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ORIGINAL ARTICLE

Relationship between total extractive content and durability of three tropical hardwoods exposed to *Coriolus versicolor* (Linnaeus) Quelet

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Abstract The relationship between total extractive content and durability of *Nauclea diderrichii* (de Wild.) Merr. and *Corynanthe pachyceras* Welw. from the Rubiaceae and *Nesogodornia papaverifera* (A. Chev.) R. Capuron. from the Tiliaceae has been investigated. The extractive content of each wood was measured and blocks were exposed to *Coriolus versicolor* (Linnaeus) Quelet for 8 weeks. An inverse relationship was found between extractive content and weight loss. From the results, it was found that *N. diderrichii* (extractive content = 13.29–13.96%; weight loss = 1.02–1.91%) is the most durable species, followed by *C. pachyceras* heartwood (extractive content = 12.56–14.19%; weight loss = 5.80–8.21%) and *N. papaverifera* (extractive content = 10.18–10.65%; weight loss = 8.22–9.01%). For these species, total extractive content is consistently related to the durability of the hardwoods.

Keywords *Corynanthe pachyceras* · Durability classes · Hot-water extraction · Incubation · *Nauclea diderrichii* · *Nesogodornia papaverifera*

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Introduction

Each wood species has unique physico-mechanical and biochemical properties which influence its strength, durability, drying and treatability with preservatives. Natural durability of timber is influenced by its extractive and lignin types and contents (Zabel and Morrell 1992; Highley 1982; Faix et al., 1985 cited in Syafii et al. 1988a, b), density (Takahashi and Kishima 1973; Wong et al. 1983, 1984), anatomy, which influences permeability (Wilcox 1965; 1973) and pH (Yamamoto and Hong 1994). However, while those of temperate species are well-documented, those that influence the durability of tropical hardwoods have received very little attention. Owing to their excellent natural durability and wood properties, many commercial timbers of the tropics have been over-exploited and the use of secondary wood species is currently advocated for sustainable production of timber products. This requires an understanding of the properties of these substitute species if they are to be accepted by end-users.

In assessing the importance of a range of factors that confer durability on Malaysian hardwoods, Yamamoto and Hong (1994) found extractives to be the most important for all the species studied. These secondary metabolites are a diverse group of organic compounds located in parenchyma cells, cell lumina, wall interstices and intercellular cavities mainly in heartwood. They may be classified into several groups (Rudman 1963; Hillis 1962, 1987; Rao 1982; Fengel and Wegener 1989; Goldstein 1991). These include terpenes and terpenoids (constituents of resin; terpenoid alcohols and ketones), tropolones (e.g. thujaplicins), phenols and polyphenols (e.g. leucoanthocyanins, stilbenes, alkaloids, flavonenes, quinones, lignans, and tannins) as well as primary metabolites and storage compounds [e.g. glycosides, low molecular weight sugars, starch and aliphatic compounds such as fatty acids, sterols and waxes] (Haack and Slansky Jr 1987). Extractive type and distribution vary with species, position in the stem or age of timber (Rudman 1963; Rao 1982; Anon 1985; Goldstein 1991; Schniewind and Brendt 1991; Zabel and Morrell 1992; Suttie and Orsler 1996; Ridout 2000), with heartwood extractive content lower in younger trees (Williams et al. 2000). A number of these extractives are often biocidal and could also be largely responsible for the colour of wood (Zavarin and Cool 1991; Zabel and Morrell 1992). They can be effective against invertebrates including termites (e.g. *Reticulitermes flavipes* (Kollar)) (Wolcott 1951, 1953, 1955, 1958; Sandermann and Dietrichs 1957 all cited in Becker 1971; Rao 1982; Hillis 1987; Goldstein 1991). Anon (1998) has also described the water-repellent properties of extractives, which also enhance the durability of timbers. In addition to being biocides, some extractives act as repellents against invertebrates (Suttie and Orsler 1996). The low molecular weight sugars, however, are a source of nutrients for wood bio-degraders (Haack and Slansky 1987). The normal procedure for testing the effectiveness of extractives in conferring durability involves exposing extracted and control wood samples to degrading organisms and comparing weight loss over time (Rao 1982; Anon 1985; Zabel and Morrell 1992; Suttie and Orsler 1996). As there is renewed interest in the use of natural compounds as wood preservatives with the aim of reducing the use of environmentally undesirable conventional types (Zabel and Morrell 1992; Suttie and Orsler 1996), there is the need to evaluate the effect of heartwood extractive content (besides extractive type) on the durability of timbers, especially tropical species. Thus, this study was carried out to determine the influence of the total extractive content on the durability of three tropical hardwoods from two families, Rubiaceae (e.g. *Nauclea diderrichii* (de Wild.) Merr. and *Corynanthe pachyceras* Welw.) and Tiliaceae (e.g. *Nesogodornia papaverifera* (A. Chev.) R. Capuron.).

Materials and methods

Determination of total extractive content

Ten blocks ($15 \times 10 \times 10\ mm^3$) were taken from the inner and outer heartwoods ((IHW and OHW, 3–8 and 19–23 growth rings from the pith respectively) from diameter at breast height of three tropical hardwoods. Samples were taken from *C. pachyceras* growing on three growth sites (Offinso, Nkawie and Bekwai Forest Districts of Ghana) and two traditional species, *N. diderrichii* and *N. papaverifera* from Nkawie. The middle sapwood (MSW) of *C. pachyceras* (growth rings 33–37), previously found durable (Antwi-Boasiako 2004), was also collected for comparison. The blocks were individually ground using a hammer mill (Fritsch Pulverisette) to pass a 40-mesh screen but to be retained on a 60-mesh screen (i.e. particle size 250–425 μm). They were conditioned (at 20°C, 65% RH) and dried to 12–14% mc. Each powdered sample (4 g) was extracted with ethanol–toluene (1:2) for 8 h and dried (to 12–14% mc) followed by a 2-h hot-water extraction (ASTM: D1105-96 [Anon 1996]). All extracted samples were oven-dried (at 105°C) and re-weighed. There were three trials for each stem position. The total extractive content was determined as:

$$Total\ extractive\ content\ (\%) = \left(\frac{Initial\ oven-dry\ weight - Final\ oven-dry\ weight}{Initial\ oven-dry\ weight}\right) \times 100$$

Incubation of stakes and relationship between total extractive content and weight loss (i.e. durability)

Ten replicate blocks ($15 \times 10 \times 10\ mm^3$) from each of the radial stem positions of each timber were exposed to *Coriolus versicolor* (Linnaeus) Quelet in Beason jars containing 150 ml of 3% malt extract agar and incubated on a mesh at 22 ± 1°C and 70 ± 5% RH for 8 weeks (EN 113 [Anon 1982]). *Fagus sylvatica* L. (beech) was employed as the reference species. Following incubation, oven-dried weights of the blocks (at 105 ± 2°C) were taken. The percentage weight losses for the replicates were determined based on corrected oven-dry weights of the blocks as follows:

$$\%\ weight\ loss = \left(\frac{Initial\ corrected\ oven-dry\ weight - Final\ oven-dry\ weight}{Initial\ corrected\ oven-dry\ weight}\right) \times 100$$

The mean weight losses of blocks from each radial position of the individual timbers were compared. Durability classes were assigned to blocks from each stem position by comparing their weight losses against those of *F. sylvatica* based on the methods described in EN 350-1 (Anon 1994). The influence of total extractive content on durability of the different stem positions of each timber was investigated by correlating the percentage weight losses (i.e. durability) of the control blocks after exposure to *C. versicolor* against the total extractive content from their corresponding blocks.

Results and discussion

The total extractive contents removed from the different radial stem positions of the three timber species show that the greatest amount is present in IHW of *C. pachyceras* from Bekwai and OHW of *N. diderrichii* (Table 1). However, the difference between the two is not significant ($P < 0.05$). This is followed by IHW of *N. diderrichii*, and IHWs and OHWs of *C. pachyceras*. The two heartwood types of *N. papaverifera* (IHW and OHW) and MSW of *C. pachyceras* from Bekwai contained the smallest amount of extractives. From their mean weight losses on exposure to *C. versicolor* and their *x*-values based on EN 113 (Anon 1982), EN durability classification classifies blocks from the radial positions of *N. diderrichii* as very durable, OHW from *N. papaverifera* as durable to moderately durable and its IHW as moderately to slightly durable. MSW of *C. pachyceras* is classified as durable to moderately durable, while all other radial positions are durable (Table 1).

Relationship between total extractive content and weight loss (i.e. durability)

For all the wood species investigated, the relationship between their total extractive content and weight losses shows that the greater the total extractive content of the stakes from the various radial stem positions, the smaller their weight losses (i.e., greater durability) following exposure to *C. versicolor*. This relationship is strongest for *C. pachyceras* ($R^2 = 0.67$) then *N. diderrichii* ($R^2 = 0.58$) and weakest for *N. papaverifera* ($R^2 = 0.48$) (Fig. 1).

The proportion of extractives in woody species ranges from less than 1 to 30% (Anon 2008). The three timbers examined in this study all lie within this range and are typical of the few tropical hardwoods whose total extractives have been determined. From ethanol:benzene (1:2) and hot-water extractions of some selected tropical hardwoods, Fengel and Wegener (1989) recorded extractive concentrations of 16.9% for odum (*Milicia excelsa* (Welw.) C. C. Berg), 10.1% for mansonia (*Mansonia altissima* A. Chev.), 9.6% for afrormosia (*Afrormosia elata* Harms. (= *Pericopsis elata* (Harms) van Meeuwen) and 4.2% for wawa (*Triplochiton scleroxylon* K. Schum.). They also recorded 1.4–13% for teak (*Tectona grandis* L.). Using methanol extraction, the extractive content of the heartwood of *N. diderrichii* has been found to be 7% (Suttie and Orsler 1996). However, this is much lower than that recorded in the present study for both its inner and outer heartwoods (i.e. 13.29 and 13.96%, respectively). This difference could be attributed to the mode of extraction since in the work currently reported, ethanol–toluene (1:2) extraction followed by hot-water was used. According to Suttie and Orsler (1996), methanol is able to remove cell wall materials such as tannins, whereas the more polar hot water also removes the materials more intimately associated with the cell wall such as phenolics.

It is well established that total extractive content varies with tree species (Hillis 1987; Fengel and Wegener 1989). The work described here has revealed that the extractive contents for the members of the Rubiaceae (i.e. *N. diderrichii* and *C. pachyceras*) were greater than those for the member of the Tiliaceae (*N. papaverifera*). It seems probable that this contributes to the greater durability of the members of the Rubiaceae examined compared with that of *N. papaverifera*. Hillis (1987), however, observed that extractive content can vary between trees of the same species. This is apparent for

Table 1 Total extractive contents and durability classes of stakes from three tropical hardwoods on exposure to *C. versicolor*

Wood species	Growth site	Position in stem	Mean total extractive content (%)[A]	Mean weight loss (%)	*x*	Durability class and EN classification[B]
N. diderrichii	Nkawie	OHW	13.96 ± 0.71[d]	1.91 ± 0.16	0.04	1
		IHW	13.29 ± 0.34[a]	1.02 ± 0.10	0.07	1
N. papaverifera	Nkawie	OHW	10.18 ± 0.19[a]	8.22 ± 0.71	0.22	2–3
		IHW	10.65 ± 0.63[a]	9.01 ± 0.70	0.27	3–4
C. pachyceras	Nkawie	OHW	12.88 ± 0.23[c]	8.11 ± 0.41	0.24	2
		IHW	11.03 ± 0.91[bc]	9.00 ± 0.46	0.26	2
	Offinso	OHW	12.95 ± 0.19[c]	8.20 ± 0.74	0.24	2
		IHW	12.78 ± 0.28[c]	8.21 ± 0.51	0.24	2
	Bekwai	OHW	12.56 ± 0.45[c]	5.80 ± 0.29	0.17	2
		IHW	14.19 ± 0.35[d]	7.50 ± 0.31	0.20	2
		MSW	9.68 ± 0.50[a]	9.84 ± 0.69	0.27	2–3

OHW, IHW and MSW = outer heartwood, inner heartwood and middle sapwood respectively

[A] Means with same letter = no significant difference ($p < 0.05$) in extractive contents (%)

*x*Mean weight loss of test sample/Mean weight loss of reference (i.e. beech)

[B] EN classification for basidiomycetes: *1* very durable, *2* durable, *3* moderately durable, *4* slightly durable, *5* non-durable (EN 113, [Anon 1982])

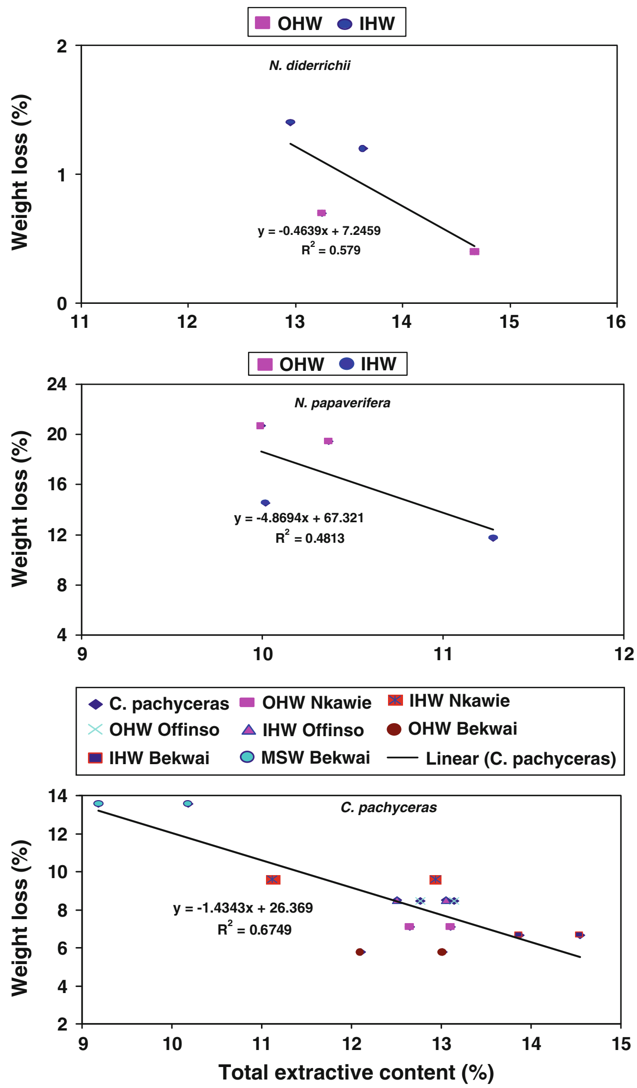

Fig. 1 Relationship between total extractive contents and weight losses (i.e. durabilities) of three tropical hardwoods on exposure to *C. versicolor*

the three stems of *C. pachyceras* taken from three different growth sites. For instance, the extractive content was greater for IHW from Bekwai than from Nkawie and Offinso. Others have also reported the existence of within-stem variation in extractive content. Hillis (1987) recorded lower extractive contents for OHW than IHW in several timber species. This work has similarly revealed clear relationships between extractive content and radial position within the stem. Thus, the total extractive content of *C. pachyceras* middle sapwood (MSW) examined from Bekwai is lower than those of OHW and IHW. A significant difference ($P < 0.05$) in extractive content exists for these three radial stem regions. A similar relationship was found for *N. diderrichii*. The only inconsistency occurred with *N. papaverifera* whose OHW and IHW extractive contents are not significantly different ($P < 0.05$).

Syafii et al. (1987) found positive correlation between wood extractive content and percentage weight loss (i.e. natural durability), and concluded that wood durability primarily depends on the amount of extractives present. In our work, a good correlation between total extractive content and decay resistance was found after exposure of the samples to *C. versicolor*. The correlation was strongest for *C. pachyceras* ($R^2 = 0.67$) and weakest for *N. papaverifera* ($R^2 = 0.48$). Based on EN Durability Classification, the mean weight losses of each stem position transposed into *x*-values, by comparing with those of the control (i.e. *F. sylvatica*), would grade the stem positions of *N. diderrichii* as very durable against *C. versicolor*, *N. papaverifera* as durable to moderately durable for its OHW and moderately to slightly durable for IHW and *C. pachyceras* as durable; its MSW would be classified durable to moderately durable. Thus, for *N. diderrichii* and *C. pachyceras* (the Rubiaceae), extractive content appears to contribute significantly to their durabilities compared with *N. papaverifera*, whose heartwoods generally recorded the lowest total extractive content and the greatest mean weight losses against *C. versicolor*.

This work has established that total extractive content is consistently correlated with durability of the wood species. This supports the importance of screening durable timbers for organic extracts which could be employed as natural substitutes for conventional preservatives. Moreover, as extractives have immense impact on wood properties and utilization in the wood industry, for timbers grown in wet conditions or their products exposed to wet sites (as in home gardens), their water-soluble extractives would likely leach out, which would result in their faster deterioration than those exposed to dry sites. Thus, the relative importance of total extractive content in conferring wood durability should not be overlooked.

Conclusion

Among the properties which influence durability, that of total extractive content for tropical hardwoods is not completely understood. However, it has been currently established that it has an inverse relationship with weight losses such that larger amount is always correlated with greater decay resistance of wood. For very durable timbers, the correlation is strongest as for *C. pachyceras* ($R^2 = 0.67$) and *N. diderrichii* ($R^2 = 0.58$) (the Rubiaceae). *N. papaverifera* (the Tiliaceae), with the least amount of extractives, has the weakest correlation ($R^2 = 0.48$) and is classified durable to moderately durable. Besides timber species, the occurrence of variation in extractive content in different positions of wood species and growth site has been established to influence durability. The degree of weight loss, found to be inversely related to wood extractive content, suggests that the latter can inhibit fungal deterioration of several timbers caused by *C. versicolor* or other fungi.

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