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IMPORTANCE OF TEAKWOOD EXTRACTIVES ON WOOD PROPERTIES AND FOR TREE BREEDING

Maruli H Simatupang
Department of Wood, Paper and Coating Technology, School of Industrial Technology,
Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia

Enih Rosamah
Department of Forest Products, Faculty of Forestry,
Mulawarman University, Samarinda, East-Kalimantan, Indonesia

Koichi Yamamoto
Japan International Research Center for Agricultural Sciences,
Forestry Division, 1-2 Owashi, Tsukuba, Ibaraki, 305 Japan

ABSTRACT

Teak is indigenous in India, Myanmar, and Thailand, but is currently cultivated in many parts of the worlds. Teakwood is one of the oldest commercial wood species. Around 4,000 years BC the wood was already shipped from India to Babylonia and Yemen, where it was used for construction and ship building. The wood is of medium density, has a very good dimensional stability, prevent iron nails from rusting, is rather resistant against chemicals, and has a high natural durability against wood destroying fungi and termites. It can, however, induces allergic reactions. The non polar extractives are responsible for the good as well as the less desirable properties.

The termicide properties are due to anthraquinones. The concentration of the active compounds may be up to two percent. Caoutchouc is the most abundant occurring compound in teakwood. Its concentration may be up to five percent. The compound is responsible for the water repellant properties of the wood. The compounds responsible for the fungal resistance are, however, still not known. Probably the synergistic effect of active and nonactive wood extractives is the cause of the durability against wood destroying fungi. A new antioxidant was recently isolated from the acetone extract of teakwood. It was postulated that this compound protect caoutchouc against oxydation and rusting of iron nails.

Teak specimens from various localities and countries show very great variations of total extractive contents as well as concentrations of single compounds. This is also true for drill cores of increment borer from teak plantations made of seed or clones. The examinations of the methanol and chloroform extracts of five clones from Thailand shows two kinds of pattern. Two clones show a desireable positive correlation between methanol extract content and tree diameter, wheres two others have a negative correlation. A positive correlation between chloroform and tree diameter was only shown by one clone.

Keywords: teak, wood extractives, natural durability, water repellancy, abrasion, contact allergy, clones.

INTRODUCTION

Teak, Tectona grandis L.f. , is indigenous in India, Burma, and Thailand. The natural distribution of teak is limited to areas with pronounced monsoons. During the dry season the tree has no leaves. The thick bark protects the tree against bush fires. Due to this fire resistance properties the tree has some advantages compared to other less resistant species, and promote its distribution. Teak is being cultivated firstly on Java, New-Guinea and recently in Africa, (e.g. Senegal; Ghana 35,000 ha; Nigeria; Ivory Coast 35,000 ha; Benin 6000 ha; Dahomey; Sudan; Kenya) with a total area of about 140,000 ha (SCHMINCKE 1992); Central America, e.g. Cuba, Jamaica, Panama, Puerto Rico, Trinidad; South-America, e.g. Brazil (BEYSE 1991); Malaysia, and many other countries. It is a rather slow growing species, but due to the high price of the logs or the wood products, teak is increasingly being used for afforestation.

Teak and Lebanon ceder, are considered to be the oldest commercial wood species. Already around four thousand year BC teak from India was shipped to Babylonia and Yemen. The wood was used for building temples, palaces, expensive houses and ships (HERMANN 1952). The utilization of teakwood has not changed much since this prehistorical time. Currently the solid wood is used for construction, for ship building, furniture, carpenter's level, and many other applications which require wood with good dimensional stability. Teak veneer is being used as overlay of particleboards or other kinds of panels to be used for high quality furniture. The wood has a good natural durability against termites and wood destroying fungi, including soft rot.

Teakwood may, however, caused allergic reactions. Laborers who work and handle this wood are especially affected.

The good and less desirable properties of this well known wood species are due to the chemical extractives. In the following a brief review is presented of the wood extractives and their influences on the properties of the wood. The results of wood extractives determinations of clones grown on an experimental plot in Thailand will be reported.

TEAKWOOD EXTRACTIVES

The results of a successive extraction with solvents of increasing polarity is presented in Table 1. According to current knowledge the advantageous as well as the disadvantage properties of teakwood are due to non-polar extractives. These active compounds are soluble in petroleum ether and ether. In this review the compounds isolated from teak are presented in Figure 1. They are fatty acids, terpenoids and polyprene compounds, naphthalene derivatives and anthraquinone derivatives.

The glyceride of the ubiquitous myristic acid, palmitic acid,

and stearic acid are the main fatty acid derivatives. Five unidentified fatty acids, occurring in traces, are detected by gas chromatography (SIMATUPANG 1963; SANDERMANN and SIMATUPANG 1966).

Compounds of the second mentioned groups are: squalene (SANDERMANN and SIMATUPANG 1966); betulinic acid in wood and root (AHLUWALIA and SESHADRI 1957, DAYAL and SESHADRI 1979); β-sitosterol (DAYAL and SESHADRI 1979); a triterpenoid (bark) (SANDERMANN and SIMATUPANG 1966); caoutchouc (SANDERMANN and DIETRICHS 1959); tectograndinol (RIMPLER and CHRISTIANSEN 1977).

In the third group, naphthalene derivatives, the following compounds were identified: dimethyl-naphthochroman (SANDERMANN and SIMATUPANG 1967); compound B_3 with the formula $C_{18}H_{16}O_2$ (SANDERMANN and SIMATUPANG 1966); deoxylapachol (SANDERMANN and SIMATUPANG 1963); lapachol (SANDERMANN and DIETRICHS 1957); alfa-dehydrolapachon (SANDERMANN and SIMATUPANG 1966); β-lapachone (KRISNHA et al. 1977); four napthaquinones A_4, A_5, A_6, and A_7 (SANDERMANN and SIMATUPANG 1965); tectol and tecomaquinone I (formerly designated dehydrotectol (PAVANARAM and ROW 1957, SANDERMANN and DIETRICHS 1959, SANDERMANN and SIMATUPANG 1963, 1964, KHANNA et al. 1987). Compound B_3 is probably identical with the antioxidant isolated from teak recently (SIMATUPANG and ROSAMAH 1984).

The anthraquinones occurring in teak are shown in Figure 1. They are: tectoquinone (2-methylanthraquinone) (KAFUKU and SEBE 1932); 1-hydroxy-2-methylanthraquinone (ROW 1960); 2-hydroxy-3-methylanthraquinone (PAVANARAM and ROW 1957); 2-hydroxymethyl-anthraquinone, anthraquinone-2-aldehyde, anthraquinone-2-carbonic acid (RUDMAN 1960); munjistin (1,3-Dihydroxy-2-carbonic acid-anthraquinone (JOSHI et al. 19977); obtusifolin (2,8-dihydroxy-1-methoxy-3-methylanthraquinone and pachybasin (1-hydroxy-3-methylanthraquinone (DAYAL and SESHADRI 1979); 1,4-dihydroxy-2-methylanthraquinone (SANDERMANN and SIMATUPANG 1965); damnacanthal (3-hydroxy-2-carbanol-3-methoxy-anthraquinone; 2,5-dihydroxy-1-methoxy-3-methylanthraquinone (tissue culture) (DHRURA et al. 1972); tectoleafquinone (structure not yet established) (CHARI et al. 1969); three not yet identified quinones A_9, A_{10}, and red compound (SANDERMANN and SIMATUPANG 1966); five leafquinones detected by paper chromatography (SANDERMANN and SIMATUPANG 1966); 9,10-dimethoxy-2-methyl anthra-1,4-quinone (SINGH et al. 1989)

Caoutchouc is the compound with the highest concentration in teakwood. It's concentration may be as high as five percent. The second highest are the anthraquinone derivatives, comprising mainly of tectoquinone. Certain teak specimens may contain up to two percent of this compound. Of the napthaquinones, lapachol is more often found than deoxylapachol. Their concentrations are in the range of about 0.1%. Tectol as well as tectol and tecomaquinone (formerly designated as dehydrotectol) occur also in this range of

concentration. All other compounds detected in teakwood are found in very small amounts. However, their occurrence give hints about the biogenetic pathways in synthesizing these extractives. The occurrence of anthraquinones together with naphthaquinone derivatives is very interesting.

INFLUENCE OF EXTRACTIVES ON WOOD PROPERTIES

NATURAL DURABILITY

The anthraquinone derivatives in teakwood are the active principles against termites (WOLCOTT 1947, 1955, SANDERMANN and DIETRICHS 1957). According to RUDMANN and GAY (1961) these compounds are repellent. Anthraquinones as well as anthrone derivatives which are substituted at the β-position of the carbonyl group with a methyl, a carbanol, an aldehyde or a carboxyl group are active against termites (SANDERMANN and SIMATUPANG 1966). The activity disappear if it is substituted by a hydroxyl group. Accordingly all anthraquinones isolated so far from teakwood are termicides. The effect of the newly isolated 1,4-anthraquinone is not known.

Of the naphthaquinone derivatives, only deoxylapachol shows a strong toxicity against termites. Lapachol, a substituted deoxylapachol is only weak toxic. However, the naphthochroman derivative is strongly termicide. No data are yet available on the activity of the other naphthaquinones and the newly isolated 1,4-anthraquinone. Tectol and tecomaquinone (formerly designated as dehydrotectol by SANDERMANN and DIETRICHS (1957) have no detrimental effect on termites.

The fungitoxic compounds in teak are, however, not yet identified. Of the known compounds only β-methylhydroxy-anthra-1,8-quinone and deoxylapachol are shown to have fungitoxic properties. The toxicity of the first mentioned compound is, however, low. According to present knowledge not only one single compound or fraction is responsible for the natural durability against wood destroying fungi. Probably the synergetic effect of the nonactive and active principles, especially in combination with the hydrophobic properties of caoutchouc, cause these advantageous properties.

ANTIRUSTING PROPERTIES

Iron nails in teakwood do not rust. The mechanism of this antirusting property is still not known. Probably the antioxidant detected in teakwood may contribute to this effect.

HYDROPHOBIC AND ABRASION RESISTANCE PROPERTIES

The hydrophobicity of teakwood is known since long time. Due to the water repellency this wood is used extensively as deck planks in ships. SCHWAB (1992) showed that oven dry teakwood absorb moisture very slowly compared to beech and spruce (Figure 2). After 28 d of exposure to a RH of 65% and 20°C the

moisture content was only 40% of the equilibrium moisture content. YOSIMOTO and SIMATUPANG (1995) extracted thin sections of teak heartwood with acetone only or acetone and chloroform successively. The untreated as well as the treated specimens were analyzed by X-ray photoelectron spectroscopy (XPS), scanning electron microscopy (SEM) and contact angle measurement (CAM) with water. Untreated specimens have a XPS spectrum rich in C1 (-CHx) compounds. Carbon atoms in woody materials have been classified into four categories according to their bindung energy into C1: -CHx; C2: hydroxyl or ether; C3: carbonyl or acetal, and C4: carboxyl or ester. The acetone extracted specimens showed a lower content of C2 components, indicating the removal of polar extractives. Successive extraction with acetone and chloroform reduced the amount of C1, also apolar components. The extracted compounds could be mainly caoutschouc. This latter extractive is not acetone soluble, but chloroform soluble. The extraction of apolar compounds reduce also the contact angle drastically. After successive treatment with acetone and chloroform the thin sections are practically devoid of extractive materials. However, the observations indicated that some couotchouc may be still available in the parencyma cell walls as shown by SEM.

According to CHAPLIN and ARMSTRONG (1951) teakwood shows a high abrasion resistance. A good correlation between density and abrasion resistance is established, as shown in Figure 3, with the exception of teak and jarrah. Teak is more resistant, and jarrah is less resistant, relatively to their respective densities. The inhibiting principle in teak is probably caoutchouc which acts as grease and prevent excessive abrasion. Jarrah contains silica, and this may cause excessive abrasion. According to NARAYANAMURT et al (1960, 1962), SANDERMANN et al (1963) the low shrinkage and the high resistant properties against chemicals of teakwood may be also due to the caoutchouc content.

CONTACT ALLERGENIC PROPERTIES

The contact allergenic properties of teakwood is a phenomenon already known for a long time (HAUSEN 1981). Persons who handle this wood are mostly affected. According to ALTONA (1924) a teak variety which causes skin itching on Java is designated as jati sempurna. Lapachol (SANDERMANN and DIETRICHS 1957) and deoxylapachol (SANDERMANN and SIMATUPANG 1966) are responsible for the contact allergenic properties of teakwood. Deoxylapachol, however, shows 100 to 200 times stronger activity than lapachol (SANDERMANN and SIMATUPANG 1966, HAUSEN 1981). Persons who are allergic against other woods containing benzo- and naphthaquinone derivatives show the same reaction with teakwood. There is a cross reaction between the various quinoid compounds (SCHULZ et al. 1979).

INHIBITING PROPERTIES OF LACQUERS

The hardening of lacquers containing polyester are inhibited

by teak wood extractives. According to SANDERMANN and SIMATUPANG (1966) pure tectol, tecomaquinone I, deoxylapachol and some naphthaquinone derivatives inhibit the drying. Black stripes of teak containing tecomaquinone I inhibit hardening of polyester lacquer. Of the anthraquinones tested only compounds which have two hydroxyl group in one ring are active. Tectoquinone does not have such groups and is therefore not an inhibitory compound. The hexane extracts of many tropical wood species inhibit the hardening of lacquers based on polyester (YATAGAI and TAKAHASHI 1980). This is in agreement with findings of SANDERMANN and SIMATUPANG (1966), since the above mentioned active compounds of teak are soluble in hexane.

DISCOLORATION OF WOOD

Freshly planed teakwood does not have an attractive color. The nice gold brown color developed under the influence of a short time exposure to sun light. According to RUDMAN (1960) this is caused by oxidation of the $-CH_2OH$ group of the anthraquinone derivatives to a -CHO group. This color is, however, not stable. The further discoloration into grey follows the same pattern as other wood surfaces of other species.

Various pattern of teakwood discoloration has been observed. The green black color, especially along the vessels, is caused by tecomaquinone I. Wood veneer with green black stripes are at one time sought. Such teak is designated as Jati Doreng on Java. White stripes in teakwood are due to calcium phosphate. An uneven distribution of wood extractives can give spots with different color nuances, undesirable in high quality veneer.

"Einlauf" is designated as the phenomenon, if black stripes along the vessels, however, not due to tecomaquinone I, occur. The undesirable discoloration start mostly from a cross cut. According to wood technicians in Cepu, Central-Java, this phenomenon occurs if logs, shortly after cutting, are stored in a wet or moist milieu. The nature of these black stripes is unknown. "Einlauf" means enema, or some medication applied into the stomach. It is complained that currently many logs from Myanmar show "Einlauf".

RESISTANCE OF TEAK TREES AGAINST INSECTS AND FUNGI

Teak trees are occasionally befallen by termites. On Java the teakwood termites (Neotermes tectonae) form cavities and make their nest between bark and wood of young trees. According to KALSHOVEN (cited according to BEEKMAN 1947) up to 80% of the trees may be infected. Duometes ceramica may made bore ducts, also in heartwood. Xyleborus destruens is another borer which may befall whole plantations. It was reported that this borer cause heavy losses in teak plantation in Thailand.

Root rot was reported to causing heavy losses in Tanzania, Benin and Sudan (DUEHOLM 1970). It is not known whether there is a correlation between susceptibility against root rot and

wood extractives.

DISTRIBUTION OF EXTRACTIVES

Figure 4 shows the distribution of tectoquinone, caoutchouc, lapachol, deoxylapachol and tectol in some teakwood specimens from various countries and localities. Great variations of the total extractive contents as well as the individual components are detected. The caoutchouc content varies from 0.2 (Jati Gembol) to 5% (Jati Sungu), and the tectoquinone content from 0.5 (Cepu) to 2% (2000 year old specimen). Even after 2 000 years these specimen still contains high amounts of tectoquinone and some caoutchouc. Apparently the wood contains compounds which protect caoutchouc from oxydation. In Figure 5 the distribution of tectoquinone and deoxylapachol in drill cores of increment borer from a teak provenance collection on Java is shown (SIMATUPANG 1964). The trees were cultivated from teak seeds collected in various countries and localities.

In an attempt to correlate wood extractive content and diameter development (also grow) drill cores of increment borer of an experimental plantation at the Thai-Danish Improvement Center, Ngao, Province Lampang, Thailand, were examined. The plantation was 10 years old at the time the specimens were collected. The schematic of the plantation is presented in Figure 6. Five clones were examined. These clones were obtained by budding of two years old trees with materials from a ten year old plantation in 1959. The plus trees were chosen according to external properties as tree height and trunk form. Each clone consist of 15-20 trees. In October 1968 drill cores of increment borer were collected from 5-8 trees per clone. At 1.30 m height two increment drill cores from each tree were made. The first one was in the direction of the greatest diameter and the other in the direction of the smallest one. At 3.0 m height an increment drill core was also made on 1-2 trees per clone. The designation juvenile and mature deals with the change from the vegetative to the generative phase. In the latter mentioned phase the tree starts to blossom and influence the crown form.

The increment drill cores were divided up according to the following method. The first three increment rings adjacent to the pith were taken together as one specimen, whereas the rest of the increment rings forms the second sample. In this way only two samples were collected form each increment drill core or four samples from each tree. Preliminary examinations shows that this method give sufficient accurate results. The wood was grounded and subsequently extracted with methanol and chloroform with the use of small Twisselmann extractors. After evaporation of the solvents the residual extractives were weighed. In this examination no chromatographic separation of the wood extractives were accomplished. The purpose of the examination was to examine the variations of the methanol and chloroform extracts as a function of the diameter. Figure 7 shows these correlation in form of graphs.

By means of statistical analysis the cause of the variation of the extractive content as a function of the environment and genetic factors are examined. The results show that extractive content is influenced by both the genetic as well as the environment. Two of the clones show a positive effect between tree diameter and methanol extract content whereas in two others the effect is negative. Only one clone shows a positive correlation between chloroform extract content and diameter. The results give an indication that the natural durability, which is a function of the extractive content, may be improved by the right selection of plus trees to be used as mother trees for future teak plantations. However, such an undertaking is not so simple as it looks, because the extractive content is not only dependent of the genetic factors but also of the environment. Theoretically a suitable clone should be selected for each environment.

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TABLE 1

SUCCESSIVE EXTRACTION OF TEAKWOOD

SOLVENT	% YIELD (OD WOOD)
PETROLEUM ETHER	5.9
DIETHYL ETHER	1.2
ACETONE/WATER (9:1)	3.8
ETHANOL/WATER (8:2)	2.3
TOTAL EXTRACT	13.2

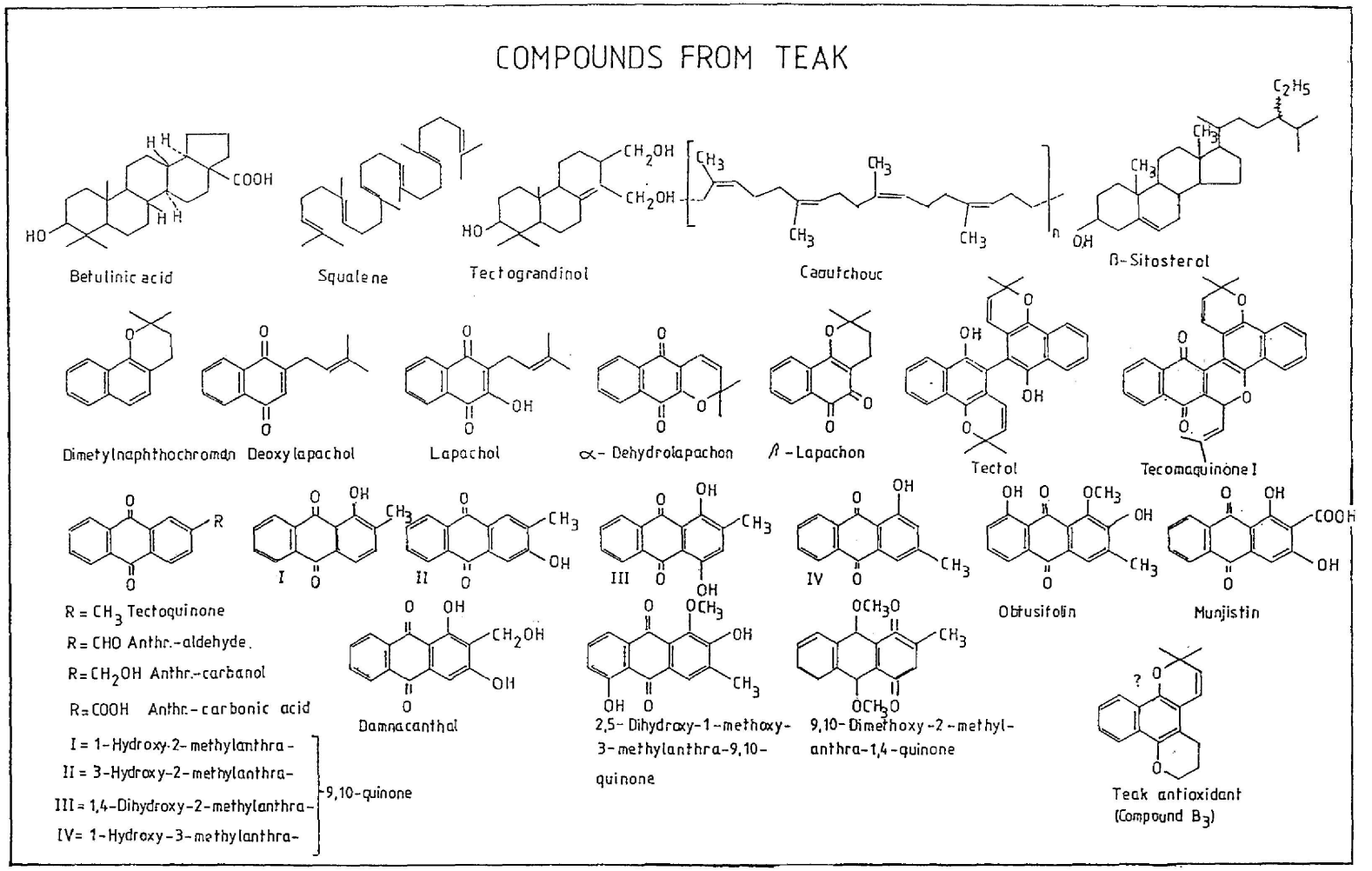
COMPOUNDS FROM TEAK
Betulinic acid
Squalene
Tectograndinol
Caoutchouc
ß-Sitosterol
Dimetylnaphthochromän
Deoxylapachol
Lapachol
α-Dehydrolapachon
ß-Lapachon
Tectol
Tecomaquinone I
R = CH3 Tectoquinone
R = CHO Anthr.-aldehyde.
R = CH2OH Anthr.-carbanol
R = COOH Anthr.-carbonic acid
I = 1-Hydroxy-2-methylanthra-
II = 3-Hydroxy-2-methylanthra-
III = 1,4-Dihydroxy-2-methylanthra-
IV = 1-Hydroxy-3-methylanthra-
9,10-quinone
Damnacanthal
2,5-Dihydroxy-1-methoxy-3-methylanthra-9,10-quinone
9,10-Dimethoxy-2-methyl-anthra-1,4-quinone
Obtusifolin
Munjistin
Teak antioxidant
(Compound B3)

FIGURE 1

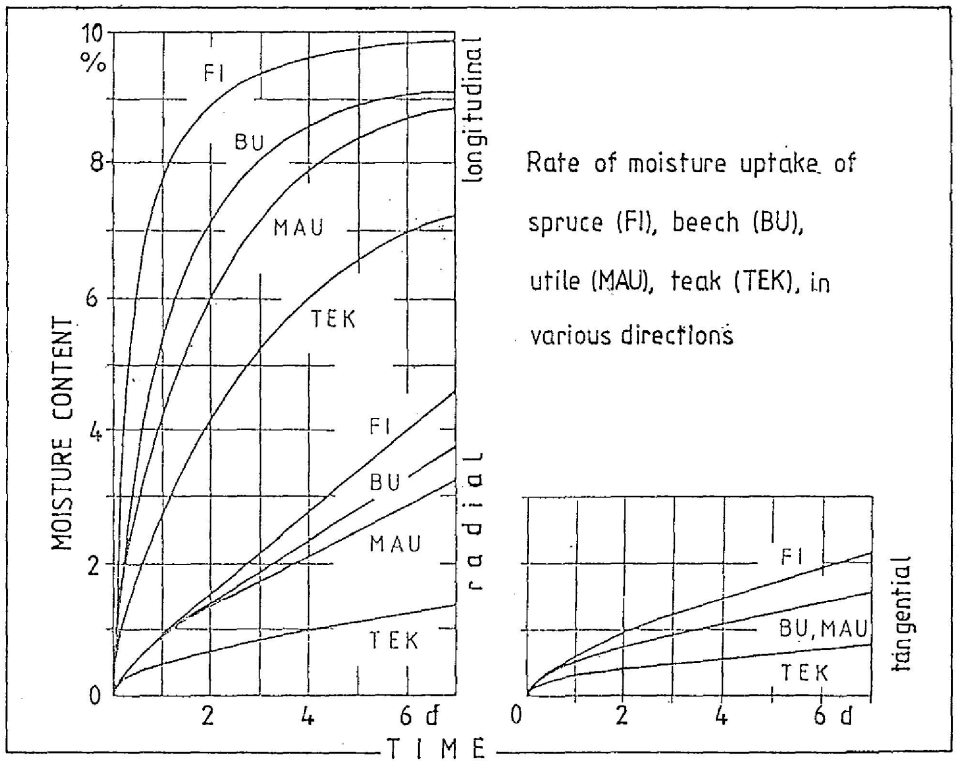

FIGURE 2. (SCHWAB 1992)

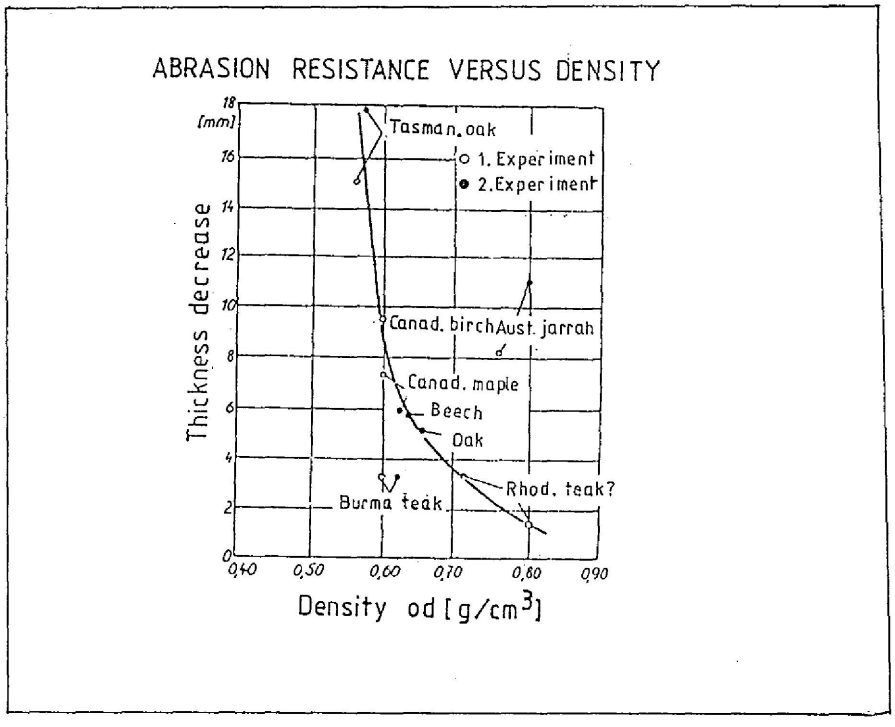

FIGURE 3. (KOLLMANN 1951)

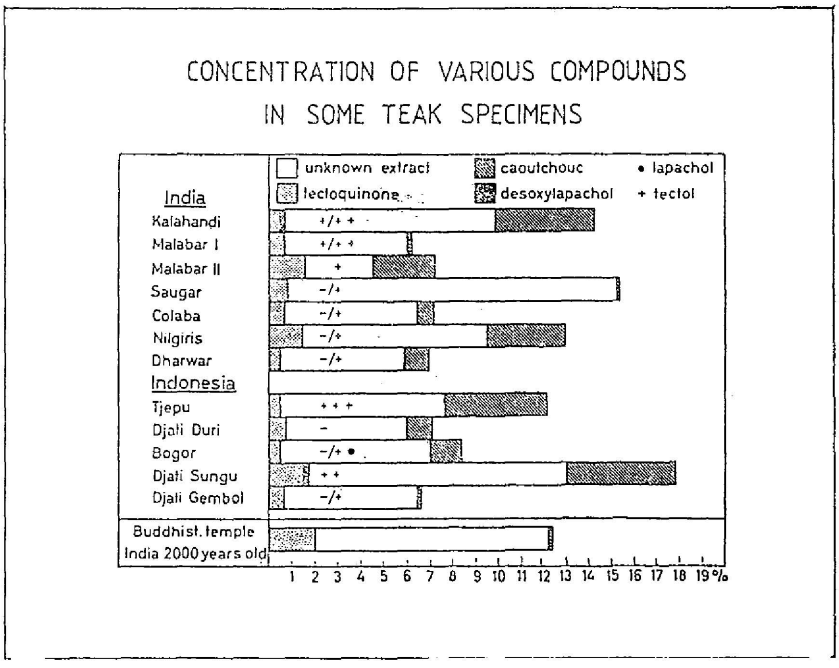

FIGURE 4. (SANDERMANN and SIMATUPANG 1961).

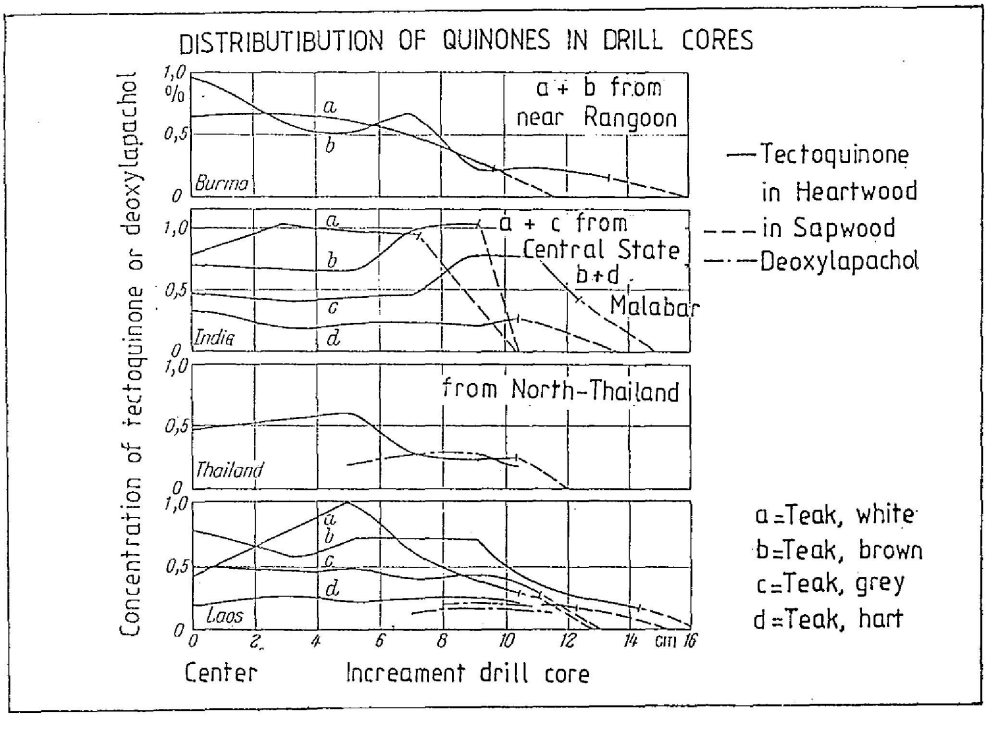

FIGURE 5. Drill cores of an increament borer of a teak plantation on Java cultivated from seeds from four countries.

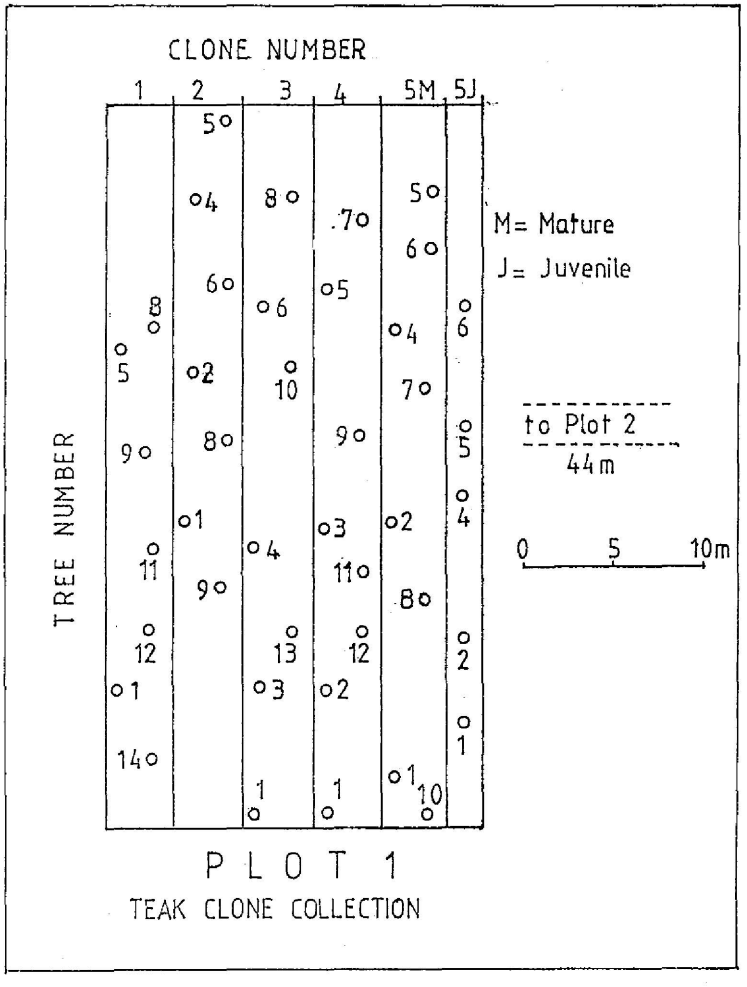

FIGURE 6. Schematic of teak clone collection at Thai-Danish Improvement Center, Ngao, Province Lampang, Thailand.

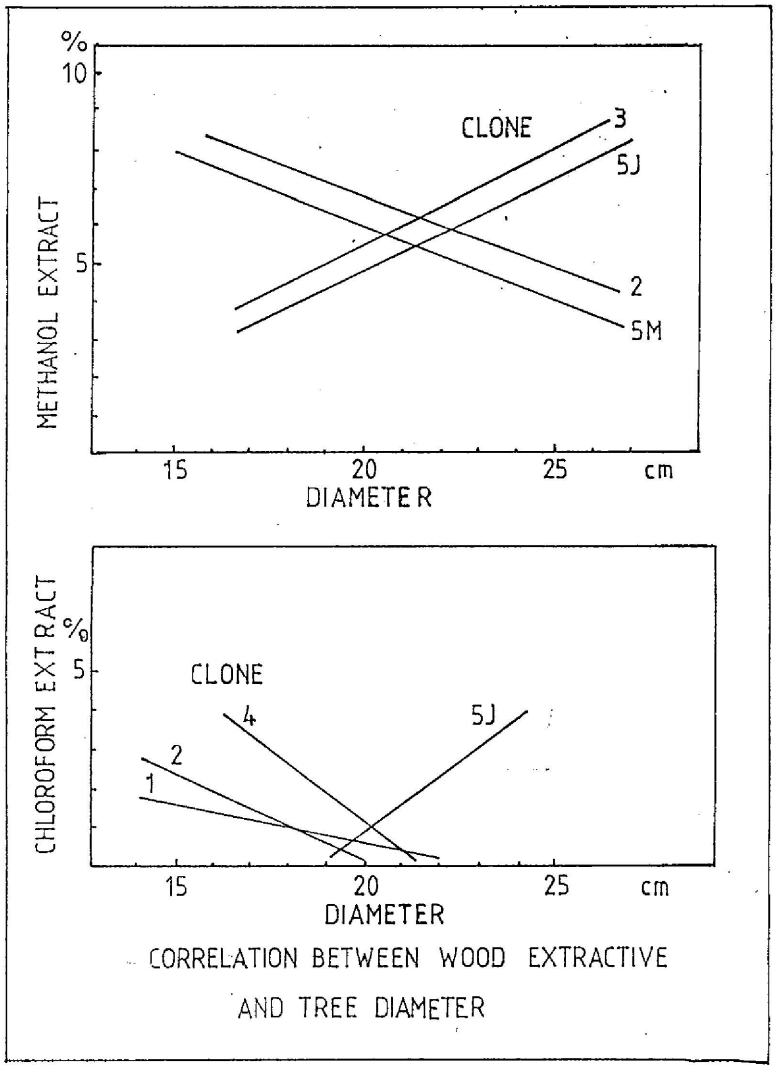

FIGURE 7. Correlation between wood extractives and tree diameter of the teak clones from Thailand (FIGURE 6).