# Biological Resistance of Coppiced and Non-Coppiced Rosewood (Pterocarpus Erinaceus Poir.) in the Field and Their Technological Performance

**Frederick Amin ANTHONIO** ( afamin@tatu.edu.gh )
Tamale Technical University
**Charles ANTWI-BOASIAKO**
Kwame Nkrumah University of Science and Technology

---

**Research Article**

**Keywords:** Coppiced wood, extractive, heartwood, natural durability, rosewood.

**Posted Date:** March 17th, 2023

**DOI:** https://doi.org/10.21203/rs.3.rs-2691890/v1



**Additional Declarations:** No competing interests reported.

**BIOLOGICAL RESISTANCE OF COPPICED AND NON-COPPICED ROSEWOOD (*Pterocarpus erinaceus* Poir.) IN THE FIELD AND THEIR TECHNOLOGICAL PERFORMANCE**

***Frederick Amin ANTHONIO***
Department of Wood Technology, Faculty of Built and Natural Environment,
Tamale Technical University, Tamale-Ghana.
Tel. +233 (0) 242782433
*Email: **afamin@tatu.edu.gh** **anthonio87ff@gmail.com**

***Charles ANTWI-BOASIAKO***
Department of Wood Science and Technology, Faculty of Renewable Natural Resources,
Kwame Nkrumah University of Science and Technology, Kumasi-Ghana.
Tel. +233 (0) 243771376.
Email: **cantwiboasiako@gmail.com**

**Abstract**

Rosewood (*Pterocarpus erinaceus*) timber is highly sought-after for furniture and building purposes due to its qualitative properties including durability. It coppices easily, which offers an essential strategy in curbing timber over-exploitation towards sustainable management. Mass loss, together with visual durability rating, was adopted in assessing the natural durability within the coppiced rosewood. Mass loss increased (i.e., durability decreased) up the coppiced (4.96±0 - 40±0.9%) and non-coppiced boles (2.9±0.06 - 15±0%), being greater for the coppiced trees (4.96± 0 - 40±0.9%) than the non-coppiced (2.9 ±0.06 - 15±0%) and for sapwoods [i.e., 26±0.3 - 40±0.9% (coppiced) and 14±0.03 - 15±0% (non-coppiced)] than the heartwoods [i.e., 4.96±0 - 5.3±0% (coppiced) and 2.9±0.06 - 5±0.07% (non-coppiced)] of both trees. The differences were significant ($p<0.05$). Heartwoods and sapwoods along the boles of each tree type would be rated very durable (0-5%) and moderately durable (11-40%) respectively. Due to their great durability, both wood types would be widely suitable for several engineering applications. Thus, promotion of the coppiced *P. erinaceus* wood production would supplement the use of its non-coppiced counterpart to increase the wood market base.

**Key wood**: Coppiced wood, extractive, heartwood, natural durability, rosewood.

## 1.0 Introduction

Wood, one of the principal resource bases common to the construction sector, is gaining significant attention owing to its environmentally-benign characteristics, capacity to store carbon in service and aesthetically appealing appearance (Tripathi *et al*., 2022). Unfortunately, during the past decades, deforestation in the tropical zones has become another most worrying environmental menace after climate change (Damette and Delacote, 2012), with the exploitation of valuable timbers approaching unsustainable levels (Kossi *et al*., 2019). Certainly, demand for timber and non-timber forest products has been escalating worldwide, and tropical forests are capable of providing multipurpose benefits to meet the needs of the growing populations. Nonetheless, over exploitative timber harvesting, agriculture and urban expansion have been some of the drivers of deforestation leading to huge habitat loss, threatened species diversity, and putting species at risk of extinction (Keenan *et al*., 2015). *Pterocarpus erinaceus* Poir. (West African rosewood) is projected to be the most heavily traded tropical hardwood owing to its high performance and technological features (Sègla, 2015; Dumenu, 2019). It is exploited not only for its timber trade but also for its wide range of non-timber products including fodder, medicine and resources for crafts, tannins, dyes, resins, among others (Karou *et al*., 2003; Anthonio and Antwi-Boasiako, 2022). The natural *P. erinaceus* stands are being over-exploited due to illegal and uncontrolled logging linked to international trade, which places a heavy pressure on the timber and has constituted a major threat to it in the last years. To this end, the need to identify sustainable measures towards conserving rosewood is paramount in the wake of the looming threats of climate change coupled with wanton forest depletion.

Coppicing is one of the early global forestry practices (Fujimori, 2001). Coppiced woods are re-growths from rejuvenated stumps or the root system after harvesting the tree (Fuller and Warren 1993). Coppices were previously utilized as fuel wood until their current conversion to high forests owing to increased demand for quality timber (Hédl *et al*., 2010; Martin *et al*., 2015). Quality wood from coppices could be as good as non-coppiced material and supplement replanting and reduce its renewal and management costs. Coppiced wood has the potential to augment the regular wood supplies (Whittock *et al*. 2004; Zbonak *et al*. 2007). *P. erinaceus* has good sprouting ability (Duvall 2008; Orwa *et al*. 2009), and its coppiced stems could be used by the Timber Industry. However, its sprouts across the West African forests are usually under threats of wildfires, pests, trampling by livestock and wild herbivores, which together with adverse climatic conditions, limit their establishment. Ouédraogo (2006) indicated that the dynamics of natural regeneration of *P. erinaceus* sprouts usually arise from underground stumps. Specifically, the best regeneration technique for this species is related to cut stems in natural conditions (Duvall, 2008). Thus, when stands of *P. erinaceus* are properly managed, fragile ecosystems could be renewed, as its regeneration will bypass the aforementioned factors, which limit the renewal of the species (Varty 1998; Abdul-Rahaman *et al*. 2016; Bandoh 2016).

West Africa is the largest supplier of rosewood logs globally, which endangers the species in the sub-region (Kousi *et al*., 2021). The species hitherto was utilized locally until the growing largescale global demand for furniture and other building purposes, which has threatened the species. Consequently, several countries have passed a total ban on harvesting and trade of *P. erinaceus* yet this illegal harvesting and trade linger on (Hoare, 2015). Salvage permits granted by the Forestry Service Division of the Forestry Commission of Ghana for the extraction of trees along construction sites (e.g., roads) heightened the extensive illegal logging and trade of the species in the northern parts of the nation (Bosu, 2013; Abdul-Rahaman *et al*. 2016). This led to the re-imposition of a ban on harvesting, processing and export of the species (Coleman 2014; Bandoh 2016). Unfortunately, these interventions seem insufficient and have failed to curtail the regional and global drivers of its illegal and unsustainable exploitation. Thus, the increased demand for the west African rosewood is a serious threat to the region's natural ecosystems, and its ability to adapt to climate change. Nevertheless, under appropriate conservation strategies, the timber would become a huge prospect for global trade.

The estimation of service life of a product manufactured from a particular timber species as well as the rating of wood based on its performance is essential in the building and construction sector (Brischke *et al*., 2014). The inherent resistance of wood species of commercial importance against attack by wood decay fungi, termites, insects and marine borers across the globe have remained topical over the years (Tripathi *et al.,* 2022) because biological deterioration usually poses economic losses to wood either in service or storage. Naturally durable timbers are sustainable in their utilization since extensive preservative treatments, which threaten the environment, are not required for their utilization. Differences in wood properties determine their utilization. *P. erinaceus*, a valuable species for building and construction due to its strength and rich hue, also has the ability to sprout. However, information on the wood quality, especially natural durability, from coppiced wood is rare. This study assessed the natural durability of the coppiced rosewood boles alongside their non-coppiced counterparts so as to establish the utilization of the coppiced materials of the timber outdoors.

## 2.0 Materials and Methods

### 2.1 Sample preparation

Three (3) defect-free coppiced and non-coppiced *P. erinaceus* trees of 40 - 45 years were randomly sampled from the natural forest of the Kumawu Forest District at Amidu of the Ashanti Region, Ghana. Billets were removed from three axial positions of each stem: the butt (1.3 m above ground), middle (50% stem height) and crown (2m to the branch attachment). They were sawn and the slabs divided to obtain heartwood and sapwood boards, while stakes (25×12.5×250 mm) were sampled from the three axial positions of both tree types. Clear wood specimens free from defects were used for the field or graveyard test. Stakes of *C. pentandra* were used as the controls.

### 2.2 Natural durability assessment

#### 2.2.1 Determination of the masses of wood samples for durability test

Each stake from the axial and radial positions of the coppiced and non-coppiced *P. erinaceus* trees as well as the reference or control stakes was weighed and the moisture content (mc) determined at 103 ± 2 ºC. Ten samples each of the sapwood and heartwood were prepared from the butt, middle and top sections of stems. Those of 10 other stakes were also determined at 103 ± 2 ºC to estimate the corrected oven-dry weights of the stakes (Antwi-Boasiako, 2004; Antwi-Boasiako and Pitman, 2009) (Equation 2.1):

$$Corrected\ Oven\ Dry\ Weight\ (CODW) = \frac{100 \times Fresh\ weight\ of\ sample}{100 + moisture\ content\ of\ sample} \qquad \textit{Equation 2.1}$$

#### 2.2.2 Field test

Ten replicates each from the coppiced and non-coppiced *P. erinaceus* and the reference species were randomly fixed into the soil to cover one third of their lengths at the test site (50×60 m²) of the Demonstration Farm of the Faculty of Renewable Natural Resources (FRNR), Kwame Nkrumah University of Science and Technology (KNUST), Kumasi-Ghana (Plate 2.1). The site is within the Semi-deciduous vegetation zone [6° 40'N and 1° 33'W] with a mean moderate temperature (25 ºC), high Relative Humidity (83%) and dominated with Ochrosol soil (Kumasi Metropolitan

Assembly, 2006; Quartey, 2009). The stakes were exposed for 12 months. The location holds many termite mounds with great decay hazard index. Subterranean termites (*Macrotermes* spp.), *Ancistrotermes* spp., *Nasutitermes latifrons* and *Anobium* spp. are the most common insects on the site (Usher, 1975).

2.2.3 Visual durability rating

The wood samples were examined every month for damages until the final exposure period. They were rated as: 0 = No sign of attack, 1 = Slight attack, 2 = Moderate attack, 3 = Severe attack, 4 = Failure (Antwi-Boasiako, 2004; BS EN 252, 2014).

2.2.4 Mass loss (%)

All the debris were carefully brushed off the stakes, oven-dried at 103 ± 2 °C and their final weights determined. The mass loss (%) for each stake was calculated (Antwi-Boasiako, 2004; BS EN 252, 2014) (Equation 2.2):

$$Mass\ loss\ (\%) = \frac{CODW - Final\ weight}{CODW} \times 100 \qquad \textit{Equation 2.2}$$

Percentage mass loss was correlated to natural durability ratings: 0 – 5% = very durable, 6 – 10% = durable, 11 – 40% = moderately durable, 41 – 100% = non-durable (Antwi-Boasiako, 2004; BS EN 252, 2014).


Plate 2.1: Stakes (**A**) implanted upright at the test site for durability assessment.
*Grid dimension:* 50×60 $m^2$

2.3 Data analysis

Data on natural durability were subjected to Analysis of Variance (ANOVA) to establish the significant differences ($p < 0.05$) between the durability parameters between the samples.

## 3.0 Results

### 3.1 Natural durability

#### 3.1.1 Visual durability

Up the coppiced boles, the sapwood was severely attacked by termites (Ranking = 3), whereas the heartwood was slightly attacked (1) (Table II; Plates 3.1 and 3.6). The non-coppiced trees recorded moderate attack (2) for their sapwoods up the stems (Plate 3.10, 3.11 and 3.12). While the butt portions of the non-coppiced stems suffered no attack (0) (Plate 3.7), the middle and top positions suffered slight attack (1) by termites for the heartwood (Table II; Plates 3.8 and 3.9). The *C. pentandra* stakes were entirely degraded (4) after the exposure period.


Plate 3.1: Coppiced *P. erinaceus* heartwood: Butt position after 12 months of field exposure (Arrow shows termite attack).

Plate 3.2: Coppiced *P. erinaceus* heartwood: Middle position after 12 months of field exposure (Arrow shows minor termite attack).

Plate 3.3: Coppiced *P. erinaceus* heartwood: Top position after 12 months of field exposure (Arrow shows termite attack).


Plate 3.4: Coppiced *P. erinaceus* sapwood: Butt position after 12 months of field exposure (Arrow shows termite attack).


Plate 3.5: Coppiced *P. erinaceus* sapwood: Middle position after 12 months of field exposure (Arrow shows severe termite attack).

Plate 3.6: Coppiced *P. erinaceus* sapwood: Top position after 12 months of field exposure (Arrow shows severe termite attack).


Plate 3.7: Non-coppiced *P. erinaceus* heartwood: Butt position after 12 months of field exposure.


Plate 3.8: Non-coppiced *P. erinaceus* heartwood: Middle position 12 months after field exposure (Arrow shows minor termite attack).


Plate 3.9: Non-coppiced *P. erinaceus* heartwood: Top position after 12 months of field exposure (Arrow shows minor termite attack).


Plate 3.10: Non-coppiced *P. erinaceus* sapwood: Butt position after 12 months of field exposure (Arrow shows termite attack).


Plate 3.11: Non-coppiced *P. erinaceus* sapwood: Middle position after 12 months of field exposure (Arrow shows termite attack).


Plate 3.12: Non-coppiced *P. erinaceus* sapwood: Top position after 12 months of field exposure (Arrow shows termite attack).

3.1.2 Mass loss (%)

Generally, percentage mass loss increased with height along the coppiced and non-coppiced boles of *P. erinaceus* (Fig 3.1); the differences were significant (p<0.05) for both trees (Table I). Mean mass loss was greater for the coppiced trees than those from the non-coppiced and for sapwoods than heartwoods for both tree types. There were significant differences (p<0.05) in mass loss between the radial positions as well as the tree types (Table I). However, according to the durability classifications based on mass loss (Hale and Eaton, 1993), the heartwoods and sapwoods would be rated very durable (0-5%) and moderately durable (11-40%) respectively along the boles of the coppiced and non-coppiced trees (Table II).

Table I: ANOVA for mass loss within the coppiced and non-coppiced *P. erinaceus* boles

| Source of variation | Df | SS | MS | F-value | P-value |
|---|---|---|---|---|---|
| Axial position | 2 | 120.3007 | 60.1504 | 213.76 | <.001$^{***}$ |
| Radial position | 1 | 3032.8885 | 3032.8885 | 10778.17 | <.001$^{***}$ |
| Tree type | 1 | 709.0681 | 709.0681 | 2519.86 | <.001$^{***}$ |
| Axial*Radial position | 2 | 69.4336 | 34.7168 | 123.38 | <.001$^{***}$ |
| Axial*Tree type | 2 | 54.0609 | 27.0305 | 96.06 | <.001$^{***}$ |
| Radial*Tree type | 1 | 565.0921 | 565.0921 | 2008.20 | <.001$^{***}$ |
| Axial*Radial*Tree type | 2 | 79.0303 | 39.5151 | 140.43 | <.001$^{***}$ |
| Error | 24 | 6.7534 | 0.2814 | | |
| Total | 35 | 4636.6277 | | | |

$^{***}$Significant: p (<0.001) < 0.05

Table II: Durability within coppiced and non-coppiced *P. erinaceus* boles and *C. pentandra* stakes after 12 months of field exposure

| Wood species | Radial position | Axial position | Durability ratings | | | |
|---|---|---|---|---|---|---|
| | | | Visual durability | | Mass loss (%) | |
| | | | Coppiced | Non-coppiced | Coppiced | Non-coppiced |
| *P. erinaceus* | Sapwood | Butt | Severe attack (3) | Moderate attack (2) | Moderately durable (26±0.3) | Moderately durable (14±0.3) |
| | | Middle | Severe attack (3) | Moderate attack (2) | Moderately durable (29±0.3) | Moderately durable (15±0) |
| | | Top | Severe attack (3) | Moderate attack (2) | Moderately durable (40±0.9) | Moderately durable (15±0) |
| | Heartwood | Butt | Slight attack (1) | No attack (0) | Very durable (4.96±0) | Very durable (2.9±0.06) |
| | | Middle | Slight attack (1) | Slight attack (1) | Very durable (5.1±0.06) | Very durable (4.7±0.3) |
| | | Top | Slight attack (1) | Slight attack (1) | Very durable (5.3±0) | Very durable (5±0.07) |
| *C. pentandra* | | | - | Failed (4) | - | Non-durable (100±0) |

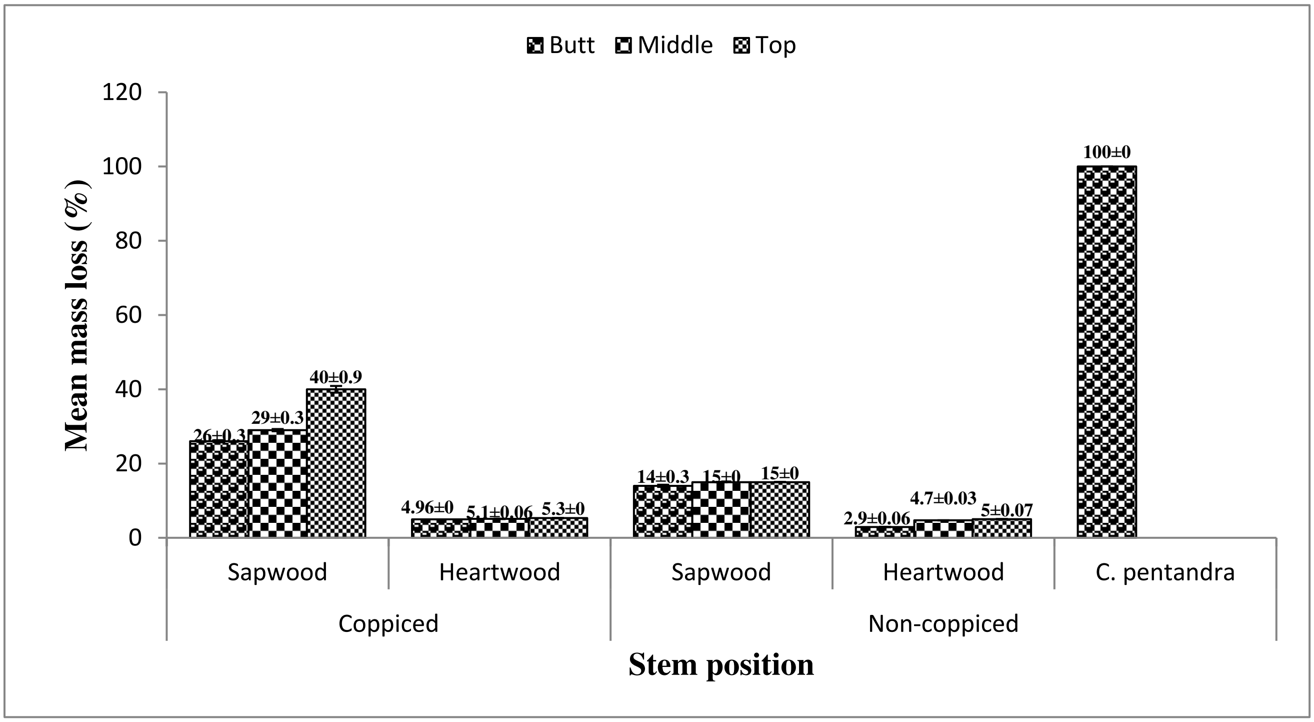


Fig. 3.1: Mean mass loss within the boles of coppiced and non-coppiced *P. erinaceus* and *C. pentandra* (the control)

## 4.0 Discussion

### 4.1 Natural durability

Natural durability is explained as the biological resistance of timber against wood-destroying agents (Taylor *et al*., 2002). Not only is it paramount for the end-use application of timber species but also for the global carbon balance in the forest ecosystem (Ulyshen *et al*., 2020). Several procedures have been used for testing the durability of wood and wood-based materials over the years. These are fundamentally categorized into field and laboratory tests determined by the European Standard EN 252 for specimens in ground contact after exposing samples to wood-destroying agents over some period and EN 113 for fungal test in the laboratory respectively. The latter allows more defined and reproducible conditions and offers advantage of shorter test durations. While laboratory test results are hardly transferable to real life situations, field tests ensure more realistic conditions. For example, natural weathering and detoxification of biocidal compounds through 'non-target-organisms' is certain only under outdoor field exposure (Meyer *et al*., 2014; Lipeh *et al*., 2021). Besides, novel non-destructive technologies, such as Attenuated Total

Reflectance-Fourier Transform Infrared (ATR-FTIR) Spectroscopy, are also emerging to effectively categorize decay resistance owing to the shift of timber utilization towards plantations or native forest regrowth (Lipeh *et al*., 2021).

However, this study adopted the field (i.e., graveyard) test in assessing the biological resistance of coppiced and non-coppiced rosewood trees so as to encourage the effective utilization of the regrowth. It was measured by mass loss since it reduces the strength properties of wood, which negatively influence its performance in service (van Acker *et al.*, 2003). The procedure (field test) is direct and monitors the deterioration level detected on stakes partially inserted into the ground and test results conventionally expressed as the relationship between the mean deterioration level and the period of exposure. Usually, wood in direct contact with soil is prone to severe situations because it remains in continual touch with moisture and wood-destroying agents. Fungal decay after lengthy moisture exposure is often a certainty for any timber species along with its changing nutrient status (Eaton and Hale, 1993; Råberg *et al.,* 2005).

4.1.1 Visual Durability Rating

This evaluates the durability of timbers from signs of attack on wooden stakes exposed to bio-deteriorating organisms in the field (Eaton and Hale, 1993; Antwi-Boasiako, 2004**;** Australian Durability Standard (AS (5604), 2005). Edlund *et al*. (2006) indicated that the rating could be subjective as a means of assessing durability. However, it could be efficient when appropriately employed (Kasal and Anthony, 2004). This method was adopted to measure the level of deterioration of the two types (i.e., coppiced and non-coppiced) of *P. erinaceus* (rosewood) timber to support their mass losses. Up the coppiced bole, the sapwoods and heartwoods were severely and slightly attacked (rating: 3 and 1 respectively) by termites (Table II; Plates 3.4 - 3.6 and 3.1 - 3.3). Thus, the heartwoods would be more durable and suitable for in-ground applications such as for heavy construction and structural supports (e.g., columns and beams) as well as those which require durability against weather conditions outside. Sapwoods could be applied for above ground and indoor purposes (e.g., cabinetry, framing and flooring). The butt portions of the non-coppiced heartwood suffered no attack (0), while the middle and top positions were slightly attacked (1) by termites (Plates 3.7 - 3.9). Hence, the butt sections of the non-coppiced *P. erinaceus* trees are most likely to be very resistant against termite attack in service more than their middle and the top positions. Sapwoods up the bole of the non-coppiced *P. erinaceus* wood recorded moderate attack (2) (Table, II; Plate 3.10 - 3.12). *C. pentandra* wooden stakes failed totally (4) by the end of the test.

Thus, the butt of non-coppiced *P. erinaceus* could be used for exterior applications with ground contact including railway sleepers, foundation piles, utility poles, retaining walls, among others (Wong *et al.,* 2004). The middle and top heartwoods for non-coppiced trees and the heartwoods of coppiced trees up the bole could also be employed in applications such as fence posts, greenhouses, pergolas (in ground), landscaping timbers, among others (i.e., European Hazard Class 4) (Wong *et al.,* 2004). However, sapwoods along the boles of coppiced *P. erinaceus* would be suitable for interior and above ground purposes such as framing, flooring, furniture and interior joinery-under dry conditions (i.e., European Hazard Class 2), whereas those from non-coppiced trees could be applicable for bathroom doors and frames, kitchen floor cabinets and floorings on exposure to wet conditions (Wong *et al*., 2004).

Differences in heartwood extractives content and concentration have been related to the existence of durability gradients in wood (Hashida *et al*., 2014). Concentration of extractives (e.g., alkaloids, phenols, flavonoids, resins, terpenes, quinones) in heartwood, which absolutely influence biological resistance of timber species against degradation could account for the variation in durability between the sapwoods and heartwoods along the boles of the coppiced and non-coppiced *P. erinaceus*. Generally, toxic extractives to bio degraders increase from the pith towards the outer heartwood and reach a maximum at the boundary between heartwood and sapwood (Hillis, 2011) because the latter is living xylem ladened with starch whilst heartwood is filled with extractives produced by parenchyma cells during the transformation of the sapwood to heartwood. Axially, the extractive concentration decreases with the tree height. The lower portions of trees have matured cambial cells, which are away from the action of the apical meristem and establish positive relation between cambial maturity and concentration of extractives (Gao, 2007; Nawrot *et al*., 2014; Shahlinney *et al.,* 2021).

Moreover, Eaton and Hale (1993), Antwi-Boasiako (2004) and Cookson and McCarthy (2013) reported that density and cell wall thickness could enhance the resistance of timbers to biological attacks such as browsing by wood-destroying agents is made difficult. Thus, density and cell wall thickness of timbers are reported by Cookson and McCarthy (2013) to be related positively with durability. They generally decrease up the boles of timber species, and are greater for heartwood than sapwood because extractives usually produced during the formation of heartwood contribute to increase the density of wood. Density can be greatly affected by the presence of extractives with varying amount within trees, which is influenced by cambial age (e.g., thicker cell wall in mature stems) and the position in the stem (e.g., greater in the heartwood) (Cown, 2001). *C. pentandra* is a light wood (380-450 $Kgm^{-3}$) with thin-walled fibres (Antwi-Boasiako, 2004; Duvall, 2011) and this could be responsible for its high susceptibility to termite attack. On the contrary, coppiced and non-coppiced *P. erinaceus* have thick-walled fibres and could be classified as moderately heavy-to-heavy density wood [679 ± 4 -859±3 kg $m^{-3}$, 0.8 ± 0.07 $g/cm^3$ (Antwi-Boasiako *et al*., 2018; Kossi *et al*., 2021)], which make them more resistant to termite attack.

4.1.2 Mass loss (%)

Natural resistance of wood is determined by its period of endurance to attack by bio-degrading organisms, or the amount of wood biomass consumed within a fixed exposure period. This could be essentially against fungal and/or insect attack (Wong *et al*., 2005). Usually, when less biomass is removed, wood slightly loses weight and becomes more resilient to bio-degradation (Ashaduzzaman *et al*., 2011). Natural durability generally decreased up the bole of the coppiced and non-coppiced, that is, both tree types of *P. erinaceus*. For the non-coppiced trees, the butt portions of the heartwood were most resistant to biological attack (i.e., mass loss = 2.9±0.06%). Likewise, the butt ends of the coppiced trees were also most resistant to termite attack (i.e., 4.96±0%) (Fig. 3.1). Thus, the butt ends of each bole are very durable and could be applied for outdoor and in-ground purposes including bridge and building construction, as well as railway sleepers. This is in concurrence with the assertion by Zabel and Morrell (1992) and DeBell *et al*. (1999) that the most durable heartwood is often located at the butt of the stem, as it is related with maximum concentrations of extractives. These chemicals are toxic to bio-degraders and, when they are in great concentrations, they offer remarkably significant immunity against termite attack to timbers (Tripathi *et al*., 2022). Haygreen and Bowyer (1996) and DeBell *et al*. (1999) agreed that the relative amounts of extractives decreased with increasing height above the ground. Juvenile wood is anticipated to increase with an increase in height (Nawrot *et al*., 2014) and mature tissues have more extractives than younger ones (Ververis *et al*., 2004). This could explain the variation in natural durability up the boles of the coppiced and non-coppiced trees. Besides, density could also influence the variation in natural durability along the tree heights. The butt sections of trees are usually expected to be heavier than the upper positions due to their mature wood characteristics (Nawrot *et al*., 2014), which could provide some level of resistance to biological attack. However, according to the natural durability classification by Eaton and Hale (1993), the heartwoods along the boles of the coppiced and non-coppiced trees were all rated very durable, while their sapwoods ranked moderately durable (Table II; Fig. 3.1; Plate 3.1-3.12).

*C. pentandra* (the reference or control timber species) lost the greatest mass (i.e., 100%) and were rated non-durable. *C. pentandra* contains a lot of carbohydrates and low amount of extractives, which make it easily prone to micro-organisms as food (Walia *et al*. 2009; Duvall, 2011). Sapwoods of all species are mostly regarded non-durable (Desch and Dinwoodie, 1996) because they also contain very little or no extractives and are laden with starches generally planned for physiological activities, which are also essential for the growth of fungi making the plant material perishable (Scheffer and Morrell, 1998). Yet, sapwoods along the stems of coppiced and non-coppiced *P. erinaceus* were moderately durable. This could be partly attributed to the presence of tyloses and prismatic crystals in the sapwoods of both trees. EN 350-1 (1994) indicated that the amounts of extractives or other deposits (e.g., tyloses, crystals) found in some sapwoods can influence their natural durability. Thus, sapwoods along the stems of both trees are most likely to contain some extraneous materials. Furthermore, their natural polymeric structure (e.g., lignin) might have offered some kind of resistance against browsing by termites (Scheffer and Morrel, 1998).

Most rosewood species (e.g., *Dalbergia nigra*, *D. latifolia*, *D. sissoo*, *Pterocarpus angolensis*, *P. dalbergioides, P. indicus*, *P. macrocarpus*, and *P. soyauxii*) are durable (Scheffer and Morrell, 1998). Coppiced and non-coppiced *P. erinaceus* trees could be classified into Use-Class 3 (i.e., suitable for exterior and above ground structures) and 4 (i.e., for exterior and in-ground applications) under EN 355 (Czichos *et al*., 2011; Boadu, 2016). They would be as good as a number of naturally durable commercial hardwoods (e.g., *Pterocarpus soyauxii*, *Diospyros* spp., *Tectona grandis*, *Dalbergia latifolia*) (Wong *et al*., 2005) commonly applied in structural supports (e.g., beams and columns), bridges, flooring, railway sleepers, utility poles, mine props, boat building coupled with highly-priced furniture and cabinets. However, the sapwoods along the boles of the coppiced and especially the non-coppiced *P. erinaceus* would be suitable for the interior-above ground purposes (i.e., ranging from dry-to-wet conditions) such as flooring, furniture and interior joinery. Consequently, sapwoods in both cases should be considered in applications where durability is not extremely paramount.

Generally, timbers from a virgin (old-growth) stand of naturally durable species are more resistant to bio-degradation than those from second-growth (plantation) stand (Zabell and Morrell, 1992; Scheffer and Morrell, 1998). It is opined that, wood from plantation growths have faster growth rates than their respective old-growth counterparts (Scheffer and Morrell, 1998), which influence the amount of wood deposits in them. Likewise, coppiced trees usually grow faster than the non-coppiced (Kauppi *et al*. 1988; Hytönen and Kaunisto 1999). Hence, differences in growth characteristics exist for these two tree types and might cause some variations in their wood formation (e.g., extractive deposits, juvenile and mature wood), which ultimately affect their wood properties including durability (Lantican 1976; Alipon and Bondad, 2011). The variation in termite resistivity for the coppiced and non-coppiced *P. erinaceus* trees could, therefore, be partly attributed to the growth differences between them. Besides, their inherent physiological and genetic properties could also account for the variation in the natural durability (Izekor and Fuwape, 2011). Nonetheless, Peralta *et al*. (2003), Antwi-Boasiako and Atta-Obeng (2009) and Cookson and McCarthy (2013) noted that density and cell wall thickness are associated positively with the durability of timbers. Humar *et al.* (2008) revealed that *Quercus* spp. (very dense timbers and famed for furniture making) were very resistant to bio-deterioration because of their thick cell walls. Thick-walled timbers hinder the penetrability of biological organisms, which limits the level of nibbling of wood substance (Schultz *et al.*, 2000). Furthermore, durability is enhanced with the occlusion of tyloses in vessels and other wood deposits (e.g., crystals), which make wood impervious to micro-organisms by blocking the cavities namely cell lumina and pits (Pitman *et al*., 1999). Thus, the durability rating of the heartwoods of the coppiced and non-coppiced *P. erinaceus* (especially the non-coppiced trees) could be attributed to the thick-walled fibres, moderately heavy to heavy density and the presence of deposits (e.g., tyloses, prismatic crystals) in the heartwood vessel (Grubben, 2004).

## Conclusion

- ✓ Generally, mass loss increased (i.e., durability decreased) with height along the *P. erinaceus* coppiced and non-coppiced boles*;* the differences were significant ($p<0.05$) for both trees. Mass loss was greater for the coppiced trees (4.96 ± 0 - 40±0.9%) than those for the non-coppiced (2.9±0.06-15±0%), and for the sapwoods [26±0.3-40±0.9% (coppiced) and 14±0.03-15±0% (non-coppiced)] than the heartwoods [i.e., 4.96 ±0-5.3±0% (coppiced) and 2.9 ±0.06-5±0.07% (non-coppiced)].

- ✓ The heartwood and sapwood would be rated very durable (0-5%) and moderately durable (11-40%) respectively along the boles of the coppiced and non-coppiced trees.

- ✓ *P. erinaceus* heartwood, in relation to durability, would be appropriate for analogous applications of naturally durable hardwoods (e.g., *Pterocarpus soyauxii*, *Diospyros* spp., *Tectona grandis*, *Dalbergia latifolia*) often utilized as structural supports (e.g., beams and columns), bridges, flooring, railway sleepers, utility poles, mine props, boat building as well as highly-priced furniture and cabinets.

- ✓ Sapwoods along the boles of both tree types would be suitable for interior and above ground purposes, which range from dry-to-wet conditions including framing, flooring, furniture and interior joinery, bathroom door and frame, kitchen floor cabinet, among other applications where durability is not a paramount requirement.

- ✓ Natural durability from coppiced and non-coppiced trees are comparable. Thus, the former could complement the latter in the famed applications for which the non-coppiced trees are known for.

- ✓ Coppicing should be promoted for timbers such as *P. erinaceus*, which have the capacity to contribute to the production of enough raw materials to sustain the Timber Industry.

Acknowledgement

We acknowledge the Staff of the Kumawu Forest District of the Forestry Services Division (FSD), Kumawu, Ashanti Region, Ghana, for providing the *P. erinaceus* (rosewood) trees for the study. We also thank Technicians at the Demonstration Farm of the Faculty of Renewable Natural Resources, KNUST, for assisting with the field work and those of the Department of Wood Technology workshop for the processing of the wood samples

References

**Abdul-Rahaman, I., Kabanda, J., and Braima, M. M. (2016).** Desertification of the Savanna: Illega Logging of Rosewood, Causes and Effects on the People of Kabonwule, Northern Region. *Saudi Journal of Humanities and Social Studies*, 1: 48-54.

**Alipon, M. A. and Bondad, E. O. (2011).** Comparative strength and related properties of yemane (*Gmelina arborea* Roxb.) coppice and planted stand. *Philippine Journal of Science,* 140(2):231-238.

**Anthonio, F. A. and Antwi-Boasiako, C**. (2022). Xylem Anatomy of Coppiced and Non-Coppiced Rosewood (*Pterocarpus erinaceus* Poir.) in relation to their Utilisation. *Journal of Science and Technology.* 7(3):80-106.

**Antwi-Boasiako, C. (2004).** Assessment of Anatomy, Durability and Treatability of Two Tropical Lesser-Utilized Species and Two Related Species from Ghana. PhD Thesis. The University of Reading. UK. Pp. 319

**Antwi-Boasiako, C., Anthonio, F. A. and Frimpong-Mensah, K. (2019).** Mechanical properties of coppiced and non-coppiced Pterocarpus erinaceus boles and their industrial application. *Journal of Forestry Research*, *30*, 1973-1980.

**Antwi-Boasiako, C. and Atta-Obeng, E. (2009).** Vessel-Fibre Ratio, Specific Gravity and Durability of Four Ghanaian Hardwoods. *Journal of Science and Technology*, 29(3): 8-23.

**Antwi-Boasiako, C. and Pitman, A. J. (2009).** Influence of density on the durabilities of three Ghanaian timbers. *Journal of Science and Technology,* 29(2): 34-45.

**Ashaduzzaman, M., Das, A. K., and Shams, M. I. (2011).** Natural Decay Resistance of *Acacia auriculiformis* Cunn. ex. Benth and Dalbergia sissoo Roxb. *Bangladesh J. Sci. Ind. Res*., (46): 225-230

**Australian Durability Standard (2005).** Timber—Natural durability ratings. AS 5604. Standards Australia. 26pp.

**Bandoh, W. K. N. (2016).** Tissue culture regeneration potential of African rosewood in Ghana: Institutional variables and implications for sustainability (Masters Dissertation, Kwame Nkrumah University of Science and Technology, Kumasi). Pp. 103.

**Boadu, K. B. (2016).** Bio-mechanical properties of *Klainedoxa gabonensis* and the strength performance of its Dovetail and Mortise-Tenon joints in leg-and-rail construction (Doctoral dissertation, Kwame Nkrumah University of Science and Technology, Kumasi).

**Bosu, D (2013).** Draft report on the dynamics of harvesting and trade in rosewood (Pterocarpus erinaceus) in Bole, Central, West and North Gonja Districts of the Northern Region, Ghana, 2013.3. National Academy of Sciences (NAS). Tropical legumes: Resources for the future. National Academy of Sciences, Washington, D.C; 1979.

**BS EN 252 (2014**). Field Test Method for Determining the Relative Protective Effectiveness of a Wood Preservative in Ground Contact. European Committee for Standardisation. 28pp.

**Brischke, C. & Thelandersson, S. (2014).** Modelling the outdoor performance of wood products–A review on existing approaches. *Construction and Building Materials*, *66*: 384-397.

**Coleman, H. (2014).** Situation of global Rosewood production and trade-Ghana Rosewood - Case Study, Timber Industry Development Division, Forestry Commission, Ghana. 27pp

**Cookson, L. J. and McCarthy, J. K. (2013).** Influence of Tree Age and Density on the Above ground Natural Durability of Eucalypt species at Innisfail. *Aust For,* 76(3-4): 113- 120.

**Cown, D. J. (2001).** Wood: density. *Encyclopedia of Materials: Science and Technology*, 9620-9622.

**Czichos, H., Saito, T. and Smith, E. L. (2011).** Springer Handbook of Metrology and Testing. Springer, 1500 pp.

**Damette, O. & Delacote, P. (2012).** On the economic factors of deforestation: what can we learn from quantile analysis? *Economic Modelling*, *29*(6): 2427-2434.

**DeBelI, J., Morrell, L.L, and Gartner, B. L. (1999).** Within-stem variation in tropolone content and decay resistance of second-growth western red cedar. *Forest Science*, 45 (2): 101-107.

**Desch, H. E. and Dinwoodie, J. M. (1996).** Timber Structure, Properties, Conversion and Use (No. Ed. 7). MacMillan Press Ltd. Houndmills, Basingstoke, Hamsphire and London, UK. 306 pp.

**Dumenu, W. K. (2019).** Assessing the impact of felling/export ban and CITES designation on exploitation of African rosewood (Pterocarpus erinaceus). *Biological Conservation*, *236*: 124-133.

**Duvall, C.S. (2008).** Pterocarpus erinaceus Poir. Fiche de PROTA4U. In: Louppe, D., Oteng-Amoako, A.A. and Brink, M., Eds., PROTA Plant Resources of Tropical Africa/ Wageningen. Pterocarpus erinaceus (PROTA) — PlantUse English (plantnet-project.org)

**Duvall, C. S. (2011**). *Ceiba pentandra* (L.) Gaertn. [Internet] Record from Protabase. Brink, M. & Achigan-Dako, E.G. (Editors). PROTA (Plant Resources of Tropical Africa/Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. www.database.prota.org/search.htm (Accessed 17/11/2020).

**Eaton, R. A. and Hale, M. D. C. (1993).** Wood Decay, Pest and Production. Chapman and Hall. London. U.K., Madison, No. 217. 28pp.

**Edlund, M. L., Evans, F., Henriksen, K. and Nilsson, T. (2006**). Testing Durability of Treated Wood according to EN 252: Interpretation of Data from Nordic Test fields. Stockholm: The International Research Group on Wood Protection (The International Research Group on Wood Protection. Document IRG/WP 06-20341).

**EN350-1 (CEN, 1994**). Durability of Wood and Wood-based Products – Natural Durability of Solid Wood: Guide to the principles of testing and classification of the natural durability of wood. Part 1: Guide to the Principles of Classification of the Wood Species.

**Fujimori, T. (2001).** *Ecological and silvicultural strategies for sustainable forest management*. Elsevier. 373 pp.

**Fuller, R. J. and Warren, M. S. (1993).** Coppiced woodlands: their management for wildlife. Joint Nature Conservation Committee, & G. Britain (Eds.). Peterborough, UK. 29 pp

**Gao, H., Shupe, T. F., Eberhardt, T. L. & Hse, C. Y. (2007).** Antioxidant activity of extracts from the wood and bark of Port Orford cedar. *Journal of Wood Science*, 53(2):147-152.

**Grubben, G. J. (2004).** *Plant Resources of Tropical Africa* (PROTA) (Vol. 1), Wageningen, Netherlands. 667 pp.

**Hashida, K., Tabata, M., Kuroda, K., Otsuka, Y., Kubo, S., Makino, R. & Ohara, S. (2014).** Phenolic extractives in the trunk of Toxicodendron vernicifluum: chemical characteristics, contents and radial distribution. *Journal of wood science*, 60(2): 160-168.

**Haygreen, J. G. and Bowyer, J. L. (1996).** Forest Products and Wood Science. An Introduction 3 Edition. IOWA State University Press, Ames, 484 pp.

**Hédl, R., Kopecký, M. & Komárek, J. (2010).** Half a century of succession in a temperate oakwood: from species-rich community to mesic forest. *Diversity and Distributions*, *16*(2): 267-276.

**Hillis, W. E. (2012).** *Heartwood and tree exudates* (Vol. 4). Springer Science & Business Media.

**Hillis, W.E. (1996).** *Formation of robinetin crystals in vessels of Intsia species. IAWA J*ournal. 17(4):405-419.

**Hoare, A. (2015).** Tackling Illegal Logging and the Related Trade: What Progress and Where Next? Chatham House. 61 pp.

**Humar, M., Fabcic, B., Zupancic, M., Pohleven, F. and Oven, P. (2008).** Influence of Xylem Growth Ring Width and Wood Density on Durability of Oak Heartwood. *International Biodeterioration Biodegradation*, 62: 368-371.

**Hytönen, J. and Kaunisto, S. (1999).** Effect of fertilization on the biomass production of coppiced mixed birch and willow stands on a cut-away peatland. *Biomass and Bioenergy*, 17: 455–469.

**Izekor, D. N. and Fuwape, J. A. (2011).** Variations in the anatomical characteristics of plantation grown *Tectona grandis* wood in Edo State, Nigeria. *Archives of Applied Science Research*, 3(1): 83-90.

**Karou, D., Dicko, M. H., Sanon, S., Simpore, J. & Traore, A. S. (2003**). Antimalarial activity of *Sida acuta* Burm. F. (Malvaceae) and pterocarpus erinaceus poir. (Fabaceae). *Journal of ethnopharmacology*, *89*(2-3): 291-294.

**Kasal, B. and Anthony, W. R. (2004).** Advances in in situ Evaluation of Timber Structures. *Prog. Struct. Eng Mater*. 6: 94–103.

**Kauppi, A. (1988).** Sprouting in birches. A morphological and ecophysiological approach. Department of Botany, University of Oulu. Acta Universitatis Ouluensis, Series A 209. 32 pp.

**Keenan, R. J., Reams, G. A., Achard, F., de Freitas, J. V., Grainger, A. & Lindquist, E. (2015).** Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. *Forest Ecology and Management*, *352*: 9-20.

**Kossi, A., Towanou, H., Habou, R., Novinyo, S. K., Elikplim, A. K., Nathalie, J. B., and Kouami, K. (2019)**. Challenges of conservation and sustainable management of African rosewood (*Pterocarpus erinaceus*) in West Africa. In *Natural Resources Management and Biological Sciences*. IntechOpen.

**Lantican, C. B. (1976).** Quality control should start in the woods. Asian Forest Industries Yearbook. Pp. 2324-7374.

**Lipeh, S., Schimleck, L., Mankowski, M. E., McDonald, A. G., & Morrell, J. J. (2021).** ATR-FTIR Study of Alaska Yellow Cedar Extractives and Relationship with Their Natural Durability. *Forests*, 12(12): 1692.

**Martin, R., Sunley, P. & Tyler, P. (2015**). Local growth evolutions: recession, resilience and recovery. *Cambridge Journal of Regions, Economy and Society*, *8*(2): 141-148.

**Meyer, L., Brischke, C., Melcher, E., Brandt, K., Lenz, M. T. & Soetbeer, A. (2014)**. Durability of English oak (Quercus robur L.)–Comparison of decay progress and resistance under various laboratory and field conditions. *International Biodeterioration & Biodegradation*, 86: 79-85.

**Nawrot, M., Pazdrowski, W., Walkowiak, R., Szymański, M. and Kaźmierczak, K. (2014).** Analysis of coniferous species to identify and distinguish juvenile and mature wood. *Journal of Forest Science*, 60(4): 143-153.

**Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. & Simons, A. (2009).** Agroforestree Database: a tree reference and selection guide. Version 4. *Agroforestree Database: A Tree Reference and Selection Guide. Version 4.*

**Ouedraogo, B. (2006).** Household energy preferences for cooking in urban Ouagadougou, Burkina Faso. *Energy policy*, *34*(18): 3787-3795.

**Peralta, R. C. G.; Menezes, E. B. Carvalho, A. G. Menezes, E. L. A. (2003).** Feeding Preferences of Subterranean Termites for Forest Species Associated or Not to Wood Decaying Fungi. *Floresta e Ambiente*, 10 (2): 58-63.

**Pitman, A. J., Gongora, A. and Smith, G. (1999).** The Decay Resistance of Four Belizean Timbers to Fungi and the Marine Borer *Limnoria tripunctata*. In: Proceedings of the fourth International Conference on the Development of Wood Science, 149-156, Missenden Abbey, UK, 14-16 July 1999, Wood Technology and Forestry.

**Råberg, U., Edlund, M. L., Terziev, N. & Land, C. J. (2005).** Testing and evaluation of natural durability of wood in above ground conditions in Europe–an overview. *Journal of Wood Science*, *51*(5): 429-440.

**Segla, K. N., Adjonou, K., Radji, A. R., Kokutse, A. D., Kokou, K., Habou, R.& Mahamane, A. (2015)**. Importance socio-économique de Pterocarpus erinaceus Poir. au Togo. *European Scientific Journal*, 11(23).

**Scheffer, T. C. and Morrell, J. J. (1998).** Natural Durability of Wood: A Worldwide Checklist of Species, College of Forestry, Forest Research Laboratory, Oregon State University. 45 pp.

**Schultz, T. P, Thomas, N. and Nicholas, D. D. (2000).** Synergistic Wood Preservatives: Terrestrial Microcosms (TMCs) and Exposure Efficacy Studies of the Synergistic Copper: Pyrithione Mixture. *Wood Fiber Science*, 32(3): 346-353.

**Taylor, A. M., Gartner, B. L. & Morrell, J. J. (2002).** Heartwood formation and natural durability-a review. *Wood and Fiber Science*, 34(4):587-611

**Tripathi, S., Ganguly, S. & Chand, S. (2022).** Natural Durability of Imported Timber in Indian Climatic Condition. *Indian Forester*, *148*(2): 133-141.

**Ulyshen, M. D., Horn, S., Brownie, C., Strickland, M. S., Wurzburger, N., & Zanne, A. (2020).** Comparison of decay rates between native and non-native wood species in invaded forests of the southeastern US: a rapid assessment. *Biological Invasions*, *22*(8): 2619-2632.

**Van Acker, J., Stevens, M., Carey, J., Sierra-Alvarez, R., Militz, H., Le Bayon, I.& Peek, R. D. (2003)**. Biological durability of wood in relation to end-use. *Holz als Roh-und Werkstoff*, 61(1): 35-45.

**Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P. and Santas, R. (2004).** Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. *Industrial Crops and Products*, 19(3): 245-254.

**Varty, N. (1998).** *Dalbergia nigra*. In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010, 2.

**Walia, Y. K., Kishore, K., Vasu, D. and Gupta, D. K. (2009).** Physico-chemical Analysis of *Ceiba pentandra* (Kapok). *International Journal of Theoretical and Applied Science*, 1 (2): 115-118.

**Whittock, S. P., Greaves, B. L. and Apiolaza, L. A. (2004**). A cash flow model to compare coppice and genetically improved seedling options for *E. globulus* pulpwood plantations. *Forest Ecology and Management*, 191:267-274.

**Wong, A. H. H., Morsing, N., Henriksen, K. and Salmiah, U. (2004**). Above ground microbial decay test of biocide treated and untreated wood exposed to Danish and humid tropical climates. *The International Research Group on Wood Preservation. Document* No. IRG/WP 04-20306.

**Wong, A. H. H., Kim, Y. S., Singh, A. P. and Ling, W. C. (2005).** Natural Durability of Tropical Species with Emphasis on Malaysian Hardwoods-Variation and Prospects. *International Research Group on Wood Protection. Document* No. IRG/WP 05-10568.

**Zabel, R. A. and Morrell, J. J. (1992).** Wood microbiology; decay and its prevention. San Diego:Academic Press Inc. 476 pp.

**Zbonak, A., Bush, T. and Grzeskowiak, V. (2007).** Comparison of tree growth, wood density and anatomical properties between coppiced trees and parent crop of six *Eucalyptus* genotypes. IUFRO-Improvement and Culture of *Eucalyptus*, Pp. 1-10.