

VARIATIONS IN THE PHYSICAL PROPERTIES OF TEAK (*Tectona grandis* L. F.) PLANTED IN THE BRAZILIAN AMAZON

VARIAÇÕES NAS PROPRIEDADES FÍSICAS DE TECA (*Tectona grandis* L. F.) PLANTADA NA AMAZÔNIA BRASILEIRA

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ABSTRACT

Tectona grandis L.f., known as teak, is considered as a promising species for sustainable development in the tropical regions where it has adapted itself. This adaptation is due to its significant plasticity, which combines with biotic and abiotic conditions to alter the properties of the wood. It is therefore, necessary to evaluate the wood in different locations where the species is grown. The objective of this study was to evaluate the performance of the physical properties of the wood as a function of the diametric class and in the longitudinal direction of the trunk, in a plantation in the Brazilian Amazon. To achieve the objective, 20 individual plants were cut down and classified into four diametrical classes. Specimens with dimensions of 2 x 2 x 2 cm³ were removed in a longitudinal direction (base, middle, and top) from the discs taken from the trees. Transverse, tangential, radial, and volumetric wood shrinkage values were obtained, along with anisotropy and density for both the diametrical and longitudinal classes. These variables were subjected to an analysis of variance, the Tukey's test at 5%, and an analysis of the main components. The values in the diameter class classification were 0.37, 1.12, 1.68, 3.04, 0.88, and 0.535, while in the longitudinal classification of the trunk they were 0.37, 1.41, 1.84, 3.42, 1.01, and 0.526 for the transverse, tangential, radial, and volumetric shrinkage, anisotropy, and density, respectively. The density was higher when the diameter varied from 21.4 cm to 32.60 cm, and the tangential shrinkage, volumetric shrinkage, and anisotropy were smaller at the base of the trunk, possibly due to the formation of adult wood, which showed a greater stability of the wood.

KEYWORDS: **Density, Wood quality, Dimensional variation.**

RESUMO

A *Tectona grandis* L. F., conhecida como teca, é considerada como uma espécie promissora para o desenvolvimento sustentável nas regiões tropicais em que se adaptou. Essa adaptação se deve a significativa plasticidade. E essa plasticidade aliada as condições bióticas e abióticas alteram as propriedades da madeira. Com isso, é necessário que se faça a avaliação da madeira nos diferentes locais em que a espécie é cultivada. Diante disso, o objetivo do presente trabalho foi avaliar o desempenho das propriedades físicas da madeira em função da classe diamétrica e no sentido longitudinal do tronco, em um plantio na Amazônia brasileira. Para atingir objetivo, foram derrubadas 20 indivíduos, classificadas em quatro classes diamétricas, retirados corpos-de-prova com dimensões de 2x2x2 cm nos discos do sentido longitudinal (base, meio e topo). Foram obtidas as contrações: transversais, tangenciais, radiais e volumétricas, anisotropia e densidade, tanto nas classes diamétricas, quanto no sentido longitudinal. Essas variáveis foram submetidas a análise de variância, teste de Tukey à 5 % de significância e análise de componentes principais. Os valores na classificação por classes de diâmetro foram de 0,37, 1,12, 1,68, 3,04, 0,88 e 0,535 e na classificação longitudinal do tronco foram de 0,37, 1,41, 1,84, 3,42, 1,01 e 0,526 para a contração transversal, tangencial, radial e volumétrica, anisotropia e densidade, respectivamente. A densidade é maior quando o diâmetro varia de 21,4 à 32,60 cm e a contração tangencial, volumétrica e anisotropia são menores na base do tronco, possivelmente, em virtude da formação do lenho adulto, demonstrando uma maior estabilidade da madeira.

PALAVRAS-CHAVE: **Densidade, Qualidade da madeira, Variação dimensional.**

INTRODUCTION

Tectona grandis L. F. belongs to the Lamiaceae family, commonly known as “teak.” It is a natural species of the Asian rainforests located between 10° and 25°N in the Indian subcontinent and Southwest Asia; found mainly in India, Burma, Thailand, Laos, Cambodia, Vietnam, and Java (TSUKAMOTO FILHO et al., 2003; POLTRONIERI, et al., 2007; LIMA et al., 2011; PELISSARI et al., 2013; COSTA et al., 2015).

Ferreira et al. (2008) reported that teak is a deciduous tree that develops in deep soils, and produces a pest and disease, resistant hardwood with medium density. It has simple, large deciduous leaves, with hair on the axial face. It has large inflorescences and the fruit is double and dry.

Teak is well known in the international timber market due to its economic and social value, and has been considered as a priority species for conservation and management by the International Tropical Timber Organization (ITTO), the International Union of Forest Research Organizations (IUFRO), and the Food and Agriculture Organization of the United Nations (FAO), because of the rampant exploitation and decline of native forests (KOLLERT & KLEINE, 2017).

Kollert and Kleine (2017) also mentioned that this species is being cultivated in more than 70 tropical countries in Asia, Africa, Latin America, and Australia (est. planting of 4.35 to 6.89 million ha.), due to its desirable characteristics, such as rapid growth, high adaptability, and high economic value.

Brazil has become an important teak producer, being one of the South American countries that have cultivated this species since the early 1960s. The production of this was implemented by the company Cárceres Florestal S.A., in Cárceres, Mato Grosso (RONDON, 2006; IWAKIRI et al., 2014; ROCHA et al., 2015).

According to the Brazilian Tree Industry (IBA), the country had about 7.83 million ha of planted forests in 2018 (93,957 ha which were teak), with planted areas increasing each year (IBA, 2019).

Due to the importance of this species, studies are being developed in several areas, especially the area of chemistry, wherein the species characteristics are analyzed with respect to the chemical components present in the species (QIU et al., 2019; SUAREZ et al., 2019; SURYANTI et al., 2020 and ROSAMAH et al., 2020). Furthermore, ecological and environmental services (PALAKIT et al., 2019; CLÉMENT et al., 2019; PEREZ et al., 2020), biotechnology (AGUILAR et al., 2019), genetics and genetic improvement (SCHUHLLI; PALUDZYSZIN FILHO, 2010;

HURTADO et al., 2020;), as well as forest productivity (PELISSARI et al., 2013; SANQUETA et al., 2015; SANTOS et al., 2019; VAIDES-LÓPEZ et al., 2019; and SOUZA et al. 2019) in different locations where this species is planted and commercialized, have been studied.

The studies are mainly focused on wood quality due to the fast growth of these trees, since it has already been shown that the speed of growth has a direct influence on quality; this can be observed when comparing fast growing trees (planted forests) to normal growing trees (native forests) (ANISH et al., 2015; LEMOS et al., 2019). The studies by Lukmandaru and Takahashi, (2008), Motta et al. (2013), Chagas et al. (2014), Queiroz et al. (2016), Oliveira et al. (2019a), Cremonez et al. (2019), Oliveira et al. (2019b), Silva et al. (2019), Batista et al. (2019), Gaitan-Alvarez et al. (2019), and Berrocal et al. (2020) serve as key examples.

The Brazilian Amazon has historically suffered from the exploitation of its native forests due to the high diversity and quality of the wood of its trees. The constant deforestation and the greater extent of degraded areas encourage the planting of production forests; which have begun less robustly compared to the southern and southeastern regions of Brazil, but has shown to be promising.

The heterogeneity of regional abiotic and biotic factors became fundamental aspects for studies regarding the development and quality of plantations, and the wood of these species. Guimarães et al. (2013) reported the need for more studies to improve species cultivation and production in Brazil, especially regarding the physical properties of wood, which involve density and its variations. These studies have been able to direct us toward the correct use of wood, and although ancient, they remain up to date for the plantation set-up in the Amazon region.

Thus, the objective of this study was to evaluate the physical properties of *Tectona grandis* wood cultivated in the State of Pará, according to their diameter class and longitudinal measurements of the log.

MATERIALS AND METHODS

The material studied came from thinning operations in an experimental plantation of *Tectona grandis* at the Pará experimental station of the Brazilian Agricultural Research Corporation (EMBRAPA), located on the Trans-Amazon Highway at km 40 (Altamira—Itaituba direction), in the municipality of Brasil Novo, western Pará state.

Twenty individuals from a heterogeneous planting

were selected, planted with a spacing of 3 m × 2 m and distributed in the following classes, according to Table 1.

Table 1. Number of individuals by diameter class

Classes	Class range	Number of individuals	Number of testing specimens
1	6.60 - 10.80	5	29
2	11.20 - 15.80	5	57
3	16.20 - 20.60	5	72
4	21.40 - 32.60	5	90

Next, three disks were sectioned from the base, middle, and top portions of each individual tree. Later 2 cm × 2 cm test specimens were collected, containing the region spanning the log pith and bark of each disk. The test specimens were weighed and measured, and then placed in a vacuum pump for saturation, where they remained for one week. They were then removed, weighed, measured again, and placed in a drying chamber at 105 ° C until the weight was constant. They were removed and weighed again for basic density analysis according to NBR 7190/1997.

To assess radial, tangential and volumetric contractions, the methodology of Miranda et al. (2011) and anisotropic factor calculated by the relationship between tangential and radial contractions.

A normality test was performed on the data and a mean comparison test was applied after the analysis of variance, where the Tukey test with 5% probability and the principal component analysis (PCA) were applied in the assessment of physical properties separately, using the software Past 4.02.

RESULTS AND DISCUSSION

The basic wood density ranged from 0.373 to 0.683 g/cm³ for the diametric classes, with the lowest value observed in class 1 and the highest in class 4, corresponding to the existing literature (FINGER & LOGSDON, 2003; MIRANDA et al 2011; LEMOS et al., 2019). It was also observed that class 4 had the highest mean value compared to the other classes and the mean basic density increased, with 0.518 g/cm³ in class 1 and 0.546 g/cm³ in class 4 (Table 2).

Similarly, Buvaneshwaran et al. (2017) discovered that the diameter of a teak tree does not correlate with density of teak wood in southeast Tamil Nadu, India. However, they discovered a correlation in the upstate area. Meanwhile, Berrocal et al. (2020) stated that there is a correlation between the diameter of a teak tree and its

density of wood, age, and height while studying plantations in Costa Rica.

Moya et al (2014) states that teaks with diameters ranging from 12 to 30 cm have substantial quantities of juvenile wood and their heartwood is approximately 6 to 10 cm in diameter, which corroborates the findings in the first three classes of this study.

The tree diameter and wood density ratio are significantly imprecise and depends on several factors such as age, height, geographical location, environmental conditions, and silvicultural treatments (MOYA et al., 2014; BLANCO-FLÓREZ, 2016). This unstable behavior was also replicated in cellular elements as observed by Souza et al. (2019) while studying the anatomical characteristics of teaks at two locations in the State of Mato Grosso, where the teak fibers and the rays exhibited a different behavior, except for vessel elements. Moreira et al., (2007) also observed radial differences in teak fibers while studying plantations in Espírito Santo and São Paulo in Brazil.

Gaitan-Alvarez et al. (2019), while analyzing teak wood via X-ray densitometry at various locations in Costa Rica, categorized four types of density i.e., uniform growth, stable growth, unstable growth, and false growth depending on growth rings formation.

This demonstrates the variety and plasticity of the wood in these species, reinforcing the theory that they undergo changes to adapt to their environment, but not following a defined pattern; their diameter can correlate with their wood density.

When comparing the average wood densities and height of teaks, the following values were enumerated: 0.501 g/cm³, 0.526 g/cm³, and 0.551 g/cm³ at the top, middle, and bottom, respectively (Table 3), indicating a decrease in wood density from the teak base upwards. BLANCO-FLÓREZ et al., (2014) also observed a similar behavior in teak plantations in the State of Minas Gerais. However, Miranda et al. (2011), observed the opposite when analyzing timber from unmanaged forests in East Timor. Therefore, proving that several factors influence growth behavior and, consequently, the quality of wood.

The anisotropy in the diameter classes varied from 0.04 to 3.6 cm, where the lowest value was observed in the third class and highest in the fourth, the averages were 0.90, 0.88, 0.85, and 0.90 in the first, second, third, and fourth classes, respectively. There was no statistical difference in the classes, owing to the formation and proportion in juvenile and adult wood.

Table 2. Mean values of the physical properties of *Tectona grandis* L. F. for classes.

Classes	Transversal contraction (%)	Tangential contraction (%)	Radial contraction (%)	Volumetric contraction (%)	Anisotropic factor	Basic Density (g/cm ³)
1	0,42 (0,4) a	1,10 (0,8) a	1,40 (0,8) a	2,80 (1,4) a	0,90 (0,7) a	0,518 (0,06) a
2	0,35 (0,3) a	1,24 (0,8) a	1,88 (1,1) a	3,32 (1,5) a	0,88 (0,6) a	0,536 (0,04) a
3	0,32 (0,3) a	0,98 (0,5) a	1,73 (1,4) a	2,94 (1,5) a	0,85 (0,6) a	0,542 (0,04) a
4	0,39 (0,5) a	1,19 (1,2) a	1,71 (1,3) a	3,10 (2,2) a	0,90 (0,7) a	0,546 (0,05) b

For each diameter class, the means followed by the same letter in the columns do not differ from each other by the Tukey test with a 5% probability of error.

These results were consistent with those of Moya et al. (2014), which reported that the formation of adult wood of diameters from 6 to 10 cm at approximately 4 to 6 years. However, Gaitan-Alvarez et al. (2019), indicated that adult wood starts forming at 8 years.

When observing lengthwise, mean values of 1.02%, 1.11 %, and 0.90% were observed at the apex, middle, and base, respectively, without any statistical difference. Confirming that teak wood has dimensional stability, considered excellent for several uses. The studies of Damayanti et al. (2007) and Bonduelle et al. (2015) corroborate these findings.

The transversal contraction ranged from 0 to 3.9, the means were 0.42, 0.35, 0.32, and 0.39 for the first, second, third, and fourth classes, respectively (Table 2). Lengthwise, the mean values of 0.34, 0.44, and 0.35 were observed at the apex, middle, and base, respectively. It can be observed, therefore, that in this section, the variation is insignificant.

The tangential contraction ranged from 0.10 to 9.8, both values found in the fourth class, the means were 1.10, 1.24, 0.98, and 1.19 for the first, second, third and fourth classes, respectively (Table 2). Lengthwise mean values of 1.99, 1.35, and 0.90 were observed at the apex, middle, and base, respectively. It can be observed, therefore, that there was significant growth in tangential contraction from the base upwards.

Radial contraction ranged from 0.05 to 7.9, the averages were 1.40, 1.88, 1.73, and 1.71 in the first, second, third, and fourth classes, respectively (Table 2). When observing lengthwise, mean values of 1.99, 1.96, and 1.57 were observed at the apex, middle, and base, respectively.

The volumetric contraction ranged from 0.29 to 9.3, the lowest value was observed in the first diameter class, and the highest in the fourth class, the averages were 2.80, 3.32, 2.94, and 3.10 in the first, second, third and fourth classes, respectively (Table 2). When observing lengthwise, the mean values of 4.04, 3.43, and 2.79 were observed at the apex, middle, and base, respectively. This implies that

the base had the lowest volumetric contraction.

The values of transversal, radial, tangential and volumetric contractions of this study were significantly lower than those discovered by Miranda et al. (2011) when studying plantations in East Timor. However, they were similar to those discovered by Bonduelle et al. (2015) when studying plantations in the Amazon that highlighted greater dimensional stability of the wood in teaks planted in the Brazilian Amazon. Blanco-Flórez et al. (2014) report that this variable contraction is common when the wood has a significant amount of juvenile xylem

Priya & Bhat (1999) and Palakit et al. (2019), reported that, compared to dry wood, the growth of teak wood is slower in tropical climates owing to the influence of climate on exchange rate activity. This slow growth influences the dimensional stability of the wood, conferring good quality.

To complement and improve the understanding of the behavior of physical properties both in the diameter class and in the position on the trunk, principal component analysis was applied.

The data were transformed for normalization, and when the parameters analysis (class and longitudinal position) was performed concurrently, the first two axes represented 66% of the data variation (Figure 1A) and formed three distinct groups: density, transversal contraction and volumetric contraction. However, Rencher (2002) mentions that for a good analysis of the components, they must represent 70% of the data variation, with this, separate analyzes of the parameters were carried out.

In the analysis only with the diameter classes (Figure 1 B) the first two axes corresponded to 80% of the data variation and the volumetric contraction is more uniform and tends to be greater in class 4 and the density and the lower and higher transverse contraction in classes 2 and 3, mainly in 3. In these classes (2 and 3), both wood contractions and anisotropy do not present a defined behavior.

Table 3. Mean values of the physical properties of *Tectona grandis* L. F. for position.

Position (stem)	Transversal contraction (%)	Tangential contraction (%)	Radial contraction (%)	Volumetric contraction (%)	Anisotropic factor	Basic Density (g/cm ³)
Top	0,34 (0,5) a	1,99 (0,9) a	1,99 (0,9) a	4,04 (1,1) a	1,02 (0,4) a	0,501 (0,04) a
Middle	0,44 (0,6) a	1,35 (1,4) b	1,96 (1,4) a	3,43 (1,5) a	1,11 (1,4) a	0,526 (0,06) a
Base	0,35 (0,3) a	0,90 (0,5) c	1,57 (1,1) a	2,79 (1,4) b	0,90 (0,9) a	0,551 (0,03) b

For each position of the log, the means followed by the same letter in the columns do not differ from each other by the Tukey test with a 5% probability of error

As for the analysis in the longitudinal position (Figure 1C) the first two axes correspond to 91% of the data variation, following behavior similar to those of the diameter class, where the volumetric contraction is less at the base and the greater transverse contraction and density are less evident at the base. In the mid-apex sense, the physical properties did not show a defined pattern.

The formation of three groups was observed, the group of well-defined and distinct density, the group of volumetric and transversal contraction, which are inversely proportional. Although the concomitant analysis of the defined parameters (class and longitudinal position) explains less than 70% of the data variation, it followed the same pattern for the definition of the groups found.

Tangential and radial contractions and anisotropy are not affected as much in the division by diameter class and along the trunk. This can be explained by being directly related, but they influence when added to other properties such as the case of volumetric contraction and density.

CONCLUSION

Given the above, variations in teak wood are observed and these variations are intraspecific, highlighting the potential, the characteristics of the wood and how this species behaves in plantations in the Amazon, highlighting the following information:

Teak plantations with diameters from 6 to 32 cm do not differ or alter the physical properties of the wood, however with increasing diameter the first property to differentiate is the basic density;

Diameters between 6 and 10 cm have no wood in formation and therefore have no pattern in the behavior of physical properties;

In the longitudinal direction Base-top, the properties of volumetric contraction and density are different, with the base having less contraction and greater density;

Tangential and radial contractions increase in the base-top direction, with a high variation;

The basic density is the property that has less variation both in the diameter class and in the longitudinal direction

of the trunk;

Thus, there is a significant plasticity and adaptability of the teak, reinforcing that the environments and management techniques can significantly improve the quality of the wood.

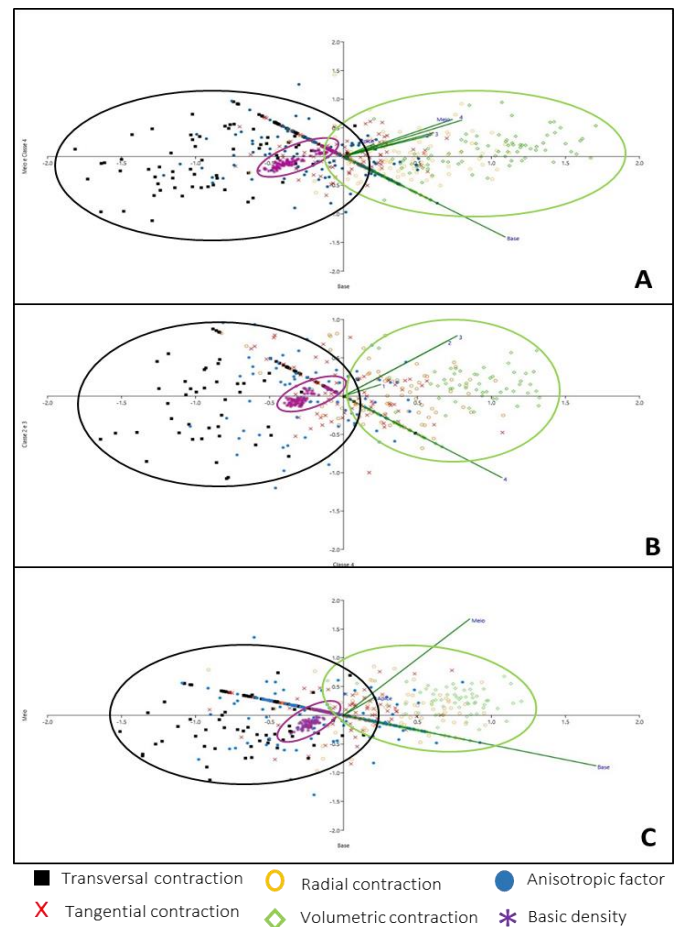


Figure 1. Sorting by principal component analysis (PCA) of the physical properties of *Tectona grandis*. A - relationship of the diameter class and the longitudinal position; B - relationship of the diameter class; C - longitudinal position relationship.

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