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Effect of Altitude on Morphological and Mechanical Properties of *Eucalyptus globulus*

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Abstract
In the Congo basin, Cameroon harbors close to 300 wood species but only one-third of this resource is exploited. Moreso, the wood construction sector relies on Eucalyptus globulus whose selection for use is influenced by growth conditions. The aim of this study was to compare the morphology and mechanical properties of wood from Eucalyptus globulus trees growing at a high (1803 m) and low altitude (1213 m) site in Mezan Division of the North West Region of Cameroon. Ten Eucalyptus globulus trees, aged 28 – 30 years old, were randomly selected from the high and low altitude sites. Leaf area, diameter at breast height, and height of the trees were measured. Wood samples of a standard dimension were obtained from the trees at each site and analyzed for flexural and compressive strength. Data were subjected to one-way analysis of variance at a significance level of 0.05. There was a significant effect of altitude on leaf area and tree height but no tree diameter. Leaf area declined from the high to low altitude site while tree height displayed a reverse trend. Both Modulus of Rupture and Modulus of Elasticity were significantly higher at low than high altitude. The findings indicate that altitude should be taken into consideration when selecting Eucalyptus globulus trees for construction and other uses.

Keywords: *Altitude, Bamenda Highlands, Eucalyptus globulus, Modulus of Rupture, Modulus of Elasticity.*

1. Introduction

The total area of woodland in the world was estimated to be at least 1.1 billion hectares equivalent to 9% of the total land area (Scherr, 1999). The ten countries with the largest area of woodland are Australia, China, Canada, the Russian Federation, Argentina, Sudan, Ethiopia, Brazil, Botswana and Afghanistan (FAO, 2020). Cameroon is among the top ten countries in Africa for biodiversity (Niobe-Eyangoh *et al.*, 2003). The forests of the Cameroon Mountains are particularly rich, with high numbers of endemic plant, mammal, bird, reptile, amphibian and insect species (Gardner, 2003). The montane forests of the Bamenda Highlands are a sub-region of the Cameroon Mountain. These montane forests are made of both primary and secondary forests with many tree species among which is *Eucalyptus globulus.* Eucalyptus is grown in varied climatic and soil conditions from semi-arid areas to highly humid dense forest and from Mediterranean climate to tropical climate (Louppe and Depommier, 2010). Eucalyptus is therefore distributed in almost all environmental conditions in Africa. Eucalyptus is identified in all the highland areas in the Bamenda highlands with diverse ecological conditions, different altitudes and rainfall regimes (Oballa *et al.*, 2010). These patches of montane forest constitute a diversity of tree species which

are continuously being lost due to anthropogenic activities. In this light, secondary forests are on the rise with eucalyptus being the dominant species. The loss of the montane forests of the Bamenda Highlands is important not only because of the potential extinction of species, but because of the impact on the people of the area. Although small, these patches are recognized as globally important sites for conservation of biological diversity. At the same time, the forests are very important for the people living around them, as they supply water, fuel wood, medicines, honey and have cultural and spiritual importance. Among the 40 tree species found in the Bamenda Highlands forest is *Eucalyptus globulus* (Gardner, 2003).
Eucalyptus wood is strong and moderately durable and is used for light and heavy construction like roofing, vehicle carriage, building, home furniture and regarded as being excellent for cellulose and paper manufacture (CABI Compendium, 2022). With origins in Australia, the species has experienced outstanding success as an exotic species in many countries, with over 1 million ha of plantations established (Turnbull, 1999).
Exploitation of the *Eucalyptus* for timber production has become increasingly common. In this process, the need to determine the relevant properties permitting its use is still a challenge. *Eucalyptus* species have interesting properties as compared to other tropical hardwoods (Sánchez *et al.*, 2005). Thus, their cultivation for use is recommended not only as a means of conserving wild woody species but because it can be cultivated under different climatic and edaphic conditions.
In the Congo basin, Cameroon harbors close to 300 woody species but only one-third of this resource is exploited although there are projections of geometric rise in exploitation of wild woody species due to exportation and the rapid population growth and human settlement expansion (Atyi *et al.*, 2013). The *Eucalyptus* genus used to be grown in plantations for fuel and paper production (Sánchez *et al.*, 2005). Its good application characteristics could replace tropical hardwoods in order to preempt extinction of other used species. Moreso, woodworkers find it difficult to choose the altitude at which *Eucalyptus globulus* wood is suitable for construction work in both form and strength. In Cameroon, precisely in the Bamenda highlands, Fogwe *et al.* (2019) reported that eucalyptus stakeholders have reaped gains from the sale of its products and have significantly increased their standard of living through sales for building materials, electricity/telephone poles and timber but no study has been conducted on the effect of altitude on the mechanical properties of *Eucalyptus globulus* in the Bamenda highlands. Given this background, and considering that defects like knots, splits cracks do occur on wood, it is important to explore the effect of altitude on strength of *Eucalyptus globulus.*

2. Materials and Methods

2.1. Description of study area

Mezam is one the seven Divisions in the North West Region of Cameroon. The Division covers an area of 1745 km^2 and as of 2005 had a total population of 524,127 (Tchombe, 2021). The capital of Mezam Division is Bamenda. The two study sites were selected from two different altitudes in Mezam; high altitude Santa (1803 m) and low altitude Bamenda II (1213 m) (Figure 1). The study area is characterized by cool tropical climate, mountainous terrain and rugged topography with an average rainfall of about 2400mm, average temperature of 23°C ranging between 15°C - 32°C. There are 2 main seasons: a long-wet season lasting for 8 months from mid-March to mid-November and a dry season which lasts for 4 months from mid-November to mid-March (Olayiwola *et al.*, 2021).

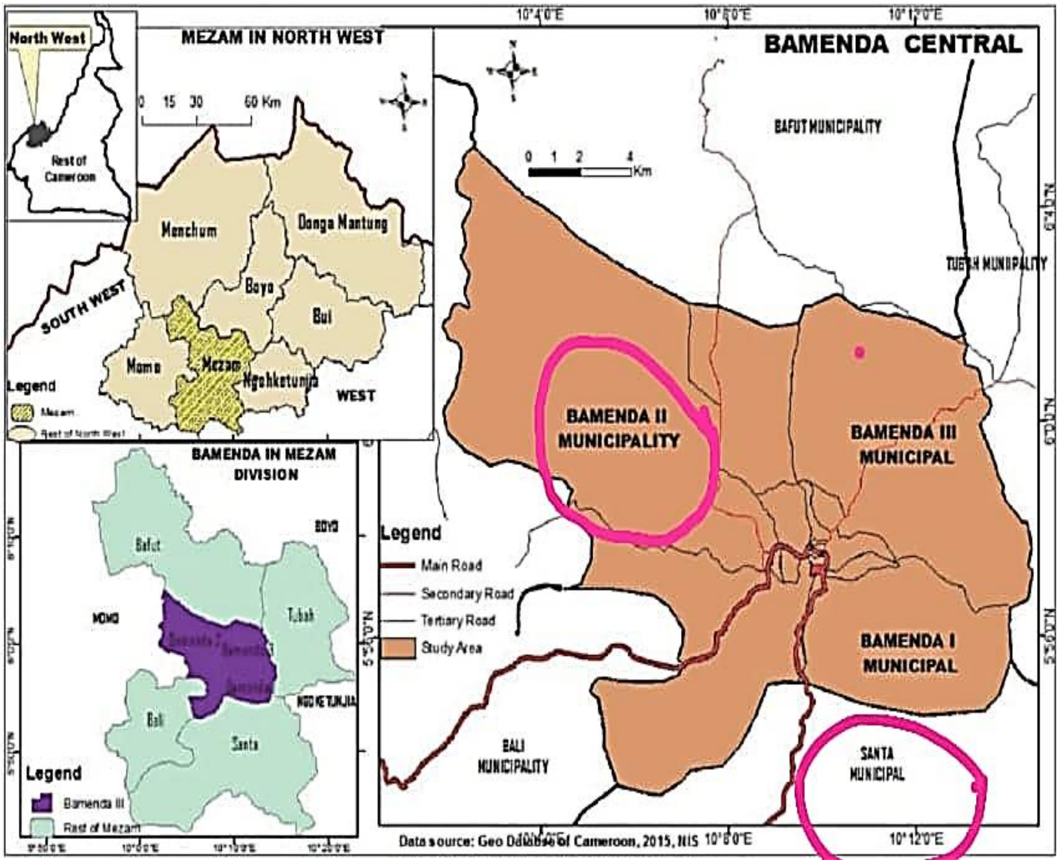

Figure 1: Location of high (Santa) and low (Bamenda II) altitude sites

2.2. Data collection

Ten *Eucalyptus globulus* trees, aged 28 – 30 years old, were randomly selected from the high and low altitude sites. The leaf area of each of the trees was taken as the average of measurements from ten randomly selected leaves from lowest branch as determined with the Petiole mobile application. The diameter at breast height was determined with a calibrated tape after which the height was measured with a range finder.

Logs were obtained from the trees and sawn into 50-mm-thick radial planks. Samples were conditioned for 2 weeks in black sealed plastic bags in order to prevent exposure to light and other weather conditions. To ensure a uniform moisture content, they were later placed in an oven at a temperature of 105 ºC for 24 hours. Ten wood samples measuring 40 × 40 × 40 mm per tree were seasoned to a moisture content of 12% then used for mechanical experiments. The compression failure (Compression stress parallel to grain) was achieved with the use of a hydraulic ring main unit (RMU) at a constant vertical dead load with a capacity range from 0 -1000 kN, acting on the specimen while another opposing force (equivalent to the vertical force) was applied to the bottom piece of the compression parallel to the grain. The main failure mode was identified with visible cracks extending across the direction of the grain. The following equations were used to calculate Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) of wood with a rectangular cross section:

$$MOE = \frac{PL^3}{48ID} \quad (1)$$

$$MOR = \frac{P_{MAX} L}{bd^2} \quad (2)$$

Where:

P = load below proportional limit (N) ; P_{MAX} = failure load (N) ; L = test span (cm) ; b = breath of the sample (in.) ; d = depth of the sample (cm) ; D= center deflection (cm) and I = moment of inertia (cm^4).

$$I = \frac{bd^3}{12} \quad (3)$$

2.3. Data analysis

The effect of altitude on tree morphological and wood mechanical properties was tested using one-way ANOVA. Results were considered significant at $p < 0.05$. The statistical test was conducted in STATGRAPHICS software.

3. Results and Discussion

3.1. Morphology

There was a significant effect of altitude on leaf area and tree height but no tree diameter. While leaf area declined from the high to low altitude site, the reverse trend was the case for tree height (Figure 2). The difference in height may be explained by differences climate between the sites. Plants at lower elevation may not receive as much solar radiation as those at higher elevations. Plant reactions to shading are two-fold. Firstly, a rich far-red light and lowered red/far-red light ratio in low light environment may trigger stem elongation as a shade avoidance strategy (Iglesias *et al.*, 2018). In contrast, the far-red light may trigger leaf expansion leading to an increased interception of radiation for photosynthetic carbon gain (Meng *et al.*, 2024). The latter hypothesis could not, however, explain the difference in height in the present study since the high altitude was superior in leaf area.

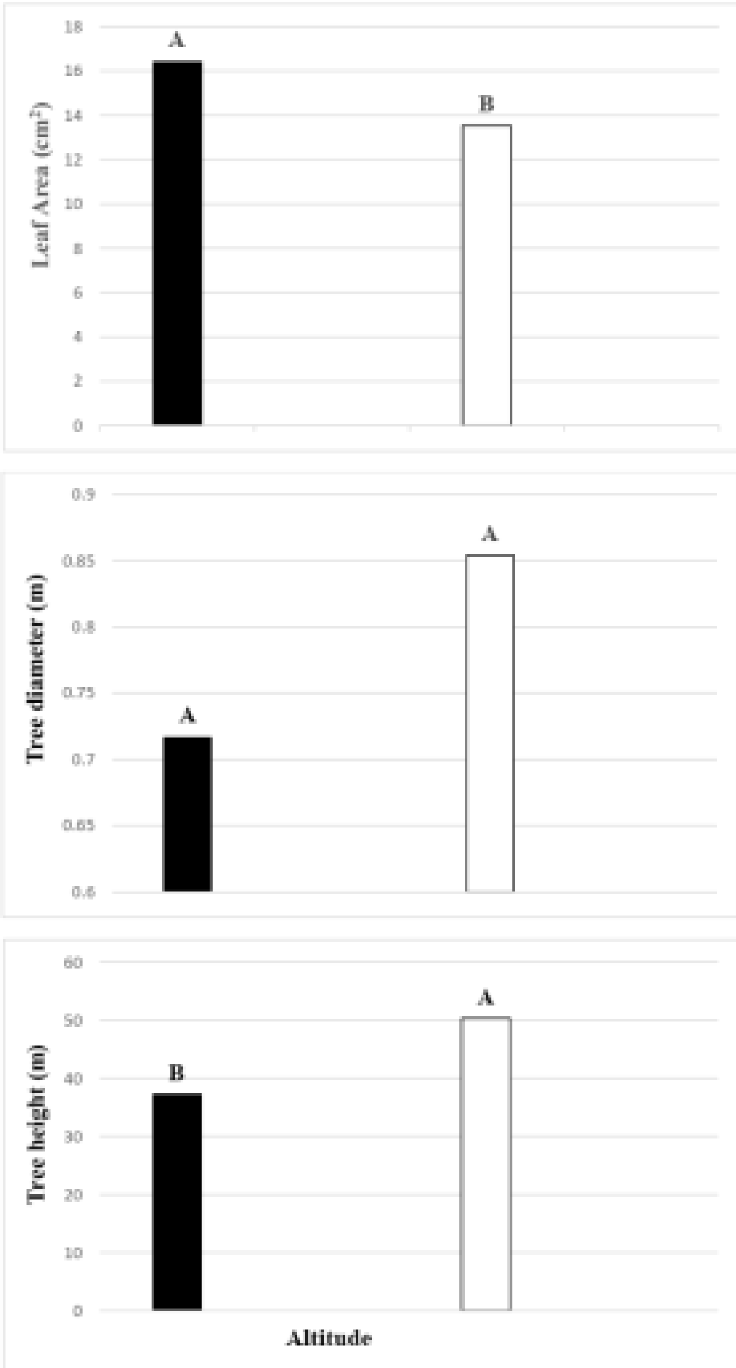

Figure 2: Effect of altitude on morphological traits of *Eucalyptus globulus*. The solid and open bars represent means for the high and low altitudes, respectively.

3.2. Mechanical properties

There was a significant effect of altitude on both MOE and MOR. Wood from the high altitude recorded lower values of the trait than those from low altitude (Figure 3).

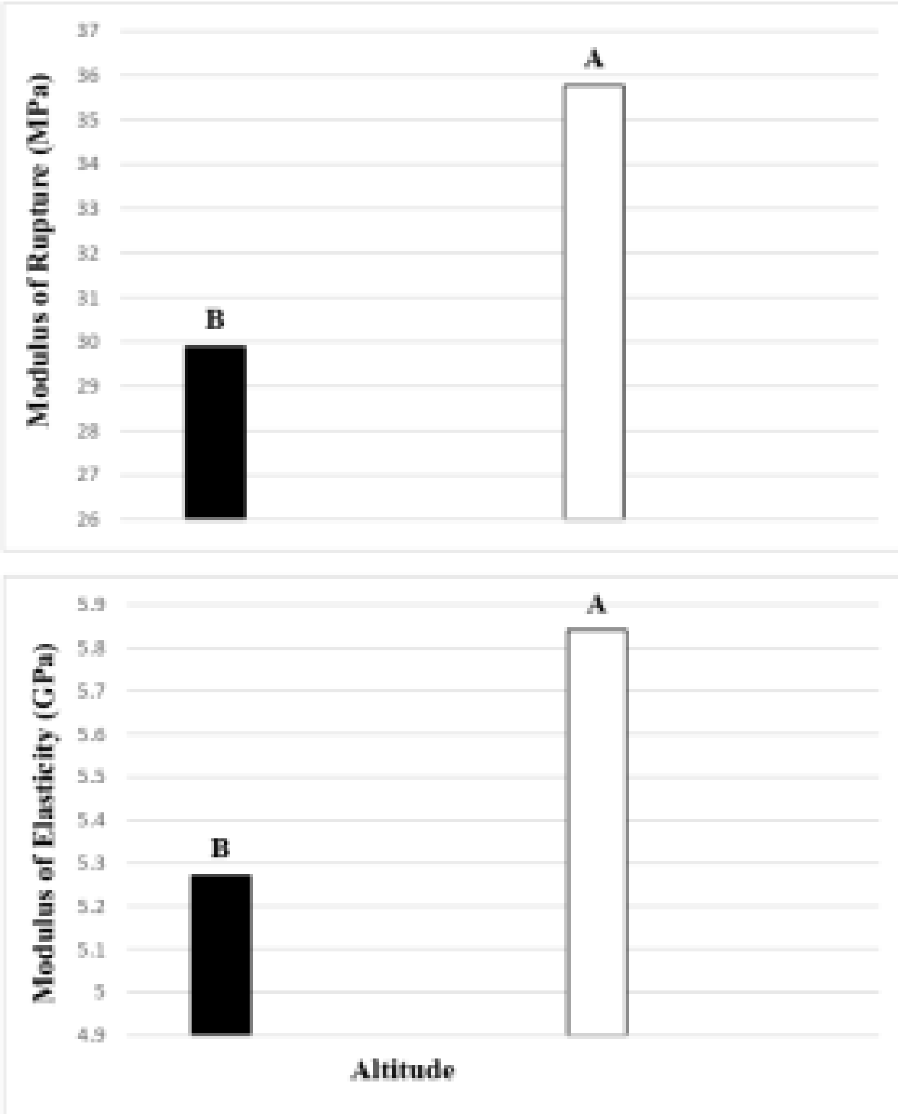

Figure 3: Effect of altitude on flexural and compressive strength of *Eucalyptus globulus*. The solid and open bars represent means for the high and low altitudes, respectively.

This difference in wood mechanical properties between the high and low altitude sites might be accounted for by the difference in soil nutrient availability in the study sites. These values for MOR and MOE are lower than those reported by Amoah *et al.* (2021) for iroko and emire species respectively. The discrepancy may be attributed to differences in size, density of wood and tree species. Not only were the samples used in this work smaller in size, the density of *Eucalyptus globulus* is lower than that of iroko. According to Knapic *et al.* (2022), the strength of wood increases with an increase in density. Density plays an important role during the axial loading of wood as a structural material. A high wood density is indicative of more and heavier fibres in a specific volume of the wood. Thus, the denser the wood, the higher its resistance to compression.

4. Conclusion

This study revealed that altitude has a significant effect on the morphology of a *Eucalyptus. globulus* tree and the strength of its wood. Though morphology may not directly determine the strength, they are crucial drivers for competitiveness, fitness and survivability of *E. globulus.*

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