



Chemical Markers of Occupational Exposure to Teak Wood Dust

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ABSTRACT

A novel high-performance liquid chromatographic/ultraviolet method was developed to detect lapachol (LP) and deoxylapachol (DLP) in wood dust as chemical markers of teak wood (a suspected human carcinogen). The specificity of this analysis was determined by noting the absence of LP and DLP in 12 other specimens of different woods belonging to the angiosperm family. The consistency was examined by analyzing teak from three different sources, where the percentages (wt/wt) of the chemicals ranged from 0.006 to 0.261 for LP and from 0.038 to 0.497 for DLP, respectively. Although the LP and DLP components of teak varied according to source, a very high correlation coefficient ($r^2 > 0.98$ always) was found between the content of the two markers in the bulk specimens and in bulk dust derived from them. The method was then applied to teak dust collected on polyvinylchloride filters from aerosol in an exposure chamber in the range of mass loadings between 0.03 and 3.65 mg, which corresponds to a dust exposure between 0.124 and 8.703 mg m⁻³ for a sampling time of 2 h. A field test was also carried out in a small factory where teak was used. A good correlation was confirmed between LP and DLP versus the dust collected on the filter in both cases. LP and DLP can be markers to estimate the true quantities of teak dust inhaled in a workplace with mixed wood dust, provided the results are matched to the content of LP and DLP in the bulk wood. LP and DLP have also been proposed as the agents responsible for allergic reaction to teak dust. Therefore, it would be useful to evaluate the exposure to these two substances even without a relationship to teak dust exposure.

KEYWORDS: deoxylapachol; lapachol; occupational exposure; teak dust; wood dust

INTRODUCTION

Teak, *Tectona grandis*, grows naturally in Southeast Asia and is one of the most common wood species in the international market due to its ease of processing, its beautiful surface, and its natural durability as a result of its resistance to mite and fungal damage. These qualities make it useful in many areas

such as construction of houses, boats, furniture, and sculptures. Further, teak wood does not expand and contract with change in moisture content due to its low shrinkage ratio, which makes it a prized wood for boat-building. Its natural durability is due to the presence of specific substances that are formed in the transformation of the sapwood into hardwood.

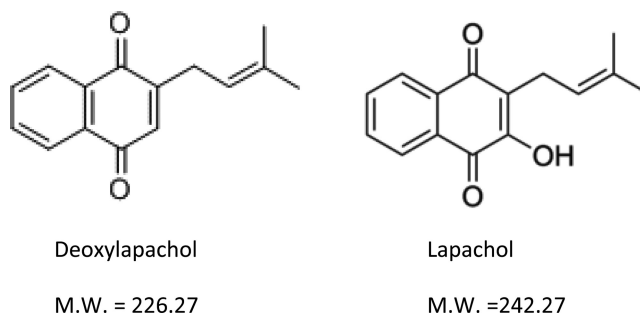
The sapwood is the younger part of the trunk tree, and it is located immediately under the bark. These substances have been identified as a mixture of naphthoquinone and anthraquinones (Singh *et al.*, 1989; Khan and Mlungwana, 1999). Naphthoquinones, and in particular lapachol (LP) and deoxylapachol (DLP), have been reported to have antimicrobial properties (Guiraud *et al.*, 1994; Gafner *et al.*, 1996; Teixeira *et al.*, 2001; Sumthong *et al.*, 2006; Bhat and Khalil, 2010).

DLP [2 - (3-methylbut-2-en-1-yl) -1,4-naphthoquinone] was identified in 1963 (Schmalle and Hausen, 1984). It is a brown viscous oil soluble in various organic solvents such as chloroform, acetonitrile, ethyl acetate, acetone, and methanol. LP was first isolated by E. Paterno in 1882 from *Tabebuia avellanae*, a tree of the Bignoniaceae family (Paterno, 1882). It is a weakly acidic, highly lipophilic yellow powder with limited solubility in water but is very soluble in alkaline solutions. The structures of DLP and LP are shown in Fig. 1.

These two chemicals could be potential chemical markers in the evaluation of occupational exposure to teak dust in workplaces. Many studies have observed an excess risk of sino-nasal cancer, particularly adenocarcinoma, among workers exposed to wood dust, and teak dust is strongly suspected to be a cause (Acheson *et al.*, 1972; Andersen *et al.*, 1977; Kleinsasser and Schroeder, 1989; Leclerc *et al.*, 1994; Demers *et al.*, 1995; IARC, 1995). The American Conference of Governmental Industrial Hygienists (ACGIH) has classified teak, together with birch, mahogany, and walnut, as suspected (and oak and beech as confirmed) human carcinogens (ACGIH, 2013). However, the mechanism by which exposure to wood dust increases the risk of cancer is not clear,

and it is possible that other wood dusts are also carcinogenic. It is normal for several types of wood to be used in any workshop, and being able to differentiate exposure to the different types of wood by the use of specific chemical markers could be very important in future studies. LP and DLP as chemical markers could, also, be useful to evaluate other adverse effects due to specific occupational exposure to teak wood dust. For example, since 1905, it has been known that teak dust can induce skin rashes (Evans, 1905). An epidemiological investigation carried out in a furniture factory in Norway, in 1960, highlighted the occurrence of allergic skin reactions to teak dust in 18.8% of workers from Southeast Asia. Allergic contact dermatitis was diagnosed in 12.5% of the workers and 6.3% were found to have latent allergy (Krogh, 1962). Subsequent studies have identified LP and DLP as the allergenic components (Schulz, 1965; Schulz and Hausen, 1975; Schultz *et al.*, 1977; Estlander *et al.*, 1999; Estlander *et al.*, 2001).

The aims of this study were to investigate the use of LP and DLP as chemical markers of occupational exposure to teak dusts, to develop a high-performance liquid chromatography–diode array detector (HPLC–DAD) method to quantify them, and to apply the method in the analysis of teak dust samples collected in an exposure chamber in order to find a correlation between the total quantity of inhalable dust collected and the amount of LP and DLP in that dust. In addition, since LP has been identified in other wood species, the composition of other hardwood species commonly used in boat-building was investigated in order to determine whether the presence of these two chemicals was unique to teak in this industry. The method was then field tested in a small factory where teak wood is used.



1 Structure and molecular weights of DLP and LP.

EXPERIMENTAL METHODS

Chemicals and suppliers

Glacial acetic acid (99%, purity), methanol (99.9% purity), acetonitrile (98%, purity), and an analytical standard of LP (98%, purity) were purchased from Sigma-Aldrich (St. Louis, MO, USA). HPLC-grade water was purchased from Fisher Chemicals (Pittsburgh, PA, USA). A HPLC column Zorbax SB-C18 (4.6 mm i.d. $\times$ 150 mm, 5 μ m) was purchased from Agilent Technologies Inc. (Santa Clara, CA, USA). DLP was synthesized (with purity above 95%) by SHIRE Tanaud International, in the Department of Chemistry, University of the West Indies–Mona (Jamaica).

Airborne wood dusts were collected on filters with three types of samplers typically used for the collection of inhalable dust: the Institute of Occupational Medicine (IOM) inhalable dust sampler (SKC Inc., Eighty Four, PA, USA), the Button sampler (SKC Inc., Eighty Four, PA, USA) and the Gesamstaub-Probenahmesystem (GSP) sampler (GSA-Neuss, GmbH, Neuss-Norf, Germany). The samplers were equipped with polyvinylchloride (PVC) membrane filters (25 mm diameter, 5 μ m pore size for button sampler and IOM; 37 mm diameter, 5 μ m pore size for GSP sampler) and connected to an air sampling pump (PCXR4; SKC Inc., Eighty Four, PA, USA). The PVC filters were chosen because they can be easily conditioned before each weighing and do not interfere with HPLC–DAD analysis.

'Southeast Asia' Teak (*T. grandis*), Purpleheart (*Peltogyne*), African Padauk (*Pterocarpus soyauxii*), Wenge (*Millettia laurentii*), and Bocote (*Cordia*) were purchased from Rockler Woodworking and Hardware (Medina, MN, USA); Iroko (*Chlorophora excelsa*), Mahogany (*Swietenia macrophylla*), Canarywood (*Centrolobium*) Beech (*Fagus sylvatica*), Birch (*Betula pubescens*), White Oak (*Quercus alba*), Ash (*Fraxinus excelsior*), and Black Walnut (*Juglans nigra*) were purchased from Wood Workers Source (Phoenix, AZ, USA). Plantation teak from Trinidad was purchased from WoodShop 102 (Key Largo, FL, USA) and 'Myanmar' teak from Advantage Trim & Lumber Co (Buffalo, NY, USA). Since Myanmar is in Southeast Asia, these two teak types might not be very different, but the 'Southeast Asia' teak may have come from Indonesia, Cambodia, Thailand, etc.

Standard solution preparation

One gram per liter stock solutions of LP and DLP in methanol were prepared and stored at 4°C for up to 4 weeks. Serial dilutions of the stocks were prepared to provide combined LP and DLP standards from 0.025 to 10 mg l⁻¹, and these were used within 1 week of preparation. A stability test was carried out and the solutions were found to be stable for more than 1 week (data not shown). The curve of the detector response (instrument calibration curve) against LP and DLP standards was obtained by transferring an aliquot (2 ml) of each standard solution to a clean tube and drying it under N₂ flow. The residue was dissolved in 200 μ l of acetonitrile, and 20 μ l of this acetonitrile solution was injected into HPLC system.

Validation of analytical method

Three independent sets of calibration curves in methanol were prepared. Each calibration curve contained seven standard samples at the concentrations of 0.1, 0.5, 1, 5, 10, 50, and 100 mg l⁻¹. The solutions were analyzed on three nonconsecutive days to determine inter-day variability. In order to determine intra-day variability, three independent replicates of seven standard samples (in the same range used to assess the inter-day variability) were prepared and analyzed on the same day. The analysis was carried out in accordance with the procedure used for the standard solutions and for the samples: an aliquot (2 ml) was transferred to a clean tube and dried under N₂ flow. The residue was dissolved in 200 μ l of acetonitrile and 20 μ l of the acetonitrile solution was injected into HPLC system.

In order to assess variability due to the extraction we weighed nine amounts of dust (~20 mg) from the three different type of teak (three for each). The dusts were extracted with 3 ml of the preferred solvent, methanol (see below), for 30 min under agitation in a vortex and centrifuged at 3000 rpm (about 700 g) for 15 min. The supernatant (2 ml) was transferred to a clean tube and dried under N₂ flow. The residue was dissolved in 200 μ l of acetonitrile, and 20 μ l of the acetonitrile solution was injected into HPLC system.

The results were used to establish the performance of the analytical method. The limits of detection (LODs) and the lower limit of quantification were defined as, respectively, 3.3 and 10 times the standard

deviation of the response divided by the slope of the calibration curve in accordance with The International Conference on Harmonization (ICH, 1996).

LP and DLP extraction from teak wood

A piece of Southeast Asia teak was reduced to fine powder with a small electric saw. Samples of the dust (100 mg each) were weighed and each extracted with one of six different solvents (3 ml) in order to select the solvent that produced the highest extraction percentages of chemicals. The solvents used were methanol, acetonitrile, ethyl acetate, water/methanol 50/50, water/acetone 50/50, and water/acetone 20/80. The samples were extracted for 30 min under agitation in a vortex and centrifuged at 3000 rpm (about 700 g) for 15 min to improve liquid phase separation from the particulate. The amounts of LP and DLP extracted as a percentage of the total wood dust ranged from 0.00% to 0.011% and from 0.014 to 0.043%, respectively. The solvents with the highest percentage of extraction for the two analytes LP and DLP were the mixture of water/acetone 50/50 and methanol; methanol was selected for the subsequent analyses.

Determination of LP and DLP content in teak wood dust

Different amounts of dust from three different types of teak were weighed in a range similar to the amounts of dust typically found in filter samples from workplaces (Harper and Muller, 2002; Magagnotti *et al.*, 2013), specifically 0.08–11.50 mg for the Southeast Asia Teak, 0.187–2.174 mg for the Myanmar teak, and 0.214–5.062 for the plantation teak, respectively. The samples were extracted with 3 ml of methanol for 30 min under agitation in a vortex and centrifuged at 3000 rpm (about 700 g) for 15 min to improve liquid phase separation from the particulate. The supernatant (2 ml) was transferred to a clean tube and dried under N_2 flow. The residue was dissolved in 200 μ l of acetonitrile and 20 μ l of the acetonitrile solution was injected into HPLC system.

Analysis of methanol wood extracts by HPLC-UV

Chromatographic analysis were carried out using an Agilent Technologies 1100 series HPLC equipped with an Agilent Technologies 1100 diode array detector (251 and 254 nm) and a Zorbax SB-C18 column, 4.6 ID $\times$ 150 mm (5 μ m) (Agilent Technologies Inc.,

Palo Alto, CA, USA). The separation was accomplished at ambient temperature at a flow rate of 1 ml min^{-1} under isocratic conditions using a mobile phase of 50% acetonitrile/0.25% (v/v) acetic acid in water. The volume injected was 20 μ l and the wavelengths used to quantify LP and DLP were 251 nm for LP and 254 nm for DLP. The absence of extraneous compound that adsorb at the same wavelength of LP and DLP was evaluated by comparison with the UV spectra of the standards recorded by diode array detector between 190 and 400 nm.

LP and DLP extraction from other woods

Other various wood types belonging to the angiosperm family and commonly used in boat-building (Purpleheart, African Padauk, Wenge, Bocote, Iroko, Mahogany, Canarywood, Beech, Birch, White Oak, Ash, and Black Walnut) were analyzed in order to assess the unique presence of LP and DLP in teak. Wooden blocks were ground to fine powder with a small electric saw. Subsequently, dust samples (100 mg each) were extracted with 3 ml of methanol for 30 min under vortex agitation, centrifuged at 3000 rpm for 15 min, and the supernatant (2 ml) was transferred to a clean tube and dried under N_2 flow. The residue was dissolved in 200 μ l of acetonitrile, and 20 μ l of the acetonitrile solution was injected into HPLC system.

Analysis of methanol teak wood extracts by gas chromatography-mass spectrometry

Approximately 100 mg of each of the three teak dusts was placed into a 15-ml vial in which 3 ml of methanol was added and stirred for 30 min to extract the target compounds. Then the methanol extracts were centrifuged at 3000 rpm for 10 min and the supernatant analyzed in a Varian 431 gas chromatograph coupled to an Ion Trap mass spectrometer (Varian 220-MS). The extracts (1 μ l) were injected into the chromatographic column RTX-200 MS 30 m, 0.25 ID, 1 μ m film (Restek Corporation, Bellefonte, PA) through the injector liner kept at 250°C. The oven temperature was kept at 45°C for 4 min, then the temperature was increased to 280°C at the rate of 5°C min^{-1} . LP and DLP were eluted by keeping the oven at 280°C for 15 min. The total run time was 66 min and the mass spectrometer conditions were in Full Scan from 45 to 650 m/z^{-1} .

Relationship of LP and DLP content to homogenized wood mass

It was noted that LP and DLP contents could vary in small scale across pieces of wood. Therefore, it was necessary to see if a better relationship between LP and DLP content per unit mass of wood existed for dust homogenized from entire pieces of wood. Entire large pieces of each of the three different teak woods were reduced to powder. The powder of each piece was separately homogenized, weighed out in different amounts, and analyzed for LP and DLP content as a function of total dust mass.

Airborne wood dust sampling in chamber

Three different samplers were placed in an exposure chamber (~45 cm high, 70 cm long, 40 cm wide): IOM (27 samples), Button sampler (22 samples), and GSP (17 samples). The flow rates were 2.0, 4.0, and 3.5 l min⁻¹, respectively, as indicated from the manufacturers. The dust was generated after sawing a piece of teak using an electric saw equipped with sand paper, simulating the work conditions. Sampling duration, ranged from 1 to 5 min, was adjusted to reflect typical mass loading levels for total dust samples in woodworking facilities. A total of 66 samples were collected in the range of mass loadings between 0.030 and 3.653 mg corresponding to a dust exposure between 0.124–8.703 mg m⁻³ for a sampling time of 2 h in a workplace.

Prior to and after sample collection, the filters were equilibrated at least 72 h at a constant relative humidity of 50 ± 2% and temperature (25 ± 2°C). All samples were weighed before and after sampling using a microbalance (UMT2; Mettler-Toledo, Columbus, OH, USA; readability ± 0.1 µg). Measurements were made after allowing exactly 180 s for balance stabilization. The PVC filters were stored at room temperature for a maximum of 2 weeks before analysis.

DLP and LP determination on air-sample filters

Each filter was placed into a 10-ml vial to which 3 ml of methanol was added and stirred for 30 min to extract the target compounds. Then the methanol extracts were centrifuged at 3000 rpm for 10 min to improve liquid phase separation from the particulate. An aliquot (2 ml) of the liquid phase was transferred to a clean tube and dried under N₂ flow. The residue was dissolved in 200 µl of acetonitrile, and 20 µl of the acetonitrile solution was injected into HPLC system.

Airborne wood dust sampling in the field

Personal and area industrial hygiene air sampling was performed in a small factory in Italy that produces teak furniture. The wood dust in the air was sampled with IOM samplers equipped with PVC filters (25 mm diameter, 5 µm pore size) at flow rate of 2 l min⁻¹. Sampling was carried out during the work phases of cutting (three samples) and sanding (three samples) where both fixed machines and portable tools were used. A sample was taken also in the office as a field blank. A total of seven samples were collected, of which three were personal samples, and thus near the air breathed by workers, and four with samplers fixed on tripods at a height of 160 cm above floor level. Sampling lasted 3 h. Gravimetric determination of dusts was carried out on an MC-5 microscale with a detection threshold of 0.001 mg (Sartorius Mechatronics, Muggio (MI), Italy), after membrane conditioning for 48 h under an Aquaria Climatic hood (Aquaria, Milan, Italy) with constant temperature and humidity. After weighing, membranes were kept away from light and stored at room temperature until analysis (max. 2 weeks).

RESULTS

Retention times for LP and DLP in the HPLC analysis were 11.8 and 21.2 min, respectively. The detector responses against LP and DLP standards were linear in the range 0.025–10 mg l⁻¹ with a correlation coefficient always greater than 0.9994. The inter-day accuracy and precision of the HPLC method were determined from the analysis on seven independent standard samples in the range 0.1–100 mg l⁻¹ tested over the 3 days of the validation study. The accuracy was determined by comparing the means of the concentrations found in the standard samples with the theoretical values and presented as percentages while the precision is expressed as the relative standard deviation of the values found over the mean for each concentration (%CV). The average inter-day accuracy was 97.3% (range 92.4–100.7%) for the LP and 96.8% (range: 90.1–113.0%) for DLP, respectively. The average %CV was 0.76% (range 0.39–1.39%) for LP and 2.26% (range 0.76–7.42%) for DLP, respectively.

The intra-day accuracy and precision were calculated by testing three independent replicate standard samples in the range 0.05–100 mg l⁻¹ on the same day. The average intra-day accuracy was 102.8% (range

97.0–107.6%) for the LP and 98.6% (range: 91.2–108.0%) for DLP, respectively. The average %CV was 0.28% (range 0.0–0.84) for LP and 2.72% (range 0.22–6.49 %) for DLP, respectively.

The variability due to the extraction was tested analyzing nine independent amounts of dust from the three types of teak (three for each) and expressed as %CV. For Southeast Asia teak, the %CV was 2.66 for LP and 2.48 for DLP; for Myanmar teak, 7.14 for LP and 14.90 for DLP; and for Plantation teak, 6.76 for LP and 5.26 for DLP. The method allows the detection of LP and DLP at concentrations 0.0008 mg l^{-1} (LOD); the corresponding limit of quantitation is 0.0025 mg l^{-1} (2.5 ng ml^{-1}), assuming no interferences.

The analysis of various amounts of Southeast Asia teak samples, as supplied, carried out in our laboratory, gave the percentages by weight of LP and DLP as $0.006 \pm 0.001\%$ and $0.038 \pm 0.002\%$, respectively. The analysis of Myanmar teak extract showed a high concentration of DLP: the percentage of DLP was of $0.497 \pm 0.013\%$, more than 10 times the percentage found in Southeast Asia teak; whereas, the percentage of LP was $0.012 \pm 0.002\%$. On the contrary, the plantation teak from Trinidad showed a higher content of LP ($0.261 \pm 0.027\%$) than DLP ($0.068 \pm 0.020\%$). Fig. 2 shows the chromatograms of the methanol extract from Southeast Asia teak wood, Myanmar teak wood, and plantation teak from Trinidad dust.

Analysis of dust from other species of wood

The dusts from the other 12 wood nontek specimens mentioned above were analyzed according to the method previously described. LP and DLP were below the LOD of the present analytical method in all species except teak.

Analysis of methanol teak extract by gas chromatography-mass spectrometry

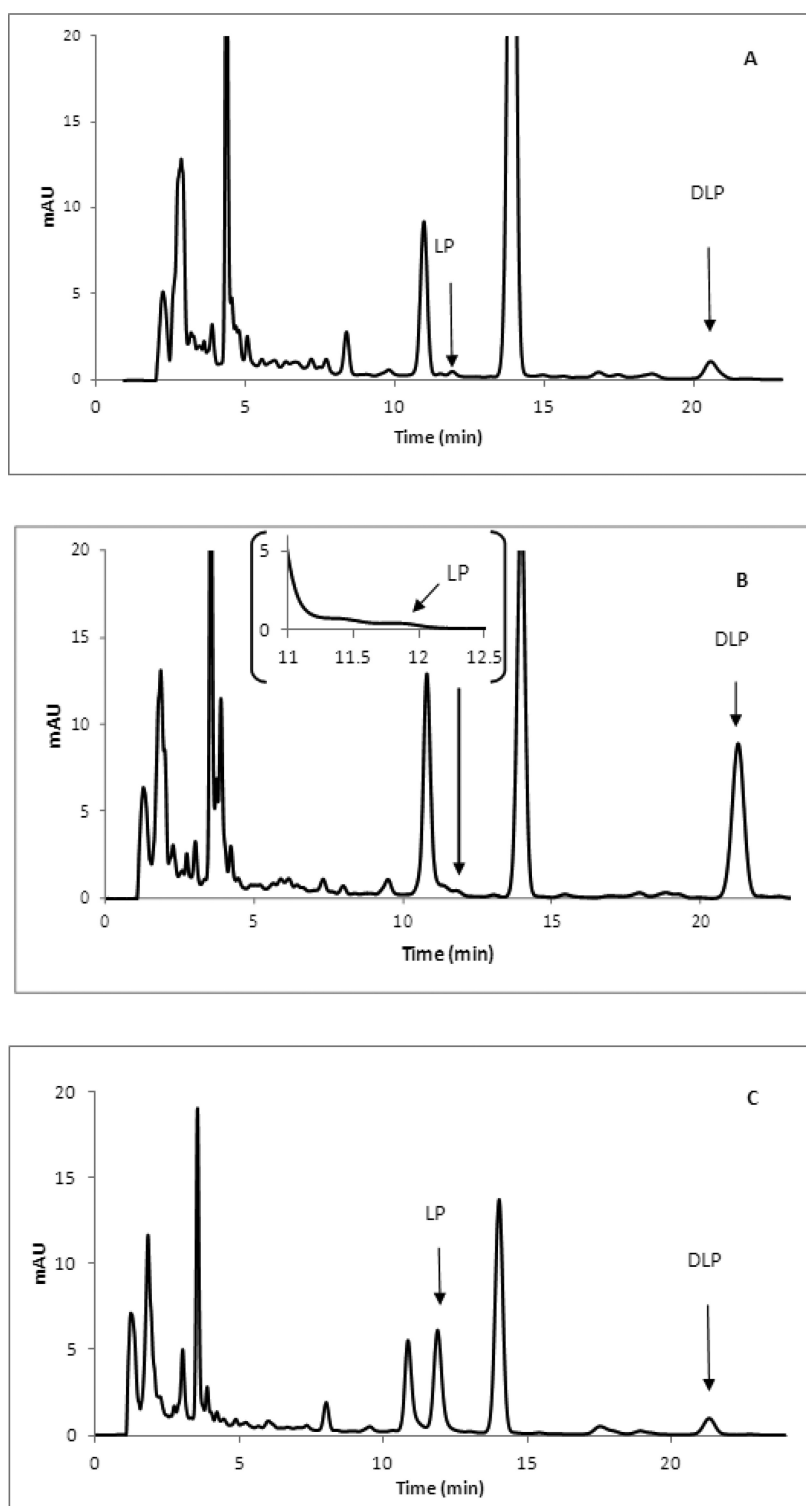
The gas chromatography analysis of methanol extract solution from teak dust showed, in addition to LP and DLP, the presence of 1,4-naphthoquinone, 2-methylanthraquinone (2-MEA; most abundant), squalene, and an unknown compound with a mass spectrum almost identical to DLP's. Lukmandaru and Takahashi (2009) found this same compound and tentatively assigned the name of isodeoxylapachol to it. The possible structure of isodeoxylapachol could have a double bond in a different position in the side chain.

DLP and LP determination on filters

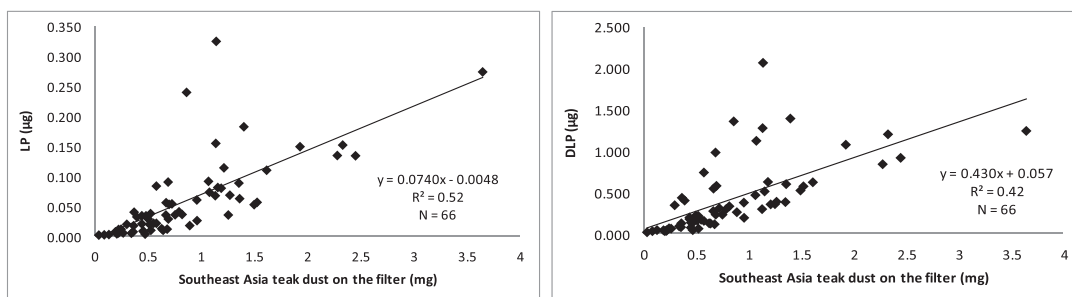
Sixty-six filters from Southeast Asia teak dust were analyzed. A good but not excellent correlation between the teak dust collected on the filters in the exposure chamber and the content of the two chemicals (Fig. 3) is probably due to the variation of chemical content across a single piece of wood. The sampling time in our experiments ranged between 1 and 5 min only, and hence different samples might have reflected any inhomogeneity within the wood block (see Discussion). A better correlation was found between the chemicals (Fig. 4), and thus there is a constant relationship between LP and DLP in the same position within the piece of wood. Splitting the samples according to the sampling day (sessions from 1 to 5) we can see the correlation improves for both the chemicals. Figs 5 and 6 show the correlations between LP and DLP versus the teak dust collected on the filters in relation to the sampling day, respectively (from 1 to 4 sessions); the correlations were very good for both chemicals, with correlation coefficients always higher than 0.94. This was likely because dust was ground from the same position on the same piece of wood, and hence there was not a large difference in LP and DLP contents. During the Sampling Session 5, seven filters were collected when the piece of wood was being ground at one end while the second group of filters was collected with the wood being ground from the opposite end. The change in chemicals content was particularly evident, especially for DLP (Fig. 7). No differences were found between the three samplers and for LP and DLP contents per mg of dust (data not shown).

Relationship of LP and DLP content to homogenized wood mass

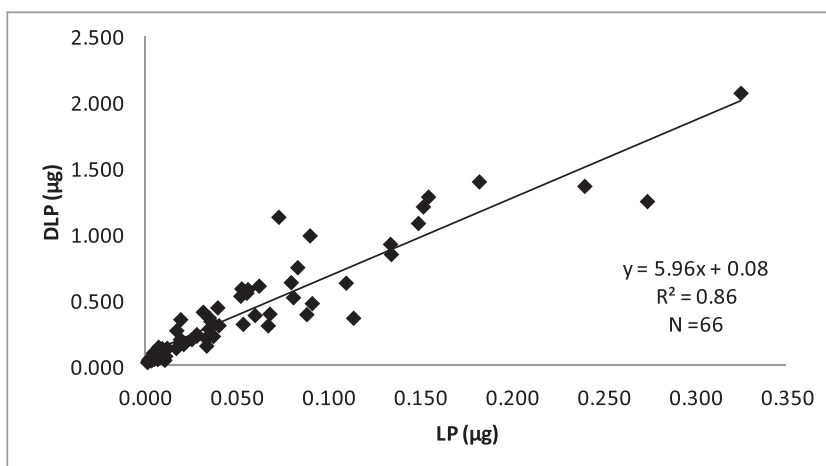
In normal woodworking environments, typically only one type of a specific wood is present, but dusts are generated from different pieces of wood and different positions along any single piece of wood so that LP and DLP levels per unit mass of dust may vary in the short term. However, filter samples collected over a longer time in these working conditions will contain a mixture of dusts from different positions. It is thus expected that long-term samples would reflect well the average DLP and LP levels throughout the wood being used. In order to show this, larger pieces of the three different teak woods were reduced to powder and separately homogenized—before being weighed out in different



2 Chromatograms of methanol extract from Southeast Asia teak (A), Myanmar teak (B), and Plantation teak from Trinidad (C).



3 Correlation of LP and DLP levels (μg) found in Southeast Asia teak dust (mg) collected on the filters.



4 Correlation between LP and DLP detected in the Southeast Asia teak dust collected on the filters.

amounts and analyzed. The results in Fig. 8 show excellent correlation between LP and DLP contents per unit mass of wood for the homogenized dust. These results support the hypothesis that LP and DLP could be used as chemical markers to evaluate the exposure of teak dusts in workplaces where blended samples of dusts will be found, provided an average level of LP and DLP in the production material can be determined.

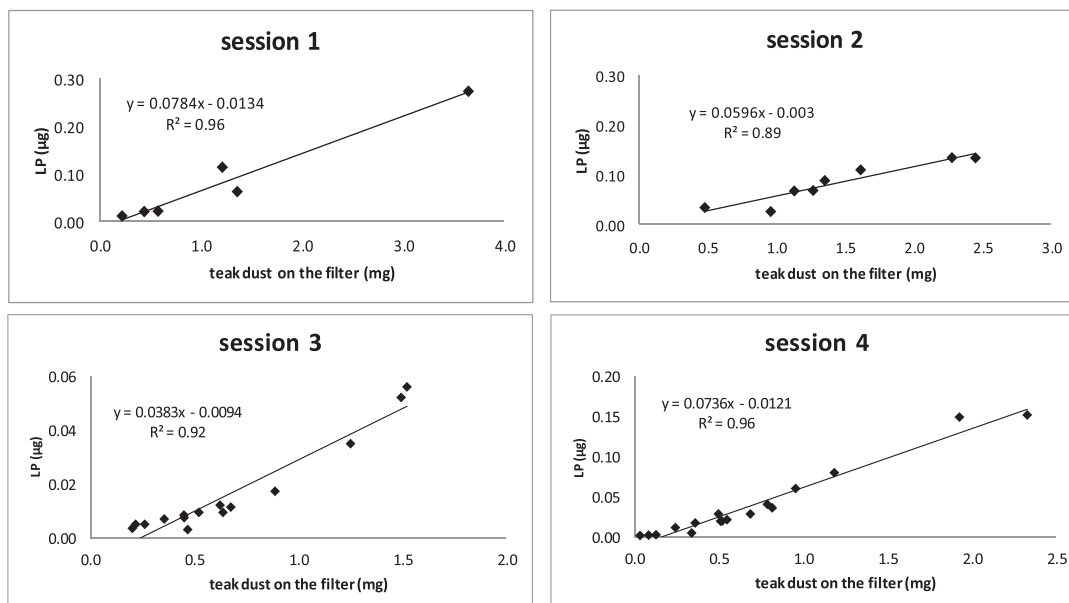
Airborne wood dust sampling in the field

In order to verify the reliability of the LP and DLP as chemical markers of teak dust, a field test was carried out in a small factory where teak was the only wood species used. Fig. 9 shows the correlation between LP and DLP levels (μg) and the amount of teak dust collected on the filters of the fixed and personal samples taken during this study.

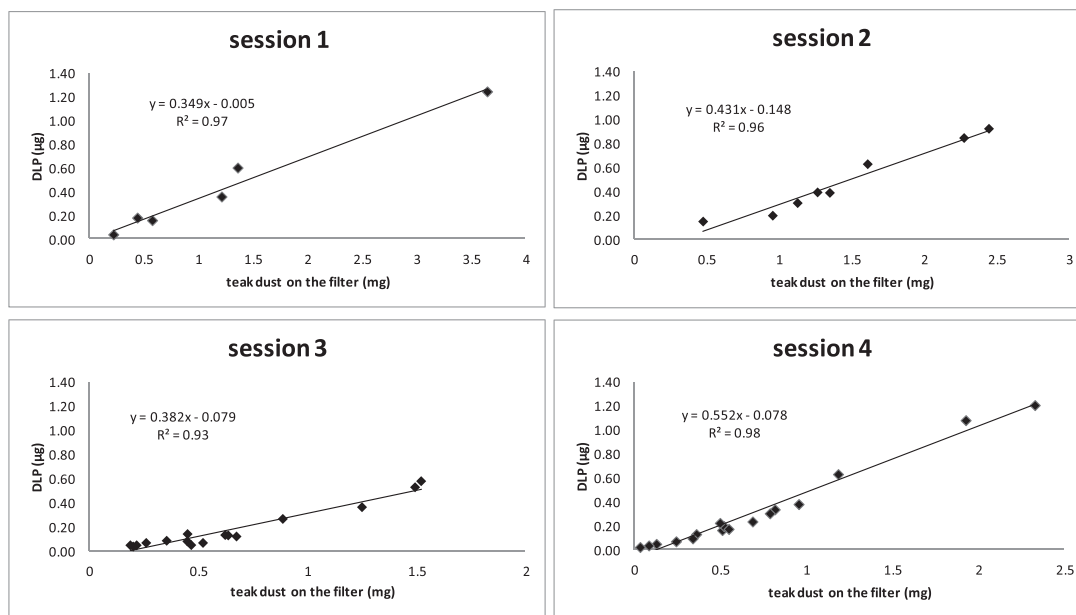
The very good correlations between the teak dust and the two chemical markers, even if based on few data, confirm the reliability of LP and DLP as chemical markers for teak.

DISCUSSION

An HPLC method for the determination of LP and DLP in wood dust as indicators of teak content has been developed. To the best of our knowledge, this is the first method developed in order to quantify LP and DLP to assess the occupational exposure to airborne teak dusts. The retention time of LP and DLP are 11.8 and 21.2 min, respectively, and the resolution with this method is very good. Other analytical methods reported in the literature have been developed in order to identify the chemicals present in teak wood,



5 Correlation of LP and teak dust (mg) collected on the filters in four different sampling sessions.

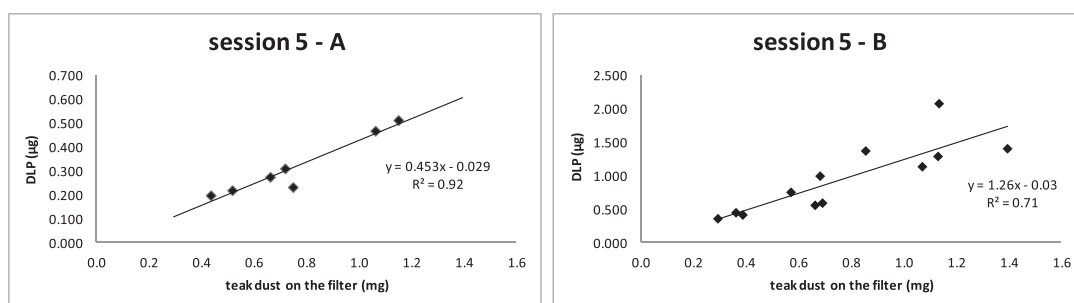


6 Correlation of DLP and teak dust (mg) collected on the filters in four different sampling sessions.

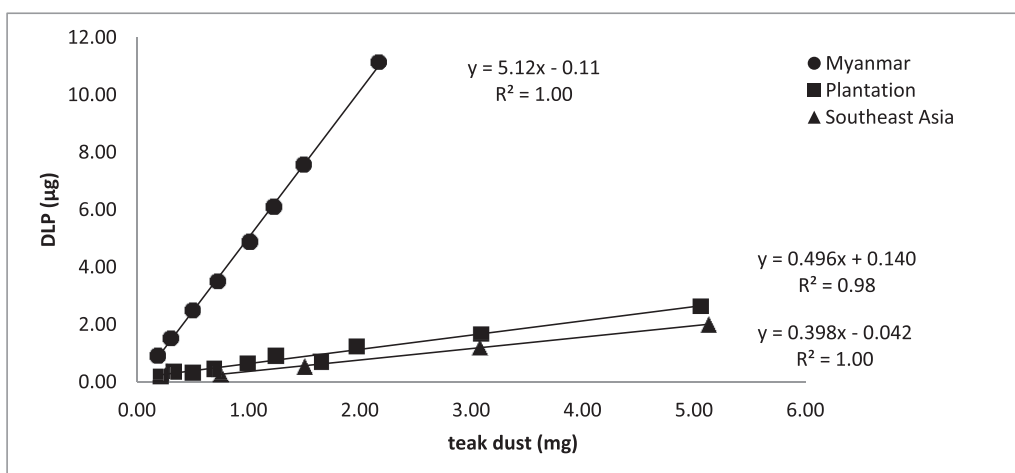
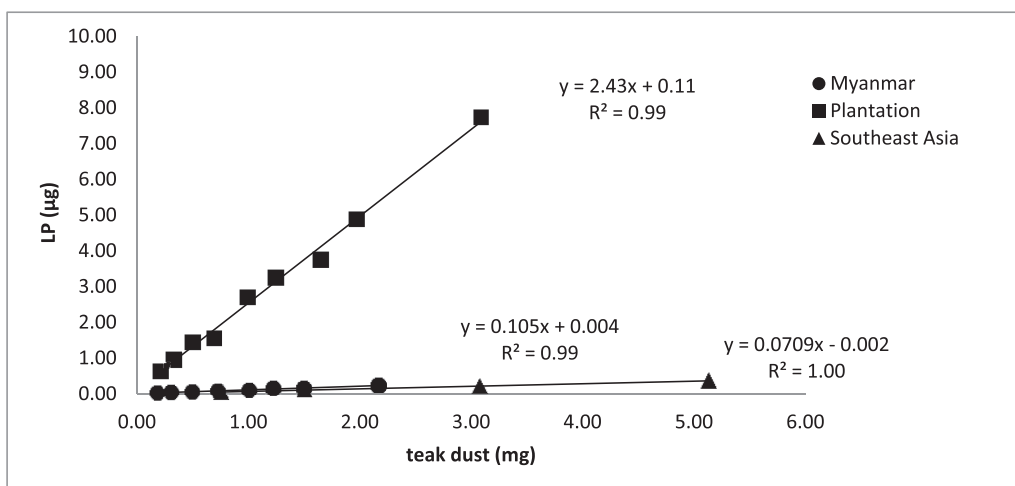
or to study the natural durability of teakwood, but they were developed for large bulk samples, and thus, in their present form, are not applicable to exposure assessment; moreover, many of them only concern the quantification of LP and not DLP (Lukmandaru and

Takahashi, 2009; Fonseca *et al.*, 2004; Niamké *et al.*, 2011).

The detection limit of the method, assuming a percentage of the markers at least equal to 0.012% (the percentage of LP in Myanmar teak), allows the analysis of



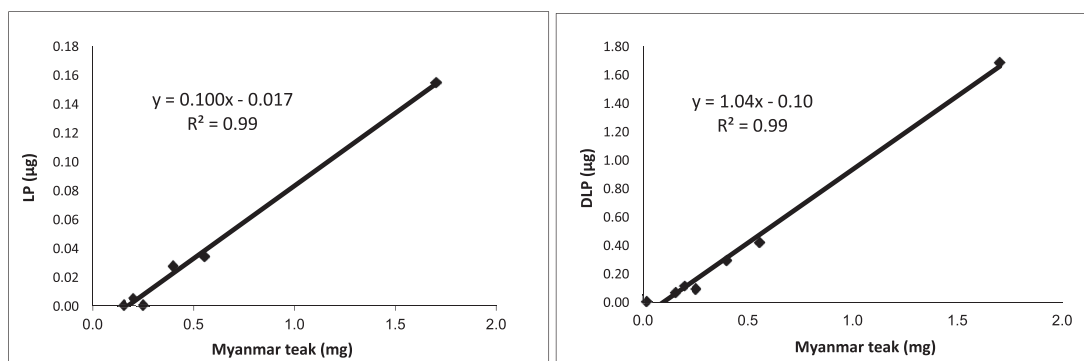
7 Correlation of DLP and teak dust (mg) collected on the filters during the sampling session 5. A: first seven filters; B: last 12 filters.



8 Correlation between LP and DLP levels (µg) and the amount of different kind of teak dust examined.

both chemicals above a minimum of 20 µg of teak dust collected on the filters, equal to 0.083 mg m⁻³ sampling with an IOM sampler for 2 h, 0.040 mg m⁻³ sampling

with a Button sampler for the same time period or 0.048 mg m⁻³ with a GSP sampler. LP and DLP are present in teak dust but not in any of the other woods used



9 Correlation between LP and DLP levels (µg) and the amount of teak dust collected on the filters.

for boat-building and furniture manufacture analyzed in this study. The method was tested on three different kinds of teak dusts from different origins, and there was a strong correlation between various amounts of teak wood dust and measured LP and DLP in the wood dust for each teak dust. No differences were found between the three samplers tested and the LP and DLP contents per mg of dust collected by them.

It was noted that the percentages of LP and DLP varied greatly with the source of the teak and slightly with position within a single piece. Different percentages in different kinds of teak also have been found by other authors, who have shown that the percentage varies with the age of tree, the geographical origin, and the location of the piece of wood in the trunk (Lukmandaru and Takahashi, 2009; Niamké *et al.*, 2011). Windeisen *et al.* (2003) found different extractive contents in two different plantation teak from Panama in relation to the position inside the tree, with the largest range of extractive content being found between sapwood and heartwood in both. Moreover, they found a more pronounced difference between the two plantation teaks for LP and DLP than for other chemicals: for both compounds, the amounts in the first teak were ~0.2%, whereas in the second one, the percentages were 0.4 for LP and 1 for DLP, respectively. However, for sampling times in the workplace ranging from 2 to 8 h, collected dusts represent an average of the wood used during the time period and hence an average of the chemical percentage contained in the teak wood. The good correlations obtained between the teak dust collected on the filters in a small factory and the two chemical markers, even based on a few data points, seem to confirm the hypothesis concerning the use LP and DLP as chemical

markers to assess occupational exposure to teak dust. However, it may be useful to analyze bulk samples of the teak actually being used in a factory on the day of sampling for most accurate correlation with the air samples.

2-MEA, which has also been tested for use as a chemical marker of occupational exposure of teak dust in a previous study (Gori *et al.*, 2009), has also been found to vary within and between teak types. In addition, 2-MEA has not been shown to have biological activity in humans, whereas LP and DLP have biological activity, making them potentially more useful for the evaluation of the health effects of exposure to teak wood dust. Several therapeutic activities are attributed to LP, some still under study (anti-abscesses, anti-ulcer, anti-inflammatory, anti-malarial, antiseptic, antiviral, bactericide, and fungicide), in particular as an antitumor agent despite the presence of toxic side effects (Block *et al.*, 1974; Goel *et al.*, 1987; Müller *et al.*, 1999; Portillo *et al.*, 2001; Maeda *et al.*, 2008).

CONCLUSION

On the basis of the good correlations obtained, LP and DLP appear to be good markers of teak dust and thus very useful for estimating the true quantities of teak dust inhaled. In principle, if the LP and DLP content of the teak being used is known, then if several other types of wood were used together with teak in the work place, it should be possible to apply the analysis of LP and DLP contents to quantify the exposure to teak dusts and to differentiate this exposure from that due to other types of woods and dusts. In addition, the analysis of LP and DLP content in the teak dust could be useful to evaluate any health effects resulting from exposure to these two biologically active substances. However, LP and DLP

contents in teak wood vary according to source and within the wood so that bulk samples from the woods being used in woodworking plants at the time air samples are collected should be analyzed with the aim of determining their average LP and DLP contents.

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DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

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