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Soil property effects on the natural durability, extractive content and colour of teak (*Tectona grandis* L.f) wood in Togo

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Abstract

Togolese teak is highly resistant to pathogen attack, but natural durability and wood colour vary according to plantation sites and geographical zones. Therefore, further information concerning the influence of environmental parameters and their effects on teak wood quality is necessary and it could be possible to improve these characteristics through tree breeding and silviculture programs in Togo. In order to examine the influence of soil properties on teak wood characteristics, 321 wood samples issued from 20 trees were exposed to two fungi: *Antrodia sp.*, and *Coriolus versicolor*. Depending on type of soil in which they grew, trees had been randomly selected in two different sites in the same climatic area in Togo. The colour parameters of each sample were measured using the CIELAB system and total extractive content was determined using the Accelerated Solvent Extraction (ASE) procedure. Results showed a significantly lower total extractive content (11.1%) for trees that grew on hydromorphic tropical ferruginous (HTF) soil than trees from drained ferruginous soil (12.8%). Samples from HTF soil were lighter and the redness a* and yellow-blueness b* were significantly higher. Independently of soil quality, all the trees were highly durable regarding decay by *C. versicolor*. With *Antrodia sp.*, 90 % of the trees from both sites were highly durable and only 10% were durable. However, samples from HTF soil were less durable with regard to the two fungi.

Introduction

Teak (*Tectona grandis* L.f) is historically well known for highly durable wood, due largely to the presence of extracts in the heartwood, e.g. anthraquinones and tectoquinones (Pahup et al. 1989; Yamamoto et al. 1998; Simatupang and Yamamoto 1999 Haluk et al. 2001). Due to this natural durability, teak is often used for outdoor purposes, for example boat decking, bridge building and garden furniture as well as for traditional indoor uses such as flooring and furnishings. Such uses require a highly stable wood with regard to physical properties as well as an aesthetically pleasing colour and adequate resistance to pathogens. Because of the high demand, teak plantations are increasing and becoming an important timber source in tropical countries especially in West-Africa, Asia and South Africa. Over 14,000 ha of teak plantation exist in Togo (Tengué 1995). Although wood density and strength properties of Togolese teak wood are not significantly different compared to those from natural forests (Kokutse et al. 2004), natural durability and wood colour shows high variability within and between stands due to tree age (Kokutse et al. 2006), extractive content (Gierlinger, 2003) and to various ecological conditions (e.g. geomorphology, topographic, soil, rainfall) (Kokutse et al. 2006, Adjonou et al. 2009). Due to the variability in environmental conditions, the reputation of teak wood for natural durability is often questioned when trees from plantations are supplied for outdoor uses (Bhat et al. 2004). Simatupang and Yamamoto (2000) have reported that teakwood from a wet plantation site is less resistant to fungi than teak from a dry site. Bhat et al. (2005) studied home garden teak and found that wood samples from a wet site with pale coloured wood and lower extractive content were more susceptible to fungi. The main objective of the present study was to examine the influence of soil properties on natural durability, wood colour and extractive content in teak wood from Togolese plantations.

Material and methods

Site description

The study sites, namely Tchorogo (established in 1972) and Oyou (established in 1966), were situated in the same area of the central part of Togo (1°00'E, 8°21'N), West Africa. This central area of Togo is covered by Guinean woody savannas and is situated at an altitude of 200-400 m. In this area, two major seasons exist annually, one long rainy season lasting 6–8 months followed by a long dry season. The mean annual precipitation is 1400-1600 mm and temperatures vary from 25°C to 40°C (Ern, 1979). The Oyou site is located on tropical ferruginous soils with a pseudogley layer and hydromorphic surface horizons. This kind of soil is periodically flooded in the rainy season. The substratum is made up of basic rocks, micashists and quartzites of Togo Mountains. The texture is muddy, sandy and clayey. Tchorogo site is located on a tropical ferruginous and well drained soil with a sandy-fine gravel texture. The description of the study sites is presented in Table 1.

Sample preparation

Twenty trees of 34 and 40 years of age, respectively were harvested in 2006 from Tchorogo and Oyou. A 550 cm long log was cut from each tree at breast height which was further sawn into boards in the radial direction (15 x 20 mm). Boards were sawn radially (550 mm in the longitudinal axis and 50 mm in the tangential axis) at breast height. Beams of heartwood (20 x 15 x 550 mm) were cut from each board and finally, 10 (20 x 15 x 50 mm in radial and tangential longitudinal directions) wood samples were cut per beam. The samples were conditioned at 20°C and 65 % RH. The location of each wood sample, according to its position in the stem, was recorded by measuring its cambial age and the distance from the pith. The samples were classed into three groups depending on cambial age of the samples: inner (5-10 years), intermediate (11-20 years) and outer heartwood (21-30 years). A total of 321 and 343 samples were used to evaluate durability and wood colour respectively. The remaining samples were then ground into wood meal for total extractive content measurement.

Extractive content

The extractive content was determined gravimetrically. The ground wood samples were extracted using a sequence of solvents: hexane, acetone and methanol 80% (technical grade). Extractions were performed with an ASE-200 apparatus (Dionex). 2.5 g of wood meal was weighed and the dry mass calculated after the determination of humidity on parallel samples. Extraction conditions were: temperature (80°C), pressure (100 bars), static time (5 min), static cycles (3), flush (100 %) and purge (90 s). Analyses were carried with three replicas. When the extraction was completed, the wood meal was removed from the cells and dried in an oven at 103°C until constant mass. The extractive content was determined using the equation: Extraction percentage = [dry mass before the extraction – dry mass after extraction] x100 / dry mass before the extraction.

Wood colour measurements

Colour measurements were performed along the tangential-radial side of the wood samples. The percentage of reflectance data was collected at 10 nm intervals over the visible spectrum (from 400 to 700 nm) using a portable spectrophotometer (Microflash Datacolor 200d). The reflectance readings were converted into L* a*b* values (CIELAB system), where L* describes the lightness (100 = white) or darkness (0 = black) of a colour, a*represents the X axis which is redness [red (+) to green (−)] and b* represents the Y axis, yellow-blueness [yellow (+) to blue (−)]. Illuminant A (representing incandescent light), 10° standard observer with 6 mm apertures chosen and specular reflection setting was excluded.

Table 1. Site characteristics. A: altitude (m). D: density (tree.ha-1). MD: mean diameter (cm) at height 1.3 m. MH: Mean height (m).

Location	A	Year of plantation	Soil type	D	MD	MH
Tchorogo	419	1972	Ferruginous soil, sandy-silt structure	2600	21.8 ± 4.4	16.1 ± 1.7
Oyou	420	1966	Ferruginous soil clay, muddy sandy-structure	2600	23.4 ± 3.1	13.6 ± 0.6

Decay measurements

After colour measurements, the wood samples were used to determine natural durability. The test was performed according to the European standards NF-EN 350-1 (AFNOR 1994) and NF-EN113 (AFNOR 1996) guidelines. Two species of basidiomycetes fungi were used; namely *Coriolus versicolor* (strain CTBA 863 A), a white rot and *Antrodia sp.* (strain CTFT 57 A), a brown rot. One hundred sixty one samples were used to test the natural durability against *Antrodia sp.* And 160 samples for *Coriolus versicolor*. Reference samples of beech and pine were used as controls to test the virulence of the fungi. The sterilised wood samples from the outer, intermediate and inner heartwood were placed over 16 weeks in glass jars previously inoculated with a mycelia suspension of fungal mycelia (75 % RH and 27°C). At the end of the test, the mycelium was removed from the wood sample prior to drying at 103°C for 48 h. The mass loss was calculated and the durability rating against wood-destroying Basidiomycetes fungi based on the EN 350-1 standard (AFNOR 1994) was determined.

Results

The total extractive content ranged from 7.8 ± 0.1 to 14.5 % ± 1.1 for the tree samples from the Oyou site and from 11.0 ± 0.7 to 15.3 % ± 1.9 for the trees of the Tchorogo site. For both sites, the variability between trees was high within the stands and explained 17% of the total extractive content variability. When taking into account the position in the tree (inner, intermediate or outer heartwood), the radial position of the wood sample explained only 3 % of the variation of the total extractive content in the Oyou site, however it explained 10 % of the variation in Tchorogo site. The variance analysis showed significantly higher extractive content for trees from drained ferruginous soil (Tchorogo site) than from the hydromorphic tropical ferruginous (HTF) soil (Oyou site) ($F_{1,19} = 5.88$, $P = 0.02$).

The mean mass loss in the beech and pine control samples were 54.9 % for *Antrodia sp.* and 38.0 % for *C. versicolor*. These values were higher than the minimal values given in the standards indicating that the fungi were very virulent under tropical conditions and validates the durability of the test results. All the trees were highly durable with regard to *C. versicolor*. The mass losses varied from 0.4 to 3.7 % when considering the tree. For individual samples, the mean mass loss varied from 0.0 to 8.4 % in the Oyou site and from 0.0 to 5.0 % in the Tchorogo site and only four samples were durable. The radial position of the sample in the tree was found to have an influence on the degree of attack of *C. versicolor* in Tchorogo ($F_{1,65} = 10.70$, $P = 0.002$) and in Oyou sites ($F_{1,58} = 10.15$, $P = 0.002$). In both cases the outer heartwood was less resistant to *C. versicolor* than the inner heartwood. However the intermediate heartwood was not significantly different from inner and outer heartwood. A significant difference was observed in the degree of decay of the teak wood, depending on the type of soil on which the trees grew, with regards to *C. versicolor*. Trees from hydromorphic tropical ferruginous (HTF) soil (i.e. the Oyou site) showed significantly higher mass losses ($F1,19 = 6.96$, $P = 0.02$). The mass losses obtained with *Antrodia sp.* were higher than those obtained with *C. versicolor* and ranged from 0.3 to 13.9 % in the Oyou samples and from 0.2 to 8.1 % in Tchorogo samples (Table 2). Out of 161 teak wood samples exposed to *Antrodia sp.*, 92 % were rated as very durable, 4 % were durable and 4 % were moderately durable for the Tchorogo site. However in the Oyou site, 89 % of samples were very durable, 4 % were durable and 7 % were moderately durable. The influence of the radial position on wood durability was not significant with the samples exposed to *Antrodia sp.*. Trees from HTF soil showed higher mass losses than trees from drained ferruginous soil even though the difference between the sites was not statistically significant.

The lightness L* parameter of wood samples ranged from 54.0 ± 0.4 in Tchorogo site to 54.8 ± 0.2 in the Oyou site. No significant differences were observed in the samples from Tchogoro and Oyou regarding their light colour. When considering the redness a* and the yellow-blueness b* of the wood samples, Oyou samples differed from Tchorogo samples (Fig. 1). Samples from HTF soil (Oyou site) were significantly redder ($F1,342 = 8.54$, $P = 0.004$) and their yellow-blueness b* value was significantly higher ($F1,342 = 20.08$, $P<0.001$) than those from the drained ferruginous soil (Tchorogo site). The influence of the radial position on wood colour parameters was not significant in either site.

Fig. 1. Mean colour parameters - Redness a* and Yellow-blueness b* were significantly higher in teak trees from hydromorphic tropical ferruginous soil (white bars) than teak trees from drained ferruginous soil (black bars).

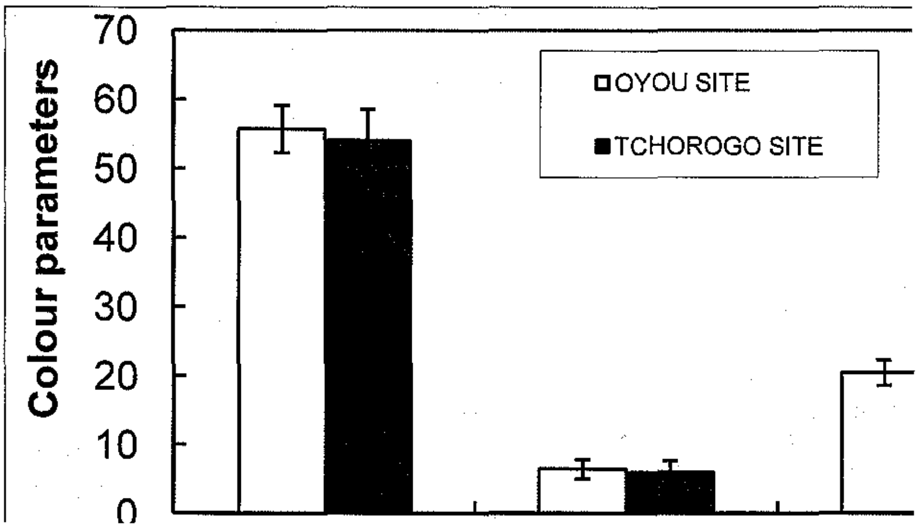

Table 2. Wood characteristics (Range, coefficient of variation CV%, and number of samples n)

	Oyou site				**Tchorogo site**			
	n	Min	Max	CV	n	Min	Max	CV
L*	203	44.0	63.5	15.9	140	45.8	64.8	11.9
a*	203	3.1	9.9	4.6	140	1.9	10.49	3.4
b*	203	16.0	26.0	11.0	140	10.5	24.2	8.7
Antrodia sp.								

(mass loss %)	86	0.33	13.9	115	75	0.2	8.1	77
Coriolus versicolor (mass loss%)	85	0.0	8.4	125	66	00	5.0	131
Total extractive content (%)	57	7.18	15.1	5.7	60	9.4	15.3	6.4

DISCUSSION AND CONCLUSIONS

This study confirmed the high decay resistance of plantation teak wood. All the wood samples exposed to *C. versicolor* were highly durable (only four samples were durable) and out of the 161 exposed to *Antrodia sp.*, only 7 % were moderately durable. *Antrodia sp.*, a brown rot fungus isolated from tropical regions caused the most damage to wood samples, with up to 0-14 % dry mass loss. The influence of the radial position on wood durability was significant in samples exposed to *C. Versicolor*. A significant difference was observed in the degree of decay on teak wood, according to the type of soil on which the trees grew. With regard to *C. versicolor* and *Antrodia* sp., the results showed that trees from hydromorphic tropical ferruginous soil were less durable compared to trees from drained soil. This loss of durability is reflected by the lower extractive content in trees grown on hydromorphic tropical soil. Many authors have found a direct relationship between wood durability and extractive content (e.g. Nelson and Heather 1972; Modesale et al. 1996; Haupt et al. 2003). Haupt et al. (2003) also showed that extractive content increased with tree age. In our study, trees from the Oyou site were older (40 years) than trees from the Tchorogo site (34 years old). Therefore, it can be expected that teak from Oyou site contained more extractives. However the results showed a significantly higher total extractive content in trees from the Tchorogo site. A genetic diversity analysis carried out on the teak plantations from Togo has shown that the genetic variability between the populations is very weak (Logossa, 2006). Our results therefore imply that the higher decay resistance and extractive contents of teak wood from well drained soil was mainly due to the environmental factors, especially the soil conditions rather than genetic diversity.

Concerning the colour of the wood which is one of the most appreciated criteria by end-users, results showed that samples from HTF soil (Oyou site) were significantly redder and their yellow-blueness b* value was significantly higher than those from drained ferruginous soil (Tchorogo site). The influence of site conditions on wood colour is still a controversial topic. According to Klumpers (1994), the wood is darker when the water content in the soil is high (wet site). Simatupang and Yamamoto (2000) have observed that teak trees from a wet site in Indonesia produced darker wood and were more susceptible to fungal decay. However, Bhat et al. (2005) studied home garden teak and found that a dry site produced darker coloured wood than a wet site. In the Ivory Coast, with similar ecological characteristics as Togo, Durand (1984) found that when the climate is humid and the soil is without hydromorphic traces, teak wood shows a greater brightness. In our study, teak from the hydromorphic Oyou and well drained Tchorogo sites, respectively, had similar lightness. However the redness and the yellow-blueness were different. Other studies on Togolese teak have showed that the plantations whose woods are redder are generally located on tropical ferruginous and ferrallitic soils which contain an important amount of clay (Adjonou et al. 2009). The existence of clay enables retention of water for a long time in the soil, leading to hydromorphy. This type of colouration is the most desirable for the end-users of teak wood, especially in Togo and in West-Africa. However, the plantations grown on hydromorphic soils are less durable, as shown by the present work. Further studies should be carried out on the mineral composition of the soils and their influence on wood colour. If the influence of the soil on wood colour and the extractive content as well as their interactions were better quantified, it may be possible to improve these characteristics through tree breeding and silviculture programs in Togolese teak plantations.

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