East African Journal of Forestry & Agroforestry
eajfa.eanso.org
Volume 8, Issue 1, 2025
Print ISSN: 2707-4315 | Online ISSN: 2707-4323
Title DOI: https://doi.org/10.37284/2707-4323

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Suitability of *Acacia crassicarpa* A. Cunn. Ex Benth., A. *Leptocarpa* A. Cunn. Ex Benth., A. *Julifera* Benth., *Brachystegia boehmii* Taub. and B. *Spiciformis* Benth. For Wood Energy Production in Tabora, Tanzania

Fortunatus Bulabo Makonda[1] & Mbonea Joshua Mweta[1]*

[1] Sokoine University of Agriculture, P. O. Box 3012, Morogoro, Tanzania.
[*] Author for Correspondence ORCID ID; https://orcid.org/0009-0007-3077-9472; Email: makonda@sua.ac.tz

Article DOI: https://doi.org/10.37284/eajfa.8.1.3192

Date Published:

23 June 2025

Keywords:

Calorific Value, Wood Fuel, Thermal Properties.

ABSTRACT

This study investigated the calorific values of five tree species, three of which are exotic and grown in agroforestry systems and the other two are naturally growing and indigenous in Tabora, Tanzania. Whereas the exotics are *Acacia crassicarpa*, *Acacia leptocarpa* and *Acacia julifera*, the indigenous species are *Brachystegia boehmii* and *Brachystegia spiciformis*. Wood fuel, primarily in the form of charcoal and firewood, is a critical energy source in developing countries, particularly for heating and tobacco curing. Understanding the calorific values of these species is essential for optimizing their use as sustainable bioenergy sources, especially in regions where biomass remains a dominant energy resource. The study was conducted at the Tanzania Agricultural Research Institute (TARI) Tumbi Centre, utilizing wood samples collected from trees at various heights and positions within the stem. Calorific values were determined using a bomb calorimeter and statistical analyses, including ANOVA and regression, were employed to compare species and assess correlations between sample positions and energy content. Results revealed that the mean calorific values of the exotic Acacia species (*Acacia crassicarpa*: 17.11 kJ/g, *Acacia leptocarpa*: 16.67 kJ/g, and *Acacia julifera*: 17.45 kJ/g) were not significantly different from each other but showed significant differences compared to the indigenous *Brachystegia spiciformis* (20.18 kJ/g). *Brachystegia boehmii* exhibited a calorific value of 16.66 kJ/g, similar to the Acacia species. Notably, *Acacia julifera* demonstrated favourable calorific properties, making it a promising tree species for further cultivation in agroforestry systems aimed at sustainable energy production. This study contributes to the growing body of knowledge on the thermal properties of agroforestry tree species, providing critical data for sustainable forestry management and energy planning. The findings underscore the importance of integrating both exotic and indigenous species into agroforestry systems to enhance energy security, support local economies, and promote environmental conservation. Recommendations are made for the adoption of *Acacia julifera* in community woodlots and plantations, alongside continued research into the thermal properties of other species to inform sustainable resource management practices in Tanzania and similar regions.

Article DOI: https://doi.org/10.37284/eajfa.8.1.3192

APA CITATION

Makonda, F. B. & Mweta, M. J. (2025). Suitability of *Acacia crassicarpa* A. Cunn. Ex Benth., A. *Leptocarpa* A. Cunn. Ex Benth., A. *Julifera* Benth., *Brachystegia boehmii* Taub. and B. *Spiciformis* Benth. For Wood Energy Production in Tabora, Tanzania. *East African Journal of Forestry and Agroforestry, 8*(1), 279-289. https://doi.org/10.37284/eajfa.8.1.3192

CHICAGO CITATION

Makonda, Fortunatus Bulabo and Mbonea Joshua Mweta. 2025. "Suitability of *Acacia crassicarpa* A. Cunn. Ex Benth., A. *Leptocarpa* A. Cunn. Ex Benth., A. *Julifera* Benth., *Brachystegia boehmii* Taub. and B. *Spiciformis* Benth. For Wood Energy Production in Tabora, Tanzania" *East African Journal of Forestry and Agroforestry* 8 (1), 279-289. https://doi.org/10.37284/eajfa.8.1.3192.

HARVARD CITATION

Makonda, F. B. & Mweta, M. J. (2025), "Suitability of *Acacia crassicarpa* A. Cunn. Ex Benth., A. *Leptocarpa* A. Cunn. Ex Benth., A. *Julifera* Benth., *Brachystegia boehmii* Taub. and B. *Spiciformis* Benth. For Wood Energy Production in Tabora, Tanzania", *East African Journal of Forestry and Agroforestry*, 8(1), pp. 279-289. doi: 10.37284/eajfa.8.1.3192.

IEEE CITATION

F. B., Makonda & M. J., Mweta "Suitability of *Acacia crassicarpa* A. Cunn. Ex Benth., A. *Leptocarpa* A. Cunn. Ex Benth., A. *Julifera* Benth., *Brachystegia boehmii* Taub. and B. *Spiciformis* Benth. For Wood Energy Production in Tabora, Tanzania", *EAJFA*, vol. 8, no. 1, pp. 279-289, Jun. 2025.

MLA CITATION

Makonda, Fortunatus Bulabo & Mbonea Joshua Mweta. "Suitability of *Acacia crassicarpa* A. Cunn. Ex Benth., A. *Leptocarpa* A. Cunn. Ex Benth., A. *Julifera* Benth., *Brachystegia boehmii* Taub. and B. *Spiciformis* Benth. For Wood Energy Production in Tabora, Tanzania". *East African Journal of Forestry and Agroforestry,* Vol. 8, no. 1, Jun. 2025, pp. 279-289, doi:10.37284/eajfa.8.1.3192

INTRODUCTION

Most of the developing countries depend on fuelwood as a source of energy. Fuelwood is mostly used for heating purposes and in tobacco curing factories; it is the raw material for curing tobacco (Nelson, 2023; Asefon and Adepoju, 2024). Many exotic trees have been introduced to Africa in an attempt to find quick-growing alternatives to native species (Evans, 1982; Eshetu, 2024). The fuelwood is mainly used in the form of charcoal as well as firewood. Usually, wood with a higher density is better suited as fuelwood because it has a high calorific value (Ishengoma, 1979; AEBIOM, 2019; Miroshnichenko and Malik, 2023). Ishengoma (1979) reported a lower price for charcoal made from softwood than that made from hardwood, which implies that the charcoal made from softwood had lower calorific values compared to that from hardwood. Mkonda and He (2017) noted that the integration of agroforestry systems has gained increasing attention in the realm of sustainable land management, especially in regions such as Tabora, Tanzania, where agriculture and forestry are pivotal to local economies and environmental health. Among the numerous benefits of agroforestry recorded by the authors is the diverse range of tree species that can be utilised for multiple purposes, including energy production.

Thakur *et al*. (2024) and Nielsen (2025) demonstrated that the calorific value of a material is always measured in units of heat per unit of weight. The calorific value of biomass is a crucial parameter in evaluating its potential as a source of renewable energy (Lunguleasa *et al.*, 2020; Fahrussiam *et al.*, 2023). It measures the amount of energy released during the combustion of a specific biomass sample and provides insights into the energy efficiency and sustainability of various species.

Wood varies considerably in density and hence calorific value; it varies within the same species and even within the same tree (Krajnc, 2015; Fialho *et al*., 2019; Spîrchez *et al*., 2021; Fahrussiam *et al*., 2023). Understanding the thermal properties of tree species, such as calorific value, specific heat capacity and thermal conductivity, is essential for optimizing their use as bioenergy sources (Duruaku *et al*., 2016). This study focuses on five significant species: *Acacia crassicarpa* A. Cunn. ex Benth., *Acacia leptocarpa* A. Cunn. ex Benth., *Acacia julifera* Benth., *Brachystegia boehmii* Taub. and *B. spiciformis* Benth. The former three species are

Article DOI: https://doi.org/10.37284/eajfa.8.1.3192

exotic and have just been introduced and cultivated in agroforestry systems in Tabora, contributing not only to the ecological balance but also to the socio-economic development of the region. *Brachystegia boehmii* and *B. spiciformis,* the indigenous species growing naturally in the area, are also highly sought after for their valued timber and bee forage.

Fialho *et al*. (2019) and Spîrchez *et al*. (2021) reported that most of the species that are grown in Tanzania and elsewhere as agroforestry trees have a lot of uses, not only improving the soil properties for the betterment of the crops associated with the trees but also used for construction as well as the source of energy.

The performance of the three exotic acacias in the study area and elsewhere, in both diameter and height increments, assessed through on-station and on-farm trials, was good. Arulmozhiyan *et a*l. (1992) reported that the best performance by *A. crassicarpa* was used in agroforestry in Tamil Nadu, India, for soil improvement. Alipon and Floresca (1991) recommended *A. crassicarpa* to be used as an agroforestry tree in the Philippines. Laurila (1995) recommended *A. crassicarpa*, *A. mangium*, and *A. auriculiformis* as the most suitable species for pulp and paper. Sim *et al*. (1991) reported that *A. crassicarppa* and *A. mangium* were superior to other species of acacia in terms of diameter and height for the agroforestry trees under trial, with *A. crassicarppa* being susceptible to stem borer attack. Hamza *et al*. (2001) and Lunguleasa *et al*. (2020) recommended the three mentioned *Acacia* species as suitable for construction purposes. From all the studies that have been carried out, there is no single study that is based on thermal properties, particularly calorific value.

In addition, there have been several initiatives in Tanzania aimed at promoting clean cooking energy, which further underscores the importance of understanding the thermal properties of these tree species. Initiatives such as the collaboration between Taifa Gas and Barrick Gold Mine Company, Oryx Gas Tanzania Limited's support for the clean cooking energy campaign and the National Strategy for Clean Cooking Energy (NSCCE) aim to increase the population of Tanzanian households using clean cooking energy from the current 10% to 80% by 2034 as reported by URT (2024). These programs contribute to environmental conservation, economic growth, and the well-being of local communities. Nevertheless, despite these initiatives, biomass remains an unavoidable energy source. For instance, in countries like Russia, government incentives boost economic viability, particularly through wood fuel (Ivantsova and Kozyaeva, 2023; Bueno *et al*., 2024). Biomass remains a crucial component of the energy mix in many regions, particularly in rural areas where access to alternative energy sources is limited, as suggested by FAO (2018), AEBIOM (2019), Nabukalu and Gieré (2019), Fadeyibi *et al*. (2020), Ivantsova and Kozyaeva (2023), Miroshnichenko and Malik (2023) and Asefon and Adepoju (2024). Therefore, it is essential to continue researching and understanding the thermal properties of biomass species to improve their efficiency and sustainability.

By analyzing the thermal properties of these species, this research enhances comprehension of their energy profiles, facilitating more informed decisions regarding their use in energy production and forestry management. The findings are anticipated to have substantial impacts on local communities and contribute significantly to wider initiatives in sustainable resource management.

The overall objective of the study was to determine the suitability of *Acacia crassicarpa, A. julifera* and *A. leptocarpa* as exotic species and *Brachystegia boehmii* and *B. speciformis* as indigenous species for wood energy in Tabora, Tanzania.

Specifically, the study aimed to determine the calorific values of the five tree species in the study area.

MATERIALS AND METHODS

Description of the Study Area

The Tanzania Agricultural Research Institute (TARI) Tumbi Centre is located in Tabora

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Municipality in Tabora Region, located in western Tanzania. The centre is approximately 16 km west of Tabora Town along the main road to Urambo District (TARI, 2025). The centre covers a total land area of 1,634 hectares, which includes farmland, forest and estate and notably, 70% of the forest area is covered by miombo woodland, providing substantial potential for research and conservation efforts. Currently, according to the author, about 40 hectares are actively utilized for research and development.

The region's vegetation is predominantly miombo woodland, characterized by species such as *Brachystegia* and *Julbernardia*, which support diverse flora and fauna (Wikipedia, 2024). Tobacco is one of the traditional cash crops which is grown by the majority of farmers within the miombo woodland of Tanzania, Tabora Region being the leading. The region has a tropical savanna climate with a monomodal rainfall pattern from November to April. The annual precipitation varies from 700 to 1,000 mm. Tabora experiences warm temperatures throughout the year, with a short cool season from June to August and an average temperature range of 22°C to 31°C (Wikipedia, 2024).

Sampling Design

A stratified random sampling design was adopted to ensure comprehensive data collection across species, age groups and tree height positions. Stratification was based on species type and age class to capture variations in calorific values. The study included both exotic and indigenous species, with a focus on *Acacia crassicarpa*, *Acacia leptocarpa*, *Acacia julifera*, *Brachystegia spiciformis* and *Brachystegia boehmii*. Six trees per species per age class were selected, with disc samples collected at four height positions (breast height, 30%, 60% and 90% of total height), as applied also by Malimbwi *et al*. (1994). Sample trees were selected from established research blocks at TARI Tumbi. Although formal rectangular plots were not demarcated, tree selection was spatially distributed across the plantation area to avoid spatial bias and to represent site variability. The sampling unit was the individual tree, and six trees per species per age class were selected, resulting in a total of 60 trees.

Sample Preparation

Disc samples measuring 2 cm in thickness were collected from each tree at four height levels: breast height (1.3 m) and at 30%, 60%, and 90% of the total tree height. Sampling was carried out on six trees per species for *Acacia crassicarpa, Acacia julifera* and *Acacia leptocarpa* at both five and ten years of age to facilitate comparative analysis of calorific values across age groups (i.e., 5-year vs. 10-year trees) and to evaluate potential trends associated with tree age. As for the indigenous species, *Brachystegia spiciformis* and *Brachystegia boehmii*, six tree samples were also collected. The study included exotic species such as *Acacia crassicarpa*, *Acacia leptocarpa and Acacia julifera* and indigenous species such as *Brachystegia spiciformis* and *Brachystegia boehmii*.

From each disc, one to three samples were extracted depending on the disc's diameter. The extracted wood samples were categorized based on their position within the disc: wood near the pith, wood near the bark, and wood from the intermediate region between these two parts. A minimum of 20 g of wood was collected from each sample and subsequently ground into a fine powder for further analysis. This method of sample preparation was also employed by Duruaku *et al*. (2016)

Grinding Procedure

The wood samples were initially chopped to a uniform size using a Wiley mill equipped with a sieve to produce coarse particles. These coarse particles were then further processed using a micro-mill to obtain fine powder. The fine powder was subsequently used to prepare pellets with an average weight of 1.10 g using a pellet press. The prepared pellets were then placed in a bomb calorimeter and ignited for energy content analysis.

Data Collection

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The sample weight of the pellet, initial temperature, and final temperature, as well as the size of the unburnt fuse wire, were recorded. The following formula was used in the determination of the calorific value.

$$\text{Calorific value} = \frac{Wt - e1 - e2}{M}$$

Where:

W_t = energy equivalent of calorimeter determined under standardisation of bomb calorimeter (calories/degree Celsius)

M = mass of sample in grams

T = net corrected temperature rises in degrees Celsius

e_2 = correction in calories for the heat of combustion in fuse wire

e_1 = correction in calories for the heat of formation of nitric acid

Also,

$$W_t = \frac{Hm + e1 + e2}{t}$$

Where:

E_1, e_2, and t are as defined above

H = heat of combustion of the standard benzol acid sample in calories per gram

M = mass of standard benzoic acid sample in grams

Data Analysis

Descriptive statistics, including mean, standard deviation, and coefficient of variation, were calculated to summarise the distribution of calorific values. One-way ANOVA was performed to assess differences in calorific values across species and age groups, providing insights into variability among categories. A t-test was conducted to compare calorific values between specific age groups (e.g., 10-year vs. 5-year samples), identifying potential age-related trends. Pearson correlation analysis was used to evaluate the relationship between age and calorific values, addressing hypotheses about maturation effects, while multivariate analysis examined the combined effects of species, tree diameter, height and sample location. These analyses were necessary to comprehensively evaluate the factors influencing calorific values and their interactions. All statistical analyses were performed using R software, with significance set at $p < 0.05$.

RESULTS AND DISCUSSION

Analysis of Exotic *Acacia* Species

The mean calorific values for the three exotic *Acacia* species are as follows: *A. crassicarpa*: 17.11 kJ/g (10-year samples), *A. leptocarpa*: 16.67 kJ/g (10-year samples) and *A. julifera*: 17.45 kJ/g (10-year samples)

The results indicate that there is no significant difference between the studied Acacia species. The calorific values of these species are comparable to those of *Brachystegia boehmii* (16.66 kJ/g for unknown age samples) but show significant differences ($p<0.05$) from *Brachystegia speciformis* (20.18 kJ/g for unknown age samples).

These findings are consistent with those reported by Goel (1987) and Destaa *et a*l. (2022) for *Acacia nilotica*, *Eucalyptus tereticornis*, *Prosopis juliflora*, and *Terminalia arjuna*, which had calorific values ranging between 16 and 17 kJ/g. Similarly, Puri *et al*. (1994) reported mean calorific values of 16.3-20.0 kJ/g for *Acacia tortilis*, *Acacia auriculiformis*, *Eucalyptus camaldulensis*, and *Eucalyptus tereticornis* as exotic species in semi-arid regions of India.

Analysis of Indigenous *Brachystegia* Species

For the indigenous species, the mean calorific values are *Brachystegia boehmii*: 16.66 kJ/g (unknown age samples) and *Brachystegia speciformis*: 20.18 kJ/g (unknown age samples)

The calorific values for *Brachystegia speciformis* show a significant difference ($p<0.05$) from those of Brachystegia boehmii. These results align with the findings of Puri *et al*. (1994) and Fahrussiam *et al*. (2023) for various indigenous species in arid regions of India, with mean calorific values

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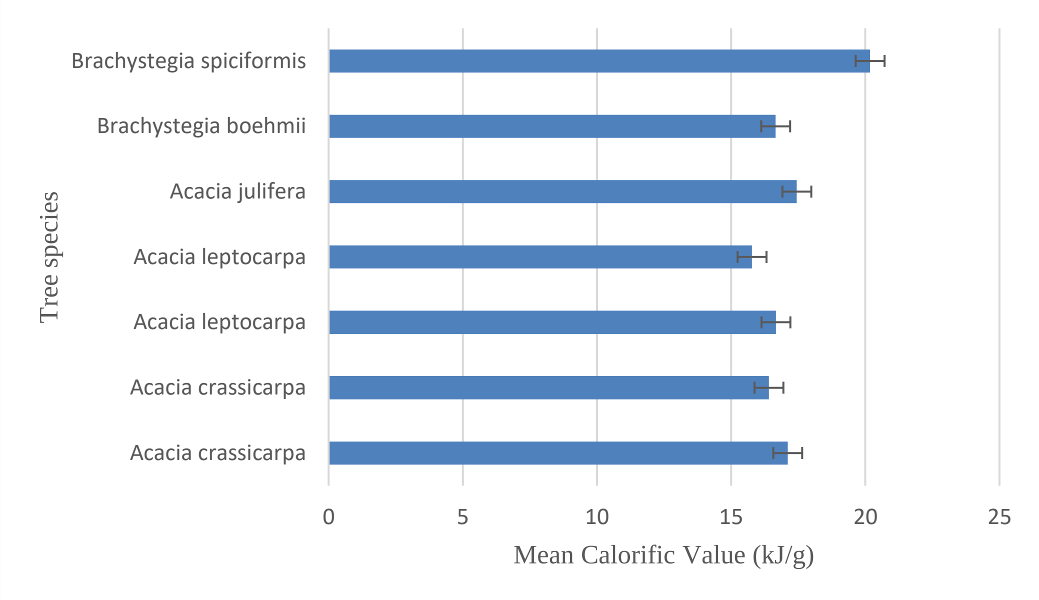
ranging from 18.7 kJ/g to 21.77 kJ/g as shown in Figure 1.

The results obtained in this study are within the range reported by Saka *et al*. (1994) for *Azanza garckeana* and *Strychnos spinosa*, which had calorific values ranging from 8.1 kJ/g to 19.23 kJ/g. These species were incorporated into agroforestry systems in Malawi.

Figure 01: Mean Calorific Values (kJ/g) by Species and Age Class



Age-wise Analysis

Ten Years of Samples

The mean calorific value for the 10-year samples across the Acacia species (*A. crassicarpa*, *A. leptocarpa*, and *A. julifera*) is as follows: *A. crassicarpa*: 17.11 kJ/g, *A. leptocarpa*: 16.67 kJ/g and *A. julifera*: 17.45 kJ/g

The overall mean calorific value for the 10-year samples is 17.08 kJ/g with a standard deviation of 0.32 kJ/g. The values range from a minimum of 16.67 kJ/g to a maximum of 17.45 kJ/g. This indicates that the calorific values are relatively high and consistent across the species for 10-year samples.

Five Years Samples

The mean calorific values for the 5-year samples are: *A. crassicarpa*: 16.41 kJ/g and *A. leptocarpa*: 15.78 kJ/g

The overall mean calorific value for the 5-year samples is 16.10 kJ/g with a standard deviation of 0.45 kJ/g. The values range from a minimum of 15.78 kJ/g to a maximum of 16.41 kJ/g. Compared to the 10-year samples, the 5-year samples have a slightly lower average calorific value and show more variation.

Unknown Age Samples

The calorific values for the unknown age samples are: *Brachystegia speciformis*: 20.18 kJ/g and *Brachystegia boehmii*: 16.66 kJ/g

The overall mean calorific value for the unknown age samples is 18.42 kJ/g with a standard deviation of 1.75 kJ/g. The values range from a minimum of 16.66 kJ/g to a maximum of 20.18 kJ/g as illustrated in Table 1. This indicates significant differences between the species, with *Brachystegia speciformis* having a much higher calorific value compared to *Brachystegia boehmii*.

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Table 2. Summary Statistics of Calorific Values by Age Group

Age Group	Minimum (kJ/g)	Maximum (kJ/g)	Mean (kJ/g)	Std. Deviation
5 years	15.78	16.41	16.10	±0.45
10 years	16.67	17.45	17.08	±0.32
Unknown Age	16.66	20.18	18.42	±1.75

Comparative Analysis

The 10-year samples generally show higher calorific values compared to the 5-year samples, suggesting that the calorific value might increase with the age of the species and unknown age samples have the highest variation in calorific values, indicating significant differences between the species.

T-Test for 10-Year vs 5-Year Samples and Pearson Correlation Coefficient

The statistical significance and correlation analysis of the calorific values for Acacia species reveal important insights. The calculated t-value and corresponding p-value indicate that the differences in calorific values between 10-year and 5-year samples for Acacia species are statistically significant ($p<0.05$). This supports the hypothesis that calorific values increase with age. Moreover, the Pearson correlation coefficient shows a positive correlation between the 10-year and 5-year samples, indicating a strong relationship between age and calorific value. As the samples age, their calorific value tends to increase, reflecting the accumulation of energy-dense components in the wood. These findings provide valuable evidence of how age affects the calorific values of Acacia species.

Regression Analysis: Relationship Between Age and Calorific Value

A simple linear regression was performed to analyze the relationship between tree age (independent variable) and calorific value (dependent variable) using data from *Acacia crassicarpa* and *Acacia leptocarpa* (age known) as shown in Table 2.

Table 2: Regression Output Summary

SN	Statistic	Value
1	R-squared (R^2)	0.81
2	Adjusted R-squared	0.77
3	Standard Error	0.12
4	F-statistic	20.45
5	p-value (Significance)	0.004

The regression model indicates a **strong positive relationship** between age and calorific value ($R^2 = 0.81$). The p-value (< 0.05) shows that the model is statistically significant. Therefore, age is a strong predictor of calorific value in the studied *Acacia* species.

Relationship to Previous Research

The study's findings align well with previous research on the calorific properties of both exotic and indigenous tree species used for wood energy. The calorific values recorded for the exotic *Acacia* species—*A. crassicarpa* (17.11 kJ/g), *A. leptocarpa* (16.67 kJ/g), and *A. julifera* (17.45 kJ/g)—fall within the range reported by Goel (1987) and Destaa et al. (2022), who studied *Acacia nilotica*, *Eucalyptus tereticornis*, and *Prosopis juliflora* (16–17 kJ/g). Likewise, Puri *et al*. (1994) reported calorific values ranging from 16.3 to 20.0 kJ/g for exotic species such as *A. tortilis* and *E. camaldulensis*, reinforcing the suitability of these *Acacia* species as viable energy sources in semi-arid regions.

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Similarly, the indigenous *Brachystegia spiciformis* showed a significantly higher calorific value (20.18 kJ/g) compared to *Brachystegia boehmii* (16.66 kJ/g), suggesting notable intra-genus variability. These results corroborate earlier studies by Fahrussiam *et al*. (2023) and Puri *et al*. (1994), which found indigenous species in arid and savanna regions to yield calorific values above 18.7 kJ/g. Saka *et al*. (1994) also reported comparable values for agroforestry species like *Azanza garckeana* and *Strychnos spinosa*, reinforcing the diversity of species with potential bioenergy applications in sub-Saharan Africa.

Theoretical Implications

The study contributes to theoretical understanding in two key areas. First, it supports the theory that wood calorific value is influenced by both genetic (species-specific) and environmental factors, including age and growth conditions. Second, the positive correlation between tree age and calorific value adds evidence to existing models suggesting that wood density and energy content increase with age due to the accumulation of lignin and extractives, both of which are energy-dense components.

These findings align with the theory that older trees invest more in structural tissues, which increases their potential as high-energy biomass. The statistically significant difference between 5-year and 10-year samples for *Acacia* species reinforces this age-related trend.

Practical Applications

The results have several practical implications for wood energy planning, agroforestry systems, and sustainable land management in Tanzania, especially in regions such as Tabora where biomass remains a primary energy source:

- Species Selection: *Brachystegia spiciformis* and *Acacia julifera* stand out as high-calorific-value species, making them suitable candidates for energy plantations and woodlot development.
- Harvest Timing: Since calorific value increases with age, delaying harvest to 10 years or beyond may enhance energy yield, improving the efficiency of wood fuel systems.
- Integration into Agroforestry: The adaptability and calorific performance of *Acacia* species, especially under semi-arid conditions, support their use in agroforestry for both fuelwood and soil improvement.
- Policy and Extension: The study supports informed decision-making by forestry extension services, helping farmers and planners select appropriate species for energy and land restoration initiatives.

Limitations of the Study

Despite its valuable findings, the study has several limitations:

- Unknown Age of Indigenous Trees: The lack of precise age data for *Brachystegia* species limits direct comparison with exotic species. Future studies should consider dendrochronological or inventory-based age assessments to improve comparability.
- Limited Plot Definition: While sampling was conducted systematically, the absence of formally established plots with fixed area and shape introduces potential variability in site conditions, which may influence tree performance.
- Environmental Factors Not Controlled: Soil type, topography, and microclimate variations were not quantified, though they may affect wood quality and energy content.
- Single-Site Study: The research was limited to the TARI Tumbi Centre. Multi-site comparisons across different ecological zones in Tanzania would provide a broader understanding of species performance.
- Narrow Species Selection: While representative, the inclusion of only five species restricts the generalizability of the findings to other potential energy species.

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CONCLUSION AND RECOMMENDATIONS

The findings from this study indicate that the mean calorific values of the three *Acacia* species (i.e., *Acacia crassicarpa*, *Acacia leptocarpa*, and *Acacia julifera*) are not significantly different ($p > 0.05$) from that of *Brachystegia boehmii*. However, they show a significant difference when compared to the calorific values of *Brachystegia spiciformis*. This suggests that while the exotic *Acacia* species have similar calorific potential to *Brachystegia boehmii*, they differ notably from *Brachystegia spiciformis* in terms of energy content. The analysis of calorific values for various species indicates that the 10-year samples of *Acacia* species have relatively high and consistent calorific values, suggesting a potential increase in calorific value with age. In contrast, the 5-year samples show slightly lower and more variable calorific values compared to the 10-year samples. The unknown age samples exhibit the highest variation, with significant differences between *Brachystegia speciformis* and *Brachystegia boehmii*. These findings provide valuable insights into the relationship between the age of samples and their calorific values, highlighting the importance of considering age in such analyses.

The study also reveals that the calorific values for both exotic and indigenous species fall within the range reported in previous studies. The absence of significant differences among the exotic *Acacia* species indicates consistency in their calorific potential, while the variation in the calorific values of indigenous species underscores their distinct energy profiles. These insights can guide sustainable forestry management practices and help in the selection of appropriate species for specific energy-related applications, contributing to long-term resource planning.

Based on these findings, *Acacia julifera* is recommended for further cultivation in plantations and community woodlots. This species exhibits a favourable calorific value, making it a suitable candidate for energy production and sustainable forestry practices.

Acknowledgement

The authors sincerely thank the **Tanzania Agricultural Research Institute (TARI) – Tumbi Centre** for providing research land, facilities, and technical support during this study.

Conflict of Interest

All authors declare **no conflict of interest** regarding the publication of this paper.

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