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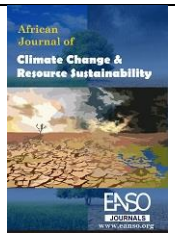

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Original Article

Timber Properties of Lesser-Known Toona ciliata M. J. Roemer from Agroforestry System in Moshi Rural District, Tanzania and Its Potential Substitution for Well-known Species

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Keywords:

Basic Density, Strength, Kilimanjaro, Khaya anthotheca, Uapaca kirkiana.

ABSTRACT

This study investigated the physical and mechanical properties of *Toona ciliata* (Australian Red Cedar), a lesser-known timber species grown in agroforestry farms in Moshi Rural District, Kilimanjaro Region in Tanzania, with a focus on some of its physical and mechanical properties and potential substitution for well-known timber species in various applications. Whereas the physical properties were Wood Colour and Basic Density, the mechanical properties were Static Bending (Modulus of Elasticity/Bending strength, Modulus of Rupture/Stiffness and Work to Maximum Load), Compression parallel to grain, Shear parallel to grain and Cleavage. Three defect-free sample trees were used for assessment of the properties using standard operating procedures stipulated by the International Standards Organization (ISO). Descriptive statistics were used to summarize the properties, and regression analysis explored relationships between basic density and mechanical properties. Results indicated that *T. ciliata* has whitish sapwood and reddish heartwood with a mean Basic Density of 531 kg/m³, classifying it as medium-density timber. The key mechanical properties include Modulus of Elasticity (4,935 N/mm²), Modulus of Rupture (49 N/mm²), Compression parallel to the grain (30.8 N/mm²), Shear (11.2 N/mm^2) and Cleavage (18.4 N/mm - width). Density revealed strong positive correlations with Modulus of Elasticity, Modulus of Rupture and Compression strength. A one-way analysis of variance (ANOVA) showed no significant radial variation in Basic Density. Comparative analysis with *Khaya anthotheca* (East African mahogany) and *Uapaca kirkiana* (sugar plum) highlighted similarities, suggesting that *T. ciliata* could substitute these species in applications requiring toughness, bending strength, and stiffness. The study concluded that *T. ciliata* is a viable alternative in timber markets, particularly where medium-density wood is required.

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INTRODUCTION

Wood is a versatile material that can be used in its raw form or processed into various products. Its effective utilization depends on selecting and processing species with the right combination of properties for specific applications. However, in Tanzania, only a few well-known timber species are harvested and utilized from natural forests, leading to over-exploitation of these prime timbers. In many cases, these well-known species are being used for purposes where lesser-known species, but potentially suitable and more affordable timbers, could serve as viable alternatives (Makonda *et al*, 2022). Some of the well-known timber species, such as *Khaya anthotheca* (Hawthorne, 1998) and *Dalbergia melanoxylon* (Nyomora *et al*., 2021), are already facing depletion.

The depletion of well-known species in the country has led to the premature harvesting of young trees, resulting in poor-quality timber with low durability and structural integrity. To address this, alternative timber sources need to be explored, including lesser-known species from natural forests and indigenous agroforestry trees. Expanding the use of lesser-known species could alleviate pressure on these high-value, well-known species by providing alternative resources. However, limited knowledge about their properties hinders their adoption in the market (Ewudzie *et al*., 2018). Meanwhile, lesser-utilized species will likely become commercially viable as more information about their properties becomes available. Research on these species' properties is essential to determine their suitability for various applications and facilitate their commercialization (Gemechu *et al*., 2022; Marbun *et al*., 2023; Oyediran *et al*., 2023).

Timber selection for specific applications depends on factors such as technical performance (determined by physical and mechanical properties), size, and availability (Bryce, 2002). Many lesser-known species remain underutilized, often due to technical challenges in processing or a lack of data on properties like density, strength, durability, and workability (WWF/GFTN, 2013). This lack of information creates difficulties in pricing and grading, further limiting their market acceptance. It is in this context that, the Department of Forest Engineering and Wood Sciences at Sokoine University of Agriculture, Tanzania, is researching to determine the properties of Tanzania's lesser-known timber species, promote their use, and provide data for timber stakeholders.

Toona ciliata, *Cordia africana*, *Olea europaea* and *Albizia schimperiana* are among the lesser-known species in agroforestry settings, which are important sources of timber. Some of these trees are already put into use by different timber stakeholders, although the properties of such tree species are not known. Among them, *Toona ciliata* M. J. Roemer is a promising agroforestry species, which is widely grown in Marangu, Moshi Rural District in Kilimanjaro Region, Tanzania. Farmers cultivate it alongside crops for shade, and it is increasingly being harvested and processed into timber. Despite its growing utilization in construction, furniture, door frames and other structural applications, its physical and mechanical properties remain largely undocumented. The lack of scientific data poses

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risks, as timber used in structural applications must meet specific strength requirements to ensure safety and durability (Oyediran, 2023).

Notably, *T. ciliata* contains a chemical compound called azadirachtin, which enhances its durability by providing resistance to beetles and fungal attacks (Morgan and Wilson, 1999). This natural resistance makes it a potentially valuable alternative to other timbers that require chemical treatments to prevent pest and fungal damage. Surprisingly, *T. ciliata* is not included in Bryce's (2002) documentation of commercially used trees and shrubs in Tanzania. However, it has been appreciated by Makonda and Ruffo (2011) as a potential good source of timber in the country. Given its prevalence in agroforestry farms and increasing use in timber applications, research on its properties is crucial to determine its suitability for commercial adoption. Establishing its technical attributes could position *T. ciliata* as a viable alternative to the already over-exploited species, supporting sustainable forestry and timber industry development.

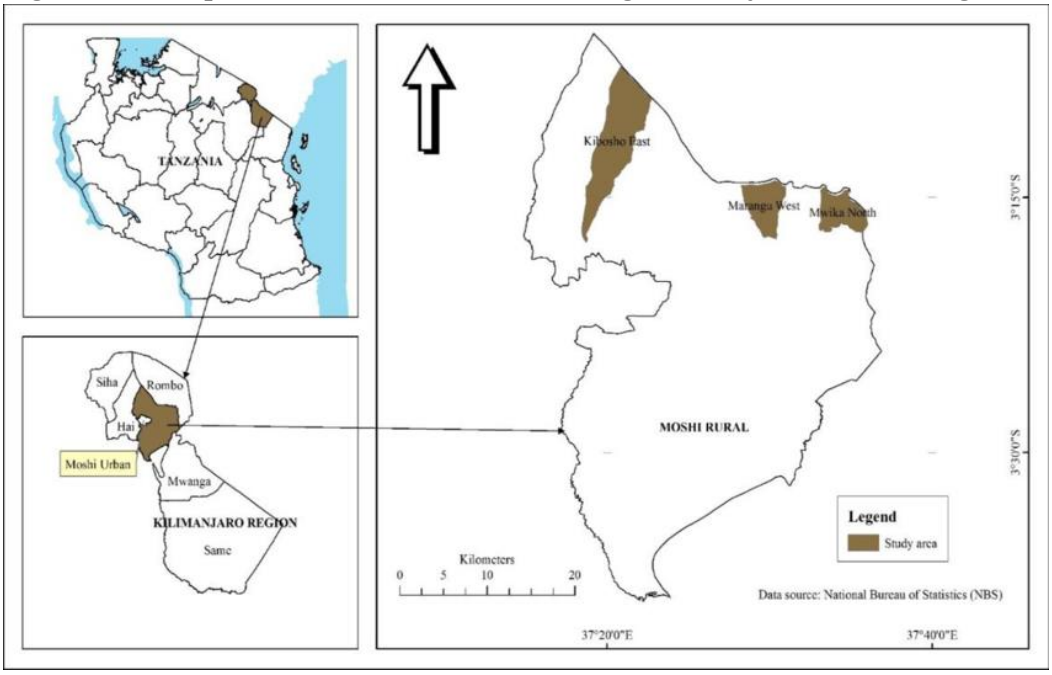
Moreover, since the Tanzanian government envisions a future where forest plantations play a central role in sustaining the timber industry (Mgaya, 2016; URT, 2021), *T. ciliata* could be promoted for plantation forestry. This study, therefore, aimed to assess some physical and mechanical properties of *T. ciliata* grown in Marangu, Moshi Rural District in Kilimanjaro Region, Tanzania and evaluate its potential for various applications. Whereas the physical properties were Wood Colour and Basic Density, the mechanical properties were Static Bending (Modulus of Elasticity, Modulus of Rupture and Work to Maximum Load), Compression parallel to grain, Shear parallel to grain and Cleavage.

METHODOLOGY

Study Area Description

The study samples were collected from private individual agroforestry farms in Nduweni Village located in Marangu West Ward in Moshi Rural District, Kilimanjaro, Tanzania. Figure. 1 shows the location of the study area. This village is situated at 3º15' - 3º420'S and 35 º 00' – 37 º 50'E. The area is elevated at 1,100 – 1,400 m.a.s.l, receiving rainfall ranging from 1,000 to 1,700 mm with a bimodal pattern, short rains from October-December and long rains from March-May. In general, according to Saria *et al.* (2024), the soil is fertile volcanic ash with a high base saturation and high cation exchange capacity.

Figure. 1: A Map of Moshi Rural District Showing the Study Area of Marangu West



Source: *Saria et al. (2024)*

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Sampling Procedures

As supported by Raut (2021), samples of *T. ciliata* were objectively selected from three mature and defect-free trees after thorough observation of their physical appearance. The study by Da Páscoa *et al.* (2020) provides valuable guidance on sample size sufficiency for estimating wood properties across tropical forests. The trees represented small, medium and large diameter classes. The trees were felled and their diameters at breast height (DBH) and total height were recorded. Three billets, each measuring 1.5 m in length, were cut from breast height (1.3m) upwards, marked and sawn to central planks. The planks were transported to the Department of Forest Engineering and Wood Sciences Laboratory of Sokoine University of Agriculture for further processing. The planks were re-sawned into 30 mm x 65 mm x 1,500 mm scantlings from the pith left and right towards the bark (Lavers, 1969; ISO 3131, 1975; ISO 3133, 1975; ISO 3349, 1975). These scantlings were then numbered and labelled sequentially to show the position of extraction and direction of sawing, and as insisted by Llana *et al.* (2020), they were stacked for drying until the moisture content was below 15 %.

Data Collection

Physical Properties

The timber's colour was assessed using standard methods described by authentic samples after seasoning and planning the specimens. The moisture content was monitored following ISO 3130 (1975). Basic density was measured using 50 mm wood test samples extracted from scantlings before drying, following the method described in ISO 3131 (1975). The randomly sampled and felled *T. ciliata* trees had a height that permitted the extraction of only one clear bole length. As a result, this study focused solely on the radial direction, without data collection on the axial variation of basic density.

Mechanical Properties

The scantlings were further reduced to 30 mm x 30 mm x 1,500 mm, dried down to a moisture content of 12%, and then planned to 20 mm x 20 mm x 1,500 mm sticks. Results for test specimens with moisture content lower or higher than 12% were adjusted according to Desch (1981). From these strips, different test samples of various dimensions were extracted (Table 1). The tests were carried out following the procedures described by BS 373 (1957; 1976), Lavers (1969), Panshin and de Zeeuw (1980), and ISO 3133 (1975) for testing clear wood specimens.

Table 1: Test Samples Used for the Determination of Mechanical Properties of *Toona ciliata* from Moshi Rural District, Kilimanjaro, Tanzania

Type of Test	Sample dimensions (mm)	Sample count
Static bending	20 x 20 x 300	68
Compression parallel to grain	20 x 20 x 60	68
Shear parallel to the grain	20 x 20 x 20	68
Cleavage	20 x 20 x 45	68

Data Analysis

Descriptive statistics were used to summarize the physical and mechanical properties of *T. ciliata*. Regression analysis was performed to assess the relationships between Basic Density and the mechanical properties of the wood. This enhanced evaluation of whether Basic Density could serve as a reliable predictor for the mechanical performance of the timber, assisting in determining its suitability for various timber applications and its potential substitution for other species. The coefficient of determination (R^2) was calculated to assess the strength of these relationships.

Radial variation in Basic Density was analyzed using a one-way analysis of variance (ANOVA) to determine if there were statistically significant differences in density across the radial positions from the pith to the bark. Additionally, a comparative analysis was performed between *Toona ciliata*, *Khaya anthotheca*, *Uapaca kirkiana* and *Pinus caribaea* to assess the relative

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mechanical properties of these species, highlighting the potential for substituting *Toona ciliata* in specific applications based on their similarities.

RESULTS AND DISCUSSION

Physical Properties

Wood Colour

The sapwood of *Toona ciliata* was observed to be whitish, while the heartwood is reddish; the colour is comparable to that of *Khaya anthotheca* (Richter *et al.*, 2014) and *Uapaca kirkiana* (sugar plum), another lesser-known timber species (Gillah *et al.*, 2007). According to Dinwoodie (2000), this implies that *Toona ciliata* can be useful for decorative works like other timber from elsewhere, including *Khaya anthotheca* (East African mahogany), *Dalbergia melanoxylon* (East African black wood), *Pterocarpus angolensis* (Mninga), *Milicia excelsa* (Mvule) and *Afzelia quanzensis* (Mkongo/African pod mahogany).

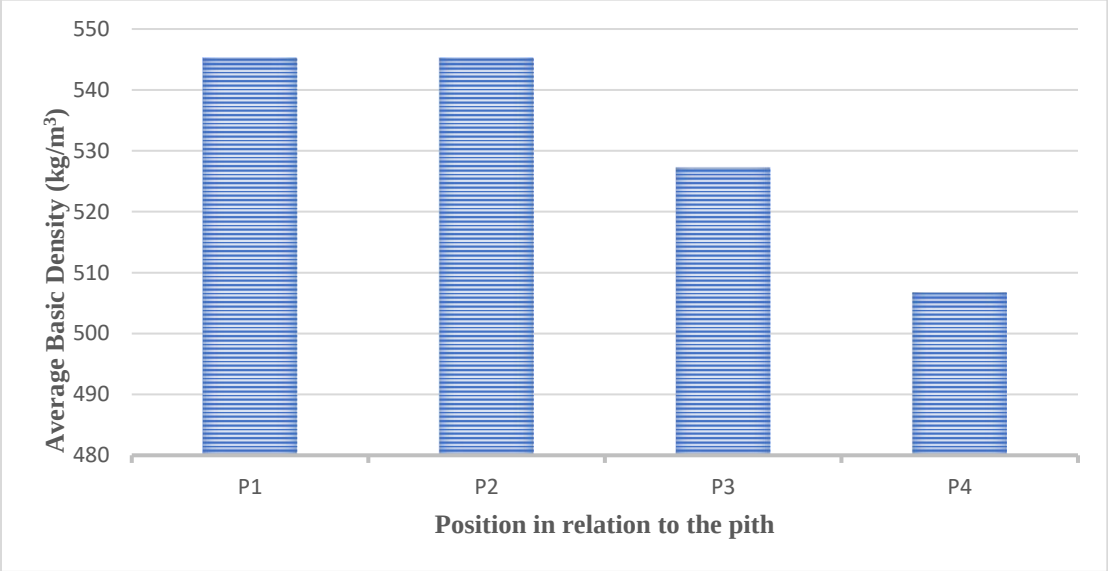
Basic Density

Results showed that *Toona ciliata* has an average Basic Density of 531 kg/m^3. Comparatively, the density is closer to that of *Khaya anthotheca* growing in Tanzania, which is medium-density tree species (Bryce, 2002) with an average of about 545 kg/m^3 and 513 kg/m^3 for the same species growing in Uganda. The average Basic Density of *Toona ciliata* is also comparable to *Uapaca kirkiana* timber, another lesser-known timber species with an average of 518 kg/m^3. Therefore, based on the result of this study, *Toona ciliata* can be classified as a medium-density timber species, capable of substituting East African mahogany and sugar plum timber.

Radial Variation in Basic Density

From Fig. 1, it is evident, though not significant (P> 0.05), that the Basic Density of *Toona ciliata* timber was highest closer to the pitch, decreasing outward towards the bark and was lowest around the bark.

Figure 1: Radial variation of Basic Density of *Toona ciliata* from Moshi Rural District, Kilimanjaro, Tanzania



Strength Properties

The highest variation of strength properties of *Toona ciliata* was observed in work to maximum load, while the lowest variation was observed in shear strength parallel to grain (Table 2). These findings emphasize the importance of understanding wood strength properties, as they guide the selection of the appropriate wood for specific uses, ensuring that it meets the required performance standards (Panshin and Zeeuw, 1980; Dinwoodie, 2000; Oyediran, 2023).

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Table 2: Strength Properties of *Toona ciliata* from Moshi Rural District, Kilimanjaro, Tanzania

Strength properties	Strength values	Coefficient of Variation (%)
Modulus of Rupture (N/mm^2)	49.0	18
Modulus of Elasticity (N/mm^2)	4,936	15
Work to Maximum Load (N/mm^3)	0.223	33
Compression parallel to the grain (N/mm^2)	30.8	19
Shear parallel to the grain (N/mm^2)	11.2	11
Cleavage (N/mm - width)	18.4	17

Relationship between Basic Density and Strength Properties

The study shows that there is a strong radial relationship between Basic Density and the key strength properties of timber from *Toona ciliata*, particularly in Static Bending (Modulus of Rupture and Modulus of Elasticity) and Compression strength parallel to the grain, indicating that these properties are directly proportional to Basic Density as depicted in Table 3. The interpretation of the relationship between Basic Density and the strength properties is adopted from the proposal by Henseler *et al*. (2009).

Table 3: Relationship between Basic Density and Mechanical Properties of *Toona ciliata* from Moshi Rural District, Kilimanjaro, Tanzania

Strength property	Regression equation	R^2	Relationship strength
Modulus of Rupture	Y = 0. 1172x – 11.909	0.971	Very strong
Modulus of Elasticity	Y = -23.855x + 17604	0.736	Moderate
Work to Maximum Load	Y = 0.0003x + 0.0559	0.541	Moderate
Compression parallel to the grain	Y = 0. 0805x – 11.939	0.822	Very strong
Shear parallel to the grain	Y = 0. 0091x + 6.368	0.262	Weak
Cleavage strength	Y = 0.0021x + 17.317	0.0004	No relationship

This suggests that *T. ciliata* could substitute for other timbers in applications requiring high bending and compression strength. An average relationship was observed between Basic Density and stiffness and work to maximum load, while a weak relationship was found between Basic Density and Shear parallel to the grain and Cleavage strengths.

Comparison between *Toona ciliata, Khaya anthotheca, Uapaca kirkiana* and *Pinus caribaea*

Toona ciliata shares comparable strength properties with *Khaya anthotheca* and *Uapaca kirkiana*. The basis for comparison is their similarity in wood colour and basic density, and strength properties. The wood of *Toona ciliata*, nevertheless, is tougher than that of *Khaya anthotheca, Uapaca kirkiana* and *Pinus caribaea* (Table 4). Moreover, *Toona ciliata* has superior properties when compared with *Pinus caribaea*, whose timber is commonly traded throughout Tanzania. For this property, *Toona ciliata* timber can substitute *Khaya anthotheca* and *Uapaca kirkiana* in all applications which require wood with high work to maximum load.

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Table 4: Comparison of Wood Properties of *Toona ciliata, Khaya anthotheca* and *Uapaca kirkiana*

Strength properties	Timber species			
	***Toona ciliata*[a]**	***Khaya anthotheca*[b]**	***Uapaca kirkiana*[c]**	***Pinus caribaea*[c]**
Basic density (Kg/m^3)	531	545	518	421
Modulus of Rupture (N/mm^2)	49.0	76.0	59.7	22.0
Modulus of Elasticity (N/mm^2)	4,935	7,800	7,185	4,145
Total work to failure (N/mm^2)	-	0. 109	0.070	-
Work to maximum load (N/mm^2)	0. 223	0.066	0.060	-
Compression strength to grain (N/mm^2)	30.8	42.4	34.4	15.5
Shear parallel to the grain (N/mm^2)	11.2	13.8	11.9	5.4
Cleavage (N/mm - width)	18.4	11.0	20.2	5.1

Source: [a] This study

[b] Bryce (2000)

[c] Gillah *et al*. (2007)

While *Toona ciliata* has lower bending strength, stiffness and compression strength than *Khaya anthotheca* and *Uapaca kirkiana*, its shear strength parallel to the grain is nearly equivalent, allowing for substitution in applications requiring this property. Additionally, *Toona ciliata* and *Uapaca kirkiana* exhibit similarities in mechanical properties such as compression strength parallel to the grain, shear strength parallel to the grain, cleavage strength, and bending strength, suggesting that these two lesser-known timber species could be marketed together for applications requiring these properties.

CONCLUSION

This study reveals that *Toona ciliata* shares many comparable properties with various well-known and utilized commercial timbers of Tanzania, making it a suitable alternative for various applications, thereby ensuring both conservation and economic benefits. Some mechanical properties of *T. ciliata* were found to be similar to or even superior to those of *Khaya anthotheca* and *U. kirkiana*. *Toona ciliata* has superior properties to those of *Pinus caribaea*. The timber is recommended for use in light construction, sporting goods, cabinets and furniture.

Further research is recommended to investigate other mechanical properties, such as impact bending, hardness and natural durability. This is essential to fully assess the species' performance in various applications and ensure its long-term suitability, safety and reliability in comparison to the well-known but over-exploited timber species. Thus, effective utilization of wood depends on selecting and processing species with the right combination of properties for specific applications.

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