

# Study of Physico-Chemical Characteristics of Tectona Grandis Spp. of Vidarbha Region, with Respect to its Various Potential Uses

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**Abstract:** Forest ecosystems and botanical resources underpin both ecological stability and economic development. In the context of tropical forestry, *Tectona grandis* species, universally recognised as Teak, stands unparalleled as one of the most premium and highly sought-after timber-yielding species globally.

The Vidarbha region of Maharashtra, characterised by its distinct climatic conditions and varied soil typologies, supports vast tracts of both natural and plantation teak forests. While the general properties of teak are well documented, the wood's precise physical and chemical traits, such as extractive content, density, and specific gravity, depend heavily on localised environmental and silvicultural factors. The morphological variations and chemical diversity inherent to the trees of this specific geographical zone warrant rigorous scientific investigation.

This study of the physico-chemical characteristics of *Tectona grandis* spp. in the Vidarbha Region, with Respect to their Various Potential Uses, was undertaken to systematically analyse species parameters across this zone. The research evaluates physical and chemical characteristics for the identification of vital phytochemicals and structural composition. By comprehensively documenting these metrics, this research aims to optimise the utilisation of Vidarbha's teak not only for traditional timber and pulp but also for emerging non-timber applications, including biofuel material and liquid smoke.

Ultimately, bridging the gap between raw botanical properties and modern potential uses will add significant economic value to regional plantation management. The empirical data and findings presented in this study will serve as a valuable reference for research students, foresters, wood scientists, pharmacologists, farmers and policymakers striving for sustainable utilisation of tropical forestry resources.

**Keywords:** Density, Green Moisture Content (GMC), Physico-Chemical Characteristics, Specific Gravity, *Tectona Grandis* spp. Vidarbha Region.

## I. INTRODUCTION

India is a land of diverse culture and nature, yet it's a united country with a large geographic area, which helps India rank seventh in the world, with 328.73 million ha. area of around 21.72 % forest cover. The diversified nature in India makes it one of the members of the group of twelve Megadiverse countries. Again, while researching the biodiversity profile across the globe, in India, 8 % of total biodiversity is found. Consistently, about 4500 plus species of plants and many more animals are found in the Indian peninsula. India's forests hold the best genetic diversity of *Tectona grandis* across its 70.17 million ha of forests. (Krishna and Nair, 2010). There are some lands in India that are exclusively suitable for *Tectona grandis*; hence, the most abundant Genetic resources of *Tectona grandis* (Teak) are observed



overall in India. Two types of teak-bearing forests, primarily natural forests of teak and secondarily planted forests of teak, are observed in India. Moreover, about 256 ha of seed orchards with seed production areas of 5540 ha are also available in India. The mandatory annual teak plantation on average is about 31,000 to 52,000 ha in India. With such highlighted features, *Tectona grandis* becomes the most promising species in India in all aspects. (Boley et al., 2009)

Teak (*Tectona grandis*) is a massive deciduous tree growing over 35 meters tall with a straight stem, a crown of small branches, and a shallow 50 cm root network. Its coarse, brown or whitish-brown bark features vertical splits, while its large leaves—shiny on top and hairy underneath—shed completely for 3 to 4 months during the dry season. The tree produces expansive apex inflorescences up to 45 cm long with tiny white-to-mauve flowers, and its timber boasts exceptional dimensional stability, high durability, and natural resistance to rot and pests due to its rich oil and silica content. (Nature Portfolio report 2022; Colbu et al., 2021).

*Tectona grandis* (teak) is a highly valuable global hardwood that occupies approximately 6% to 10% of all tropical forests, prized for its natural oil and silica content, which provide exceptional resistance to rot, fungus, and decay (Chakraborty et al., 2017; Pandey and Brown, 2000). Due to its extraordinary durability and strength, it is a preferred material for the marine, construction, and furniture industries (Pandey and Brown, 2000). In the Vidarbha region, an area covering roughly 31.6% of eastern Maharashtra in central India, teak forests serve as a vital cornerstone alongside agriculture, driving both the local economy and environmental sustainability. This study is carried out in five divisions of the Vidarbha region of Maharashtra, India, namely Nagpur, Bhandara, Gondia, Yavatmal, and Chandrapur, because, after thorough observations and a literature review, it is decided that as the above divisions have good *Tectona grandis* population and study of this plant species will provide crucial data for benefit of Vidarbha region. Accordingly, the study locations were selected. Figure 1.1 shows the region and division maps of the selected divisions.

Studying the physicochemical profiling and physiological traits of Vidarbha's *Tectona grandis* (teak) is crucial for the region's economy and ecology, as it provides the scientific data needed to validate the timber's premium durability and protect it from cheaper substitutes. Grown in nutrient-rich, basaltic soil, Vidarbha teak is historically renowned for its high quality, making this research highly beneficial for local farmers and stakeholders.



Figure 1.1 Study area: the Vidarbha region.

## II. MATERIALS AND METHODS

For the study of physical characteristics, the areas that are representative of that division are identified, and the boundaries of plantations are verified. When a large plantation is divided into sections. To study the growth variations of *Tectona grandis* across different planting environments, forest stock maps were used to select 28 suitable sites across five divisions in the Vidarbha region. plantation boundaries were verified, division into the large sections, and representative sample plots were established for 100% tree enumeration. DBH, height class, and girth class measurements were carried out. Site qualities were determined using top height data from the Maharashtra Forest



Records No. III Silviculture Manual, and chemical characteristics were analysed using 20 mm x 100 mm x 200 mm wood samples to identify location-specific physical characteristics. For the study of chemical characteristics, samples were also collected from the selected trees of the sample plots. To study chemical characteristics of this species, green density, basic density, shrinkage percentage, thermal conductivity, and specific heat capacity, elemental carbon, ash content percentage and temperature were calculated using standard operating procedures. The Figure 2.1 Shows the representative sample plot.



**Figure 2.1. Representative Sample Plot**

To maximise the value of *Tectona grandis* species by searching for more and more potential uses that help to value this species is needed. Hence, some potential uses of this species, like preparation of bio-pellets and preparation of liquid smoke from this species, are carried out. The calorific value is also calculated by using a bomb calorimeter and following standard operating procedures and compared to assess its energy potential.

#### Calorific value determination

The calorific value of the prepared biomass samples was determined using a digital bomb calorimeter manufactured by Labsoul India. This instrument is commonly used to measure the heat released during the complete combustion of solid fuel materials. A precisely weighed sample was placed in a crucible located inside a heavy-duty stainless steel combustion chamber, commonly referred to as the bomb. The chamber was sealed and filled with pure oxygen under high pressure to facilitate complete combustion. The ignition of the sample was carried out electrically using a fine ignition wire. Combustion of the sample resulted in the release of heat, which caused a measurable increase in the temperature of the surrounding water bath. The temperature change was recorded by a digital temperature sensor integrated with the calorimeter system (Vasudevan et al., 2005). Before sample analysis, the calorimeter was standardised using benzoic acid pellets of known calorific value. Approximately one gram or less of benzoic acid was combusted in the oxygen-sealed bomb to determine the water equivalent of the calorimeter system. This water equivalent value was subsequently used in the calculation of calorific values for the wood samples. For each measurement, a known mass of the prepared wood pellet sample was placed inside the crucible, and the bomb was filled with oxygen at the required pressure. The bomb was then immersed in a copper calorimeter vessel containing a measured quantity of water and equipped with a stirrer and thermometer to ensure uniform heat distribution. Ignition of the sample produced heat that raised the temperature of the surrounding water. The observed temperature rise, together with the calorimeter water equivalent and sample mass, was used to calculate the calorific value of the sample. The experimental setup used for calorific value determination is illustrated in Figure 2.2. The calorific value of the sample was calculated using the following equation. (Singh et al., 2005).

#### Where:

CVs=Calorific value of the sample

T=Final rise in temperature

W = Water equivalent of the calorimeter (calories per degree Celsius)

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CV<sub>t</sub> = Calorific value of the ignition thread (2.1 calories per centimetre)

CV<sub>w</sub> = Calorific value of the ignition wire (2.33 calories per centimetre for 6 mm wire)

M = Mass of the sample

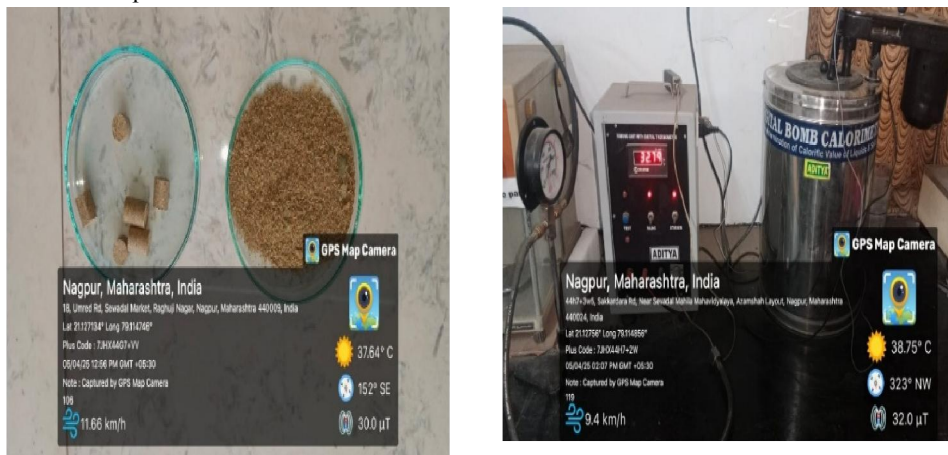


Figure 2.2: Biomass pellets prepared from wood samples for calorific value analysis and Experimental setup showing determination of calorific value using a digital bomb calorimeter

### Preparation of Liquid Smoke

Teak sawdust and wood waste are collected from a known source. The pre-weighed (500 g to 2 kg) teak Wood chips were soaked in distilled water overnight. A semi-batch pyrolysis reactor/furnace, a condenser with a water-cooled piping system, beakers, a funnel, filter paper, an analytical balance, and distilled water are used for the preparation of *Tectona grandis* Liquid Smoke. The soaked teak material is measured and weighed out and then placed into the volumetric flask. The flask is sealed tightly to restrict excessive oxygen intake, ensuring that smouldering rather than open combustion occurs in the biomass. The flask is heated to a pyrolysis operating temperature, and the process is allowed to run for 2 hours. Cellulose, hemicellulose, and lignin are decomposed by the heating into volatile smoke vapours. The hot smoke vapour is funnelled out of the reactor and passed through the condenser. It is ensured that the condenser is kept cold (using circulating water) so that the gas is rapidly cooled. The condensed liquid droplets, known as crude liquid smoke, are collected into a collection flask. The collected liquid smoke is filtered using filter paper to remove any remaining suspended tar particles. Figure 2.3 shows the step-by-step preparation of *Tectona grandis* Liquid Smoke.

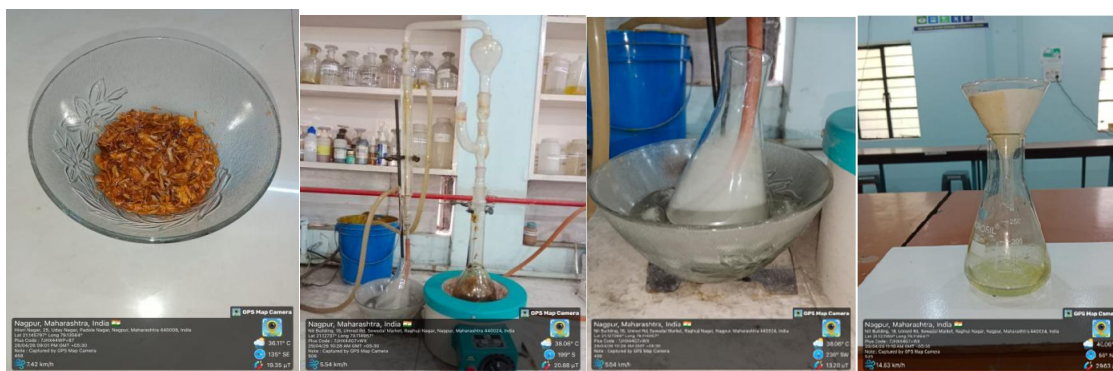


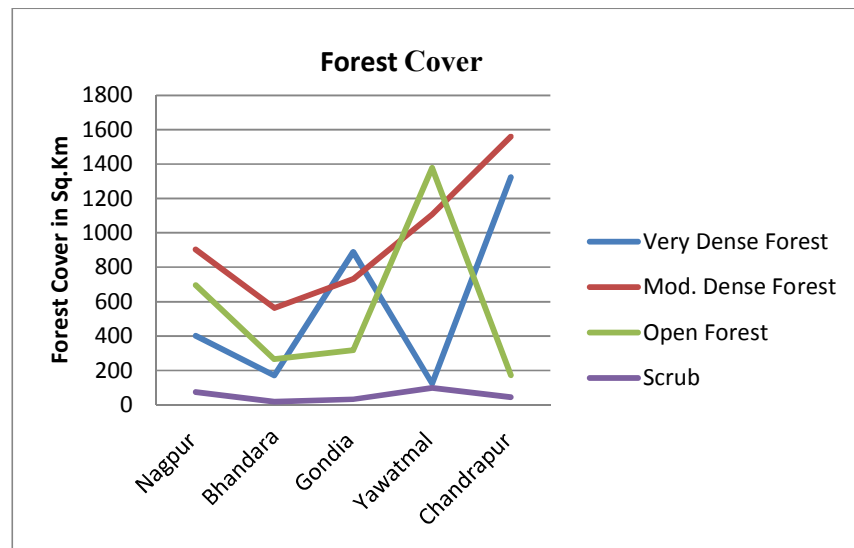
Figure 2.3: Preparation of *Tectona grandis* Liquid Smoke.



### III. RESULTS AND DISCUSSIONS

#### 3.1 Study of Physical characteristics of *Tectona grandis* spp. of Vidarbha region

Graph 3.1 depicts the total forest cover under the five selected divisions: Nagpur, Bhandara, Gondia, Yavatmal, and Chandrapur. In Maharashtra, moist teak forest cover is 10.71%, and dry teak forest cover is 17.40 % means out total teak forest cover is 28.11%, and out of these, major *Tectona grandis* (teak) forests are found in the above-mentioned five districts. Different *Tectona grandis* (teak) plantation sites are selected from the above five divisions, and physical characteristics of *Tectona grandis* spp. are observed and calculated. Representative Sample plots are laid, and 100% enumeration of every sample plot is done. Local Volume Table is used to determine site quality and age.

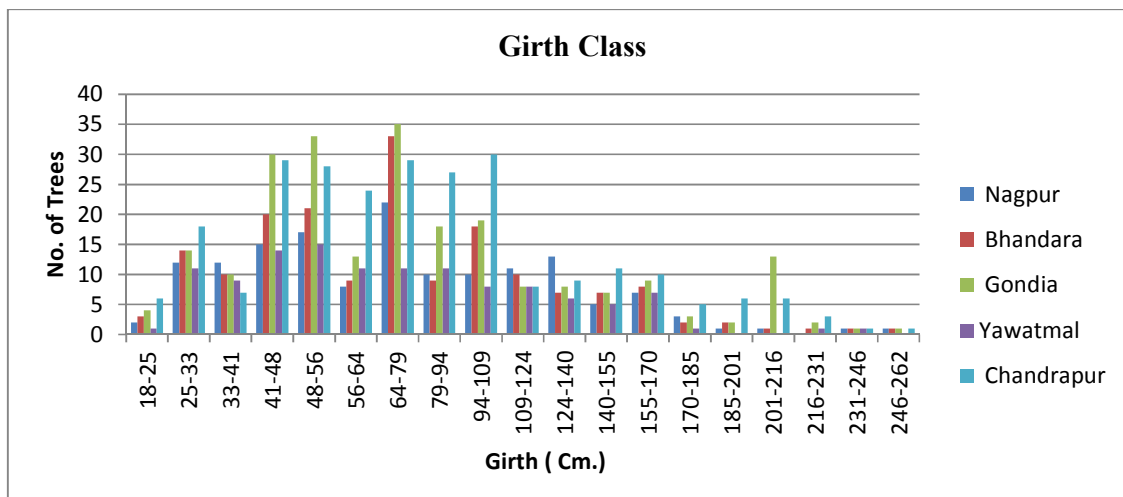


Graph 3.1 Forest cover of selected region for this study.

#### Girth Class

After enumeration of different sample plots in the height class and girth class, the above five divisions were calculated/determined. With the help of the height and girth of the tree, the volume of the tree is calculated using the quarter-girth formula, and accordingly the average volume is calculated for each plantation site. Graph 3.2 shows that, in *Tectona grandis* spp., the minimum girth of trees is 18-25 cm, and the maximum girth observed is 262 cm. The maximum *Tectona grandis* species are found in all five divisions is between 64 cm to 79 and 94-109 cm girth class. From the above girth class, it is observed that the crop/ plantation are having uneven age group of trees, and most of the trees are middle-aged.

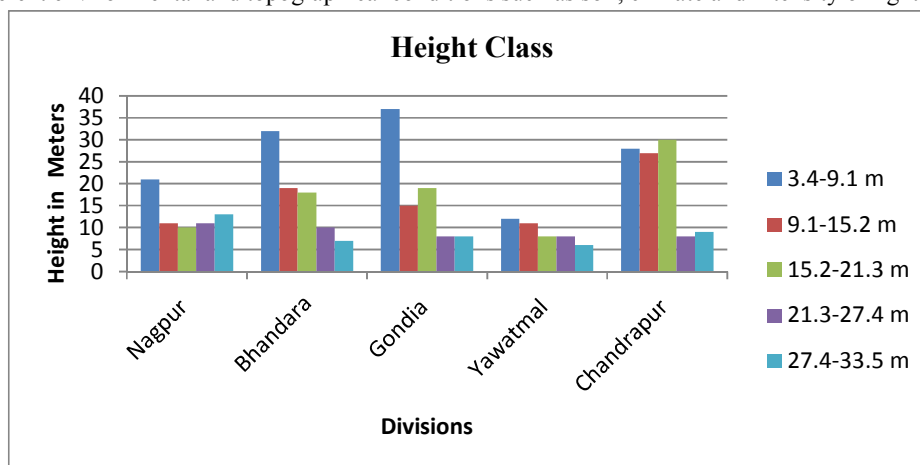




Graph 3.2 Girth class of Tectona grandis spp. in the selected region for this study.

### Height Class

Height class ranges between 3.4 meter to 33.5 meters. After studying height class, it is observed from Graph 3.3 that the Gondia division has the maximum number of tall Tectona grandis spp. compared to the Yawatmal and Nagpur divisions. The minimum height attained by Tectona grandis spp. in Yawatmal division is 3.4-9.1 meters, and the maximum height is found in Gondia division is 27.4-33.5 meter. Average Age of plantations is calculated by knowing height and girth class, plantation year, plantation history and with the help of a local volume table, and the average age of trees found in Nagpur Division is 30 years, Bhandara Division 45 years, Gondia Division 50 years, Yawatmal Division 40 years and Chandrapur Division 55 years. Different height and girth classes observed in different divisions is due to different environmental and topographical conditions such as soil, climate and intensity of light.



Graph 3.3 Height class of Tectona grandis spp., at selected region for this study.

### Morphology:

Table 3.1 shows the Morphological characteristics details of Tectona grandis spp. of Vidarbha region.

**Outer Bark-** outer bark is brown or light brown in colour

**Leaves-** leaves are opposite, broadly elliptic-obovate, about 30-70 cm long and 20-40 cm broad, at the base rounded to acute and at the apex obtuse to acute, and the petiole stout and 5-6 cm long. Tectona grandis spp. sheds its leaves from



November to February and remains leafless for 2-3 months, and the new leaves appear from April to June according to locality.

**Flowering Phenology-** The *Tectona grandis* spp. observed in the above five divisions, generally flowering occurs in trees with an age group of 6 – 40 years, but profuse flowering occurs in trees that are having age more than 15 years. The flowering phase commences immediately after the new shoot and leaf flushing stage in late May and continues up to August or September, which coincides with the southwest monsoon.

**Fruit-** Fruit is a drupe, globose, 5-20 mm in size, enclosed by an accrescent calyx with thick shaggy exocarp of matted hairs, epicarp inflated, spongy and stellate pubescent, endocarp stony, 4 celled seeds 1-4, oblong and exalbuminous. The fruit ripens from November to January and falls gradually, some remaining on the trees throughout the hot season. The fruits are yellowish and brownish in colour, and the number varies from 1150 to 2800 per kg.

Table 3.1 Morphological characteristics details of *Tectona grandis* spp. of Vidarbha region.

| Name of the Division | Location           | Leaf Characteristics |             |                      |               |           |                |          | Bark Color  |            |                |                 |                  |                  |                               |
|----------------------|--------------------|----------------------|-------------|----------------------|---------------|-----------|----------------|----------|-------------|------------|----------------|-----------------|------------------|------------------|-------------------------------|
|                      |                    | Leaf Tip             | Leaf Margin | Leaf Surface Texture | Leaf Venation | Flowering | Fruit          | Seed     | Inner Bark  | Outer Bark | Shape of trees | Avg. Height (M) | Avg. Girth (Cm.) | Avg. Age (Years) | Avg. Green Moisture Content % |
| Nagpur               | 21.3 17N 79.2 00E  | Tapered              | Flat        | Rough                | Pinnate       | Profuse   | Drupe, Globose | Brownish | Whitish     | Brown      | Tapered        | 7.95            | 7.947            | 30               | 40                            |
| Bhandara             | 21.0 73N 79.8 29E  | Tapered              | Flat        | Rough                | Pinnate       | Profuse   | Drupe, Globose | Brownish | Light green | Brown      | Tapered        | 9.32            | 9.316            | 45               | 38                            |
| Gondia               | 20.3 90N 86.4 20E  | Tapered              | Flat        | Rough                | Pinnate       | Profuse   | Drupe, Globose | Brownish | Whitish     | Brown      | Tapered        | 12.11           | 12.105           | 50               | 36                            |
| Yavatmal             | 20.1 17 N 78.1 10E | Tapered              | Flat        | Rough                | Pinnate       | Profuse   | Drupe, Globose | Brownish | Whitish     | Brown      | Tapered        | 6.32            | 6.316            | 40               | 39                            |
| Chandrapur           | 20.2 09N           | Tapered              | Flat        | Rough                | Pinnate       | Profuse   | Drupe          | Brown    | Whitish     | Brown      | Tapered        | 13.             | 13.              | 55               | 35                            |



|            |             |      |  |    |     |    |                        |           |      |         |      |    |     |  |  |
|------------|-------------|------|--|----|-----|----|------------------------|-----------|------|---------|------|----|-----|--|--|
| drapu<br>r | 79.5<br>60S | ered |  | gh | ate | se | pe,<br>Glo<br>bos<br>e | wnis<br>h | tish | ow<br>n | ered | 58 | 579 |  |  |
|------------|-------------|------|--|----|-----|----|------------------------|-----------|------|---------|------|----|-----|--|--|

### 3.2 Study of Chemical Characteristics of *Tectona grandis* Spp.

*Tectona grandis* possess some different chemical characteristics as it is a hardwood species. The chemical analysis of this species helps to know the parameter study like green density, basic density, moisture content, shrinkage percentage, ash content, thermal conductivity, specific heat capacity, elemental carbon content, etc. The chemical analysis results for the *Tectona grandis* species in the Vidarbha Region are in Table 4.5. Based on the data provided in Table 3.2, a detailed analysis of the chemical characteristics across five divisions, Nagpur, Bhandara, Gondia, Yawatmal, and Chandrapur, is as follows.

#### Density Analysis (kg/m<sup>3</sup>)

The highest green density was found in the Chandrapur division that is 1059 kg/m<sup>3</sup>, and it is close to Gondia, 1024 kg/m<sup>3</sup>. The lowest green density is in Yawatmal 856 kg/m<sup>3</sup>. Bhandara has the basic density of 56 kg/m<sup>3</sup>, while Yawatmal has the lowest 39 kg/m<sup>3</sup>.

#### Thermal Properties

**Thermal Conductivity:** The numbers are almost the same, from 0.116 W/m•K in Nagpur to 0.125 W/m•K in Yawatmal. Higher conductivity in Yawatmal means it conducts heat more than the others.

**Specific Heat Capacity:** Chandrapur has the highest, 1.76 J/kg which means it takes energy to change its temperature, while Gondia has the lowest, 1.46 J/kg.

**Temperature:** Chandrapur has the highest temperature, 40°C and Bhandara has the lowest, 30°C.

Chemical & Compositional Analysis Percentage

**Ash Content:** Yawatmal has the most, 4.9%, which might shows the higher levels of minerals or impurities. Chandrapur has the least, 3.0%.

**Elemental Carbon:** Carbon levels are highest in Chandrapur, 0.8% and lowest in Yawatmal, 0.2%.

**Moisture Content:** The numbers are the same with Bhandara having the most, 7.23% and Chandrapur the least, 6.2%. Chandrapur has the material profile with the highest green density, highest carbon, highest specific heat and the lowest ash and moisture. On the other hand, Yawatmal has the lightest material, with the highest ash and thermal conductivity.

Table 3.2 Chemical Characteristics of *Tectona grandis* spp. of Vidarbha region

| Name of Place | Green Density (Kg/m <sup>3</sup> ) | Basic Density (Kg/m <sup>3</sup> ) | Shrinkage % | Thermal Conductivity (W/m. k) | Specific Heat Capacity (J/Kg) | Elemental Carbon % | Ash Content % | Temperature °C | Moisture Content % |
|---------------|------------------------------------|------------------------------------|-------------|-------------------------------|-------------------------------|--------------------|---------------|----------------|--------------------|
| Nagpur        | 927                                | 50                                 | 5.6         | 0.116                         | 1.7                           | 0.6                | 3.7           | 35             | 7                  |
| Bhandara      | 1003                               | 56                                 | 4.7         | 0.118                         | 1.63                          | 0.7                | 4.2           | 30             | 7.23               |
| Gondia        | 1024                               | 43                                 | 2.3         | 0.121                         | 1.46                          | 0.4                | 4.1           | 35             | 6.9                |
| Yawatmal      | 856                                | 39                                 | 4.1         | 0.125                         | 1.67                          | 0.2                | 4.9           | 35             | 7.1                |
| Chandrapur    | 1059                               | 41                                 | 3           | 0.117                         | 1.76                          | 0.8                | 3             | 40             | 6.2                |



### 3.3 Determination of potential uses

#### Calorific value determination

Based on the forest crop assessment and species distribution patterns, representative tree species were selected for calorific value analysis using a bomb calorimeter. The measured calorific values of the examined species varied considerably. The results indicate that *Tectona grandis* showed a calorific value of approximately 20.2 megajoules per kilogram, while the highest calorific value among the studied species was recorded for *Buchanania lanzan* at approximately 27.2 megajoules per kilogram. The overall range of calorific values among the studied tree species varied from about 5.02 to 27.2 megajoules per kilogram (Table 3). Higher calorific values generally indicate greater energy efficiency and higher heat output during combustion. Wood with higher energy content can therefore serve as a more efficient biomass fuel compared with lower-grade fuel materials. The relatively high calorific value observed in teak wood reflects its dense structure and relatively high carbon and extractive content. These characteristics contribute to slow combustion and sustained heat release, which are desirable properties for biomass fuel applications. Similar observations regarding the energy potential of woody biomass species have been reported in earlier studies (Nair, 1983). The findings of the present study demonstrate that several forest tree species possess significant energy potential when converted into biomass fuels such as pellets and briquettes. However, the calorific values observed in this study may also be influenced by factors such as wood density, chemical composition, moisture content, and site conditions. Therefore, further investigations integrating chemical and physical properties of biomass may provide deeper insights into the suitability of different forest species for renewable energy production. Overall, the results contribute to the broader understanding of forest biomass resources and their potential role in sustainable energy systems. By combining forest crop assessment with calorific value evaluation, the study provides useful information for forest management, biomass energy planning, and the sustainable utilisation of forest resources. Table 3.3 shows the Calorific values of selected forest tree species in the Vidarbha region

| Sr. No. | Species Name                      | Calorific value<br>millijoule per kilogram (MJ/kg) |
|---------|-----------------------------------|----------------------------------------------------|
| 1       | <i>Tectona grandis</i>            | 20.2                                               |
| 2       | <i>Terminalia tomentosa</i>       | 18.6                                               |
| 3       | <i>Terminalia arjuna</i>          | 5.03                                               |
| 4       | <i>Pterocarpus marsupium</i>      | 19.7                                               |
| 5       | <i>Chloroxylon swietenia.</i>     | 21.51                                              |
| 6       | <i>Aegle marmelos</i>             | 20.4                                               |
| 7       | <i>Hardwickiabinata</i>           | 20.5                                               |
| 8       | <i>Terminalia bellerica</i>       | 20.9                                               |
| 9       | <i>Buchanania lanzan</i>          | 25.3                                               |
| 10      | <i>Albizia odoratissima</i>       | 18.15                                              |
| 11      | <i>Anogeissus latifolia</i>       | 16.6                                               |
| 12      | <i>Grewia tiliacifolia</i>        | 16.0                                               |
| 13      | <i>Cleistanthus collinus</i>      | 19.1                                               |
| 14      | <i>Cochlospermum religiosum</i>   | 17                                                 |
| 15      | <i>Adina cordifolia</i>           | 20.24                                              |
| 16      | <i>Acacia catechu</i>             | 22                                                 |
| 17      | <i>Mitragyna parviflora</i>       | 15                                                 |
| 18      | <i>Miliusa velutina</i>           | 10                                                 |
| 19      | <i>Holarrhena antidysenterica</i> | 14                                                 |
| 20      | <i>Buchanania lanzan</i>          | 27.2                                               |
| 21      | <i>Lagerstroemia parviflora</i>   | 18                                                 |



|    |                              |      |
|----|------------------------------|------|
| 22 | <i>Lanneacoromandelica</i>   | 18.3 |
| 23 | <i>Madhuca indica</i>        | 15   |
| 24 | <i>Butea monosperma</i>      | 20.4 |
| 25 | <i>Soymidafebrifuga</i>      | 18   |
| 26 | <i>Boswellia serrata</i>     | 18.2 |
| 27 | <i>Bombax ceiba</i>          | 20   |
| 28 | <i>Dalbergia latifolia</i>   | 21   |
| 29 | <i>Ougenniaooegeinensis</i>  | 20.5 |
| 30 | <i>Diospyros melanoxylon</i> | 20.1 |

The results show that *Tectona grandis* has the highest frequency in the forest area of the all the divisions in the Vidarbha region, having a calorific value of 20.2 MJ/kg, *Buchanania lanzan* has the highest calorific value, which is 27.2 MJ/kg; and the overall range of calorific values of different species is 5.02 to 27.2. MJ/kg. The high calorific value of wood pellets signifies greater energy efficiency, higher heat output, and cost-effectiveness compared to lower-grade alternatives and traditional fuels. A high calorific value means that more heat is generated per unit of fuel burned. The high calorific value of teak wood signifies a superior energy output, making it a highly efficient and cost-effective biofuel, like other biofuel species. The high calorific value of teak signifies that this species can be used as a better fuel resource by converting it into pellets and briquettes. As the calorific value is directly proportional to the density of wood and high carbon content, indicating teak as a strong, durable, slow-burning wood and proved as an excellent resource for sustainable energy generation.

#### IV. CONCLUSION

This study was carried out to examine the *Tectona grandis* species of the Maharashtra Vidarbha region belonging to five forestry divisions, namely Nagpur, Bhandara, Gondia, Yavatmal, and Chandrapur. The main purpose of this study is to work on and find out the physical and chemical properties of the *Tectona grandis* species of the Vidarbha region and elucidate some potential uses of this species.

This study found that the abundance of *Tectona grandis* species in the Vidarbha region is due to its environmental adaptations and shows a constant and consistent growth pattern across the region. This study also provided adequate baseline data needed for the establishment of long-standing, healthy, and commercially productive forests with a steady yield of timber with good physical and mechanical properties.

Major findings of this study on the distribution and physical characteristics of this species include that:

Favourable monsoon and alternate dry spells promote the growth and population of *Tectona grandis* species in the Vidarbha region. When talking about girth class and height class distribution compared to other divisions, Gondia and Chandrapur have the best growth results, likely the consequence of old and mature plantations. Around the region, teak looks pretty similar, except in a few places of the Bhandara division. Except for a few exceptions found in a few places in the Bhandara division, Teak seems relatively uniform elsewhere in Vidarbha. Teak cultivation in Chandrapur shows higher maturity, better yield and better health in comparison to the shrub-like plantations of teak in Yavatmal, where the forests are younger. The spread of mature teak throughout the region is depicted, and the distribution of young and old teak in individual divisions is calculated. Tree morphology, as seen throughout Vidarbha, is good. Steady growth rate indicates stable yields with good dispersion. However, tree height is a bit low since Teak requires full sunlight. Tree height is expected to increase rapidly soon to attain the required height and girth classes. In general, height and girth of *Tectona grandis* of Vidarbha are acceptable and well distributed.

For growth distribution, the diameter at breast height value found was satisfactory for the entire region, which means the population structure is balanced and stable, with healthy tree enhancement and constant maturity. For height classes, there seems to be variation, which indicates that the growing environment supports the tree. Looking at morphology, Teak plantations of the Vidarbha region are fine; no stress signals or diseases were detected in the wood of Teak.



Such physical characteristics like diameter, girth and height are of great importance in Forestry for planning better management options for the Maharashtra Forest Department. This Specific data collected enables the Forest Department to build working plans based on rotational felling and logging strategy, as sustainability is the focus. Similarly, individual farmers will know exactly when to harvest in order to achieve highest gain and continuous supply to the market. Beyond forest policy formulation, this information serves as concrete evidence during the legal cases, providing the standpoints for different divisions in Vidarbha.

#### **Chemical Properties study of *Tectona grandis* spp.**

Density at Chandrapur (Green density; 1059 Kg/m) & Bhandara (Basic density; 56 Kg/m) is highest, showing high strength, better durability and energy content. As well, the shrinkage rate for Nagpur (5.6%) was highest, while for Gondia lowest (2.3%); however, no correlation between density and percentage shrinkage was found, but shrinkage indicates stability of the wood for furniture application.

Thermal conductivity is nearly uniform, from 0.116 W/m.K at Nagpur to 0.125 W/m.K at Yawatmal. *Tectona grandis* grown in Yawatmal possesses the highest thermal conductivity. Specific heat capacity for wood varies from 1.46J/kg at Gondia to 1.76J/kg at Chandrapur.

Wood from Chandrapur consumes a significant amount of heat to increase temperature (hence holds heat efficiently), whereas wood from Gondia requires the lowest energy consumption (thermal inertness).

Overall thermal properties vary between sites, with Chandrapur having maximum specific heat and Gondia the lowest specific heat value. Such properties can be effectively used in building construction where there is no heat transfer from/ to the surroundings, thereby helping in reducing the energy consumption within the building.

These differences in density, shrinkage, and thermal conductivity within different sites of Vidarbha emphasise their utility value in construction (low shrinkage, resistance to decay, and resistance to wood borers and termites. Still, such variable properties indicate that the teak might not be a uniform material, and careful analysis of material requirements would be beneficial during its application.

Looking at chemistry, Carbon percentage (0.8%) at Chandrapur is highest, making the wood of teak good for use as fuel, whereas the percentage of Ash content at Yawatmal (4.9%) is highest, which shows that the wood is of poor fuel quality. Biomass fuel must have low ash and high Carbon content. Hence, to be used as fuel, Chandrapur teak is preferred; Yawatmal teak can only be considered as a low-grade option.

Moisture content is within an acceptable range throughout all the divisions, which means these regions are good for biofuel production.

All divisions have some unique characteristics; Chandrapur has optimum wood density, maximum carbon, and minimal Moisture and Ash content, which makes the wood of Chandrapur ideal for fuel. Lower percentage shrinkage for Gondia has proved it suitable for construction, whereas for Yawatmal it cannot be used as good fuel due to the highest Ash content. Chemical features also prove useful in the site-specific treatment of wood. Additionally, antioxidants and antimicrobial agents can also be derived from leaf extract and bark of *Tectona grandis* at Vidarbha which could prove as profitable for small-scale industrialists as well as for farmers.

#### **Elucidation of Potential Uses of *Tectona grandis* spp.**

It's a tropical hardwood with natural chemicals that guard against pests and rot. Teak is remarkably stable and valuable. Few studies have described all its uses, but India and Indonesia lead global production, which reinforces their importance in the timber supply chain. The evaluation of calorific values of selected tree species further highlighted the potential of forest biomass as a renewable energy resource. Differences in calorific values among species reflected variations in wood density, chemical composition, and carbon content. Among the studied species, *Tectona grandis* demonstrated relatively high calorific value along with notable ecological dominance within the forest stands. These characteristics indicate that teak wood possesses favourable properties for biomass-based energy production. The ability of this species to produce sustained heat output suggests that it may serve as an efficient raw material for the preparation of biomass fuels such as pellets and briquettes.

The present investigation provided an evaluation of the calorific value characteristics of forest crop species of dominant



tree species occurring in the Vidarbha region. The findings demonstrate that calorific values of selected tree species further highlighted the potential of forest biomass as a renewable energy resource. Differences in calorific values among species reflected variations in wood density, chemical composition, and carbon content. Among the studied species, *Tectona grandis* demonstrated relatively high calorific value along with notable ecological dominance within the forest stands. These characteristics indicate that teak wood possesses favourable properties for biomass-based energy production. The ability of this species to produce sustained heat output suggests that it may serve as an efficient raw material for the preparation of biomass fuels such as pellets and briquettes. These evaluations contribute to a better understanding of how forest resources can support both ecological sustainability and renewable energy development. Overall, the study highlights the ecological richness of the Vidarbha Forests and demonstrates the importance of assessing biomass energy potential. Such information is valuable for sustainable forest management, conservation planning, and the development of environmentally responsible bioenergy strategies.

Liquid smoke is generated from the wasted part of the teak tree. As it is rich in phenolics and acetic acid, it has various uses, including natural fertiliser, food flavouring, bioherbicide, biocide, pesticide and insecticide, disinfectant, cleaning agents, etc. Proper utilization of Forest waste products for Liquid smoke production would reduce the fire hazard especially when the waste material is present in a large amount all across Vidarbha.

#### **Conflict of Interest**

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Data availability: All data are available with the corresponding author on a reasonable request

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