Effect of phloem sap deposition on properties of sapwood in *Pterocarpus angolensis* (Mukwa) following bark stripping by elephants in Chobe forests reserves in northern Botswana

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ABSTRACT

An investigation was carried out to assess properties of sapwood in *Pterocarpus angolensis* following debarking by elephants in Botswana. The objective of this study was to assess the effect of phloem sap deposition on properties of *P. angolensis* wood in northern Botswana. Wood samples were obtained from bark stripped trees in the Chobe district. Ten samples were obtained for the different woods types each for assessing density, compression and modulus of elasticity (MOE) and wood colour. Wood colour was evaluated using the Munsell Color chart. Wood density was derived by dividing wood sample weight by its volume. Compression and elastic properties were determined using a Llyods intruments10 kN materials testing system according to British Standard 373 for testing small clear wood samples. Debarked stems yielded red discoloured sapwood. The discoloured sapwood yielded the highest density at 537.7±17.26 kg m^{-3} where the lowest density was recorded in the sapwood ($F=25.98$ and $P<0.05$). Compression stress was highest in phloem sap discoloured wood of 59.38±2.46 MPa, followed by the heartwood at 55.67±1.87 MPa and the lowest in sapwood at 39.66±1.61 MPa ($F=30.64$ and $P<0.05$). Modulus of elasticity showed no significant differences in between samples obtained from the different parts. The discoloured sapwood however yielded the higher MOE values. Overall, the wood with bark stripped by elephants and discolouration showed superior properties. It is therefore recommended that phloem sap discoloured wood be used for structural timber.

Key words: Botswana, colour, compression stress, density, and modulus of elasticity

INTRODUCTION

Perocarpus angolensis belongs to the family Leguminosae. It is a medium size tree growing up to the height of 10 – 12 metres or 15 – 20 metres in better sites (Coates-Palgrave, 1992). Wood of *P. angolensis* tree is used for household and office furniture and household artifacts (Lumbile *et al.*, 2007). The tree produces timber of attractive appearances. Timber of this tree is used for making boats, canoes, canoe paddles and curios. Wood used for this purposes has to posses good mechanical properties. Previous publications showed that *P. angolensis* wood possess medium density of 590 kg m^{-3}, modulus of elasticity of 8, 412 M mm^{-2} and modulus of rupture M mm^{-2} (Ali *et al.*, 2008).

P. angolensis trees in the Chobe forest reserves have been affected by elephants (Ben-shir, 1996, Rampart *et al.*, 2009). Elephants peel bark of *P. angolensis* which exposes the tree to factors such as fires, insects and diseases. Following the peeling of the bark or damage on the bark, red phloem sap is deposited into the sapwood resulting in layer of red wood (Riet *et al.*, 1998). The phloem sap is reported to contain lactic acid, phosphoric acid, glycerol, succinate, saline and other compounds (Riet *at al.*, 1998). Production of phloem sap has been reported in other trees such as red alder

(Kreber, 1994). Discolouration due to this biochemical deposition in the sapwood is similar to the effects of extradictives deposited in the heartwood (Nilsson *et al.*, 2002). The discolouration of wood due to deposition of phloem sap is reported to improve properties of wood (Larsen, 2004). Literature is however scanty on the effect of phloem sap on properties of wood shortly after stripping in *P. angolensis* wood and the possible effect on mechanical properties and use for timber. The objective of this study was to assess the effect of phloem sap deposition on mechanical properties of wood in *Pterocarpus angolensis* following debarking by elephants in northern Botswana.

MATERIALS AND METHODS

Collection and preparation of wood samples

Ten *P. angolenses* wood samples were collected in the Chobe district at the site (S18° 26'.38, E25° 35'.32) in the northern part of Botswana in 2008 to evaluate colour, density, compression stress and elasticity in phloem discoloured wood and its suitability for structural purposes. Bark stripping by elephants occurred at random within the tree bole. Therefore discoloured sapwood was sampled at random at the tree base, at 1.3 metres and approximates 2.6 metres above ground. Samples were collected from the phloem stained sapwood, heartwood and from non-stained sapwood (control).

Wood samples were air dried and then reduce to sub-samples of approximately 20 by 20 mm in dimensions. These were further air dried and later cut and planed to 9 x 9 mm and cut to a length of 140 mm. The samples were further air dried to a constant weight. Moisture content was evaluated using the oven-dry method and yielded an average moisture content of 14.3% on tested samples.

Colour change

A Munsell Soil Colour chart was used to evaluate colour in the different types of wood (Munsell Soil Color Charts, 1992). A photographic image was obtained to illustrate the variations in colour between sapwood, the heartwood and discoloured phloem sap stained wood.

Air-dry density

Density was calculated using the height and diameters of the samples measuring approximately 30 x 9 x 9 mm. The formula 1 was used to calculate the density of wood. Weight was obtained using a Toppan balance AFP 2100 L scale with an accuracy of 0.01 grams.

$$\rho = \frac{m}{v} \qquad (1)$$

Where ρ - density in kg m^{-3}
m – mass in kg
v – volume in m^3.

Modulus of elasticity (E)

Ten sample pieces of 9 x 9 mm and 140 mm length, the recommended span to depth ratio, were tested for elasticity at 6 mm min^{-1} (British standard 373), in the sapwood, heartwood and discoloured wood. Tests were carried out using a Lloyds instrument 10 kN material testing system operated using a Nxygen plus software. Loading was applied on the longitudinal side to avoid the influence of growth rings in the sample. Samples were pushed till they reach the point of failure. The formula 2 was used to calculate elastic properties (Desch and Dinwoodie, 1996).

$$E = \frac{P'L^3}{4\Delta' bd^3} \qquad (2)$$

Where E – the modulus of elasticity, N mm^{-2}.
P' – the load in N, at the limit of proportionality.
L – is the span in mm.
Δ' – the deflection in mm at the limit of proportionality
b – the width in mm
d – the depth in mm.

Compression stress

Compression stress test was carried out

using Lloyds material testing system on ten samples measuring approximately 9 x 9 x 30 mm. Pressure was applied at the rate of 6 mm min^{-1}. The force was applied on the longitudinal side of the sample parallel to the grain of the samples and the maximum load was calculated and obtained as an output from the computer.

Data analysis

Density, compression and modulus of elasticity values were analysed using ANOVA to test their differences between the phloem stained sapwood, the sapwood and the heartwood in Minitab release 13 (Minitab Inc. 2000)

RESULTS AND DISCUSSION

Colour change in wood

Sapwood below the wounded areas were stained with red phloem sap to depth of less than 3 cm. Non stained sapwood was light brown in colour with hue 10YR (8/3) and phloem discoloured sapwood was red colour with hue 10R (4/8) (Munsell Soil Colour Chart 1992) (Figure 1). Such deposition may have similar effects as extractive deposits occurring when sapwood transforms into heartwood (Desch and Dinwoodie, 1996). Taylor and Cooper (2002) reported change in wood properties due to change in extractive concentrations in the sapwood due to girdling of tree stems.

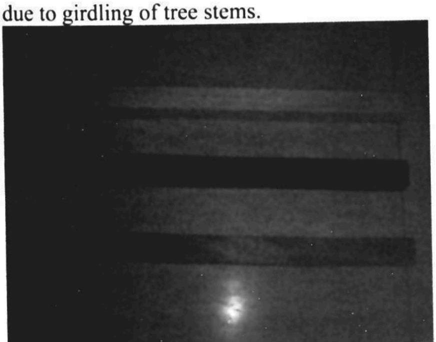

Figure 1. *Pterocarpus angolensis* wood showing sapwood (top), phloem stained wood (middle) and heartwood (bottom)

Density

The highest density was recorded in the discoloured wood at 537.7 ± 17.26 kg m^{-3} and 511.1 ± 5.82 kg m^{-3} in heartwood. The lowest density was observed in the sapwood at 405 ± 12.11 kg m^{-3} (Figure 2). There were significant differences in density between the different wood types from *P. angolensis* (F, 30.64 $P < 0.05$). Ali *et al.*, (2008) reported density values ranging between 480.6 and 784.9 kg m^{-3} and these are similar to those observed in this study. The increase in density may be attributed to deposition of extractives in the pore spaces within the wood (Taylor and Cooper, 2002).

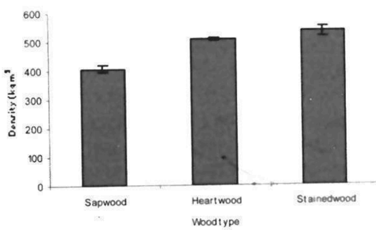

Figure 2. Density of sapwood, heartwood and stained wood in *Pterocarpus angolensis*.

Compression stress

There were significant differences in compression stress between the different types of wood (F, 25.98 and $P < 0.05$). Both the sap stained wood and the heartwood yielded the high strength properties at 59.38 ± 2.45 and 55.67±1.87 MPa respectively. The lowest measurements were recorded in sapwood at 39.66±1.61 MPa (Figure 3). Increase in wood density in the discoloured wood due to deposition of phloem sap resulted in increased compression stress properties. The results are in agreement with Desch and Dinwoodie (1996) that extractives added to wood leads to changes in density and stress values of wood.

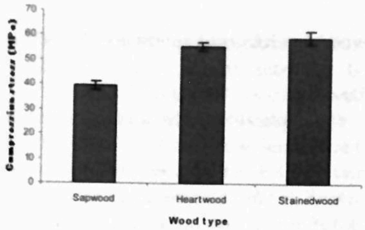

Figure 3: Compression strain in different *Pterocarpus angolensis* wood types.

Modulus of Elasticity

Modulus of elasticity of 10468.8±554.58, 12362.2±1057.78 and 14447.6±1714.96 MPa were measured in the sapwood, heartwood and discoloured wood (Figure 4). Phloem sap discoloured wood yielded the highest results but there were no significant differences in modulus of elasticity (F, 1.49 and $p < 0.05$). Ali *et al.* (2008) reported lower values of 8, 274 MPa on wood of *P. angolensis* endemic to Mozambique. Results reported in this study are not in agreement with reports by Welch and Scott (2008) who measured strength properties of wood in Sitka spruce wounded by red deer (*Cervus elaphus* L.), which resulted in reduced strength properties.

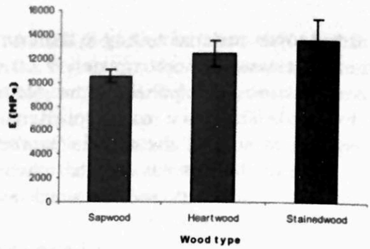

Figure 4. Modulus of elasticity in different types of wood in *P. angolensis* wood

CONCLUSION

P. angolensis trees in northern Botswana are damaged by elephants where majority of the trees have bark stripped. This results in phloem sap deposited in the sapwood resulting in red discoloured wood. The deposition resulted in improved compression properties of wood. There were no differences in modulus of elasticity in between the discoloured sapwood, sapwood and the heartwood. Therefore stems with stripped bark and possessing phloem sap discoloured wood can potentially be harvested and used for structural timber.

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