealed that better teak growth was obtained when pH of the soil was moderately acid to near neutral , with medium to very high available P, high to very high exchange Ca, medium to high base saturation and high to very high cation exchange.

Growth conditions and silvicultural practices like spacing and thinning generally influence the rate of tree growth which in turn influences the anatomical characteristics. Teak responds to cultural operations and fertilizer application only in younger stages with no significant improvement in volume increment in older plantations (Balagopalan *et al.*, 1998).

Edaphic characters mainly the parent material or the nature of underlying rocks from which soils are formed influence the quality and distribution of natural teak. Tree growth and cell characteristics were largely influenced by physical and chemical properties of soil. Thus edaphic and climatic factors may have greater impact on wood quality than cultural and silvicultural operations (Varghese *et al.*, 2000).

Abod & Siddiqui (2002) studied growth response of teak seedlings to N, P, K fertilizers. The results of the study indicated that indicated that root weight, leaf area and total plant weight of the teak seedlings were significantly affected by all the three main factors i.e. N, P and K. They also observed that height increment, leaf weight, shoot weight and root length showed statistically significant responses to Nand P fertilizers.

Teak grows well on sandy loam soil implying good water drainage with a depth greater than 90 cm and near neutral status; pH range between 6.5 and 7.5 (Zanin 2005, Alvarado, 2006).

2.7. PRICE VARIATION OF TEAK IN MARKET

Troup (1921) judged teak as an important timber tree of India. The unique qualities of teak like durability, aesthetic quality, workability, relative resistance to damage by moisture and insects, medium hardness, outstanding dimensional stability, low thermal conductance and a highly favorable strength to weight ratio, make teak timber the most valuable and most preferred one for diverse end-uses. Teak is adopted as a standard for deciding the suitability index of other timbers used in varied uses (Krishnankutty and Chundamannil., 2011).

Teak is the most valued species in India for structural and non structural applications and has always commanded a premium price in retail market and this has been deeply grained in the Indian consumer mindset (Shukla and Viswanath, 2014). Establishment of teak plantations in India date back to 1840s .One of the oldest teak plantation established during that time known as Connolly's plot still exists in Nilambur, Kerala as a national heritage (Pandey and Brown, 2000). Teak production in India alone is estimated to be about 0.25 million cubic metre while annual global production is in the range of 1.5–2.0 million cubic metre (Pandey, 2009). The current domestic resources of teakwood are not able to meet the huge market demand. Non availability of quality planting material and unscientific management practices has greatly hampered production of quality teak wood (Ball *et* *al*., 2000). Despite the increasing demand of teak timber, its full potential for providing direct revenue as well as value-added down-stream processing which might have benefitted the teak growers has not been capitalized.

Keogh (2005) stated that teak has a strong reputation for high prices, excellent wood quality and its silviculture is understood making it one of the most valuable multipurpose timbers of the world. The ever-increasing demand for teak timber has resulted in large scale plantations both within and outside its range of natural distribution. Subramanian *et al*. (2000) reported that about 1.5 million hectare of teak plantations exists in the country and around 50,000 hectares of teak plantations were raised annually.

Krishnankutty *et al*. (2005) found that apart from teak plantations, home gardens also act as a major source of the teak wood supply in Kerala. Most of the teak wood produced in the state was consumed mainly for building construction and furniture making. The study also observed that out of the total timber consumption in the state, about 12 % is teak.

Krishnankutty and Chundammanil (2011) found that sawmills in Kerala mainly depends on timber imported from aboard and from homegardens.

Krishnankutty (1998) studied timber price trends in Kerala and future prices of teak logs in girth- classes 1,2 and 3 were predicted for the years up to 2015-16, using autoregressive integrated moving average models based on current prices for a 53-year period from 1941-42 to 1993-94. The study showed that the price forecasts for teak logs in girth-classes 1, 2 and 3 for the year 2015-16 at current prices are Rs. 90,000 per m^3 with 95 % confidence limits from Rs. 45,000 to 135,000 per m^3, Rs. 71,000 per m^3 with limits from Rs. 39,000 to 103,000 per m^3 and Rs. 67,000 per m^3 with limits from Rs. 37,000 to 98,000 per m^3 respectively.

FAO (2013) reported that out of the four countries of natural grown teak, only Myanmar and Indonesia continue exports; India and Thailand now import teak. African logs are reported exported to India and Carribean, logs and conversions to Cannada. India, with its expanding population and growing economics, may be considered as a major player in the global teak trade. In the recent years, the timber market has been opened up with a drastic reduction in import duty on logs and veneers. The rationale for this import policy has been to meet the needs of timber industry in India to overcome shortage of logs. The volume of log trade between South East Asia and India has already exceeded 1 million m^3 and it is quite likely that this increasing trend will continue.

MATERIALS AND METHODS

MATERIALS AND METHODS

3.1 MATERIALS

3.1.1. Species studied

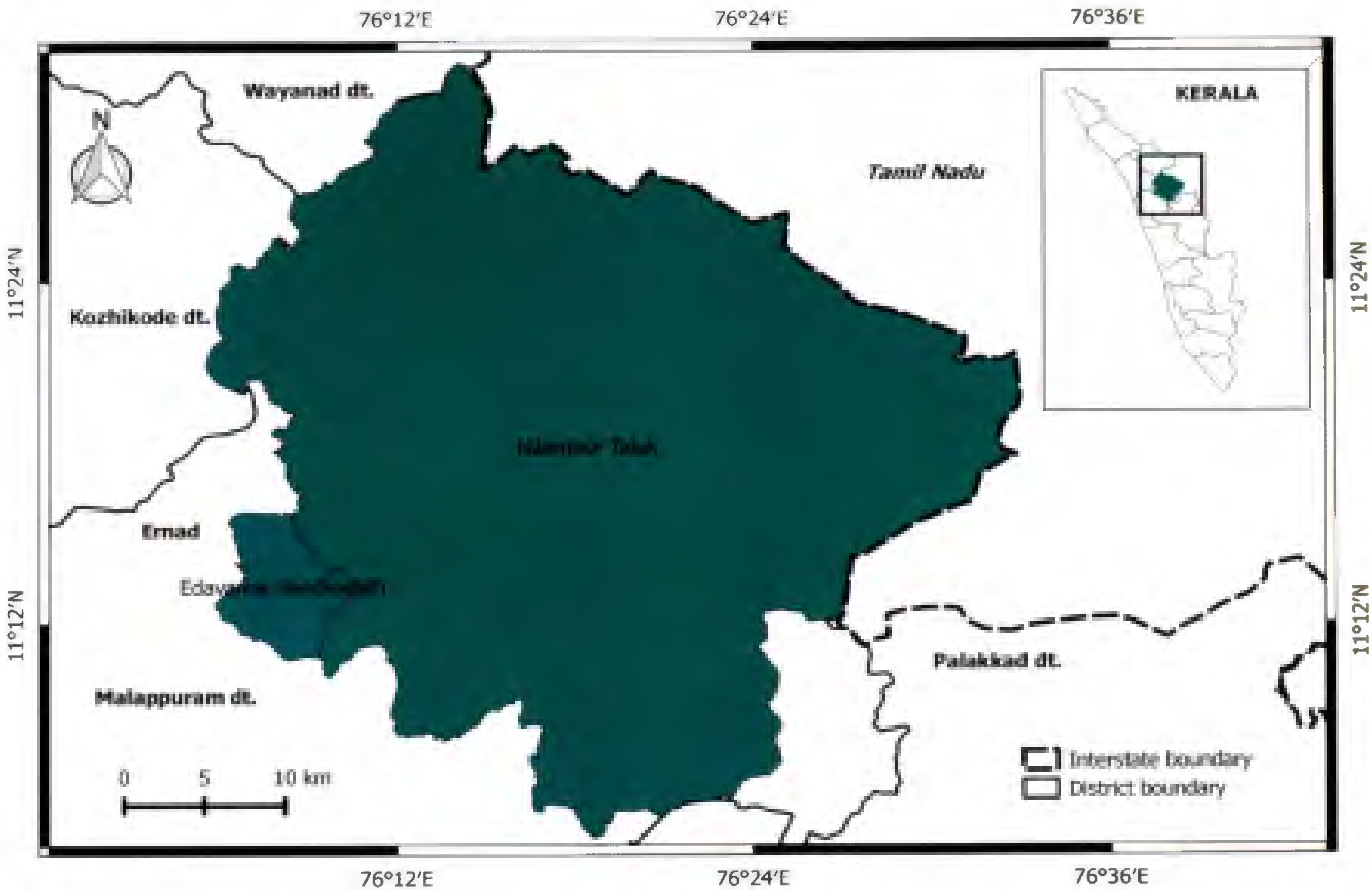
The species studied was Nilambur teak (*Tectona grandis* L.f) and is locally known as Nilambur thekku. Its ring porous wood is moderately hard, moderately heavy and medium coarse textured with straight grain. Heartwood and sapwood are distinct from each other. Sapwood is pale yellow or grey, heart wood is golden brown or dark brown occasionally with black streaks with a waxy feel and is lustrous (Anish, 2013). The wood has an attractive figure produced by distinct growth rings. The wood has characteristic smell. The wood is well known for its quality and is often used as a standard for comparison for other timbers. It has a wide range of uses; from ship building, construction, paneling, interior fittings, railway sleepers, furniture and cabinet making. It is an outstanding timber for joinery.

3.1.2. Location

The study was done in three best teak growing areas of same age class in Nilambur of Malappuram district of Kerala. The study areas included teak plantations of Aryavallikavu, Elencheri, and Kanakuthu in Nilambur (north) division, the details of which are provided below.

3.1.2.1. Aryavallikavu

Aryavallikavu is at 11^0 11' 39"N and 76^0 07' 30" E of Nilambur range, Nilambur north division. The teak plantation was established in the year 1975. It covers an area of 25 hectares.



GIS Lab, College of Forestry, KAU

Fig. 1. Geographical location of the study area

3.1.2.2 Elencheri

Elencheri is at 11^0 16' 24"N and $76^0$12' 32" E of Edavanna range, Nilambur north division. The teak plantation was established in the year 1976. It covers an area of 25.80 hectares.

3.1.2.3 Kanakuthu

Kanakuthu is at 11^0 12' 28"N and 76^0 8' 06" E of Nilambur range, Nilambur north division. The teak plantation was established in the year 1977. It covers an area of 40.05 hectares.

3.2 METHODS

The following growth measurements and measurements using non-destructive instruments were carried out on selected trees of above 100 cm girth at breast height and grown in the three teak plantations at Aryavallikavu, Elanchery and Kanakuthu. A total of 30 trees were taken from each study plot established in the plantation. Soil profile study was also conducted in each of these regions. Heartwood – sapwood ratio and heartwood colour were analyzed from the sample collected from the three plots.

3.2.1 Measurement of growth characteristics

Growth characteristics such as total tree height and girth at the breast height of the trees were measured. Height measurements were taken using a Haga altimeter. The Haga altimeter has a gravity controlled pivoted pointer with a series of scales (15, 20, 25 and 30 m) and a percent scale. In the present study, height measurements were obtained using the 15 m scale of the instrument. Girth was measured at breast height using a measuring tape.

3.2.2 Measurements using non-destructive instruments

Pilodyn and tree sonic micro second timer were the two non-destructive equipment used in this study.

3.2.2.1 Pilodyn measurement

Pilodyn is an instrument used for indirect non-destructive assessment of basic density (Greaves et al., 1996 and Raymond and Macdonald, 1998) of logs as well as standing trees. Pilodyn drives a steel pin and the penetration (referred as pin penetration depth – PPD) is indicated on the instrument and is inversely proportional to the density of the wood (Hansen, 2000). In the present study, Pilodyn 6 J (FUJITECK, Tokyo, Japan) with 2.5 mm pin diameter was used for taking measurements. Using Pilodyn, readings were taken from the selected trees of the study area. In the present study, PPD was taken from three sides of well grown standing trees at the breast height and their average was calculated for getting PPD value representing a tree. The penetration depth was recorded by pressing the Pilodyn 6 J against the bark removed portion of the tree. Selected standing trees from the three plots were subjected to pilodyn measurements. The penetration was read in millimeters (0-40 mm) on the scale on one side of the instrument.

3.2.2.2 Tree sonic micro second timer measurement

Tree sonic micro second timer (Fakkopp, Hungary) is used to rapidly predict wood stiffness (MOE) of standing trees (Wang *et al.*, 2000; Lindstorm et al., 2002; Kumar *et al.*, 2002; Toulmin and Raymond, 2007; Dhanya 2012). The instrument is designed and patented by Wayerhaeuser Co. (Chin-Lin, 2005). The timer consist of two transducers, the longer and flat shaped transducer with red mark is the start and the shorter and cube shaped one is the stop transducer. The transducers were inserted into the tree and the breast height point comes between the two transducers. The start transducer was hit with a sliding hammer. The measurements were repeated thrice in

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Pin Penetration Depth measurement using pilodyn (6J)

Stress Wave Velocity (SWC) measurement using Tree Sonic Micro Second Timer (FAKOPP)

Plate 1. Measurement using non-destructive instruments

each tree at two exactly opposite sides of well grown standing trees. The time required for the sound waves to pass from the start transducer through the log was noted from the timer. Velocity was calculated by dividing the distance travelled by the stress wave by the time taken (Mochan *et al.*, 2009). Dynamic MOE (Modulus of Elasticity) or stiffness was measured using the one dimensional relationship: $E= \rho \times v^2$, where E is the modulus of elasticity, ρ is the actual density of the wood at the time of measurement in Kg/m^3 and v is the velocity in m/s (Dhanya , 2012; Chauhan et al., 2005; Chauhan and Walker, 2006; Lasserre *et al.*, 2007)

3.2.3. Physical Properties of Wood

Heartwood colour and heartwood- sapwood ratio were the two physical properties studied, the details of which are provided below.

3.2.3.1. Heartwood colour

Heartwood colour determination of the samples was conducted using munsell system (1976). From the air dried (12% moisture content) 5 cm thick cross sectional disc, a radial strip of 3 cm width was cut from inner to outer heartwood in both radii excluding pith. The two cut samples were ground in a mechanical grinder separately. The powder was passed through No. 40 (420μm) sieve and retained in No. 60 (250 μm) sieve respectively. The colour of the samples was determined within a day after the sample preparation to avoid colour changes caused by oxidation or light.

Munsell notation of colour difference is considered for visual interpretation as influenced by personal judgement of colour. The powdered wood sample placed under the colour chart appears through the round openings, allowing easy comparison with the rectangular colour chips. The colour is then identified by its hue, value and chroma. Hue value ranges from 9.9 R to 1.0 Y from red to yellow. The scale of value ranges from 0 for pure black to 10 for pure white. Value indicates the lightness/ brightness of a colour. Chroma is the departure of a colour from its neutral colour of

Wood discs used for heartwood percentage estimation

Determination of hardwood colour using Munsell Colour System

Plate 2. Measurement of heartwood percentage and colour

the same value. Colours of low chroma are sometimes called weak, while those of high chroma are said to be highly saturated, strong or vivid.

3.2.3.2. Heartwood - Sapwood ratio

Heartwood-sapwood ratio was measured from the collected wood discs. The image of the collected wood samples was taken and analyzed using Digimizer software.ver.4.

3.2. Soil analysis

To analyze the soil physical properties and nutrient contents of Nilambur soil, profile wise study was conducted. Two profiles of 1m depth were taken from each of the three sites belonging to site quality II. Soil samples were collected from five soil depths (0-20 cm, 21-40 cm, 41-60 cm, 61-80 cm and 81-100 cm) from each profile and the collected samples were analysed for soil organic carbon content, pH, bulk density, colour, texture, total N, P and available K contents following standard analytical methods.

3.2.1. Physical properties of Soil

Physical properties of soil like soil texture and bulk density were estimated using standard analytical methods. The details of which are provided below.

3.2.1.1 Soil texture

Particle- size seperates were analyzed by International Pipette method (Piper, 1942). 20 gm of soil was treated with 100 ml of 30 % H_2O_2 to destroy the organic matter in the soil. It was stirred well and kept on a hot plate for 30 minutes or until effervescence ceased. After cooling 200 ml of 0.2N HCL was added and kept overnight to remove $CaCO_3$. The extract was then filtered and washed until it was free of chlorine. The extract in the filter paper was then transferred to a 500 ml beaker. To this, 400 ml distilled water and 8 ml of 1 N NaOH was added and stirred for 5-10 minutes using a mechanical stirrer. This soil water suspension was

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Plate 3. Collection of soil samples from the study area

transferred to a 1 L measuring cylinder by pouring the suspension through a 0.2 mm sieve. The residue retained in this sieve corresponds to the content of coarse sand. The residue was transferred to a pre- weighed china dish and kept it to be settled and supernatant liquid was washed until a clear solution appeared. This was then dried in an oven at 105^0C and weighed after cooling to get the measure of coarse sand. Again the suspension was made to 1 L. The temperature of the suspension was noted and contents were shaken thoroughly. 20 mL suspension was pipetted out from the cylinder to find out clay, silt and fine sand particles based on their sedimentation time. The weight of particles measured using a weighing balance.

3.2.1.2. Bulk Density

Bulk density was estimated by taking out a core of undisturbed soil by using a core sampler. The core was taken out without pressing the cylinder too hard on soil, so that the natural bulk density of soil does not get disturbed. The soil was oven dried and weight was determined. The volume of soil was calculated by measuring the volume of cylinder. Bulk density was then calculated by dividing the oven dry weight of soil samples (g) by volume of soil.

3.2.2. Chemical properties of soil

Chemical properties of soil like soil pH, organic carbon content, total nitrogen, total phosphorus, available potassium were estimated using standard analytical methods and are discussed below.

3.2.2.1. Soil pH

Soil pH was calculated using an aqueous suspension of soil (soil and water in 1:2.5 ratio) using an Elico pH meter (Model Li 613) as described by Jackson (1958).

3.2.2.2. Soil Organic Carbon

Soil organic carbon was determined by wet digestion method (Walkley and Black, 1934). The soil samples were dried and fine-grained using mortar and pestle and then passed through 0.2 mm sieve. 1 g sieved soil samples was transferred into a 500 ml conical flask to which 10 ml of 1 N $K_2 Cr_2 O_7$ and mixed thoroughly. 20 ml of Conc. H_2SO_4 was added to the conical flask and then kept for 30 minutes for oxidation.

Then 200 ml distilled water was added with four to five drops of ferroin indicator. It was titrated against 0.5 N $FeSO_4$ solution until dark green color to chocolate brown color. A blank was also run simultaneous and readings were noted.

$$\text{Soil organic carbon (\%)} = \frac{\text{Amount of 1 N } K_2Cr_2O_7 \text{ used x 0.003 x 100}}{\text{Weight of soil sample (g)}}$$

Soil organic matter was calculated by multiplying the value of organic carbon by 1.724 (Van Bemmelen factor).

3.2.2.3. Total Nitrogen

Total nitrogen content in soil samples was determined by using Continuous flow analyser (SKALAR).

Sulphuric acid and Selenium powder mixture – one litre of conc. $H_2SO_4$was poured carefully into a two litre beaker. Selenium powder (3.5g) was then dissolved into the H_2SO_4 by heating the beaker for 4 to 5 hours at 300^0C. The black colour of the solution changed to deep blue colour and then light yellow. The solution was then cooled.

Digestion mixture - 10.8 g salicyclic acid was weighed and added into 150 ml of H_2SO_4 Selenium mixture which was already prepared. For estimation of N, 0.4 g of the soil sample was taken in the digestion tube. Then 2.5 ml of the digestion mixture was poured into the digestion tube. The tube was then swirled well and allowed to stand for 2 hours or overnight. It was then inserted into the digestion block and heated at 100^0 C for 2 hours. After cooling, the tubes were removed from the block and 1 ml of 30% H_2O_2 was added. After the reaction ceased, they were again placed in the digestion block and heated at 330^0 C for 2 hours. When the digest turned colourless, the digest was made upto 75 ml in a standard flask. The reagents were added and the readings were then read directly from the Continuous Flow Analyzer.

Determination of Nitrogen and Phosphorus using Continuous flow analyser

Determination of Potassium using flame photometer

Plate 4. Analysis of soil samples for NPK

3.2.2.4. Phosphorus

Total phosphorus content in the soil samples was also determined by using Continuous Flow Analyzer. The digestion mixture and the procedure followed for digestion were same as described for nitrogen.

3.2.2.5. Available Potassium

Available potassium was determined by flame photometry using 1N neutral normal ammonium acetate solution as the extractant (Jackson, 1958).

3.2.4. Participatory Rural Appraisal (PRA)

PRA approach is a grouping activity with an aim of obtaining data with better quality than those are normally obtained through questionnaire surveys. Moreover, PRA techniques collect and analyse data more quickly, efficiently and cost-effectively than the conventional questionnaire methods (Waters- Bayer and Bayer,, 1994 and Mukherjee, 2002). In addition, participants' knowledge about the history of Nilambur teak was collected by the PRA tool- Timeline analysis.

3.2.4.1. Timeline analysis

Historical narration of events, their impact and changes can differ across participants depending on their perceptions, and it is useful to keep track of the broad time period to which they refer to rather than specific dates. Important events/ changes of recent and not so recent origin, having an important bearing on the local community, can be discussed with a group of elderly community members and their time periods can be identified by the members in that process. This helps in contextualizing any relevant issue through a chain of events and provides a historical perspective to the same.

In order to construct a timeline, one sits with elderly men and women in a community who slowly try to reconstruct the historical pattern of changes in different variables that have been take place in their locality/community. They may or may not

Plate 5. Participatory rural appraisal with various stakeholders at Nilambur

be able to state precise time/ year of such changes but they are generally able to connect such changes with major historical events, whether political, economic or social. The present study identified the different time periods of major events/ activities in Nilambur.

3.2.5. Survey of saw mills

A survey was carried out in the sawmills of Thrissur, Ernakulam and Palakkad to collect data about the reputation and importance of Nilambur teak among the sawmill owners with the help of a questionnaire.

3.2.5.1. Data collection

The reputation and importance of Nilambur teak among the mill owners were analyzed with the help of a questionnaire survey. A preliminary sawmill based survey was carried out to identify the timber markets that deals with different varieties of teak. On the basis of the details obtained, sawmills in Central Kerala (Ernakulam, Thrissur, and Palakkad) was selected for conducting the survey activity. A sample size of fifty sawmills were selected randomly from different parts of Central Kerala.

3.2.5.2. Questionnaire survey

A detailed survey interview schedule was prepared to gather information from the mill owners. The responses were set on different scales depending up on the nature and type of questions. The responses to certain questions were plotted on a five point Likert scale namely, strongly agree, agree, neutral, disagree and strongly disagree and were assigned scores 5,4,3,2 and 1 respectively. Similarly for certain questions 3 point likert scale namely, high, medium and low and the scores were assigned as 3, 2, and 1 respectively, were also used.

3.2.5.3. Variables selected for the study

Age of sawmill, years of experience of the sawmill owners in this field, major timber species sold out through sawmill were studied in the first part. In the second part, the perception of the respondents towards Nilambur teak, quality variations

Logs piled up in the saw mills

Interaction with saw mill owners

Plate 6. Questionnaire surveys in the saw mills

among different teak varieties, their timber preferences, were analyzed. Price and demand for different teak varieties were also studied.

3.6. STATISTICAL ANALYSIS

The data were subjected to statistical analysis by analysis of variance (ANOVA) in SPSS version 20.0 (SPSS Inc.,USA) to ascertain the significance of various parameters.

RESULTS

RESULTS

The present study was undertaken to elicit information required to assess the potential of securing Geographical Indications status for Nilambur Teak. The study attempted to explore the history of Nilambur teak using the timeline tool of participatory rural appraisal. The study also included assessment of certain tree growth parameters and wood properties of teak grown in three superior quality teak plantations of Nilambur viz., Aryavallikkavu, Elencheri and Kanakuthu. To analyse the soil properties of the region, profile-wise study was conducted at three locations of Nilambur. To explore the reputation of Nilambur teak among the timber merchants, a sawmill based survey was also conducted.

4.1. HISTORY OF MAJOR EVENTS RELATED TO NILAMBUR TEAK USING TIMELINE TOOL

Timeline tool of PRA helped to reveal the history of Nilambur teak over decades, and is presented in Table 1. It revealed that the history of Nilambur teak started as early as 14th century, where, Arabs started Uru/Dhow manufacturing units at Beypore, Kozhikode. The respondents said that Nilambur teak was largely used for the construction of certain historically important monuments and also in some historically important battles during this period.

Table 1. Timeline of major events related to Nilambur Teak

YEAR	EVENTS
Early 14th century	Arab's dhow/ uru making units were started at Beypore, Kozhikode. Uru was manufactured and exported to Arab countries.
1705	Nilambur teak was used in the construction of Buckingham palace.
1792	Under the Sriranga Pattanam treaty the entire Malabar area (except Wayanad) came under British rule.
	An order was issued by the Bengal-Bombay joint commission prohibiting felling of teak below 21 cm of girth from Malabar forests.

1796	Britishers established a timber syndicate in Malabar to ensure steady supply of Nilambur teak for the British Navy.
1800	Rafts were used for teak transportation through river.
1806	Captain Watson was appointed as the 'Conservator of Teak'
1815	Used in the battle of Waterloo.
1841	Mr. Smith was entrusted with the mission to increase forest land by regenerating teak artificially.
	Lease agreement on forest land between Nilambur Thirumulpad and the Government.
1842	Sir. H. V. Connolly appointed as the Collector of Malabar. With the assistance of Sri Chathu Menon, the then Sub Conservator, he raised the first teak plantation in the world on the northern banks of Chaliyar river in Nilambur.
1843	Forest area of Zamorin of Calicut were given in lease to the Government.
1844-62	Teak raised in about 1515.71 acres of land in Nilambur.
1867	The largest plantation of teak was established in the Nellikuthu-Karulai region.
1871	Forest area of Edavanna Kovilakam were given in lease to the Government.
1887	Government purchased New Amarambalam Reserve in public auction from Edavanna Kovilakam
1893	First organized wood processing (saw milling) unit in Kerala set up at Kallai by A. Brown.
1894	First working plan of Nilambur division was prepared by P. M. Lushington.
1900s	Private forests were over-exploited and mismanaged.
1910	Nilambur teak was used in the construction of RMS Titanic (Majority of interior works of the ship were believed to be constructed using Nilambur teak).

1914-18	Nilambur teak is used in first world war for making guns.
1927	Nilambur- Shornur railway line was laid for the transportation of wood from Nilambur.
1928	Nilambur teak was used for renovation purpose in Kaaba (holiest shrine of Islam) located in Mecca, Saudi Arabia.
1930	Britishers established LOCAMP (logging camp) for giving training for the extraction of quality timber without wastage.
1939	Nilambur teak was used in the second world war.
1947	Britishers established teak plantations in Karulai. Timber exported to Qatar.
1949	The Madras Preservation of Private Forest Act came into force.
1971	A huge log of teak retained to be, about '10000' years old discovered during a well construction in Pilakkal mosque, Nilambur.
1985	Preservation of Trees Act 1985, came into force. Teak cutting in notified village, considered as an offence.
1989	After removing sapwood, the timbers were transported from Kulikapara to Thengilakadavu in rafts through Chaliyar river.
1990	The Punam cultivation (shifting cultivation) that started during the Britishers period came to an end.
1995	Kerala Forest Research Institute established a teak museum in Nilambur.
2013	Nilambur teak recommended for Geographical Indications status.

4.2 CLIMATE

Kerala fall under a tropical climate where the coastal location and high variation in relief influences the climatic characteristics to a large extent. While most of the areas are under tropical dry and wet conditions with high maritime influence, certain areas in the eastern parts experience subtropical type of climate.

4.2.1 Temperature

The average annual temperature in Nilambur is 25.86 °C. The average monthly temperature in summer (February to May) is 27.37 °C (Fig 2). April was the hottest month with an average monthly temperature of 28.36 °C. From June onwards, the temperature gradually comes down due to the advent of monsoon. An increasing trend in temperature was noted in September and October. The average temperatures of 24.77 °C during December to January were the coolest months.

4.2.2 Rainfall

The highest amount of rainfall was received in the months of June and July; the average monthly rainfall received in June and July was 474.65 and 523.85 mm respectively (Fig 3). From July onwards, the rainfall gradually comes down. In certain months there receives no rainfall in a year.

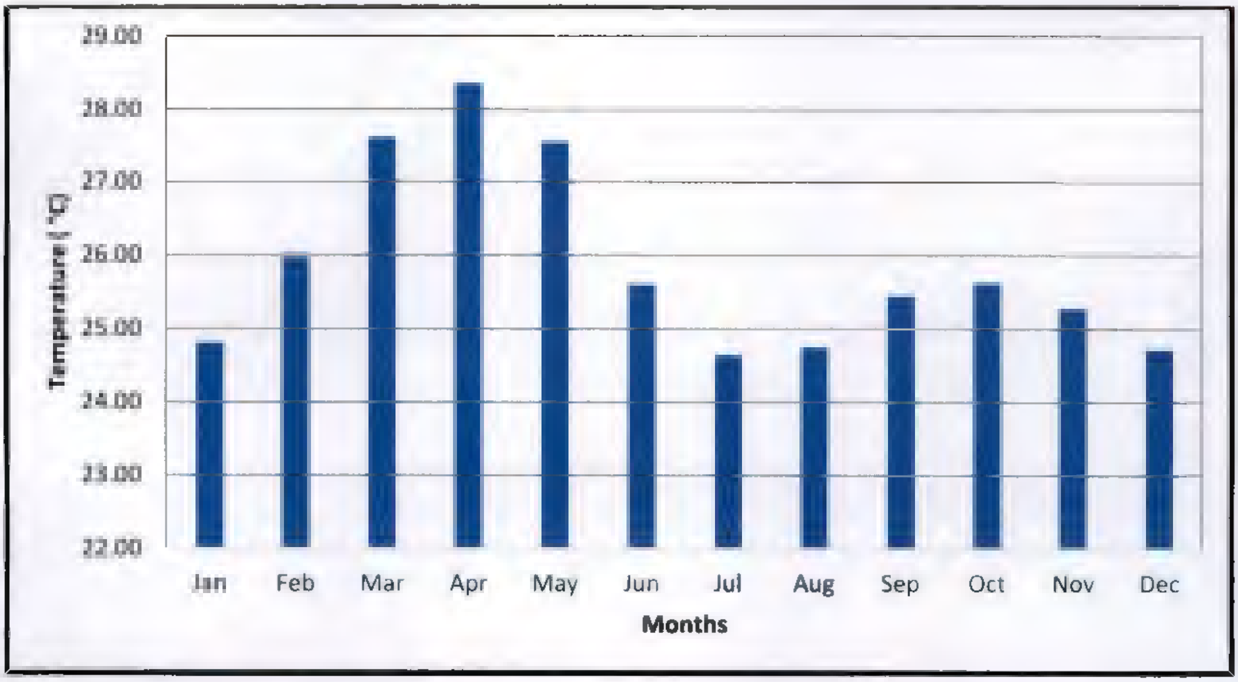

Fig 2. Average monthly temperature in Nilambur (1960-2016)

(Source: Kerala Agricultural University)

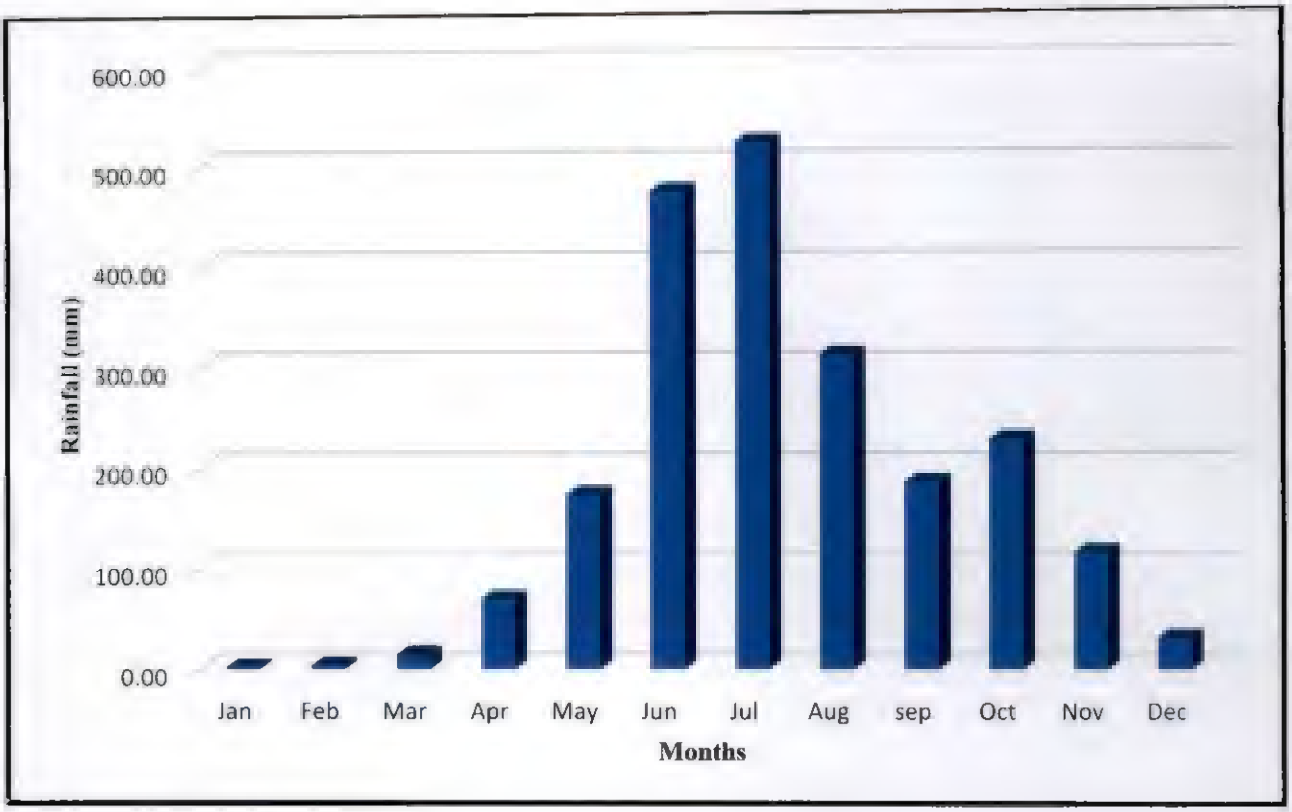

Fig. 3. Average monthly rainfall in Nilambur (1960-2016)

(Source: Kerala Agricultural University)

4.3 GROWTH ATTRIBUTES

Growth attributes like Girth at breast height and height were measured for selected trees in the three plots and results were given below.

4.3.1 Girth at Breast Height (GBH)

In the three tree plots analyzed, Girth at Breast Height (GBH) was found to have no significant difference between the plots and within the plots (Table 2). Mean tree GBH was found to be highest in plantation from Kanakuthu (126.04 cm), followed by Aryavallikkavu (121.47 cm) and Elencheri (120.5 cm).

4.3.2. Height

Height was found to have significant difference between the sites. Mean tree height was found to be highest in the plantation from Kanakuthu (16.93 m), followed by Elencheri and Aryavallikkavu plantations with mean tree height of 16.05 and 14.86 respectively (Table 2).

Table 2. Variation in tree growth parameters in (38 to 40 year old) teak plantations from three regions of Nilambur taluk.

Location	Girth (cm)	Height (m)
Aryavallikkavu	121.47^{ns} (13.58)	14.86** (1.68)
Elencheri	120.5^{ns} (16.39)	16.05** (2.03)
Kanakuthu	126.04^{ns} (14.23)	16.9** (2.11)
F Value for height (Location) – 8.583**		

*ns: non- significant; **: significant at 0.001 level,* Value in parenthesis shows standard deviation

4.4 NON DESTRUCTIVE EVALUATION

Results of measurements taken from the selected trees of three teak plantations like Pilodyn penetration depth and stress wave velocity using non-destructive instruments such as Pilodyn and tree sonic timer respectively were given below.

4.4.1. Pilodyn Penetration Depth (PPD)

There was no significant difference found in the pilodyn penetration depth between the three regions of Nilambur (Table 3). Pilodyn penetration depth was found to be highest in teak plantation of Aryavallikkavu followed by Kanakuthu and Elencheri with 13.31 mm, 13.23 mm and 12.73 mm respectively.

4.4.2. Density from pilodyn penetration depth

Density was not found to be significantly different between the plots and within the plot also. Density was found to be highest in teak plantation of Elencheri followed by Kanakuthu and Aryavallikkavu with 563.21 kg/m3, 550.59 kg/m3 and 548.99 kg/m3 respectively (Table 3).

Table 3. Variation in Pilodyn penetration depth (PPD) and density in (38 to 40 year old) teak plantations from three regions of Nilambur taluk

Location	Pilodyn penetration depth (mm)	Density (kg/m3)
Aryavallikkavu	13.31^{ns} (1.94)	548.99^{ns} (40.12)
Elencheri	12.73^{ns} (1.95)	563.21^{ns} (40.45)
Kanakuthu	13.23^{ns} (1.76)	550.59^{ns} (35.97)

ns: non- significant; Value in parenthesis shows standard deviation

4.4.3 Stress Wave Velocity (SWV)

Stress wave velocity was found to have no significant difference between the three regions and also within the region. The highest value for stress wave velocity was found in the plantation from Kanakuthu followed by Aryavallivaku and Elencheri with 3153.84 m/s, 3063.69 m/s and 3038.15 m/s respectively (Table 4).

4.5.4 Dynamic Modulus of Elasticity (Dynamic MOE)

Dynamic modulus of elasticity was found to have no significant difference between the three regions of Nilambur and also within the region (Table 4). The highest value for dynamic modulus of elasticity was found to be from plantations of Kanakuthu (547665 kg/cm^2) and the lowest in plantation from Aryavallikkavu region (515292.9 kg/cm^2).

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Table 4. Variation in stress wave velocity and dynamic MOE in (38 to 40 year old) teak plantations from three regions of Nilambur taluk.

Location	Stress wave velocity (m/s)	MOE (Kg/cm²)
Aryavallikkavu	3063.69 ^{ns}	515292.9 ^{ns}
Elencheri	3038.15 ^{ns}	519867 ^{ns}
Kanakuthu	3153.84 ^{ns}	547665 ^{ns}

ns: non- significant

4.5 Heartwood Colour

Heartwood colour determining components (hue, value and chroma) did not show any significant variation between the sites (Table 5). Among the teak samples of three study areas, a total of nine colour variations were described with the help of Munsell system (i.e. Brown, Yellowish Brown, Dark Yellowish Brown, Brownish Yellow, Very Dark Greyish Brown, Dark Reddish Brown, Light Yellowish Brown, Pale Brown and Yellowish Brown) (Table 6).

Table 5. Mean colour values as determined by Munsell system for (38 to 40 year old) teak from three regions of Nilambur taluk. (n=6)

Location	Munsell System		
	Hue	Value	Chroma
Kanakuthu	9.167 (1.29)	5.00 (0.63)	5.00 (1.67)
Aryavallikkavu	9.167 (2.04)	4.50 (1.38)	3.50 (0.84)
Elencheri	7.50 (2.73)	3.83 (0.75)	4.67 (1.63)

Value in paranthesis shows standard deviation.

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Table 6. Variation in heartwood colour in the samples collected from the selected plantations of Nilambur.

Location	Sample no.	Munsell system			Colour description	
		Hue	Value	Chroma		
Kanakuthu	1	10YR	4	3	10YR/4/3	Brown
	2	10YR	3	2	10YR/3/2	Very Dark Greyish
	3	10YR	4	4	10YR/4/4	Dark Yellowish Brown
	4	10YR	4	4	10YR/4/4	Dark Yellowish Brown
	5	10YR	5	4	10YR/5/4	Yellowish Brown
	6	10YR	5	4	10YR/5/4	Yellowish Brown
Aryavallikkavu	1	10YR	3	2	10YR/3/2	Very Dark Greyish Brown
	2	10YR	4	4	10YR/4/4	Dark Yellowish Brown
	3	5YR	3	4	5YR/3/4	Dark Reddish Brown
	4	10YR	5	4	10YR/5/4	Yellowish Brown
	5	10YR	6	4	10YR/6/4	Light Yellowish Brown
	6	10YR	6	3	10YR/6/3	Pale Brown
Elencheri	1	10YR	3	4	10YR/3/4	Dark Reddish Brown
	2	10YR	4	4	10YR/4/4	Dark Yellowish Brown
	3	5YR	3	4	5YR/3/4	Dark Reddish Brown
	4	5YR	4	4	5YR/4/4	Reddish Brown
	5	5YR	4	4	5YR/4/4	Reddish Brown
	6	10YR	5	8	10YR/5/8	Yellowish Brown

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4.6 Heartwood Content

The variation in heartwood percentage between the selected three study areas were found to be non- significant (Table 7), while higher percentage was found for the samples of Kanakuthu plantation, followed by Elencheri (85.27 %) and Aryavallikkavu (83.52 %).

Table 7.Variation in heartwood content

Location	Heartwood content Mean (cm^2)	Heartwood percentage
Aryavallikkavu	1068.65 ^{ns}	83.52%
Elencheri	1170.80 ^{ns}	85.27%
Kanakuthu	902.92 ^{ns}	87.06%

ns: non-significant

4. 7 Soil studies

Results obtained from the analysis of soil physical properties such as bulk density, soil texture and chemical properties such as soil pH, total nitrogen content, total phosphorus, available potassium and soil organic carbon content are given below.

4.7.1 Physical properties

Results of the study on physical properties viz., bulk density and soil texture in teak plantations of Nilambur are presented below.

4.7.1.1 Bulk Density

Bulk density was found to have significant difference between the three regions and also within a profile. Generally, bulk density values were higher in deeper layers of the soil (Table 8). In the depth of 0-20 cm, 21-40 cm, 41-60 cm, 61-80 cm, 81-100 cm, bulk density values varied from 1.32 to 1.39 gcm^{-2}, 1.46 to 1.49 gcm^{-2}, 1.45 to 1.58 gcm^{-2}, 1.39 to 1.83 gcm^{-2}, 1.52 to 1.92 gcm^{-2} respectively between the three regions.

Table 8. Bulk density at different depths in (38 to 40 year old) teak from three regions of Nilambur taluk

Depth (cm)	Aryavallikkavu (g/cm^2)	Elencheri (g/cm^2)	Kanakuthu (g/cm^2)
0-20	1.39 (0.70)	1.14 (0.09)	1.32 (0.06)
21-40	1.49 (0.17)	1.36 (0.03)	1.43 (0.19)
41-60	1.58 (0.13)	1.54 (0.06)	1.45 (0.11)
61-80	1.83 (0.13)	1.65 (0.04)	1.39 (0.14)
81-100	1.92 (0.06)	1.80 (0.11)	1.52 (0.05)
F value (Location) - 22.56 **			
F value (Layer) – 33.35**			

Value in parenthesis shows standard deviation; ** - significant at 1% level

4.7.1.2 Soil Texture

The soil texture analysis reveals that sandy loam soil was found in all the three sites and at the different depth of soils in teak plantations of Nilambur (Table 9). Generally, sand content decreases with increase in depth while silt and clay content increases with depth. The percentage of sand varied from 72.31 to 81.31 % at a depth of 0-20 cm. The silt content varied from 20.56 to 10.81 %, while the percentage of clay varied from 7.87 to 5.27 % at 0- 20 cm. The sand content at 21-40 cm was found to be from 80.87 to 71.19 %. The silt content at this depth was 20.19 to 11.09 % while the clay content ranged from 8.62 to 5.06 %. In the deeper layer (81-100 cm), sand content varied from 79.25 to 68.87 %, while silt and clay content ranged from 20.25 to 12.31 % and 10.94 to 6.25 % respectively.

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Table 9. Particle size distribution of soil at different depths under (38 to 40 year old) teak plantations from three regions of Nilambur taluk

Depth (cm)	Aryavallikkavu			Elencheri			Kanakuthu		
	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt(%)	Clay(%)
0-20	79.13±0.44	15.54±0.53	5.27±0.81	81.31±1.37	10.81±0.96	7.87±1.37	72.31±0.24	20.56±0.24	7.12±0.14
21-40	78.81±0.58	16.13±0.52	5.06±1.05	80.87±0.85	11.09±0.31	8.03±0.85	71.19±0.43	20.19±0.80	8.62±0.52
41-60	77.79±0.47	16.81±0.75	5.44±0.77	79.91±0.66	11.94±0.47	8.19±0.66	70.25±0.20	20.12±1.13	9.62±0.95
61-80	77.62±0.92	16.84±0.90	5.53±0.74	79.81±1.28	12.06±0.62	8.12±1.28	69.50±0.41	19.87±0.72	10.62±0.66
81-100	76.31±0.32	17.45±1.75	6.25±1.84	79.25±1.46	12.31±0.69	8.44±1.46	68.87±0.78	20.25±0.35	10.94±0.47

4.7.2. Chemical properties of Soil

Results of the study on chemical properties viz., soil pH, total nitrogen, total phosphorus, available potassium and soil organic carbon content are presented below.

4.7.2.1. Soil pH

The analysis of variance indicated that there was no significant difference found in the soil pH between the three regions of Nilambur but there exist a significant difference between different layers of soil profile within a region. Soil pH value showed a decreasing trend with increase in soil depth. The soil pH varied from 5.88 to 6.05, 5.61 to 5.83, 5.45 to 5.34, 5.25 to 5.20 and 4.79 to 5.00 at a depth of 0-20 cm, 21-40 cm, 41-60 cm, 61-80 cm and 81-100 cm respectively (Table 10).

Table 10. Soil pH at different depths in (38 to 40 year old) teak from three regions of Nilambur taluk

Depth (cm)	Aryavallikkavu	Elencheri	Kanakuthu
0-20	5.88 (0.15)	6.05 (0.26)	5.99 (0.25)
21-40	5.66 (0.16)	5.83 (0.10)	5.61 (0.19)
41-60	5.34 (0.10)	5.45 (0.11)	5.40 (0.14)
61-80	5.20 (0.10)	5.25 (0.16)	5.20 (0.17)
81-100	5.00 (0.15)	4.86 (0.23)	4.79 (0.24)
F value (Location) – 1.40 ^{ns}			
F value (Layer) – 67.52**			

Value in parenthesis shows standard deviation; ** - significant at 1% level; *ns: non-significant*

4.7.2.2. Total Nitrogen

Total nitrogen content in teak plantations ranged from 237.72 to 294.23 kg/ha at 0-20 cm depth and it varied from 145.00 to 185.23 kg/ha, 100.66 to 115.50 kg/ha, 72.43 to 83.86 kg/ha and 50.85 to 58.02 kg/ha at the depth of 21-40 cm, 41-60 cm, 61-80cm and 81-100 cm respectively. The total nitrogen in soils was highest in the surface and decreased down to the profile in all the three teak plantations (Table 11).

The analysis of variance indicated that, there is a significant difference of total nitrogen in soils from all three teak plantations of Nilambur and also between different depths within a region. The highest total nitrogen was recorded from teak plantation in Kanakuthu region (294.23 kg/ha) and lowest was at 50.85 kg/ha from teak plantations of Elencheri at a depth of 81-100 cm.

Table 11. Depth-wise distribution of mean soil Nitrogen content in (38 to 40 year old) teak plantations from three regions of Nilambur taluk

Depth (cm)	Aryavallikkavu (kg/ha)	Elencheri (kg/ha)	Kanakuthu (kg/ha)
0-20	237.72 (12.76)	260.26 (12.04)	294.23 (7.34)
21-40	149.70 (14.96)	145.00 (11.94)	185.23 (8.33)
41-60	109.10 (9.26)	100.66 (12.73)	115.50 (5.89)
61-80	74.40 (9.95)	72.43 (11.70)	83.86 (9.67)
81-100	52.65 (8.05)	50.85 (6.67)	58.02 (6.27)
F value (Location) – 31.36**			
F value (Layer) – 806.06**			

Value in parenthesis shows standard deviation; ; ** - significant at 1% level

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4.7.2.3. Total Phosphorus

Total phosphorus varied from 163.58 to 140.94 kg/ha at a depth of 0-20 cm. Highest values were recorded at 0-20 cm depth and decreased with the depth in all three teak plantations of Nilambur (Table 12). The analysis of variance shows that there exists a significant difference in total phosphorus between these three regions and also between different depths.

Table 12. Depth-wise distribution of Mean soil phosphorus content under (38 to 40 year old) teak plantations from three regions of Nilambur taluk

Depth (cm)	Aryavallikkavu (kg/ha)	Elencheri (kg/ha)	Kanakuthu (kg/ha)
0-20	140.94 (10.34)	148.35 (10.83)	163.58 (9.62)
21-40	94.67 (10.22)	91.11 (8.61)	111.90 (4.01)
41-60	69.15 (6.85)	60.94 (8.06)	70.04 (3.34)
61-80	53.11 (5.20)	41.39 (6.14)	47.86 (4.83)
81-100	33.12 (5.30)	27.66 (3.36)	31.63 (4.24)
F value (Location) – 12.06 **			
F value (Layer) – 522.148**			

Value in parenthesis shows standard deviation; ** - significant at 1% level

4.7.2.4 Available Potassium

Among the three teak plantations, Elencheri was recorded the highest mean available potassium followed by Kanakuthu (208.54 kg/ha) and Aryavallikavu (197.11 kg/ha) at a depth of 0-20 cm. Available potassium decreased with increase in soil depth. The lowest value of mean available potassium recorded at 81-100 cm depth at Aryavallikkavu, Elencheri and Kanakuthu were 55.64 kg/ha, 31.25 kg/ha and

31.04 kg/ha respectively (Table 13). The analysis of variance indicated that there exists a significant difference between the three teak plantations of Nilambur region.

Table 13. Depth-wise distribution of Mean soil available potassium content under (38 to 40 year old) teak plantations from three regions of Nilambur taluk

Depth (cm)	Aryavallikkavu (kg/ha)	Elencheri (kg/ha)	Kanakuthu (kg/ha)
0-20	197.11 (13.07)	216.87 (5.03)	208.54 (4.20)
21-40	144.04 (10.28)	171.75 (21.54)	138.49 (9.87)
41-60	106.13 (12.01)	103.21 (9.94)	80.39 (12.82)
61-80	90.08 (8.73)	63.08 (7.49)	45.73 (9.26)
81-100	55.64 (6.42)	31.25 (4.42)	31.04 (5.42)
F value (Location) – 18.36 **			
F value (Layer) – 515.42**			

Value in parenthesis shows standard deviation; ** - significant at 1% level

4.7.2.5 Soil Organic Carbon

Generally, soil carbon in soils was highest in the surface and decreased down to the profile. The analysis of variance for soil carbon showed significant difference among three teak plantations and also in different depths of soil profile. When comparing the three teak plantations, the highest soil organic carbon was found in Kanakuthu (1.83%) followed by Elencheri (1.58%) and Aryavallikkavu (0.82%) at a depth of 0-20 cm (Table 14). Soil organic carbon content decreased with increase in soil depth. The lowest value for soil organic carbon was observed at 81-100 cm depth at Aryavallikkavu plantation (0.25%).

Table 14. Soil organic carbon at different depths in (38 to 40 year old) teak from three regions of Nilambur taluk

Depth (cm)	Aryavallikkavu (%)	Elencheri (%)	Kanakuthu (%)
0-20	0.82 (0.85)	1.58 (0.18)	1.83 (0.14)
21-40	0.64 (0.12)	1.17 (0.17)	1.57 (0.14)
40-60	0.54 (0.15)	0.97 (0.18)	1.37 (0.14)
60-80	0.38 (0.16)	0.43 (0.09)	1.06 (0.21)
80-100	0.25 (0.16)	0.35 (0.13)	0.63 (0.25)
F value (Location) – 112.96 **			
F value (Layer) – 72.99**			

Value in parenthesis shows standard deviation; ** - significant at 1% level

4.8. SAW MILL SURVEY

Results of the questionnaire survey are presented below. It includes details about the period of establishment of sawmills, experience of sawmill owners in the business, the major timber species used in the sawmill, the preference of national/ international teak varieties among sawmill owners , perception of sawmill owners about Nilambur teak and the price variation of different teak varieties sold through the sawmills.

4.8.1. Period of establishment of sawmill

Table 15, reveals that most of sawmills (42 %) in the present study were established during the period 1990-2005, however some of the sawmills (6 %) were established even before 1975.

Table 15. Period of establishment of sawmill.

Period of establishment (years)	Frequency (n=50)	Percentage (%)
After 2005	10	20
1990-2005	21	42
1975-1990	16	32
Before 1975	3	6

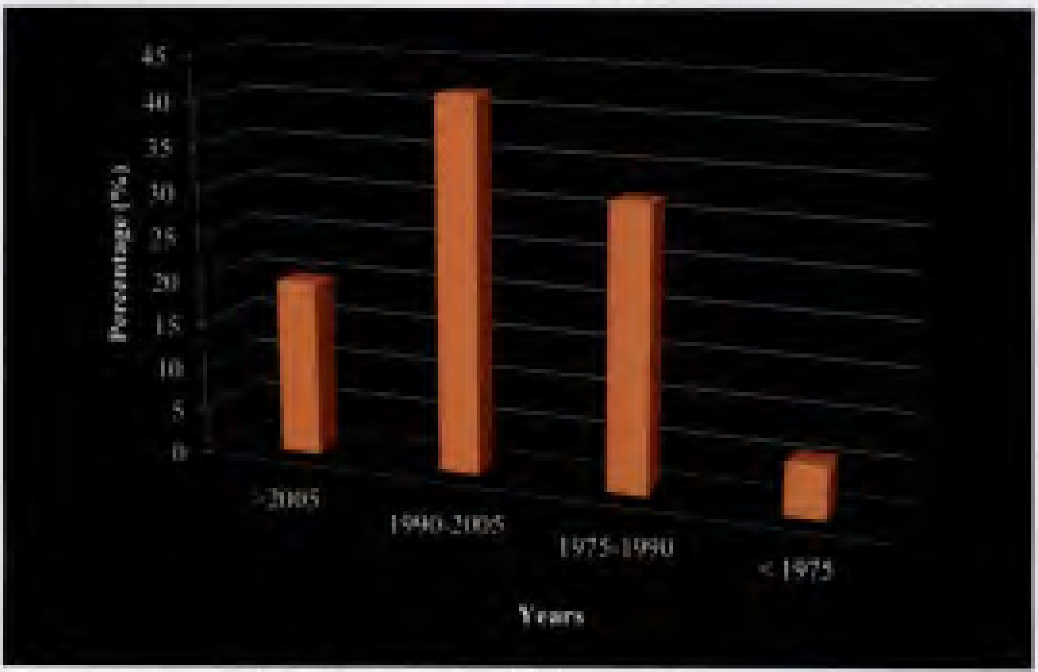

Fig.4. Period of establishment of sawmill

4.8.2. Years of experience of sawmill owners in the field

From the data analysed, it was found that 36 per cent of mill owners has 20-30 years of experience followed by 30-40 years and 10-20 years, below 10 years and 40-50 years with 26, 24, 8 and 4 per cent respectively. Only one person has an experience of more than 50 years (Table 16).

Table 16. Experience of sawmill owners in the business.

Experience (Years)	Frequency (n=50)	Percentage (%)
Below 10	4	8
10-20	12	24
20-30	18	36
30-40	13	26
40-50	2	4
Above 50	1	2

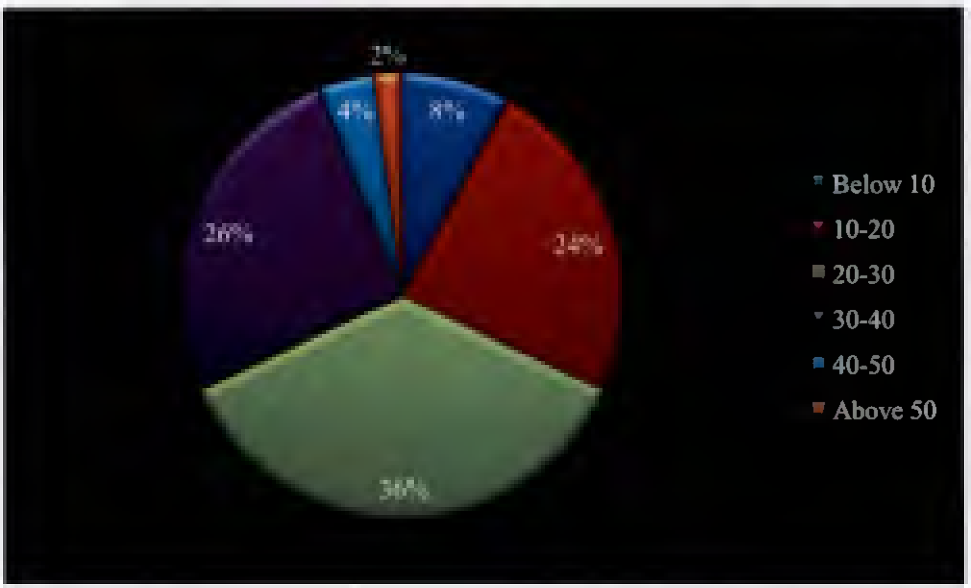

Fig.5. Experience of sawmill owners in the business

80

4.8.3. Major timber species used in the sawmill

From table 17, a total of fifteen major timber species were found to be traded in the sawmills of Central Kerala. *Tectona grandis* is one of the major timber species used in all sawmills studied. However, some species like *Artocarpus heterophyllus*, *Swietenia macrophylla* and *Dalbergia latifolia* were seen used predominantly at 80, 70 and 52 per cent respectively.

Table 17. Major timber species used in the sawmills of Thrissur, Palakkad and Ernakulam districts of Kerala.

S. No.	Scientific name	Presence of timber species in sawmill (%)
1.	*Acacia mangium*	14
2.	*Albizia odoratissima*	18
3.	*Artocarpus heterophyllus*	80
4.	*Artocarpus hirsutus*	14
5.	*Bridelia retusa*	12
6.	*Dalbergia latifolia*	52
7.	*Grewia tiliifolia*	40
8.	*Mangifera indica*	42
9.	*Pterocarpus marsupium*	30
10.	*Swietenia macrophylla*	70
11.	*Tamarindus indica*	14
12.	*Tectona grandis*	100
13.	*Terminalia paniculata*	42
14.	*Xylia dolabriformis*	30
15.	*Xylia xylocarpa*	22
16.	Others	90

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4.8.4. Preference of national/international teak varieties among sawmill owners

From fig 6, it can be inferred that around sixty per cent of the mill owners showed high preference for national teak varieties and forty percent of mill owners preferred international teak varieties.

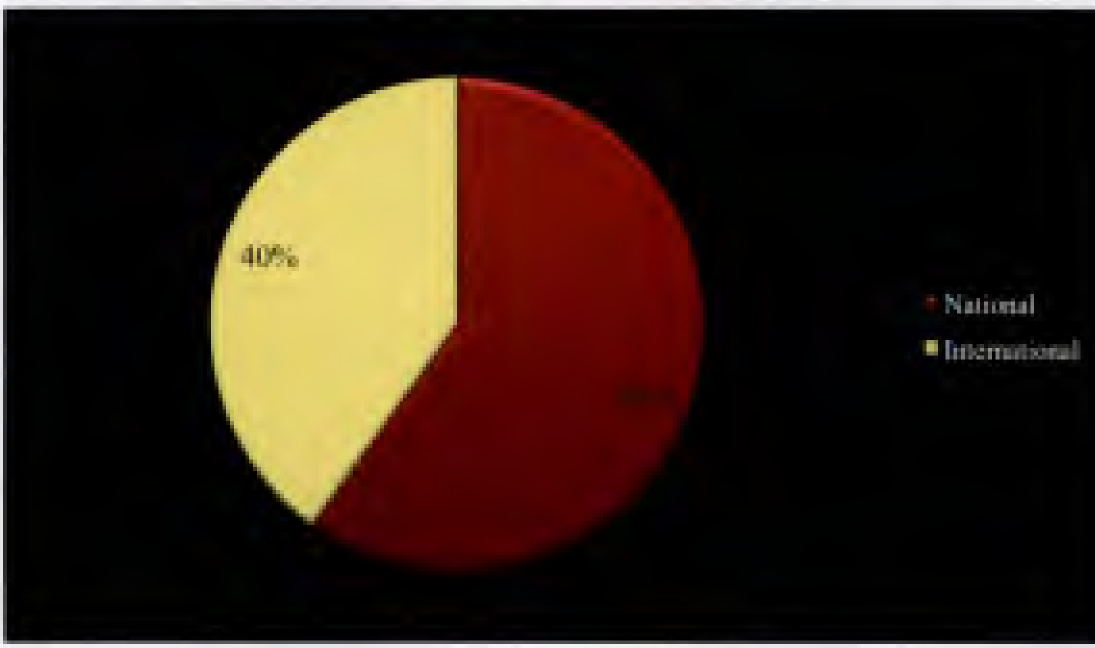

Fig 6. Preference of teak varieties (National/International) among sawmill owners

4.8.5. Opinion about National teak varieties among sawmill owners

Result showing knowledge and preference of different national teak varieties among sawmill owners are presented below.

4.8.5.1. Knowledge of different national teak varieties among sawmill owners

From the data analysed, it was found that all sawmill owners have knowledge about Nilambur teak variety. However, sawmill owners were also aware about Assam, Konni, Malayattoor and Karnataka teak varieties (Fig.7).

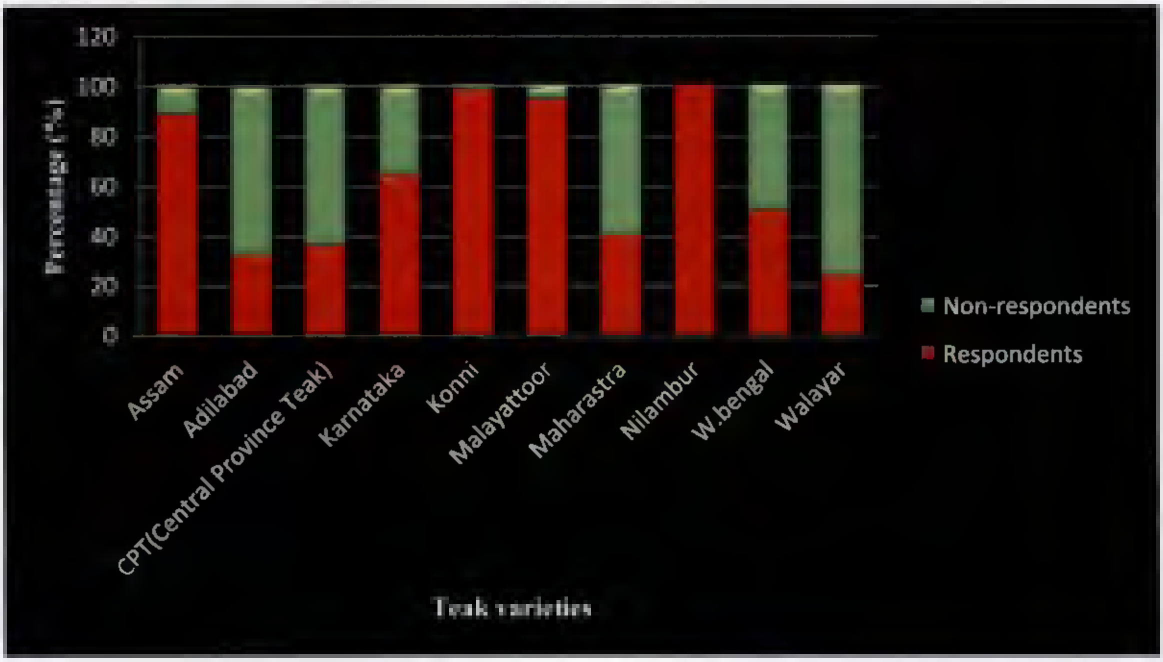

Fig.7. Knowledge of different national teak provenances among sawmill owners

4.8.5.2. Preference of National teak varieties among sawmill owners

Table 18 shows that, around 82 per cent of respondents highly preferred Nilambur teak among the national teak varieties. However, Karnataka (81.25%) and Maharashtra (65%) teak varieties have moderate level of preference among national teak provenances.

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Table 18. Preference of National teak varieties among sawmill owners

S. No.	Teak varieties	Frequency			Total
		High	Medium	Low	
1.	Assam	Nil	20 (45.45)	24 (54.54)	44 (100)
2.	Adilabad	Nil	2 (12.5)	14 (87.5)	16 (100)
3.	CPT	Nil	6 (33.33)	12 (66.67)	18 (100)
4.	Karnataka	Nil	26 (81.25)	7 (21.87)	32 (100)
5.	Maharashtra	Nil	13 (65)	7 (35)	20 (100)
6.	West Bengal	Nil	13 (52)	12 (48)	25 (100)
7.	Konni	22 (44.90)	25 (51.02)	2 (4.08)	49 (100)
8.	Malayattoor	20 (42.55)	23 (48.94)	4 (8.51)	47 (100)
9.	Nilambur	41 (82)	9 (18)	Nil	50 (100)
10.	Walayar	10 (83.33)	2 (16.7)	Nil	12 (100)

Values in parenthesis shows percentage

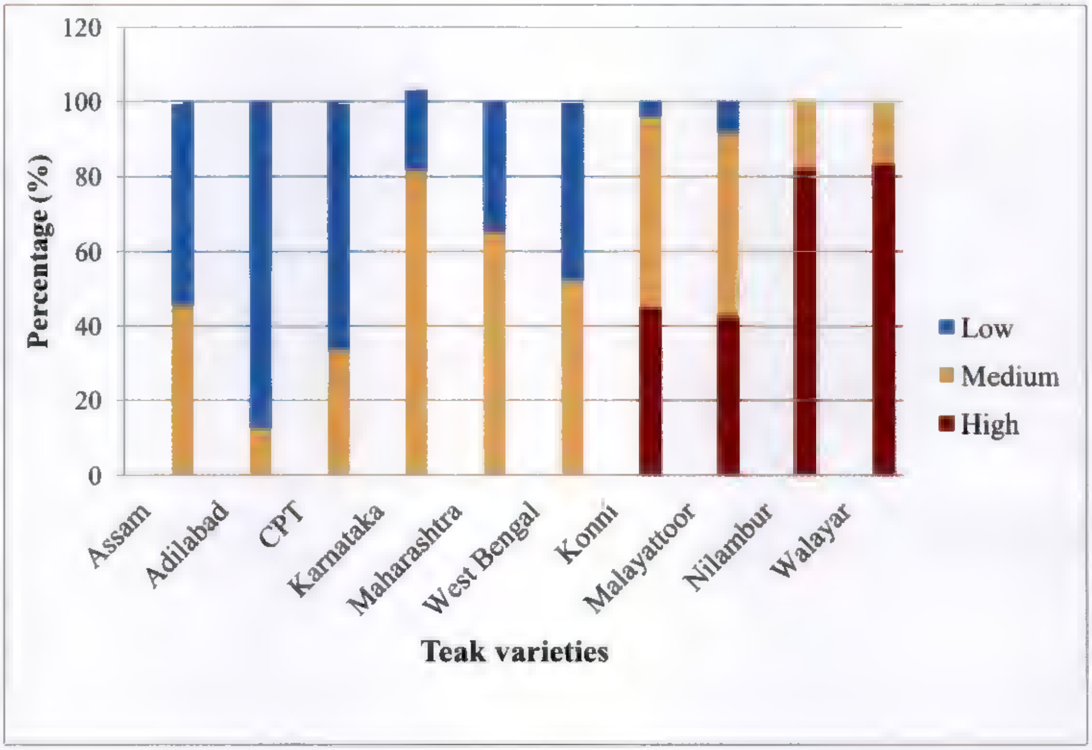

Fig.8. Preference of national teak varieties among sawmill owners

4.8.6. Opinion about International teak varieties among sawmill owners

Result showing knowledge and preference of different international teak varieties among sawmill owners are presented below.

4.8.6.1. Knowledge about different International teak varieties among sawmill owners

The data analysed from sawmill survey reveals that Burmese teak was more popular among the sawmill owners followed by Benin, Ghana and Tanzanian teak varieties. The knowledge about African teak varieties among sawmill owners was very less (Fig. 9)

85

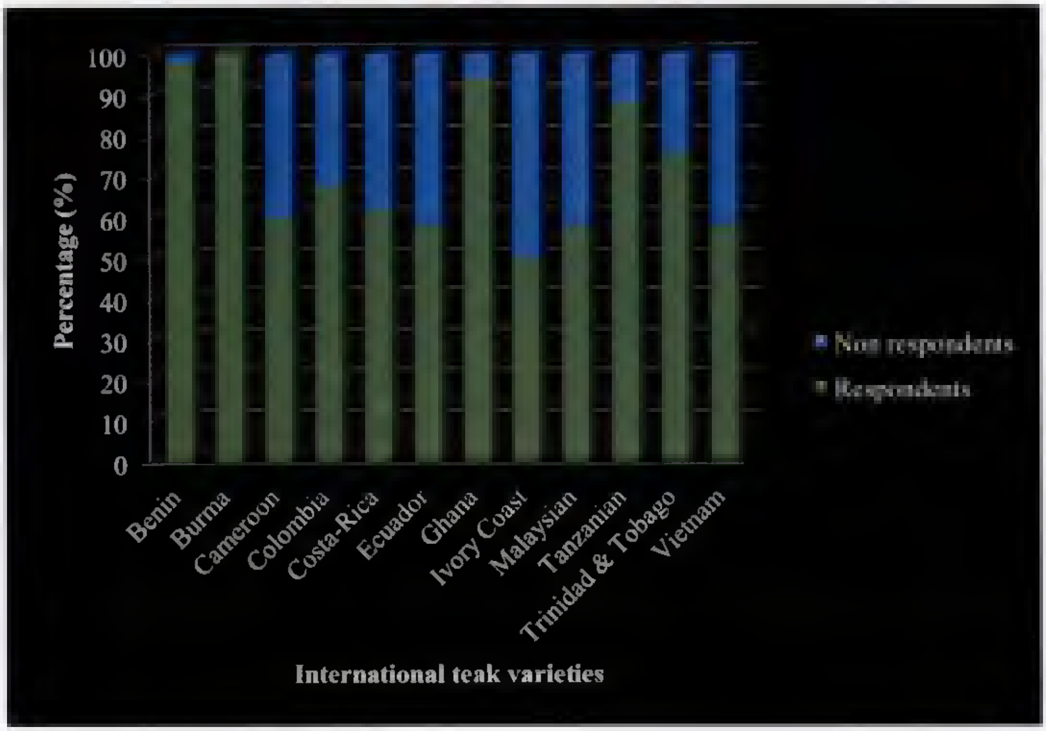

Fig.9. Knowledge about different International teak varieties among sawmill owners

4.8.6.2. Preference of international teak varieties among sawmill owners

The data given in the Fig 10, reveals that, about 72% of the respondents highly preferred Burmese teak over the other exported teak varieties. However Benin teak has a moderate preference among international varieties. All other African teak varieties were least preferred by the sawmill owners.

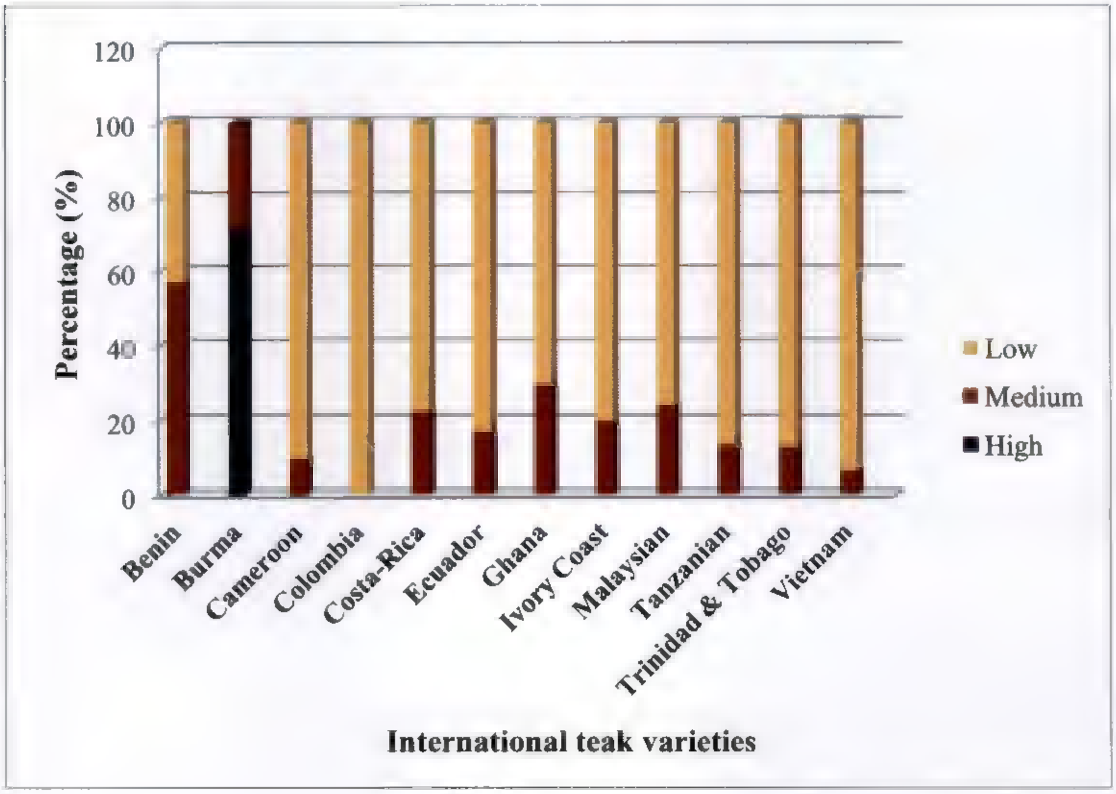

Fig 10. Preference of international teak varieties among sawmill owners

4.8.7. Perception of sawmill owners about Nilambur teak

Perception about Nilambur teak among sawmill owners was measured from member's responses to the same and is presented in Table 19. The majority of members (56 %) agreed to the statement "Nilambur teak possess a good reputation in the timber market" helped to understand the fact that Nilambur has a good reputation among the sawmill owners and customers. According to the member's responses, the statement such as "Site factors and climate contributes to its better quality and growth" and "Soil of Nilambur have greater influence on its colour" were agreed to by 56 per cent and 62 per cent respectively. About 64 percent of members agreed to the statement "Nilambur teak possess good colour than other available teak wood in the market", helped to understand that colour of Nilambur teak was outstanding than other available teak wood in the market. Also 72 per cent of respondents agreed to the statement "Seedlings of Nilambur teak raised outside the Nilambur provenance do not have the same quality", indicated that the respondents believed that the soil and climate of Nilambur region have a major impact on the quality of wood produced there. The study showed that about 40 per cent of respondents agreed to the statement "Increased price for Nilambur teak diminishes the purchasing power of the customers" and 42 per cent of respondents have a neutral response on the statement "Timber merchants prefer to buy Nilambur teak over other available teak woods", helped to understand that to the increased price and shortage in the availability of Nilambur teak made it difficult for them purchase Nilambur teak.

Table 19. Opinion of sawmill owners about Nilambur teak

S. No.	Statements	Likert scale					
		SD %	D %	N %	A %	SA %	Maximum response
1	Nilambur teak possess a good reputation in the timber market	0	0	0	56	44	Agree
2	Site factors and climate contributes to its better quality and growth	0	0	4	56	40	Agree
3	Soil of Nilambur have greater influence on its colour	0	0	4	62	34	Agree
4	Nilambur teak possess good colour than other available teak woods in the market	0	0	12	64	24	Agree
5	Workability of Nilambur teak is good compared to other national and international teak varieties	0	2	6	72	20	Agree

6	Physical appearance of Nilambur teak earns it a good price in the market	0	0	2	82	16	Agree
7	Historical importance of Nilambur teak helps to gain a good reputation in the international market	0	0	0	94	6	Agree
8	Seedlings of Nilambur teak raised outside the Nilambur provenance do not have the same quality	0	2	16	72	10	Agree
9	Quality of plantation teak is better than homestead teak	0	48	16	36	0	Disagree
10	Increased price for Nilambur teak diminishes the purchasing power of the customers	0	16	30	40	14	Agree
11	Timber merchants prefer to buy Nilambur teak over other available teak woods	0	18	42	40	0	Neutral

Note: SD – Strongly disagree, D- Disagree, N- Neutral, A- Agree, SA- Strongly agree

4.8.8. Grouping of teak varieties based on the similarity in wood quality as perceived by sawmill owners

On analyzing Table 20, it can be seen that Nilambur, Konni, locally grown and Burmese teak form a cluster, which means that they have similarity in selected wood characteristics. Similarly Benin and Ghana teak, and Cameroon, Colombia, Costa Rica, Ecuador, Ivory Coast, Karnataka, Maharastra, Malaysia, Tanzania and Walayar teak form different clusters respectively. Nilambur teak has shown higher statistic value compared to other teak varieties.

Table 20. Similarity of different wood quality attributes among different varieties of teak as perceived by sawmill owners

S. No.	Teak variety	Statistic value	Std. Error	Cluster membership
1.	Burma	17.38[a]	0.219	1
2.	Homegarden (local)	17.48[a]	0.210	1
3.	Konni	18.38[a]	0.634	1
4.	Nilambur	22.22[a]	0.184	1
5.	Assam	12.14[b]	0.923	2
6.	Benin	9.20[c]	0.252	3
7.	Ghana	5.04[c]	0.710	3
8.	Cameroon	2.10[e]	0.568	4
9.	Colombia	1.62[e]	0.494	4
10.	Costa Rica	2.74[e]	0.599	4
11.	Ecuador	1.08[e]	0.479	4
12.	Ivory Coast	0.54[e]	0.305	4
13.	Karnataka	2.52[e]	0.826	4
14.	Maharastra	0.32[e]	0.320	4
15.	Malaysian	1.73[e]	0.678	4
16.	Tanzania	0.30[e]	0.300	4
17.	Walayar	2.08[e]	0.738	4
18.	Malayattoor	5.00[d]	1.156	5

4.8.9. Variation in market price of different teak varieties sold through the sawmills

Fig. 11. showed that among teak woods available in the timber market of Central Kerala, Nilambur teak has high market price per cubic feet ranging from 6000-8000 rupees. Burmese, Konni, Malayattoor and Walayar teak were sold out at a price ranging

from 4000-6000 rupees per cubic feet. Price of locally grown teak ranged from 2000-4000 rupees per cubic feet. Teak from Benin, Cameroon, Colombia, Costa-Rica, Ecuador, Ghana, Ivory Coast, Malaysia, Tanzania, Trinidad and Tobago and Vietnam come under low price category (below 2000 rupees per cu. ft).

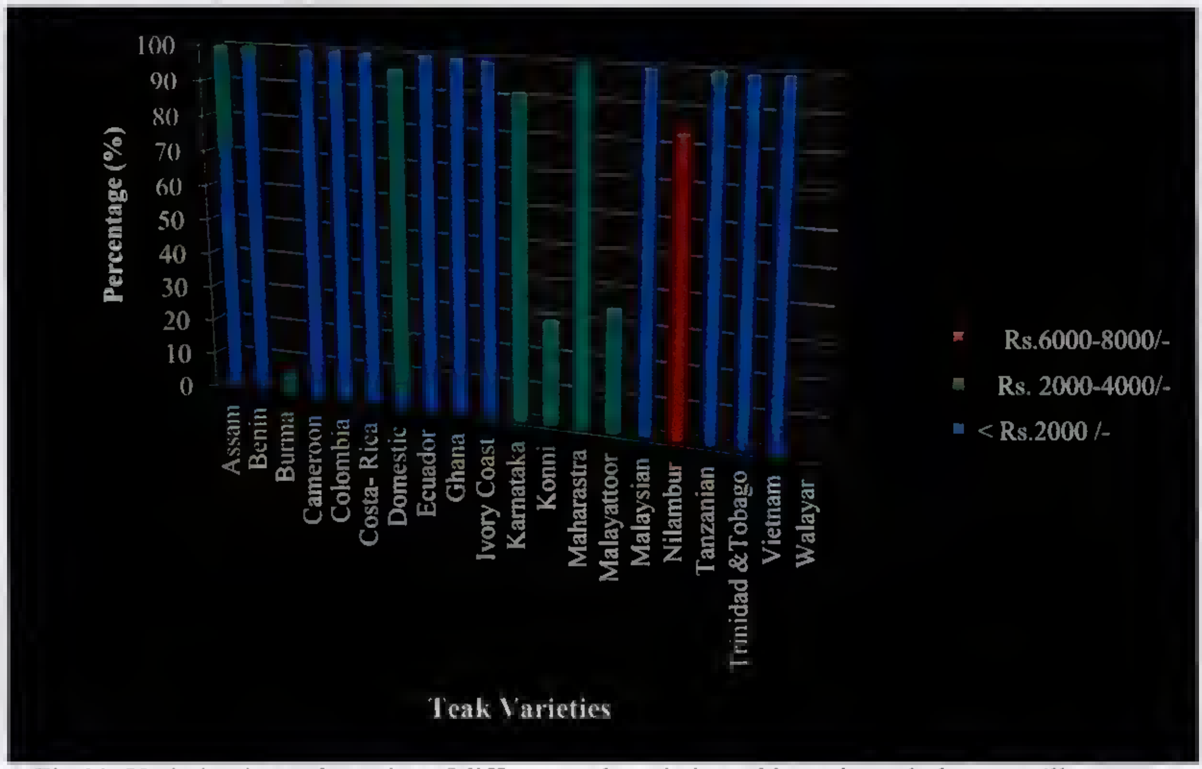

Fig.11. Variation in market price of different teak varieties sold out through the sawmills

DISCUSSION

DISCUSSION

Results of the investigation on "Geographical Indications status for Nilambur teak (*Tectona grandis* L.f)" are discussed here under.

5.1 History of major events related to Nilambur teak using timeline tool

Nilambur teak has a long history which helped it to acquire a good reputation in the international timber market. It revealed that the history of Nilambur teak started as early as 14th century, where Arabs started manufacturing units of sails boat at Beypore, Kozhikode. It was believed that Nilambur teak was largely used for the construction of certain historically important monuments. In 1792 an order was issued by the Bengal- Bombay joint commission prohibiting fellingof teak below 21 cm of girth from Malabar forests and in 1806, Captain Watson was appointed as the conservator of Teak in Malabar (Lushington, 1896). In 1893, the first organized wood processing unit in Kerala was established by A. Brown (Muraleedharan and Bhat, 1989). The first working plan of Nilambur division was prepared in 1894 by P. M. Lushington (Srinivasan, 2004). In 1927 Nilambur- Shornur railway line was laid for the transportation of wood from Nilambur. Nilambur teak was used in the first and second world war. The excessive timber extraction during the two World Wars (1914-18 and 1939-1945) contributed to the expansion of the road network in the forests of Nilambur (Chundamannil, 1993). In 1990, the punam cultivation (shifting cultivation) that started during the Britishers period came to an end. The Kerala Agricultural University (KAU) along with the local self-government at Nilambur, the Kerala Forest Department, Kerala Forest Research Institute took initiative for the GI registration of Nilambur teak in 2013.

5.2 Climate

The climate in Nilambur is tropical and has received rainfall in most months, with a short dry season. The average annual temperature in Nilambur is 25.86^{0}C and the annual precipitation is about 2675 mm. The heavy rainfall and bright sunshine lead to a humid and warm climate, excellent for luxuriant plant growth. Frost is generally absent. In the plains and foothills, humidity varies from 30% to 90% reaching saturation point during monsoons.

5.2.1 Temperature

The period, March- May, is the hottest when temperature reaches a maximum (>28° C). From June, it gradually comes down due to heavy monsoon. Again, an increasing trend is noticed in September and October, followed by lower temperature (<24° C) in the months of December and January.

5.2.2 Rainfall

Nilambur receives rainfall for almost ten months in a year from both monsoons and local systems, though most of the rainfall occurs the southwest monsoon period (Fig 3). Both Southwest and Northeast monsoon bring rains. From May to October, the area receives Southwest monsoon with bulk of the rain during June-July. Little showers are also received from Northeast monsoons during October-November. The area also receives pre-monsoon showers during April-May.

5.3 GROWTH ATTRIBUTES

The mean girth values of trees in the selected teak plantations ranged from 120.5 cm to 126.04 cm (Table 2). The study showed that there was no significant difference between the teak plantations in terms of girth. Varghese *et al.*(2000) observed that teak from Nilambur had the largest values in tree girth followed by Konni, Topslip and Mudumalai trees. Bhat and Indira (1997) reported that relatively faster grown 55 year old trees sampled from riverside plantations in Nilambur, displayed greater dbh than 65 year old trees of the same locality probably due to the availability of more moisture in the soil. It was also reported that radial growth is slow and tree size small in Konni and Karwar plantations as compared to Nilambur and Arienkavu plantations.

A significant difference in height was observed between the selected teak plantations. The mean tree height varied from 16.93 m to 14.86 m (Table 2). Varghese *et al.* (2000) observed that in terms of height Nilambur and Topslip had the highest values followed by Konni, Topslip and Mudumalai trees.

5.4. NON-DESTRUCTIVE TESTING METHODS

Results obtained using non-destructive testing methods like pilodyn pin penetration depth, stress wave velocity and dynamic MOE were discussed below.

5.4.1. Pilodyn Penetration Depth

In the present study no significant difference was found in the pilodyn penetration depth between the three selected teak plantations of Nilambur. The value ranged from 12.73 to 13.31 mm (Table 3). The density estimated using pilodyn also showed no significant difference between the sites. The value of density ranged from 548.99 to 563.21 kg/ m^3. In a study conducted by Jiljith (2016) in teak plantations of Kerala, pilodyn penetration depth (PPD) was found to have a negative correlation with basic density. Also the value obtained for PPD of teak was comparable with the present study. A similar finding was reported by Ponneth *et al.* (2014) who observed significant negative correlation between specific gravity (oven dry) and PPD in different tropical hard wood species including teak. They reported a highest correlation in teak (-0.907). Wu *et al.* (2010) tested the effectiveness of pilodyn in evaluating wood properties including basic density. The study also reported a strong negative correlations between pilodyn penetration and wood properties. In the present study, the density of teak obtained using non- destructive method was comparable with the basic density of teak from Nilambur teak plantations observed in various other studies (Anish, 2013; Jiljith, 2016; Varghese, 2000). Bhat and Indira (1997) studied wood density differences among the six 60- year-old provenance trials (viz. Nilambur, Anamali, Travancore, South Bombay, South Burma and North Burma). They observed that fast grown Nilambur provenance displayed the basic density (oven dry weight to green volume basis) of 539 kg/m^3 while the slow grown North Burma provenance had nearly the same value of 538 kg/m3. The value of basic density were very close to value of the density obtained by NDT method in the present study.

5.4.2. Stress Wave Velocity (SWV) and Dynamic MOE

In the present study, stress wave velocity and dynamic MOE was found to have no significant difference between the three regions. Stress wave velocity records ranged from 3038.15 to 3153.84 m/s (Table 4). The findings were similar to the observations by Dhanya (2012) and Jiljith (2016) in teak. They also observed that stress wave velocity had a significant correlation with static MOE, Modulus of Rupture and horizontal shear stress at maximum load. In similar studies, Mochan *et al.* (2009) observed a very strong relationship between dynamic MOE and its static equivalent for small, defect- free samples and sawn timber. Searles and Moore (2009) reported that portable stress-wave based tools provide a cost effective means for predicting the stiffness of the resource, either in standing tree or in log form.

5.5 HEARTWOOD COLOUR

The mean colour values determined using Munsell system is presented in Table 5. In the present study, Munsell notations for the samples collected from the three study sites were comparable with regard to hue (redness to yellowness), value (lightness) and chroma (saturation). Similarly, Thulasidas *et al.* (2006) observed no significant difference in hue and value for wet and dry teak, while the results were contradictory to the findings of Derkyi *et al.* (2009) where they reported that teak wood colour tends to be darker in wetter areas than the drier ones. Phelps *et al.* (1983) reported that the primary cause of heartwood colour variability was due to the variability in luminance (i.e. darkness or lightness). In the present study, all the samples were found to be having a red colour tending more towards yellow red in Munsell system.

Minemura *et al.* (1998) observed a similar trend in 32 Japanese hardwoods and 60 Malaysian timbers.

Teak is a premium hardwood valued for its attractiveness with golden brown colour. Wood colour as determined by Munsell notation varied among for sample locations from yellowish brown to dark yellowish brown, pale brown to very dark greyish brown and also reddish brown to dark reddish brown (Table 6). In the study conducted by Anish (2013) reported that Nilambur and Betul teak showed brown colour. Bhat *et al.* (2007) observed that teak samples collected from Nilambur region showed dark yellowish brown colour. Teak samples from Vadavar, Myanmar, Trinidad and Sudan were yellow to yellowish brown in colour. Higher variability in the heartwood colour was displayed by the samples from Asia compared to those from Africa. All other samples of African origin except for Sudan were found to be of darker colour, while Asian teak which included sample from teak homelands viz. India, Thailand, Myanmar showed varying degrees of paler as well as darker heartwood colour irrespective of growth rate of the samples.

These variations in wood colour supports the findings of Koasa-ard (1995) who reported that wood colour and texture in teak were greatly influenced by planting locations. Some of the earlier studies revealed that within a species wood colour vary greatly due to different environmental conditions and silvicultural treatments (Sullivan, 1967; Nelson *et al.*, 1969; Wilkins and Stamp, 1990). Derkyi *et al.* (2009) reported that environmental factors had a stronger effect on the colour of teak heartwood than the age of stand. However the exact cause of such variation is not known but is possibly due to differences in soil chemistry and moisture content in different localities.

5.6 HEARTWOOD PERCENTAGE

The heartwood proportion, which is also a contributing factor which determines the timber value in the market as it is the durable part of the timber for which teak has world wide reputation. In most cases, heartwood colour and content determine whether the log will fetch high or low price, with a corresponding gain/ loss of upto

50% of its potential value (Moya and Perez, 2008) In the present study, the heartwood percentage showed no significant difference between the sample studied from the three study areas. Heartwood accounted for a mean value of 83.52 per cent, 85.27 per cent, and 87.06 per cent for Aryavallikkavu, Elencheri and Kanakuthu region respectively (Table 7). It was similar to the study conducted by Bhat (2000) who found that the heartwood percentage did not show significant variation with tree size and locality of planted site as it was reported to vary more with age. However, in another study study conducted by Bhat *et al.* (2007) reported that teak samples in the same age class collected from different ecological zones showed variation in diameter at breast height (DBH) and heartwood percentage and it means that ecological zone has an important role in determining wood quality. In the same study Nilambur teak was reported to have higher heartwood percentage despite of its faster growth rate compared to teak from other provenances. These results were also similar to the study conducted by Anish (2013) who observed that fast grown Nilambur teak showed little variation in heartwood percentage compared to slow grown teak of similar age.

5.7 SOIL STUDIES

Results obtained from the analysis of soil physical properties such as bulk density, soil texture and chemical properties such as soil pH, total nitrogen content, total phosphorus, available potassium and soil organic carbon content were discussed below.

5.7.1 Physical properties of soil

Table 8, shows that the bulk density values were generally higher in deeper layers of the soil. The mean bulk density values were in the range 1.0 to 1.92 g/cm^3. Bulk density showed significant variation within the profile and also between plantations. This might be due to differences in organic matter content at different plantations and also at different soil depth. Bulk density is negatively correlated with organic matter content. In a study conducted by Manjunatha (2015) a similar trend in bulk density with increase in the soil depth was observed and value ranged from 1.0 to 1.36 g/ cm^3 from teak plantations in Kerala. According to his studies, bulk density of soil under natural forest is lesser compared to that of plantation soils. Mechanical compaction occurred during clear felling of natural forest and also the initial stages of plantation establishment may be responsible for the higher values of bulk density under plantations soils. A similar finding was reported by Balagopalan (1995) that there was a loss in loose surface soil due to plantation activities. Rathod and Dewar (2003) found soils of the both teak and eucalyptus plantations to be more compacted to natural forests. Amponsah and Meyer (2000) also observed significant increase in bulk density values in soils of natural forests converted to teak. A study conducted by Sharma (2015) observed that teak plantations had higher amounts of bulk density compared to other land use systems. In a study conducted by Balagopalan and Rugmini (2006) found that there was no significant relationship between soil properties and tree growth in first depth level. They concluded that this may be due to plantation activities, soils in the surface layer would have been erode and soils in the sub surface layer exposed. The study also found that in the 20-40 cm depth level, with the increase in soil bulk density , there observed a subsequent decrease in tree diameter growth. This clearly indicate that the soil compaction and soil reaction affects the growth of trees. The study concluded that about 33 per cent of the variation in tree growth could be explained by soil properties (bulk density and pH) belonging to sub surface layer.

Table 9, shows that soils in the selected teak plantation, were mainly sandy loam in texture. It was also noticed that texture of soil did not vary with depth. In the present study sand content showed an inverse relation with increase in soil depth and silt and clay content increased with increase in soil depth. Proximity of the selected plantations to the river may be the cause of increased sand content in the selected plantations of Nilambur. Teak grows well in perfectly drained alluvial soil. Increased sand content in the soil helps in better drainage and also the roots can go much deeper and get moisture from lower levels. In the study conducted by Balagopalan and

Rugmini (2006) revealed that soils in the teak plantations at Nilambur (North and South) forest divisions belonging to site quality classes I,II and III did not show much variation among the different site quality classes with respect to soil properties. Soils were reported to be loamy in all site quality classes. Alexander *et al.* (1987) observed that, with site quality improvement decreases in gravel and increases in sand and exchangeable bases are seen. Similar to the findings Sharma (2015) reported that in teak plantation of Assam, coarse or sandy textured soil was found. Soil in the bamboo plantation and shifting cultivation was fine textured, clay or silty clay soil. But in the natural forest, rubber plantation and Orange orchard, texture of soil was silty loam, sandy loam or loam. Geetha (2008) observed that soils in younger age teak plantations and natural forest were sandy clay loam while in older plantations, the soils were sandy loam. As the plantations were established after clear felling natural forest, it can be assumed that plantation soils initially were similar to those in the natural forest. It was also reported that the soil texture did not vary with depth in the natural forest. In a study conducted by Alexander *et al.* (1987) noticed that 31 per cent of variation in top height was accounted by soil variables viz., gravel, sand, pH, EA and EB.

5.7.2 Chemical properties of soil

Generally soils of the teak plantations were acidic in nature. Teak grows well in slightly acidic soil. Soil test results showed that soil pH records ranged from 4.79 to 6.05 (Table 10). A similar finding was reported by Asubonteng *et al.* (1995), Okoro *et al.* (2000) and Chamshama *et al.* (2000) in single age teak plantations and adjacent natural forests. In the present study, pH values were found to decrease with increase in soil depth. Balagopalan and Jose (1997) also observed lower pH values in soils of different aged teak plantations compared to natural forest. The study conducted by Geetha (2008) also reported that soils of both teak plantations and natural forest, were moderately to strongly acidic in nature. Balagopalan and Rugmini (2006) found that tree growth was significantly influenced by soil pH in the 20-40 and 40-60 cm depth levels. The result revealed that with increase in soil pH in both depth levels, there was a corresponding increase in the tree diameter growth. They also observed that when properties of soils in all layers (0-20, 20-40, and 40-60 cm layer) were taken together, bulk density and soil pH in the 20-40 cm layer showed significant influence on tree diameter growth. Similar finding was reported by Bhatia (1955) and Akinsanmi (1985). Ezenwa (1988) reported that soil pH is positively correlated with tree heights and basal area.

The total nitrogen content in teak plantations varied from 50.85 kg/ha to 294.23 kg/ha (Table 11). The total nitrogen in soils was highest in the surface and decreased with depth in the selected plantations. It was similar to findings of Manjunatha (2015) where, total nitrogen content in teak plantations varied from 0.07 % to 0.34 % and in natural forests , the variation was from 0.43% to 1.23 % . Total nitrogen content was higher in soils under natural forest than soil under teak plantation. For both teak plantation and natural forest, total nitrogen was found to be highest in the surface and decreased with the soil depth. Due to the plantation activities in the initial year of its establishment, loss of top soil and accompanying nitrogen leaves behind a soil that is low in nitrogen content. As the plantation ages, addition of litter, its mineralization and incorporation into soil improved the nitrogen content of soil. Lal (2008) reported that total nitrogen is significantly and positively correlated to organic carbon and mirrors the variation of organic carbon in soil. In the present study also a similar trend was observed. The total nitrogen content in the Kanakuthu region was higher followed by Elencheri and Aryavallikkavu respectively. Organic carbon was also found to be higher in this region followed by Elencheri and Aryavallikkavu.

The mean values of total phosphorus in selected teak plantations varied from 163.58 to 140.94 kg/ha (Table 12). Also higher phosphorus content was observed in the top layer and decreased with increase in soil depth. Similar trend was observed in a study conducted by Ombina (2008) who reported higher phosphorus content in both available and total form in the top soil followed by subsoil of teak plantations in Sudan. The study also reported that available and total phosphorus pools were dictated by the level of soil organic matter. Organic matter content was higher in the top layers. The present study also showed a positive relation between soil organic matter and total phosphorus content. Ali *et al.* (2010) also observed that phosphorus content decreased down the profile. This was due to the fact that P fixation tends to be more pronounced and ease of phosphorus release tends to be lowest in those soils with higher clay content (Brady and Weil, 2002). Okoro *et al.* (2000) reported lower phosphorus values in teak soils compared to natural forests. Manjunatha (2015) observed that there was no significant difference in available P values of teak plantation and natural forest.

The available potassium content in teak plantations varied from 216.87 to 31.04 kg/ha (Table 13). Higher K content was observed in the top layers and gradually decreased with increase in soil depth. Geetha (2008) observed that higher amount of available K in the top layers compared to the bottom layers of soil. The study also reported that there was no significant difference between the soils of younger teak plantations and natural forest with respect to the amount of available potassium. In contrast to it a small but significant decrease was observed between soils of older teak plantations and natural forests. Mongia and Bandyopadhyay (1994), Balagopalan and Jose (1993) and Amponsah and Meyer (2000) observed lower exchangeable potassium in plantation soils compared to natural forest.

Soil carbon can be considered as the single most important indicator of soil quality and a major component in the assessment of soil quality (Sikora *et al.*, 1996). In this study, soil carbon was highest in the surface and decreased with the depth in all the selected teak plantations (Table 14). Organic carbon content varied from 1.83 to 0.25 per cent with depth. Similar findings were seen in the study conducted by Manjunatha (2015) who observed similar trend of organic carbon content with soil depth in both teak plantation as well as natural forest. In that study, organic carbon in teak varied from 0.76 to 2.07 per cent and in natural forest, it varied from 1.35 to 2.88 per cent. The sharp decrease from surface to the subsurface may be due to the accumulation of organic matter through leaf litter in the upper layer. Lundgren (1978) reported that the occurrence of more organic matter content in natural forest is due to a number of factors including diversity of vegetation cover. Also in natural forest, greater diversity of species results in diversity of litter substrate and faster mineralization leading to enhanced organic carbon content compared to teak. Lower erosion in natural forest results in greater conversion of organic matter (Maro *et al.*, 1993). Sharma (2015) observed lowest organic matter content in teak plantation and highest in bamboo grooves. Lower organic carbon content in plantation soils compared to that of natural forest was also observed by Balagopalan (1995a, 1995 b). In a study conducted by Gunaga *et al.* (2011) in growth status and site quality of different seed production areas of teak observed that organic carbon and available potassium showed significant variations at different depths, where the highest content was recorded in the top layer, followed by middle and bottom layers. Considering associations between soil properties and tree growth, organic carbon was positively associated with dbh (diameter at breast height; $r = 0.500$), stem roundness ($r = 0.351$) and stem volume ($r = 0.250$).

5.8 SAWMILL SURVEY

Table 15 shows that most sawmills (42 %) in the present study were established during the period 1990-2005. Only 20 per cent of sawmills were established after 2005. The study also found that mill owners have a long term experience in the business. About 36 per cent of them working in this field have an experience of 20 to 30 years (Table 16). Only 8 per cent of the total showed less experience in the business. The emergence of number of new mills and new entrepreneurs in this business showed a decreasing trend. Sawmilling is reduced to a secondary source of income to many sawmill owners. This might be due to more competition in the field from other well established sawmills and also the establishment cost and maintenance cost of sawmills, restrictions in the export –import policies of timber, lack of sufficient availability of timber, restrictions in timber felling are high which act as a major constraint for starting a new business in this field. Lack of experienced labourers in this field is also a problem.

A study conducted by Muraleedharan and Bhat (1989) observed a rapid growth of sawmills since 1960. The main reasons of this increase was due to the increased availability of timber as a result of large scale clear felling of natural forests for plantation programmes which has been carried out since 1960. The massive deforestation in the private forests in Malabar region prior to its nationalization in 1971 increased the supply of timber and also the second five year plan which favoured industrialization resulted in starting of new industrial units in Kerala. It was also found that about 85 per cent of sawmills in Kerala were started during the period,1950-1980. This period was considered as the golden period of sawmilling as raw material supply and capacity utilization was high.

5.8.1 Major timber species used in the sawmills

The present study observed that a total of fifteen major timber species were found to be traded in the sawmills of Central Kerala (Table 17). *Tectona grandis* was a major timber species present in all the surveyed sawmills. Species like jack (*Artocarpus heterophyllus)*, mahogany (*Swietenia macrophylla*) and veeti (*Dalbergia latifolia*) were the other major timbers found in the sawmills. The other species used were mango (*Mangifera indica)*, Chadachi (*Grewia tiliifolia*), Pynkado (*Xylia dolabriformis*), maruthu *(Terminalia paniculata*), *irul (Xylia xylocarpa*), anjily (*Artocarpus hirsutus*), *Acacia mangium,* kunnivaka *(Albizia odoratissima)* and mulluvenga *(Bridelia retusa).* They were all used by less than 50 per cent of sawmills for trade purposes. Teak is an important timber species which has more demand in the market. Krishnankutty *et al.* (2005) has reported that of the total timber consumption in the state, about 12 per cent is teak. Also other than teak, jack (*Artocarpus heterophyllus*), mango (*Mangifera indica*), Cashew (*Anacardium occidentale*), tamarind (*Tamarindus indica*), anjily (*Artocarpus hirsutus*), matty (*Ailanthus triphysa*), coconut (*Cocos nucifera*), rosewood (*Dalbergia latifolia*) and imported timbers uch as Pynkado were the commonly consumed timbers in the state.

GOK (2016) reported that about 26 species were processed by sawmills for direct sale and for making doors, windows and furniture in Kerala. The study also found that the major forest timber species sold and used for making doors, windows and furniture were teak (56.3%), Mahogany (8.3%), Veeti (6.7%), Anjily (6%) and Irul (5%). The most preferred species for house construction and furniture were teak and mahogany. The sources of supply of teak wood were reported to be homegardens, forests and import (from abroad and other states). Homegardens accounted for 63% of the total supply during 1987-88.

Muraleedharan and Bhat (1989) reported that government forest depots, estates, homegardens and imports from other states (Assam, Orissa, Bihar, Karnataka, etc.) as well as overseas (mostly Malaysia and Myanmar) were the sources of supply of timber for sawmills of Kerala in which, homegardens act as a major source of supply of timber to the sawmills.

The present study observed that most of the timbers traded through sawmills were from homegardens. For teak, the major sources are the state forest depots. Due to the high demand for teak timbers in the market, teakwood is being imported from other countries to meet the demand. Most of the teak wood produced is consumed within the state mainly for building construction and furniture making (Krishnankutty *et al.*, 2005). A study conducted by Sivaram (2008) reported that the long term revenue and expenditure in plantation sectors of Forest Department in Kerala have been centered on teak plantations, which form the major source of teak wood supply. Apart from teak plantations, home gardens are also major source for the teak wood supply in Kerala. Similar findings were observed by Krishnankutty *et al.* (2005) who reported that there occurred a transformation in the role of supplier in timber sector. Government managed forests changed from the role of major timber supplier, now areas outside forests, particularly homehardens and rubber estates, supply almost all industrial wood requirements and a major share of the construction timber in Kerala. The present study also observed that teak was imported from countries like Benin, Cameroon, Cambodia, Colombia, Costa-Rica, Ecuador, Ghana, Ivory Coast, Malaysia, Sudan, Tanzania, Trinidad & Tobago and Vietnam etc. It was also found that species other than teak that were imported are Pynkado, Koyla, Green heart, Violet, Malaysian irumullu, Brazilian irumullu, Millinga, Basra, Nora, Purple heart etc. The study also found that Pynkado is a major imported species in the timber market of Kerala due to its higher demand in the market.

5.8.2 Opinion about National and International teak varieties among sawmill owners

Fig 6 shows that, about 60 per cent of the mill owners highly preferred national teak varieties and forty per cent of mill owners highly preferred international teak varieties. Those who highly preferred national varieties cited quality of national teak varieties were much better than some of the imported varieties. As the reason in most of the sawmills, domestic teak was more consumed than any other varieties of teak. Domestic teak was easily available and cost effective to the customers. The preference of mill owners are dependent on the consumers taste, availability of raw materials and price of the teak. Those who highly preferred international varieties are due to lower price and based on customers demand. Customers preferred international varieties even though some of the international varieties are inferior to national varieties in wood quality because of the lower price and easy availability of rawmaterials.

The present study found that sawmill owners have knowledge and are familiar about national teak varieties. However, some of the sawmill owners are not very familiar with all the teak varieties. Nilambur teak was found to be familiar with all the sawmill owners because of its high reputation in the market. The main reasons for preferring Nilambur teak was due to its higher heartwood – sapwood ratio, golden brown colour, continuity of grains, high oil content, high pest resistance, good workability and better strength properties. Bhat *et al.* (2007) observed higher heartwood percentage for Nilambur teak compared to teak from other provenances. However, other teak varieties like West Bengal teak, Central Indian teak, Karnataka teak, Adilabad teak, Maharastra teak were not so popular among all the sawmill owners. So the number of respondents who rated the teak varieties varied with respect to their knowledge about the national teak varieties (Fig 7). Also their preference varied in accordance with the demand, price trends and nature of the timber market. Table 18 shows that 82 % of respondent's highly preferred Nilambur teak among the national teak varieties. However, Karnataka (81.25%) and Maharashtra (65%) teak varieties have moderate level of preference among national teak varieties out of those who responded. Locally available homegarden teak from homegardens were found to have a good role in meeting the demands of customers because of its easy availability and lesser price compared to other national varieties. Also Konni and Malayattoor teak from Kerala also had a good reputation in the market. Teak from Karnataka, Maharastra,and Assam also have a place in the timber markets of Kerala. The demand for teak varieties varied in accordance with the change in price, availability and quality, of which price was found to be an important factor than others in dictating timber market. Although most of them preferred Nilambur teak because of its better quality than other available teak varieties, but its rate of consumption is less due to the higher price and also lower available quantity of Nilambur teak.

Fig 10 shows the popularity of international teak varieties among the sawmill owners. Teak from Burma, Benin, Ghana and Tanzania were most popular among the international teak varieties, although teak from Cameroon, Colombia, Costa-Rica, Ecuador, Ivory Coast, Malaysia,Trinidad & Tobago and Vietnam also found a place in timber market of Kerala. Out of the international teak varieties Burmese teak was the highest demanded one among the mill owners. The demand for Burmese teak were high among the customers too. Some of the mill owners preferred Burmese teak varieties over national teak varieties because of their good wood quality. The round shape of the log, darker colour, good strength properties, workability and lesser sapwood content helped Burmese teak to find its own market in Kerala compared to other international varieties. Due to the ban in the export of Burma teak, the availability of Burmese teak decreased in the market. Also, the market for other international teak varieties increased due to its lower price and availability.

5.8.3 Perception of sawmill owners about Nilambur teak

Perception about Nilambur teak among sawmill owners was measured from member's responses to the same and is presented in Table 19. The majority of members (56 %) agreed to the statement "Nilambur teak possess a good reputation in the timber market" helped to understand the fact that Nilambur teak has a good reputation among the sawmill owners and customers. The present study also supports this result (Table 19). According to the member's responses, the statement such as "Site factors and climate contributes to its better quality and growth" and "Soil of Nilambur have greater influence on its colour" were agreed to by 56 per cent and 62 per cent respectively. Nilambur teak plantations ascribe good site quality to high silica-sesquioxide ratio, alluvial soils, moisture availability, drainage, sandy loam texture and higher levels of bases (Davis 1940, Laurie and Griffith, 1942). It is the general observation that good-quality teak is restricted to strips along river banks and further inwards there is lowering of the quality. About 64 per cent of members agreed to the statement "Nilambur teak possess good colour than other available teak wood in the market", helped to understand that colour of Nilambur teak was outstanding than other available teak wood in the market. Also 72 per cent of respondents agreed to the statement "Seedlings of Nilambur teak raised outside the Nilambur provenance do not have the same quality", indicated that the respondents believed that the soil and climate of Nilambur region have a major impact on the quality of wood produced there. Bhat *et al.* (2007) reported that, Malabar teak (Nilambur, Kerala) from the Western Ghats region in India, generally displaying good growth and log dimension with desired wood figure (golden yellowish brown colour), has a wide reputation in the world trade for ship building. Ecological zones has an important role for determining the wood quality (Bhat *et al.*, 2007). The present study showed that about 40 per cent of respondents agreed to the statement "Increased price for Nilambur teak diminishes the purchasing power of the customers" and 42 per cent of respondents have a neutral response on the statement "Timber merchants prefer to buy Nilambur teak over other available teak woods", helped to understand that the increased price and shortage in the availability of Nilambur teak made them difficult to purchase.

5.8.4 Cluster analysis of teak varieties

In the present study, teak varieties were grouped according to the similarity in selected wood characters on the basis of knowledge and information provided by the mill owners. Eight commercially important wood characters that determine the teak market were selected. The selected wood characters were colour, figure, odour, strength, hardness, workability, durability and oil content. Table 20 shows that, Nilambur, Konni, homegarden (local) and Burmese teak forms a cluster, which means that they have similarity in selected wood characteristics. The study observed that teak from Nilambur, Konni, Burma and homegarden teak have attractive colour, excellent figure, good workability, better strength properties compared to other national and international teak varieties available in the market as per the perception of mill owners. Varghese *et al.* (2000) observed that the very moist population (Nilambur, Kerala) had best growth and form but comparatively lower wood density on par with the slightly moist natural stand (Nasik) and the dry teak population (Pandarkwada, Maharastra). Similarly Benin and Ghana teak, and Cameroon, Colombia, Costa Rica, Ecuador, Ivory Coast, Karnataka, Maharastra, Malaysia, Tanzania and Walayar teak formed different clusters respectively. Nilambur teak has shown higher statistical value compared to other teak varieties. It shows that Nilambur teak is excellent from the commercial point of view expressed by the mill owners compared to other teak varieties in the same group and in different groups.

5.8.5 Variation in market price of different teak varieties sold through the sawmills

Teak has a strong reputation for high prices, excellent wood quality and its silviculture is understood making it one of the most valuable multipurpose timbers of the world (Keogh, 2009). It is difficult to get accurate and regular wholesale and export prices for teak wood. In most cases heartwood color and content determine, whether the log will fetch high or low price with a corresponding gain / loss of upto 50 per cent of its potential value (Moya and Perez, 2008). GOK (2016) reported that the prices of teak wood have increased substantially since 1976-77 and the upward trend continues. The study also reported that the increase in price can dampen the demand and at the same time can make way for increased supply in the future. Trees are slow growing crops; it is not possible to increase the timber production within a short period of time in response to the change in price.

The present study was based on the information provided by the sawmill owners. Fig. 11 showed that among teak woods available in the timber market of Central Kerala, Nilambur teak has high market price per cubic feet ranging from 6000-8000 rupees. The high price of Nilambur teak may be due to its attractive colour, figure, higher heartwood percentage, good shape, workability, durability and good strength properties. Varghese *et al.* (2000) observed that sapwood content was negatively correlated with growth rate with significantly lower values for very moist and moist populations (Nilambur, Konni, Topslip). Good reputation of Nilambur teak in the world timber market and increased demand for it also act as a reason for the its high price in the market. Burmese, Konni, Malayattoor and Walayar teak also fetches good price ranging from 4000-6000 rupees per cubic feet. Price of domestic teak ranged from 2000-4000 rupees per cubic feet. Teak from Benin, Cameroon, Colombia, Costa-Rica, Ecuador, Ghana, Ivory Coast, Malaysia, Tanzania, Trinidad and Tobago and Vietnam comes under low price category (below 2000 rupees per cu. ft.). The poor aesthetic appearance, higher sapwood content and low strength properties compared to other teak varieties may be the reason for its lower price in the timber market. The wood quality, demand and availability of the teak varieties have more influence in dictating the price of teak.

5.9. GEOGRAPHICAL INDICATIONS STATUS FOR NILAMBUR TEAK

Wayanad Gandhakasala Rice is a GI registered product from Kerala. It is the most popular traditional aromatic rice cultivar of Wayanad District. This scented, nonbasmati rice is famous for its characteristic fragrance and aroma. The distinctive, exclusive and rare qualities of Wayanad Gandhakasala Rice could be the result of several factors including genotype, climate, soil and other ecological factors and system of cultivation based on traditional and tribal knowledge (GI Registry, 2010).

Similarly, Darjeeling tea is a premium quality tea produced in the hilly regions of the Darjeeling district West Bengal, India, which is the first GI registered product from India. Among the teas grown in India, Darjeeling tea offers distinctive characteristics of quality and flavour, and also a global reputation for more than a century. Broadly speaking there are two factors which have contributed to such an exceptional and distinctive taste, namely geographical origin and processing. The main factors that contributed to obtain GI tag were its historical importance, reputation in the global market, its unique characteristics contributed by the geographical location (Ravindran and Mathew, 2009).

In the present study it was found that Nilambur teak has a long history that helped it to secure a place in the international timber market. Unique characteristics of Nilambur teak includes its colour (Golden brown colour), higher heartwood – sapwood ratio, moderate values for density and higher values for dynamic MOE. The climate and soil also act as contributing factors that influence the uniqueness of Nilambur teak. The presence of site quality I and II in the area contribute to the superior quality of Nilambur teak. The study also found that Nilambur teak has a good reputation among the timber merchants. The factors like historical importance, reputation in the timber market and its unique characteristics as a result of genotype, climate and soil make Nilambur teak a potential candidate for obtaining GI status.

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SUMMARY

SUMMARY

The study on "Geographical Indications status for Nilambur teak (*Tectona grandis* L.f)" was carried out in teak plantations of Nilambur and in Central Kerala during 2014-2016. This chapter presents a summary of the findings of the study. The main objective of the study was to analyze the potential of securing geographical indications status for Nilambur teak by exploring the historical importance of Nilambur teak with the help of PRA tool timeline, comparing certain wood quality parameters with other national and international varieties. The study also aimed to analyse the soil properties and climatic factors that are responsible for the uniqueness of Nilambur teak and to find the popularity of Nilambur teak among the merchants.

For studying wood properties, three best teak growing plantations in the Nilambur (Aryavallikkavu, Elencheri and Kanakuthu) were selected. Thirty trees were selected randomly from each plantation. Growth parameters such as girth and height were taken from the selected trees; also non destructive testing methods using Pilodyn and Tree sonic timer were used to estimate wood physical and mechanical properties. For analyzing soil properties two soil pits of 1 m * 1 m* 1 m were dug from each of three plantations. Soil samples were collected from 0-20, 21-40, 41-60, 61-80 and 81-100 cm depth. Popularity and reputation of Nilambur teak among the merchants were studied by a questionnaire survey conducted in sawmills of Central Kerala (Thrissur, Palakkad and Ernakulam).

The objective based conclusions of the study are presented under 6.1, 6.2 and 6.3.

6.1 Historical importance and reputation of Nilambur teak

6.1.1 Nilambur teak has a long history which helped it to acquire a good reputation in the international timber market. It revealed that the history of Nilambur teak started near the beginning of 14th century, where Arabs started manufacturing units of sails boat at Beypore, Kozhikode. It was also assumed to be used for the construction of certain important monuments and also in some historically important battles like battle of Waterloo, first and second world war.

6.1.2 The study found that mill owners have a long term experience in the business. About 36 per cent of them working in this field have an experience of 20 to 30 years. Only 8 per cent of the total showed less experience in the business. Most of sawmills (42%) in the present study were established during the period 1990-2005. Only 20 per cent of sawmills were established after 2005. The emergence number of new mills and new entrepreneurs in this business showed a decreasing trend.

6.1.3 A Total of fifteen major timber species were found to be traded in sawmills of Central Kerala. *Tectona grandis* is one of the major timber species used in all sawmills studied. Some species like *Artocarpus heterophyllus*, *Swietenia macrophylla* and *Dalbergia latifolia* were seen used predominantly with 80, 70 and 52 per cent respectively.

6.1.4 Around sixty per cent of the mill owners highly preferred national teak varieties and forty per cent of mill owners preferred international teak varieties. In the present study, around 82 per cent of respondents' highly preferred Nilambur teak among the national teak varieties. Among international teak Burmese teak were more popular among the sawmill owners followed by Benin, Ghana and Tanzania teak varieties.

6.1.5 Among teak woods available in the timber market of Central Kerala, Nilambur teak has high market price per cubic feet ranging from 6000-8000 rupees. Burmese, Konni, Malayattoor and Walayar teak were sold out at a price ranging from 4000-6000 rupees per cubic feet.

6.2 Comparison of wood quality of Nilambur teak with teak from other provenance

6.2.1 Wood properties like heartwood- sapwood ratio, heartwood colour, dynamic MOE were studied.

6.2.2 Heartwood accounted for a mean value of 83.52 %, 85.27 % and 87.06 % for Aryavallikkavu, Elencheri and Kanakuthu region respectively. The comparison of heartwood percentage of Nilambur teak from the present study with the secondary data of heartwood percentage of teak grown in various other provenances collected from other studies showed that Nilambur teak had highest heartwood percentage compared to the teak from other provenances.

6.2.3 Heartwood colour determining components (hue, value and chroma) did not show any significant variation between the three sites. Total of nine colour variations were described with the help of Munsell system (i.e. Brown, Yellowish Brown, Dark Yellowish Brown, Brownish Yellow, Very Dark Greyish Brown, Dark Reddish Brown, Light Yellowish Brown, Pale Brown and Yellowish Brown). The comparison of heartwood colour of from the present study with the secondary data collected from other studies showed that Nilambur teak has attractive colour compared to teak from other provenances.

6.2.4 Mean tree GBH was found to be highest in plantation from Kanakuthu (126.04 cm), followed by Aryavallikkavu (121.47 cm) and Elencheri (120.5 cm). Mean tree height was found to be highest in plantation from Kanakuthu (16.93 m), followed by Elencheri and Aryavallikkavu plantations with mean tree height of 16.05 and 14.86 respectively.

6.2.5 No significant difference found in the pilodyn penetration depth between the three regions of Nilambur. Pilodyn penetration depth was found to be highest in teak plantation of Aryavallikkavu followed by Kanakuthu and Elencheri. The value ranged from 12.73 to 13.31 mm. The value of density obtained using Pilodyn instrument ranged from 548.99 to 563.21 kg/ m^3. It was similar to the basic density values obtained for Nilambur teak in the previous studies. The highest value for stress wave velocity was found in the plantation from Kanakuthu followed by Aryavallivaku and Elencheri with 3153.84 m/s, 3063.69 m/s and 3038.15 m/s respectively. It represents the soundness of wood. The higher value in dynamic MOE indicates better strength properties of Nilambur teak. The highest value for dynamic modulus of elasticity was found to be from plantations of Kanakuthu (547665 kg/cm^2) and the lowest in plantation from Aryavallikkavu region (515292.9 kg/cm^2).

6.3 Potential agro-ecological and biophysical factors responsible for the uniqueness of Nilambur teak

6.3.1 The average annual temperature in Nilambur is 25.86^{0}C. April was the hottest month with an average monthly temperature of 28.36 $^\circ$ C. Nilambur receives rainfall for almost ten months in a year from both monsoons and local systems though most of the rainfall occurs during the southwest monsoon period. The average annual rainfall is 2675 mm. The heavy rainfall and bright sunshine lead to a humid and warm climate, excellent for luxuriant plant growth.

6.3.2 The result of soil study showed that soil of Nilambur is contributing to its better growth performance.

6.3.3 The bulk density values were generally higher in the deeper layers of soil. The mean bulk density values were in the range 1.0 to 1.92 g/cm^3. The soil texture was sandy loam in all the sites and at different depths of soils in the selected teak plantations. Increased sand content in the soil helps in better drainage and also the roots can go much deeper and get moisture from lower levels. Soil pH value ranged from 6.05 to 4.79 from top to bottom layer indicating moderate acidity in teak plantations. By analysing the several studies found that teak grows well in slightly acidic soil and soil pH positively correlated with tree heights and basal area.

6.3.4 The total nitrogen content in teak plantations varied from 50.85 kg/ha to 294.23 kg/ha. The total nitrogen in soils was highest in the surface and decreased with the depth in the selected plantations. The mean values of total phosphorous in selected teak plantations varied from 163.58 to 140.94 kg/ha. Also higher phosphorous content was observed in the top layer and decreased with increase in soil depth. A positive relation was observed between soil organic matter and total phosphorous content. The available potassium content in teak plantations varied from 216.87 to 31.04 kg/ha. Higher K content was observed in the top layers and gradually decreased with increase in soil depth. Soil carbon was highest in the surface and decreased with the depth in all the selected teak plantations. Organic carbon content varied from 1.83 to 0.25 per cent with depth. Carbon content was lower in plantation soils compared to that of natural forest. Organic carbon was positively associated with dbh.

It can be concluded from the study that, there was not much variation in growth, physical and mechanical properties of teak of same age- class grown in the similar sites of Nilambur region. Nilambur teak has a long history that helped it to secure a good place in international teak market. Soil properties and climate also influences the teak growth and wood quality. The study also found that Nilambur teak has a good reputation among the timber merchants of Ernakulam, Thrissur and Palakkad districts.

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APPENDIX

APPENDIX- I

Questionnaire for Data collection from Sawmill Owners

<u>Geographical Indications Status for Nilambur Teak (*Tectona grandis*.L.f)</u>

Department of Wood Science
College of Forestry
Kerala Agriculture University
Vellanikkara, Thrissur.

Interview Schedule for data collection from Sawmill Owners

Declaration

The information provided will be used only for the research work for thesis for Master's Degree and the identity of the respondent/information provided by them will not be revealed to a third party.

SOCIO ECONOMIC DETAILS

1. Name of the saw mill : ....

2. Address : ....
....
....

3. Telephone Number : ....

4. How old is your saw mill:

1). < 10 yrs   2). 10-20 yrs   3). 20-30 yrs   4).30-40 yrs   5).40-50 yrs   6). >50yrs

5. Years of experience in this field:

1. <10   2). 10-20   3). 20-30   4). 30-40   5). 40-50   6). >50

6. Major timber species in the saw mill:

1

2

3

7. Imported timbers from other countries?

8. Which Teak variety does you favours the most?

International ☐ National ☐

9. Rating of national teak varieties

(1-low, 2-medium, 3-high)

Teak types	1	2	3
Assam teak			
Adilabad teak			
CPT(Central Province Teak)			
Karnataka teak			
Konni teak			
Malayattoor teak			
Maharastra teak			
Nilambur teak			
West Bengal teak			

10. Rating of International teak varieties

10. Rating of International teak varieties

(1-low, 2-medium, 3-high)

Teak types	1	2	3
Benin teak			
Burmese teak			
Cameroon teak			
Colombia teak			
Costa-Rica teak			
Ecuador teak			
Ghana teak			
Ivory Coast teak			
Malaysian teak			
Tanzanian teak			
Trinidad and Tobago teak			
Vietnam teak			

11. Characteristics of teak varieties (using 3 point Likert's scale)

Teak types								
	Colour 1-Low 2-Medium 3-High	Figure 1- Poor 2-Good 3- Excellent	Odour 1- no odour 2- Poor 3- Strong	Strength 1-Low 2-Medium 3-High	Hardness 1- Low 2- Medium 3- High	Workability - Poor 2-Good 3- Excellent	Durability 1-Low 2-Medium 3-High	Oil content 1- Low 2- Medium 3- High
Assam teak								
Beninteak								
Burma teak								
Cameroon teak								
Colombia teak								
Costa-Rica teak								
Domestic teak								
Ecuador teak								
Ghana teak								
Ivory Coast teak								
Karnataka teak								
Konni teak								

Malayattoor								
Malaysian teak								
Nilambur teak								

12. Perceptions of saw mill owners about Nilambur teak

Sl no.	Perceptions	1	2	3	4	5
1	Nilambur teak possess a good reputation in the timber market					
2	Site factors and climate contributes to its better quality and growth					
3	Soil of Nilambur have greater influence on its colour					
4	Nilambur teak possess good colour than other available teak woods in the market					
5	Workability of Nilambur teak is good compared to other national and international teak varieties					
6	Physical appearance of Nilambur teak earns it a good price in the market					
7	Historical importance of Nilambur teak helps to gain a good reputation in the international market					
8	Seedlings of Nilambur teak raised outside the Nilambur provenance do not have the same quality					
9	Quality of plantation teak is better than homestead teak					
10	Increased price for Nilambur teak diminishes the purchasing power of the customers					
11	Timber merchants prefer to buy Nilambur teak over other available teak woods					

13. Price Variation in teak Varieties per cubic feet.

Teak types	1 Price range < Rs.2000 /-	2 Price range b/w Rs. 2000-4000/-	3 Price range b/w Rs. 4000-6000/-	4 Price range b/w Rs.6000-8000/-	5 Price range b/w Rs.8000-10000 and above
Assam teak					
Beninteak					
Burma teak					
Cameroon teak					
Colombia teak					
Costa-Rica teak					
Domestic teak					
Ecuador teak					
Ghana teak					
Ivory Coast teak					
Karnataka teak					
Konni teak					
Maharastra teak					
Malayattoor					

Malaysian teak					
Nilambur teak					
Tanzanian teak					
Trinidad and Tobago					
Vietnam teak					

Geographical Indications status for Nilambur Teak (*Tectona grandis* L.f.)

By

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(2014-17-107)

ABSTRACT OF THE THESIS

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ABSTRACT

A study on the "Geographical Indications status for Nilambur teak (*Tectona grandis* L.f)" was carried out in teak plantations of Nilambur and in Central Kerala (Thrissur, Palakkad and Ernakulam) during 2014-2016. The investigation focused on analyzing the potential of securing Geographical indications status for Nilambur teak by exploring the historical importance of Nilambur teak with the help of PRA tool timeline, comparing its wood quality with other National and International provenances and analysing the soil properties and climatic factors that are responsible for the uniqueness of Nilambur teak and to assess the popularity of Nilambur teak among the timber traders.

Wood properties of three best teak growing plantations in Nilambur viz., Aryavallikkavu, Elencheri and Kanakuthu were analysed. Growth parameters such as girth at breast height (GBH) and height were taken from the selected trees; also non destructive testing methods (NDT) using Pilodyn (6J) and Tree Sonic Timer (FAKOPP) were used to estimate wood physical and mechanical properties. Heartwood percentage and colour were estimated in the teak discs collected from the selected plantations. No significant variation was found in Pilodyn penetration depth (PPD), Stress wave velocity (SWV), dynamic modulus of elasticity, heartwood percentage and GBH between the three plantations of Nilambur region. Heartwood colour determining components (hue, value and chroma) did not show any significant variation between the sites. In general, there was not much variation in physical and mechanical properties of teak grown in the various sites of Nilambur region.

For analyzing soil properties, two soil pits of 1 m * 1 m* 1 m were dug from each of these plantations. Soil samples were collected from 0-20, 21-40, 41-60, 61-80 and 81-100 cm depths. The soil texture was sandy loam in all the sites and at different depths of soils in the selected teak plantations. Soil pH ranged from 6.05 to 4.79 from

top to bottom layer indicating moderate acidity which measured with soil depth in teak plantations. The bulk density values were generally higher in the deeper layers of the soil. The mean bulk density values were in the range 1.0 to 1.92 g/cm^3. Soil N, P, K content was lower in all the three sites compared to natural forests. Organic carbon content varied from 1.83 to 0.25 per cent with depth.

Popularity and reputation of Nilambur teak among the traders studied through a questionnaire survey in sawmills of Thrissur, Palakkad and Ernakulam revealed that Nilambur teak has a high reputation among sawmill owners. Among teak woods available in the timber market of Central Kerala, Nilambur teak fetches high market prices per cubic feet. It is concluded that Nilambur teak has good potential for securing Geographical Indications status owing to its historical importance, good reputation, excellent colour, higher heartwood percentage and better strength properties.