TIMBER TECHNOLOGY BULLETIN

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Observations of Termite-Fungus Interactions of Potential Significance to Wood Biodeterioration and Protection

by

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1. Diversity of Malaysian termite fauna and mycoflora – a threat to timbers

The food of termites is essentially cellulosic materials. Degradation of wood by termites is a chronic problem in many tropical and even some temperate regions of the world, resulting in serious monetary and material losses with far reaching impact on the increasing demand for timber. In Peninsular Malaysia, the termite fauna is diverse, represented by three families, comprising a total of 175 species from 42 genera (Tho 1992), among which the subterranean termite *Coptotermes* appears to be the most prevalent genus foraging around buildings and in houses (Rath & Tidbury 1996, Tho & Kirton 1990), infesting also forest plantation living trees (Kirton *et al.* 1999). Additionally, termites of the genera *Schedorhinotermes*, *Globitermites*, *Odontotermes*, *Macrotermes* and *Microtermes*, are also reported as important pests in agricultural crops (Rath & Tidbury 1996), trees, logs, timbers and other cellulosic materials. There are far fewer Malaysian timber species nowadays with proven termite resistance (Grace *et al.* 1998, Wong *et al.* 1998), implicating that the vast remaining termite susceptible Malaysian woods would require some treatment to enhance their service life.

The humid tropics of Malaysia is also favourable for growth and development of decay fungi, where both white rot (Basidiomycetes) and soft rot (Ascomycetes and Deuteromycetes) decay are the most common types of fungal attack of Malaysian timbers (Wong & Pearce 1997, 1998). Studies have shown that many Malaysian timber species are susceptible to soft rot decay (Wong & Pearce 1998, Wong & Peek 1997). Another group, the sap-stain and mould fungi (loosely called the non-decay fungi) causes serious discoloration (Wong *et al.* 1999) of fresh-felled sapwood timbers without affecting the wood structure. It is well observed that termites are associated with fungi as joint colonisers and degraders of wood material (wood biodeterioration), while instances of fungal attack or termite infestation of wood materials occurring singly or the same structure are also observed. Hence observations of both positive (synergistic) and negative (antagonistic) interactions between the two groups of tropical degraders suggest a potential for tapping this information to develop strategies for wood protection and termite control in plantations and buildings.

2. Wood protection and termite control strategies available

Typical termite control strategies are designed to protect vulnerable timber structures and building components by establishing chemical barriers or physical barriers around buildings, thereby preventing the movement of termites from infected sites to the wood components in buildings. However, drenching or filling the soil around a building with hazardous termiticides or other non-degradable materials is not always effective against a broad spectrum of termite species, especially against drywood termites. Nor is soil treatment preferred in some industrialised countries concerned with the environmental pressures of certain soil termiticides.

Another option, widely used, is an industrial timber preservation system where wood can be treated against rot fungi and termites (Plate 1). Usually insecticides and fungicides are used in combination to provide protection for the wood. Currently wood preservatives used in Malaysia for permanent wood protection against decay fungi and/or termites are Copper-Chrome-Arsenic (CCA), Boron Compounds, Creosote, Light Organic Solvent Preservatives (LOSP) (Wong 1999), while anti-sapstain chemicals provide only temporary defence against stain and mould fungi (Wong *et al.* 1999).

However, given the varying hazardous nature of these industrial wood preservatives, yet another option is to seek potential microorganisms, which can control biological degradation of wood. A full fledge biological control option in wood protection is not yet available commercially, but has enjoyed some success in the control of insect pests in forestry and agriculture sectors. However biological control of termite attack of tropical timbers by fungi has been a recent area of interest, which requires a foremost understanding of the complex interactions between fungi and termites in the soil and wood environment. There are limited studies on biological control aimed to lessen the dependency on hazardous chemicals for termite control in wood protection (Hanel & Watson 1983, Milner *et al.* 1996, Ahmad Said & Yaacob 1997, Suzuki 1991,1995), although the findings have yet to be adopted commercially.

3. General categories of termite-fungus interactions

The susceptibility of wood to attack by a diversity of fungi and insects provides a rationale to investigate the mode of insect-fungus interactions that cause morphological, chemical or structural changes to the wood substrate. Termites are usually closely associated with fungi in the wood, due to the fact that conditions favourable for termite activity are also favourable for fungal growth *in situ* (Plates 2 to 5). When both these organisms occur together, they may become associated in a way so that they influence each other (Bakshi 1962), such as:

- Some termites cultivate fungus in their nests,
- Some fungi play their role as food for termites, and
- Some fungi exert injurious effects on the termites.

The association of termites and fungi could be further refined into four different aspects (Sands 1969), viz.:

- Fungi in relation to nutrition of termites,
- Fungi saprophytic in termite nests structure,
- Fungi parasitic or pathogenic to termites, and
- Termites as carriers of fungi.

These patterns of termite-fungus interactions present opportunities to determine specific fungal materials (eg. spores, metabolites) which are potentially useful for termite control strategies (biopesticides or bait systems) or even indirect termite identification *in situ* (through knowledge of associated fungus) in connection with termite-fungus symbiosis. Some research findings to unravel and demonstrate these interactions are provided below for clarity.

4. Types of termite-fungus interactions reported

The environment of termites normally includes a wide variety of fungi, some of which compete with them for the plant remains that provide their food. Such competition may lead to habitat partition and subsequently to the evolution of symbiotic and other synergistic interactions, antagonistic, pathogenic or parasitic relationship (Sands 1969). Some of these interactions may benefit future biological control approach to wood protection and termite control.

4.1 Termite-fungus symbiosis

Symbiosis is an interaction between individuals of different species, benefiting the participating species. Such a phenomenon in termite-fungi symbiosis is reported in Peninsular Malaysia on the edible termite mushroom (a Basidiomycete), *Termitomyces albuminosa*, shown in Figure 3. This fungus is cultivated by termites of the genus *Odontotermes* (Mah & Tho 1978). In another example, elsewhere an unknown fungus in the nest of the termite *Macrotermes gilvus*, helps to breakdown the cellulose in the termite nest while fungal spores and mycelium are eaten as food, especially by the larvae and nymphs (Tho 1978). More recently, the termite species *Macrotermes carbonarius* is reported to benefit from lignin degradation by another unknown fungus, eventually facilitating cellulose digestibility for the termite (Hyodo *et al.* 1999). These examples of termite-fungus symbioses are compiled in Table 1. It is likely that such symbioses provide indicators for the detection of particular termite and fungal species at a given site, given the known symbiotic relationship between the two organisms, and subsequent termite control operations.

Table 1. Examples of fungi symbiotic to termites

Fungus	Target termite
1. *Termitomyces albuminosa*	*Odontotermes* sp. (Mah & Tho 1978)
2. unknown	*Macrotermes gilvus* (Tho 1978)
3. unknown	*Macrotermes carbonarius* (Hyodo *et al.* 1999)

4.2 Fungi as precursors or attractants of termite attack

As termites do not produce cellulose-dissolving enzymes, the digestion of cellulose in the gut of termites is carried out with the aid of micro-fauna including possibly fungi, which occur in the intestine of termites (Bakshi 1962). It is commonly observed that damage to wood by termites is often preceded by fungal infection of the wood, where the enzymatic hydrolysis of cell-wall cellulose and/or lignin by the fungus, eventually aids in the digestibility of wood by termite (Bakshi 1962).

Since pre-decayed termite-susceptible, as compared to sound termite-susceptible wood is readily colonised by termites (French *et al.* 1987), some researchers have suggested using such materials to attract/bait large populations of termites in field studies involving wood durability and evaluation of preservative-treated wood against subterranean termites. On the other hand, the existing fungus-termite interactions in nature suggest that determining the termite resistance of woods from in-ground or above-ground field tests would be partially meaningful, if these woods are found to be simultaneously colonised by fungi and termites in such tests (Plate 4).

In situations where brown rot fungi are prevalent, wood colonised by brown rot fungi surpassed both white rot and soft rot fungi as being relatively more attractive to termite feeding (Tho 1992). Even the common Malaysian strain of the blue stain fungus, *Botryodiplodia theobromae*, which attacks rubberwood and several other Malaysian light hardwoods, is found to be as attractive to termites as the decay fungi (Plate 5).

The various degrees of attraction of termites to the various soil fungi (both decay, stain or mould fungi) have also been demonstrated (French *et al.* 1987, Tho 1992). Examples of fungi studied as attractants of termites are given in Table 2.

Table 2. List of a few fungi that has been studied for attractants for certain termite species

Fungus	Target termite
1. *Coniophora olivacea*	*Coptotermes lacteus* (French *et al.* 1987)
2. *Poria monticola*	*Microcerotermes beesoni* (Tyagi *et al.* 1984)
3. *Botryodiplodia theobromae*	*Microcerotermes beesoni* (Tyagi *et al.* 1984)

4.3 Fungi as antagonists of termites

Although some decay and sapstain fungi have been reported to favour termite attacks in wood (Figures 4 and 5), one field study (Amburgey & Beal 1977) however indicated an antagonistic effect when Southern pine stakes colonised by white rot fungi were not a preferred food for the subterranean termite, *Reticulitermes* spp.. It was also reported that the metabolite (termed fungal siderophore) of the brown rot fungus *Gloeophyllum trabeum* deterred feeding of the *Coptotermes formosanus* (Grace *et al.* 1992). These examples (Table 3) show that in some cases decayed wood is not always attractive to termites, possibly due to the potency (antagonism) of the fungal siderophores. It is thus likely that certain fungal metabolites could be utilised as bioprotectants against termites.

Table 3. Examples of fungi antagonistic to termites

Antagonistic fungi	Target termite
1. *Gloeophyllum trabeum* metabolite	*Coptotermes formosanus* (Grace *et al.* 1992)
2. *Ganoderma applanatum*	Unknown (Amburgey & Beal 1977)

4.4 Fungi as insect pathogens of termites

Fungi are regarded as pathogens of a host if the organisms permeate and poison the host quickly. For example, it was reported that the fungus *Conidiobolus xoronatus*, isolated from diseased termite workers, was entomopathogenic on termites in the laboratory, since the presence of dead worker termites infected by *C. coronatus*, had a strong pathogenic effect on the other sound workers (Yoshimura *et al.* 1992). In another example (Suzuki 1995), the mould fungi *Metarhizium anisopliae*, *Paecilomyces fumosoroseus*, *Beauveria bassiana* and *Aspergillus niger* were effective pathogens to the subterranean termite, *Coptotermes farmosanus* and *Reticulitermes speratus* while the stain fungus *Cladosporium cladosporioides* was ineffective. Table 4 shows some fungi with potential as pathogens of termites.

Similarly, successful use of *Metarhizium anisopliae* for termite control via infection of the Australian termite colony of *Coptotermes acinaciformis*, *C. frenchi* and *Nasutitermes exitiosus* with fungal conidia or spore is reported (Milner *et al.* 1996). From this, various options for using *M. anisopliae* as biological insecticides in the field are recommended (Kirton *et al.* 1999), such as:

- Direct application to the termite nest,
- Spraying directly on to and/or into timber structure or infected timber structure,
- Mixing of conidia into soil to create a barrier around timber structure, and,
- Use of the fungus as the controlling agent in bait system and the spore will be carried by the termite to the nest and introduced to other healthy termites.

An illustration of a typical laboratory petri-dish fungal pathogenicity test is extracted from Suzuki (1991, 1995) showing that some test termites were killed by *Metarhizium anisophliae* in the dish containing termite-susceptible wood blocks and filter paper pre-infected by this fungus (Plate 6). Significant pathogenic effects displayed by many fungi, reported in the literature, holds promise for utilising selected fungi for biological control of termites in buildings and plantation forest trees.

Table 4. List of some fungi as potential pathogens of termites

Pathogenic fungus	Target termite
1. *Metarhizium anisopliae*	*Coptotermes formosanus* (Suzuki 1991, 1995)
	C. acinaciformis (Milner *et al.* 1996, Ahmad Said *et al.* 1997)
	C. frenchi (Milner *et al.* 1996)
	Reticulitermes speratus (Suzuki 1991, 1995)
	Nasutitermes exitiosus
	(Hanel & Watson 1983, Milner *et al.* 1996, Ahmad Said *et al.* 1997)
2. *Beauveria bassiana*	*C. formosanus* (Suzuki 1991, 1995)
	R. speratus (Suzuki 1991, 1995)
3. *Conidiobolus coronatus*	*C. curvignathus* (Ahmad Said & Yaacob 1997)
4. *Paecilomyces fumosoroseus*	*C. formosanus* (Suzuki 1991, 1995)
	R. speratus (Suzuki 1991, 1995)
5. *Aspergillus niger*	*C. formosanus* (Suzuki 1991, 1995)
	R. speratus (Suzuki 1991, 1995)

4.6 Fungi as parasites of termites

There is a vague distinction between parasitism and pathogenicity of fungi, which makes detection of parasitic fungi problematic. Nevertheless, fungi are regarded as being parasitic if the organisms can be clearly demonstrated to invade and feed on the host slowly without exerting marked toxic effects until the development of the fungal coloniser on the host is complete.

Apparently only a few fungi, mainly those of the Ascomycetes or Deuteromycetes, are parasitic on termites. The genus *Termitaria* is a well-known example, while others belong to the genera such as *Laboulbenia*, *Antennopsis* and *Cordycepioideus* (Suzuki 1995). Table 5 shows examples of fungi parasitic on termites. It is conceivable that there may be several other fungi awaiting detection as potential parasites of termites.

While the discovery of true parasitic fungi would also offer promise for future biological control of termites, research currently emphasises on developing the development of bioprotectants from pathogenic fungi instead.

5. Conclusion

Given the relative hazards of wood preservatives available to protect timbers against degradation by termites and fungi, options for non-toxic treatments such as biological control of wood degradation are being explored for future use. Already

Table 5. Summarised list of a few fungi as parasites of termites

Parasitic fungus	Termite
1. *Laboulbenia hageni*	*Macrotermes bellicosus*
2. *Termitaria snyderi*	*Reticulitermes flavipes*
	R. virginicus
	R. lucifungus
3. *T. coronata*	*Nasutitermes costalis*
4. *Antennopsis gallica*	*Kalotermes flavicollis*

Source: Sands (1969)

studies have been initiated to unravel the interactions between termites and fungi in natural ecosystems, which helps pave the way to a future application of certain potential fungi, particularly pathogenic strains, as bioprotectants to control termite degradation of wood products.

Of potential significance too, certain decayed woods can provide effective baits of termites in wood protection research work, perhaps even increasing the effectiveness of commercial bait toxicant systems for termite control.

Acknowledgement

Plate 3 was extracted with permission from the book entitled: "Windows on the forest: glimpses of FRIM for the nature loving visitor" by L. Ratnam (1995) 2nd Edn. 1997, Forest Research Institute Malaysia, FRIM Special Publications No. 1, 143 pp.

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Plate 1. Industrial wood preservation system versus future bioprotection of wood - detailed information on termite-fungus interactions is needed to devise methods for biological control of termite attack in wood

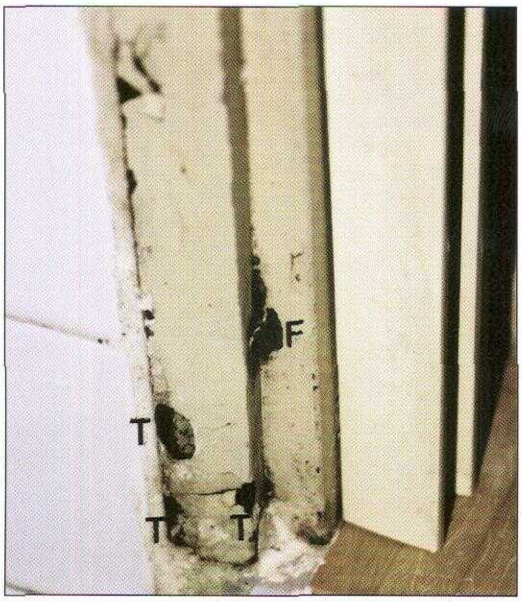

Plate 2. Part of a door-frame simultaneously attacked by subterranean termites (T) and unknown Basidiomycete (F) at the same location of the wood . An evidence of symbiotic and other synergistic termite-fungus interaction?

Plate 3. *Termitomyces* sp. cultivated by subterranean termite species – a symbiotic interaction (Source: Ratnam 1995)

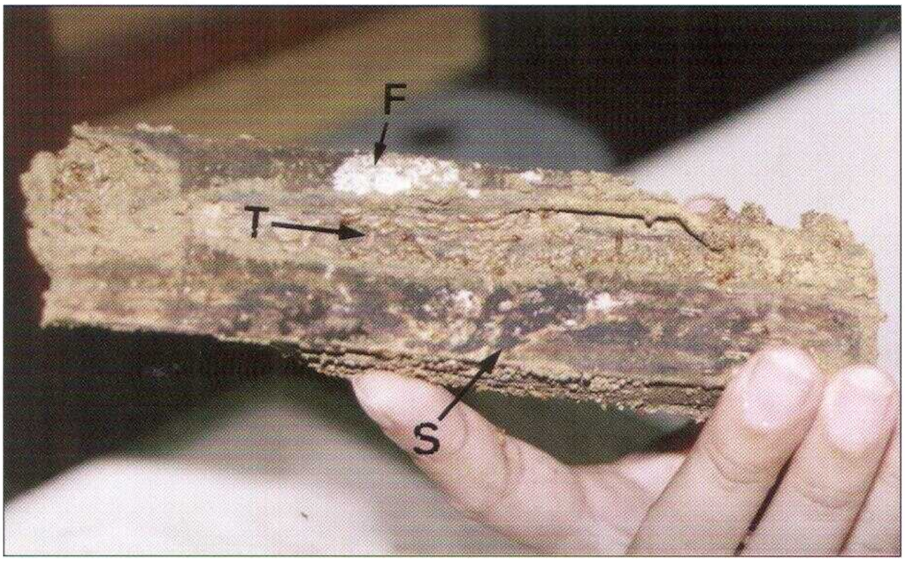

Plate 4. Wooden stake previously degraded by stain (S) and decay fungi (F) and subsequently attacked by subterranean termite (T) – indication of synergistic interactions

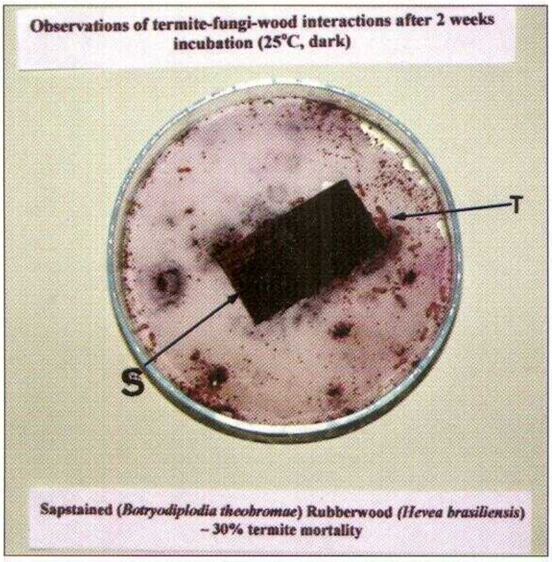

Plate 5. Blue-stained (S) rubberwood readily attacked by subterranean termite species (T)

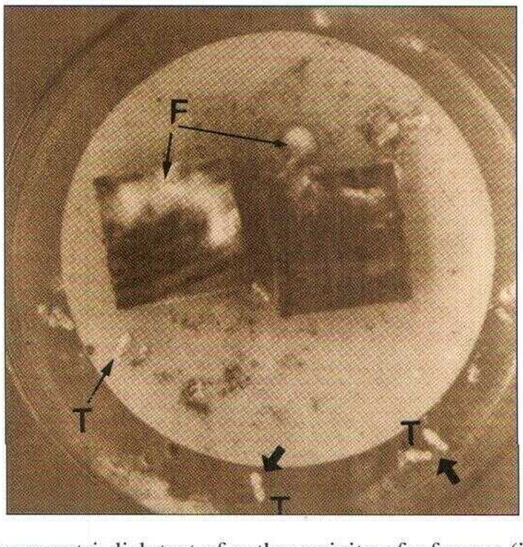

Plate 6. A typical laboratory filter paper petri-dish test of pathogenicity of a fungus (in this case *Metarhizzium anisopliae*) against subterranean termites (T) using fungal infected (F) termite-susceptible wood blocks. Some termites were killed by the fungus (➔) (Source: Suzuki 1995)

BACKGROUND INFORMATION

1. **Tree type and distribution**

The distribution and size of tree are given.

2. **Wood characteristics**

The colours of sapwood and heartwood, figure, appearance on planed surface and any other characteristic features of the timber.

3. **Timber classification**

Under the Malaysian Grading Rules (1984), timbers are classified as Heavy Hardwood (HHW) when their density exceeds 800 kg m^{-3} and the timbers are naturally durable. Medium Hardwoods (MHW) are timbers with density exceeding 729 kg m^{-3} but lack sufficient natural durability. Light Hardwoods (LHW) are timber with density below 720 kg m^{-3} and not naturally durable in exposed condition.

4. **Wood density**

Green density of freshly sawn board, defined as green mass divided by green volume. It varies with the freshness of the log in the log yard before processing and seasoning. Air dry density is the average mass divided by volume at 15 per cent moisture content.

5. **Drying and relative movement**

Air drying time for 13 mm and 40 mm boards and moisture content are from Grewal (1979). "Air-seasoning Properties of Some Malaysian Timbers", Timber Trade Leafet No. 41. Suitable kiln drying schedule is mentioned [Schedules based on Grewal (1988) , "Kiln Drying Characteristic of Some Malaysian Timbers", Timber Trade Leaflet No.42]. The relative movement (whenever is available) is defined as the change in dimension of a piece of timber when exposed to the service conditions of 60% RH/ 30 °C and 95% RH/ 30 °C respectively, and expressed as percentage of the value at 60% RH/ 30 °C. The movement ratings stated are based on values of the corresponding tangential movement [Choo *et al.* (1998),"Movement of Seasoned Timber in Service", FRIM Technical Information Handbook No. 18].

Movement rating	Tangential movement
Class I	< 1.5 %
Class II	1.5% to 2.0%
Class III	2.1% to 2.5%
Class IV	2.6% to 3.0%
Class V	> 3.1 %

6. **Machining properties**

Comments are made on the comparative ease or difficulty of sawing, planing, turning, boring, peeling, gluing and other wood working properties.

7. **Durability**

Durability ratings of Malaysian Timbers are based on performance of test-sticks in graveyard testing. Test-stakes of 50 x 50 x 600 mm are buried in test grounds and their performance monitored. The number of years that the timber can last under such conditions is used to classify the durability of the timber. Under the system, timbers are classified as follows;

Rating	Number of years
Very durable	more than 10 years
Durable	5-10 years
Moderately durable	2-5 years
Non-durable	0-2 years

Susceptibility to fungal and termite attacks may be mentioned.

8. **Strength grouping**

In the strength grouping of timber under each trade name, ranking is allocated from A (strongest) to D (weakest). Minimum values for strength groups based on common grade for dry timber (below 19% moisture content) (units are in MPa).

Strength group	A	B	C	D
Modulus of elasticity	9700	6600	5500	3100
Bending and tension parallel to grain	12.41	9.65	7.24	4.83
Compression parallel to grain	11.03	7.93	5.51	4.14
Compression perpendicular to grain	1.45	0.90	0.55	0.45
Shear parallel to grain	1.45	0.90	0.62	0.62

9. **Strength properties**

Values are from Lee *et al.* 1979, "The Strength Properties of Some Malaysian Timbers". Malaysian Forest Service Trade Leaflet No. 34.

10. **Uses**

Various past and potential uses are given, but the list is obviously not exhaustive.