



UNIVERSITI PUTRA MALAYSIA

***FEEDING PREFERENCE OF SUBTERRANEAN TERMITE
COPTOTERMES CURVIGNATHUS HOLMGREN (INSECTA:
ISOPTERA: RHINOTERMITIDAE) ON SELECTED TIMBER SPECIES***

CHAN SEOW PHAN

**Ip
FSPM 2008 12**

**FEEDING PREFERENCE OF SUBTERRANEAN TERMITE
COPTOTERMES CURVIGNATHUS HOLMGREN (INSECTA: ISOPTERA:
RHINOTERMITIDAE) ON SELECTED TIMBER SPECIES**

By

CHAN SEOW PHAN

**A Project Report Submitted in Partial Fulfillment of the Requirement for the
Bachelor of Science Bioindustry in the
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia Bintulu Campus**

2008

ABSTRACT

Feeding preference of *Coptotermes curvignathus* on ten selected planted tree species, namely *Acacia mangium*, *Acacia auriculiformis*, *Acacia crassicarpa*, *Eucalyptus* hybrid, *Macaranga gigantea*, *Gmelina arborea*, *Tectona grandis*, *Azadirachta excelsa*, *Hevea brasiliensis* and *Pentaspadon motleyi* were determined using four feeding preference tests. It consists of a multiple choice test using both fresh and oven-dried wood (sapwood and heartwood), and force feeding test and multiple choice test within a single harbourage using oven-dried wood (sapwood and heartwood). Rubber wood (*H. brasiliensis*) was significantly preferred with total consumption of 554.97 mg, 391.63 mg, 179.78 mg and 159.83 mg in all preference test respectively. This is followed by *P. motleyi* with total consumption of 215.47 mg, 165.39 mg, 146.07 mg and 81.22 mg respectively. The least preferred species were *A. crassicarpa*, *T. grandis*, *A. mangium*, *M. gigantea*, *E. hybrid*, *A. auriculiformis*, *G. arborea* and *A. excelsa* in descending order where most of them were non significantly different or with minor significant level in certain test. The significant preference in sapwood was also seen in total consumption of 163.03 mg, 151.40 mg and 51.49 mg compare to heartwood with total consumption of 91.73 mg, 46.22 mg and 22.85 mg in all test except multiple choice test with oven-dried wood with no difference between them. This result concluded the high potential of pelajau as bating matrix besides rubber wood in peat soil oil palm plantation and timber plantation sectors.

ABSTRAK

Ujian untuk menentukan kegemaran *Coptotermes curvignathus* terhadap sepuluh jenis tanaman ladang hutan iaitu *Acacia mangium*, *Acacia auriculiformis*, *Acacia crassicarpa*, *Eucalyptus hybrid*, *Macaranga gigantea*, *Gmelina arborea*, *Tectona grandis*, *Azadirachta excelsa*, *Hevea brasiliensis* dan *Pentaspadon motleyi* telah dijalankan dengan menggunakan empat jenis ujian. Ujian tersebut terdiri daripada ujian pelbagai pilihan makanan dengan menggunakan kayu segar dan kayu yang dikeringkan dengan ketuhar (kayu gubal dan kayu teras), dan ujian pemakanan paksaan serta ujian pelbagai pilihan makanan tanpa ruang makanan dengan menggunakan kayu yang telah dikeringkan (kayu gubal dan kayu teras). Kayu getah (*H. brasiliensis*) merupakan kayu yang paling digemari dengan jumlah jisim yang dimakan sebanyak 554.97 mg, 391.63 mg, 179.78 mg dan 159.83 mg dalam setiap ujian. Kegemarannya diikuti dengan kayu pelajau dengan jumlah jisim yang telah dimakan sebanyak 215.47 mg, 165.39 mg, 146.07 mg and 81.22 mg masing-masing. Antara spesies tanaman ladang hutan yang kurang diminati adalah *A. crassicarpa*, *T. grandis*, *A. mangium*, *M. gigantea*, *E. hybrid*, *A. auriculiformis*, *G. arborea* and *A. excelsa* mengikut urutan menurun kerana terbukti tiada perbezaan secara statistik dan mempunyai perbezaan yang tidak ketara dalam sesetengah ujian. Kegemaran *C. curvignathus* terhadap kayu gubal juga terbukti secara statistik lebih daripada kayu teras, dengan jumlah jisim yang dimakan sebanyak 163.03 mg, 151.40 mg dan 51.49 mg berbanding dengan 91.73 mg, 46.22 mg and 22.85 mg. Tetapi, tiada perbezaan secara statistik didapati dalam ujian pelbagai pilihan makanan yang menggunakan kayu yang dikeringkan antara kedua-dua bahagian tersebut. Secara kesimpulannya, selain daripada kayu getah pelajau mempunyai potensi yang tinggi untuk digunakan

sebagai bahan pengumpan dalam ladang kelapa sawit dan ladang perhutanan atas tanah gambut.



ACKNOWLEDGEMENT

Kindness is the language which the deaf can hear and blind can see

(Mark Twain)

I have learnt so much in the course of conducting this project and I am indebted to many people. These people have aid me in many ways during this time.

First and foremost, I would like to extend my heartfelt gratitude and appreciation to my supervisor, Assoc. Prof. Dr. Joseph Bong Choon Fah for his invaluable support, advice and guidance for me throughout the course of this final year project.

I would also like to extend my immeasurable gratitude to Dr. Ong Kian Huat for his advice, the Sentang samples and his expertise. The gratitude is also forwarded to Assoc. Prof. Dr. Rajan Amartalingam for guidance in correcting my thesis and his advice in my statistical analysis for the experiment.

A word of thanks also forwarded to Mr. Flor Agbayani and his staff of the Research and Development Department of Grand Perfect Sdn. Bhd. for their Acacia samples, hospitality and their advice.

The word of thanks is also forwarded to Mr. Semsolbokhari for allowing me to use his wood technology laboratory and providing me with all the material needed. This appreciation is broaden to laboratory assistant Mr. Arni and Mr. Muish

for advice, guidance and his free time. A word of gratitude is also forwarded to staff of the Landscape Department, Mr. Effendi and Mr. Haidir for their help during my sampling period.

My sincere thanks also goes to all the staffs at the Department of Crop Sciences, Universiti Putra Malaysia Bintulu Campus, especially to the lab assistants who had helped me in finding and providing me with the materials I needed to run the experiments. This word of thanks is especially forwarded to Mdm. Siti Fatimah from the Biotechnology and Molecular Biology Laboratory and Mr. Suring from the Wood technology Laboratory.

A graceful thank you is forwarded to all my friends cum seniors for supporting me throughout the period of this final year project. They are especially Miss Hoe Pik Kheng, Miss Lee Jia Huey, and Mr. Lim Guan Miaw. They have helped in me every way that friends help one another in this project; from encouragement and support to opinion and suggestion for the project and mostly of their experience. I would also like to extend a word of thanks to my friends cum course mate of Bachelor of Science Bioindustry, Lau Kah Ho, Wong Ling Chie and Tan Wee Cheat for all their help and aid in every manner throughout this long journey of carrying out this final year project. I shall cherish your friendship always. This word of thank you is also extended to my juniors cum friends of Bachelor of Science Bioindustry, Cheah Poh Meng and Chok Chun Kit for their free time and help during the completion of the project.

Finally, I would like to say a word of thank you to my family; my dad, mum, two brothers and my deceased grandmother for their love, support and encouragement not only during this period of time but in every seconds of my life. I love you all.

There are many people that had helped me in this project. I may have left out their names but I really do appreciate all they had done very much.

Thank you.



I certify that this research project report entitled “Feeding preference of subterranean termite, *Coptotermes curvignathus* Holmgren (Insecta: Isoptera: Rhinotermitidae) on selected timber species” has been examined and approved as a partial fulfillment of the requirement of the degree of Bachelor of Bioindustry Science in the Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Campus.

Assoc. Prof. Dr. Joseph Bong Choon Fah
Supervisor
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia Bintulu Campus

Assoc. Prof. Dr. Japar Sidik Bin Bujang
Dean
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia Bintulu Campus
Date: 24-09-2028

TABLE OF CONTENT

ABSTRACT	ii
ABSTRAK	iii
ACKNOWLEDGEMENTS	v
APPROVAL	vii
TABLE OF CONTENT	viii
LIST OF TABLES	xi
LIST OF FIGURES	xiii
LIST OF ABBREVIATIONS	xiv
CHAPTER	
1 INTRODUCTION	1
2 LITERATURE REVIEW	4
2.1 Biological description of subterranean termite, <i>Coptotermes curvignathus</i> Holmgren	4
2.2 Plantation forestry	6
2.3 Properties of planted timber species	7
2.3.1 <i>Acacia auriculiformis</i> A. Cunn. Ex Benth	7
2.3.2 <i>Acacia mangium</i> Willd	9
2.3.3 <i>Acacia crassicarpa</i> A. Cunn. Ex. Benth	10
2.3.4 Rubber tree, (<i>Hevea brasiliensis</i> Kunth. Muell.)	11
2.3.5 Sentang (<i>Azadirachta excelsa</i> (Jack) Jacobs)	12
2.3.6 Teak (<i>Tectona grandis</i> Linn. F.)	13
2.3.7 <i>Gmelina arborea</i> Roxb.	14

2.3.8	Mahang (<i>Macaranga gigantea</i> (Rchb. f. and Zoll.) Mull. Arg.)	16
2.3.9	<i>Eucalyptus</i> hybrid	17
2.3.10	Pelajau (<i>Pentaspadon motleyi</i> Hook.f.)	18
2.4	Damage to crops and timber	19
2.5	Wood preference and feeding activities	21
3	METHODOLOGY	27
3.1	<i>Coptotermes curvignathus</i> culture	27
3.2	Wood blocks	27
3.3	Experiment 1: Multiple choice feeding with oven-dried woods (heartwood and sapwood)	29
3.4	Experiment 2: Multiple choice feeding test using fresh woods (heartwood and sapwood)	31
3.5	Experiment 3: Force feeding test using oven-dried wood (heartwood and sapwood)	32
3.6	Experiment 4: Multiple choice tests using oven-dried within a same harbourage (heartwood and sapwood)	33
4	RESULTS	34
4.1	Multiple choice test using oven-dried wood (heartwood and sapwood)	34
4.2	Multiple choice test using fresh wood (heartwood and sapwood)	35
4.3	Force feeding test using oven-dried wood (heartwood and sapwood)	37
4.4	Multiple choice tests using oven-dried within a same harbourage (heartwood and sapwood)	39

5	DISCUSSION	42
6	CONCLUSION	46
	REFERENCES	47
	APPENDICES	52



LIST OF TABLES

Tables	Page
3.1 Species of planted forest trees for multiple choice test	28
4.1 Oven-dried wood consumption by <i>Coptotermes curvignathus</i> for multiple choice test	34
4.2 Comparison between parts of wood (oven-dried) of all tree species consumed by <i>Coptotermes curvignathus</i>	35
4.3 Fresh wood consumption by <i>Coptotermes curvignathus</i> from multiple choice test	36
4.4 Comparison between parts of wood (fresh) of all tree species consumed by <i>Coptotermes curvignathus</i>	36
4.5 Comparison between parts of wood (fresh) of each species consumed by <i>Coptotermes curvignathus</i>	37
4.6 Comparison of wood (oven-dried wood, sapwood and heartwood) consumed in a force feeding test.	38
4.7 Comparison between parts of wood (oven-dried) of all tree species consumed by <i>Coptotermes curvignathus</i>	38
4.8 Comparison between parts of wood (oven-dried) of each species consumed by <i>Coptotermes curvignathus</i>	39
4.9 Comparison of wood consumed (oven-dried wood, sapwood and heartwood) by <i>Coptotermes curvignathus</i> in a multiple choice test without feeding chamber	40
4.10 Comparison between parts of wood (oven-dried) of all tree species consumed by <i>Coptotermes curvignathus</i>	40

4.11	Comparison between parts of wood (oven-dried) of each species consumed by <i>Coptotermes curvignathus</i>	41
------	---	----



LIST OF FIGURE

Figure		Page
3.1	Multiple choice feeding test, apparatus setting	30



LIST OF ABBREVIATIONS

α	Alfa
mg	Milligram
kg	Kilogram
°C	Degree Celcius
RH	Relative Humidity
DNMRT	Duncan's New Multiple Range Test
%	Percent
kGy	Kilo Gray
mm	Mili metre
TFGTS	Tropical fast-growing tree species
N	Nitrogen
ha	Hectare
yr	Year
e.g.	Example
m ³	Cubic metre
NaOH	Natrium hydroxide
cm	centimetre
Kcal	Kilo calory
MC	Moisture content
ca.	Average consumption
g	Gram
FC	Feeding Chamber
ANOVA	Analysis of Variances

UV

Ultra violent



CHAPTER 1

INTRODUCTION

Termites are social insects comprise in the Order of Isoptera. They are categorised into 7 families; Mastotermitidae, Kalotermitidae, Hodotermitidae, Termopsidae, Rhinotermitidae, Serritermitidae and Termitidae (Krishna and Weesner, 1969).

Coptotermes curvignathus, under the subfamily of Rhinotermitidae had caused a lot of damages in the oil palm plantation especially in Indonesia (Sudharto *et al.*, 1991) and had become a serious pest to other plantations in the South East region (Wood, 1968; Zulkefli *et al.*, 2000; Lim and Silek, 2001). They have been reported to damage forest trees and crops in the peat swamp forests such as Anacardiaceae (*Camposperma* spp.), Dipterocarpaceae (*Shorea* spp.), Sapotaceae (*Palaquium* spp.), coconut (*Cocos nucifera*) (Sudharto *et al.*, 1991), *Acacia mangium* (Chey and Intachat, 2000), rubber (*Hevea brasiliensis*), mango (*Mangifera* spp.), and papaya (*Carica papaya*) (Khoo *et al.*, 1991; Sudharto *et al.*, 1991).

Many methods had been applied for controlling termite infestation. The most popular methods include chemical control using organophosphorous insecticide such as Chlopyrifos, Alphamethrin and Aluminium phosphide, mechanical control by eradicating the queen and caste off the main nest and biological control using entomopathogenic fungi for instances, *Beauveria* spp., *Paecilomyces* spp., and some strains of *Metarhizium anisopliae*. However, only biological control (Sudharto *et al.*, 1991) and termite baiting (Lim and Silek, 2001) seem to be able to avoid the

damages caused by *C. curvignathus* in oil palm plantation, especially in recently developed peat soil areas and deep peat.

Plantation forestry nowadays play an important role in providing sufficient demand for wood and wood derivatives, other roles include provide working opportunity and infrastructure development and prevent soil degradation (Ti and Tangau, 1991). Some of the preferred species such as *Tectona grandis*, *Durio zibethinus*, *Hevea brasiliensis*, *Acacia mangium* and *Gmelina arborea* are selected for their special characteristic (Appanah and Weinland, 1993). As Malaysian government acknowledge the importance of planted forest, the Sarawak Government commissioned a mega cultivation of Acacia trees in Bintulu Division. The total area cultivated is around 54, 000 hectares between 2003 and 2005.

Little is known about the foraging preference of *Coptotermes curvignathus*. Ngee *et al.* (2004) had done a preference test using 15 kinds of Malaysian and Japanese heartwood. There are several reports on wood preferences of *Coptotermes formosanus* (Katsumata *et al.*, 2006; Nakayama *et al.*, 2005; Nakayama *et al.*, 2004; Chen and Henderson, 1996) and of *Incisitermes minor* (Indrayani *et al.*, 2007). However, there is no detailed study done on wood preferences on planted forest tree species.

Therefore, the study is conducted to study the feeding preference of subterranean termite *Coptotermes curvignathus* on selected planted species. The objective of the study is to determine more suitable woods for potential use as a

baiting system and comparing preferences of oven-dried and fresh woods, heartwood and sapwood.



CHAPTER 2

LITERATURE REVIEW

2.1 Biological description of subterranean termite, *Coptotermes curvignathus* Holmgren

Termites are social insects of the Order Isoptera. They are categorised into 7 families, namely Mastotermitidae, Kalotermitidae, Hodotermitidae, Termopsidae, Rhinotermitidae, Serritermitidae and Termitidae. Under the family of Rhinotermitidae, there are 6 subfamily; Psammotermitinae, Heterotermitinae, Stylotermitinae, Coptotermitinae, Termitogetoninae, and Rhinotermitinae (Krishna and Weesner, 1969).

Termites of Rhinotermitidae are all wood feeders that are distributed widely around the tropical, sub tropical and temperate regions, but there are no endemic genera in Africa. They also inhabit a very wide range of habitats from wet to dry (Eggleton, 2000).

Generally, subterranean termites are termites that live and build their nests underground and or in mounds above ground, up the trees or in sheltered places where constant moisture can be obtained. All termite individuals are differentiated into various morphological forms or castes which exhibit division of labour, performing different biological function. Their specific roles are reproduction by the Queen and King, defend system by the soldiers and labour by the workers. The termites live in highly organised and integrated units within the societies or colonies (Krishna and Weesner, 1969).

Coptotermes curvignathus Holmgren is the largest in size among all oriental *Coptotermes* species. The workers are yellowish in colour and have a much darker head compare to the pronotum and brownish yellow abdominal tergites. They possess a light brownish yellow forewing scale, which are paler than bases of wings; the wings base is also encrustated and strongly brown on the base. The hairs in the wings are dense and relatively long. The pronotum in the middle is strongly emarginate than in *Coptotermes formosanus*, while whitish yellow meso and meta-notum are located towards the anterior. The termite possessed 8 branches of widely separated cubitus and 20-21 segment of antenna (Thapa, 1977).

The soldier has distinct head which is yellow or orange in colour, yellowish antennae, labrum and pronotum, whitish anteclypeus, dark reddish brown mandible and pale abdominal tergites and leg. As for the external anatomy, it has an oval head capsule, large fontanelle, and an antenna with 15-16 segments. The labrum is slightly longer than wide, and the mandibles are sabre-shaped and strongly incurved apically. The postmentum is more than twice as long as wide anteriorly at widest point as posteriorly at waist. The pronotum is emarginated in anterior and posterior margins. The anterolateral corners are narrowly rounded and lateral margins nearly straight with sloping posteriorly, while posterolateral corners are broadly rounded. Finally, they have long legs, with hind tibia around 1.20-1.25 mm and apical tibial spurs at 3: 2: 2 (Thapa, 1977).

2.2 Plantation forestry

Plantation forestry enhances the creation of wood resources to meet the demand of wood and wood products. It yields many kinds of resources for different sizes and types of products such as pulpwood, fuelwood crops, veneer logs and many more. Moreover, it also contributes to the growth of a country by providing high level of employment opportunities because plantation establishment is labour intensive. Furthermore, forest plantation catalyzes the development of infrastructure such as roads, hospitals, services, communication, shops and schools to the remote area of the plantation. Nevertheless, it also provides the benefits of integration of tree planting with other land-uses and role of forest to the environment (Ti and Tangau, 1991).

Planted forest trees, also known as tropical fast-growing tree species (TFGTS) are fast growing trees because of shorter rotation or life cycle compare with other tropical trees in natural forests. Thus, TFGTS are able to provide adequate coverage on denuded, open or degraded forest land in a relatively shorter time, while investor of forest plantation will have shorter gestation period. Selection of preferred tree species in an area for plantation development are influenced by suitability of species to site, resistance to pest and disease, popularity and marketability, the end use product, drought tolerance, suitable tree form and fast growth rate and, the cost of establishment. Some example of potential planted forest trees includes *Tectona grandis*, *Durio zibethinus*, *Hevea brasiliensis*, *Acacia mangium*, *Gmelina arborea* and etc. (Ti and Tangau, 1991).

2.3 Properties of planted timber trees

2.3.1 *Acacia auriculiformis* A. Cunn. Ex Benth

The plant is distributed in New Guinea, Kai Islands and Queensland and Northern Territory. It is also planted in plantations and naturalised in western Malesia. It is often used as wattle (poles) in house building, furniture making and veneer. It is also employed for pulp and firewood. The bark is collected locally as tanning material and lastly use as an ornamental wayside tree to control erosion and provide shade especially in western Malesia (Lemmings *et al.*, 1995).

Acacia auriculiformis wood consists of 66% holocellulose, 35% α -cellulose, 31% lignin, 16% pentosan and 1.5% ash; the solubility is 3.8% in alcohol-benzene, 10.6% in hot water and 24.0% in alkaline. The plant is a medium-weight hardwood. The heartwood is pale olive-brown, grey-brown to pink, darkening to reddish-brown or dark red, and often attractively streaked. The sapwood is yellowish-white, cream or straw-coloured and distinctly demarcated from heartwood. *Acacia auriculiformis* can be attacked by root fungus *Ganoderma lucidum* and is liable to marine borer attacks (Lemmings *et al.*, 1995).

All Acacias share some similar characteristic such as rapid early growth, able to fix nitrogen from air, being tolerance to adverse condition, conserve the soil and finally toxic free and have aesthetic value.

The rapid growth ability helps the plant to compete in grassland full with *Imperata cylindrica* (Pinyopusarerk, 1990). It is estimated that, there are 20 million hectares of *I. cylindrica* in South East Asia and 60% belongs to Indonesia (Van Den Beldt, 1993). Acacia species being pioneer species in this grassland after human clearing and prove to inhibits or suppress the population of *I. cylindrica* after 2-3 years of planting. This is because of the early rapid growth and the shade that blocks the sunlight with high rate of little successfully inhibits the regeneration of *I. cylindrica* in the grassland (Pinyopusarerk, 1990). Nowadays fast-growing Acacia species such as *Acacia aulacocarpa*, *A. auriculiformis*, *A. crassicarpa* and *A. mangium* have been successfully planted in *I. cylindrica* area in Indonesia, Malaysia, Philippines and Thailand (Awang and Taylor, 1993).

Acacias are leguminous plants that promote nitrogen fixation from the atmosphere with the help of *Rhizobium* genus bacteria. The bacteria will form nodule in acacia dense rooting system. The efficiency of N-fixation is so significant that it has positive influence on yield in N-deficient soil, while the litter of acacia that is full with N content increases the soil total N content. Dela Cruz and Luna (1992) found out that planting of *A. auriculiformis* can improve soil characteristic of degraded grassland. The rate of fixation is highly dependable on many factors such as; number, size, longevity of nodule, strains of bacteria and availability of soil water (Pinyopusarerk, 1990). Chakraborty and Chakraborty (1989) reported surface soil N content increase from 0.364% to 0.504% after 3 growing season of *A. auriculiformis* trees, while Kushalapa (1991) reported a 72/kg/ha/yr. of N release from the leaf litter of a 8 year old *A. auriculiformis*. Studies conducted in natural

forests in Australia revealed that the concentration of N in fine roots of *Acacia* was generally higher than in *Eucalypts* (CSIRO, 1993).

Some acacia species are found to be able to tolerate 5 times salinity level that kills other plants such as *Acacia ampliceps*, *A. auriculiformis*, *A. ligulata*, *A. maconochieana*, *A. salicina* and *A. stenophylla*. All the species appears naturally on saline soil in northern Australia except *A. auriculiformis* (Thomson, 1987). *A. auriculiformis* has been used successfully in rehabilitating tin tailings in Malaysia (Ahmad and Ang, 1993) and Thailand (Pinyopusarerk, 1990). While *A. crassicarpa* and *A. mangium* are among the species used in revegetating bauxite mines in North Queensland.

A. auriculiformis tends to have superficial root coverage that promotes aeration in soil while in directly decrease the bulk density and lastly improves the soil characteristic. The litter seems to be harder to decompose compare to *Gmelina arborea* thus provide continuous protection from erosion and prevent moisture loss from the soil (Dela Cruz and Luna, 1992). In Thailand, the thick leaf litter and increased soil moisture under the shade of *A. aulacocarpa*, *A. auriculiformis* and *A. crassicarpa* create a favourable condition for growing *Tylopilus felleus*.

2.3.2 *Acacia mangium* Willd

It is distributed around Sula Islands, Seram, Aru Islands, Irian Jaya, Western Province of Papua New Guinea and north eastern Queensland; planted elsewhere in

Malesian region, especially in Sabah, Sarawak and Peninsular Malaysia (Lemmens *et al.*, 1995).

The plant is morphologically similar with *Acacia auriculiformis*. It mostly used as wattle timber; wood for construction, boat building, furniture and cabinet-making and veneer. It also makes excellent particles board. The pulp is readily bleached to high brightness levels and is excellent for paper making. The tree is also used for firewood, ornamental plant, erosion control, firebreak and windbreak. The leaves served as forage for cattle. *Acacia mangium* wood consists of 78% holocellulose, 46.5% α -cellulose, 27.0% lignin, 14% pentosan and 0.2% ash; the solubility is 3.8% in alcohol-benzene, 3.3% in hot water, 13.4% in alkali (Lemmens *et al.*, 1995).

2.3.3 *Acacia crassicarpa* A. Cunn. Ex. Benth

Acacia crassicarpa is distributed around South Western Papua New Guinea and Australia (coastal Queensland) and in some plantation in Sarawak and Kalimantan (Lemmens *et al.*, 1995).

The wood is used for wattle, for instance for heavy construction, furniture, flooring, cabinet making, boat building, panelling, hardboard and veneer. It also widely used as native building posts and has a reputation for being durable (Lemmens *et al.*, 1995).

2.3.4 Rubber tree (*Hevea brasiliensis* Kunth. Muell.)

The plant is distributed naturally around Brazil to Venezuela, from Colombia to Peru and Bolivia. It is cultivated in most parts of the lowland humid tropics. It was introduced into South-East Asia (Sri Lanka, Singapore and Bogor, Indonesia) in 1876 and into Peninsular Malaysia in 1877. Since then, it is being widely cultivated in the country to produce latex from the bark and made into natural rubber (Lemmens *et al.*, 1995).

Rubber wood was formerly a by-product of the rubber plantation and used for the production of charcoal or as fuelwood, for brick making, tobacco and rubber drying. Nowadays the potential of the rubber as timber production is being recognized, most of the timber is used to manufacture furniture. Other uses include interior finish, moulding (e.g. wall panelling, picture frame, drawers guide, cabinet handles, parquet flooring, many household implements), block board cores, pallets, crates, coffins, veneers, and glue laminated timber for instance staircases, door and window components. Since the timber is moderately durable and may not be suitable for exterior used. Off cuts and other rubberwood residue have been used successfully in Malaysia for the production of particle board, wood cement board, and medium density fibreboard. Rubberwood waste is also an excellent medium for growing of mushrooms (*Pleurotus* spp.) (Lemmens *et al.*, 1995).

2.3.5 Sentang (*Azadirachta excelsa* (Jack) Jacob)

Azadirachta excelsa is a native to Peninsular Malaysia, Sumatra, Borneo, Sulawesi, the Aru Islands, New Guinea and Philippines. Sentang wood is valued for light construction (under cover) and is used for joinery, furniture, interior finishing, panelling, partitioning, sliced veneer, flooring, turneries and matches. In Philippine, Sentang wood is also used for piano cases, matches, decorative engraving and cigar boxes, while in Papua New Guinea, other applications include louvred doors and canoe making (Lemmens *et al.*, 1995).

In Peninsular Malaysia, the young shoots, leaves, and flowers are consumed as vegetables. Sentang is a lightweight to medium-weight hardwood. The heartwood is pale reddish brown to dark reddish brown and distinctly demarcated from the yellowish-white, grayish-white or sometimes grey-pink sapwood. The density is 550–780 kg/m³ at 15% moisture content. Heartwood is considered non-durable to moderately durable. The sapwood is susceptible to dry wood termites, powder post beetles, and also fungal attacks. Sentang wood contains 45% cellulose, 27% lignin, 16% pentosan, and 1.0% ash. The solubility is 2.3% in alcohol-benzene, 2.4% in cold water, 6.6% in hot water and 21.4% in a 1% NaOH solution (Lemmens *et al.*, 1995).

Some *Azadirachta* species is known to have azadirachtin. It is a tetranortriterpenoid plant limonoid with potent insect antifeedant and growth disrupting properties. It was first isolated from neem seeds (*Azadirachta indica*) by Butterworth and Morgan (1968). Azadirachtin is a highly oxidised limonoid with

many reactive functional groups in close proximity to each other. Its biosynthesis is thought to involve tirucallol, a tetracyclic triterpenoid, and a series of oxidation and rearrangement reactions which producing tetranortriterpenoids salannin, nimbin and azadirachtin (Ley *et al.*, 1993; Mordue and Blackwell, 1993)

2.3.6 Teak (*Tectona grandis* Linn. F.)

It belongs to the Family Verbenaceae and is indigenous to Burma, India, Indonesia, Thailand and the western part of Vietnam. This species is not an indigenous in Peninsular Malaysia, for it was introduced from Medan, Sumatra and Java for teak timber production in the early 1800s (Ti and Tangau, 1991).

Teak is a tropical hardwood species highly prized by the wood industry due to its superior mechanical and physical properties, as well as its pleasing aesthetic appearance (Kjaer *et al.*, 1999; Kokutse *et al.*, 2004). It is a deciduous, large tree, reaching height of 45 m with diameter of 100 cm. Differences do occur between the provenances; teak from Thailand and Burma have a straight bole while Indian and Javanese provenances have low growing branches. The leaves are elliptical, large and leathery. The top surface is like sandpaper while the lower surface is densely pubescent. The flower is whitish and small, while the fruit is like a spherical brown stone with 1–3 seeds (Appanah and Weinland, 1993).

Teak occurs in isolated tracts, usually on hilly or undulating ground but sometimes on plains and alluvial flats. It thrives in very moist to dry tropical conditions, with rainfall of 640–5130 mm per year and within a temperature range of

2–48 °C. It cannot tolerate water-logged ground or sites subject to prolonged inundation, laterite stiff clay, black cotton soils and deep dry sand. It is light demanding and requires plenty of growing space. It likes an occasional dry spell to promote best growth (Ti and Tangau, 1991). Thus it only does well in northern States of Kedah, Perlis and Langkawi where dry season is more pronounced (Appanah and Weinland, 1993). Teak is used mostly in ship-building, heavy construction in general and bridge-building in particular, piles and harbor-works, railway and other coach-building, furniture and cabinet making, flooring, joinery and general carpentry, poles, posts and fuel. The wood is moderately hard and heavy, extremely durable, easy to work good finish, straight-grained, good appearance and has golden-brown heartwood (Ti and Tangau, 1991).

2.3.7 *Gmelina arborea* Roxb.

The tree belongs to Verbenaceae family, also known as Yemane or Gmelina. Although it is indigenous to Burma and India, it is widely found in country in the tropics and sub-tropics. Besides that, it also grows in southern China and Philippines while in Burma-Bangladesh it grows in mixed forests with *T. grandis* and *Terminalia tomentosa* (Appanah and Weinland, 1993).

Gmelina arborea is a deciduous species that can grow up to 30 m height with 80 cm diameter at breast height with simple broadly oval leaf. The flower is in labiates shape and reddish in colour with yellow calyx and finally the fruit is fleshy with 2–3 seeds (Appanah and Weinland, 1993). It prefers moist fertile alluvium and deep sandy soil with good drainage and aeration. It is able to withstand moderate

frost, fire and strong winds because of the thick bark but unable to tolerate extreme drought and water-logged condition. It grows well in tropical regions with distinct dry season at a temperature range 18 °C to 35 °C and annual rainfall of 750–4500 mm (National Research Council, 1980).

The great interest generated by the species is attributed to rapid early growth with high initial volume production, simplicity and cheapness of plantation establishment (availability of seeds and ease of propagation), early economic returns and easily utilisable wood. However it demands good soil and climatic conditions, and requires extra care in initial stage especially weeding, and declining growth rate in older tree. In addition of poor tree form but can be mitigated by using improving planting material (Wong and Khoo, 1980).

Gmelina arborea is yellowish, shiny and soft wood. It does not warp, easy to work with and can be readily stained. Besides that, it also durable and resistance to insect attacks. *Gmelina arborea* is already being planted for fuel in Malawi (especially for tobacco curing), Sierra Leone and Nigeria. The sapwood contains about 4,800 Kcal per Kg and its charcoal burns well without smoke but leaves a substantial ash residue (National Research Council, 1980). Thus it is potentially introduced in rural area of the third world country for as fuelwood (Bhatt and Tomar, 2002). Its straw-coloured wood which turns reddish-brown with age is one of the best utility timbers of the tropics. It is useful for particle board, plywood core stock, pit props, matches and sawn timber. Moreover, it's also used in general carpentry, light construction, packing and furniture industry. It gives an average yield of paper with properties superior than those obtainable from most heartwood

pulp. It also used in producing short fibre pulp because of good pulping properties and a basic density about 400 kg per cubic metre (National Research Council, 1980). The flowers produce abundant nectar which can be used in producing high quality honey. Lastly the fruit and bark are used in Sri Lanka for treatment of bilious fever (Wong and Khoo, 1980). It is now becoming an important source of sulphate pulp (Appanah and Weinland, 1993).

2.3.8 Mahang (*Macaranga gigantea* (Rchb. f. and Zoll.) Mull. Arg.)

Macaranga consists of 250 species, all distributed around the world including tropical Asia and Africa to Northern Australia and East Fiji. Most of the species centred in Malesia where around 160 species occur with an exceptionally high number of endemics in Borneo and New Guinea. Most *Macaranga* species are pioneers and form a characteristic of secondary forest especially along the roadsides of Malesia and New Guinea (Sosef *et al.*, 1998).

Peeled *Macaranga* poles are frequently used for temporary construction and usually for parts of native houses that is not in contact with the ground. The wood is used as light framing, interior trim, moulding, shingles, packing cases, outriggers for canoes and match splints. In the Philippines, it is favourite in making wooden shoes. *Macaranga indica* has been used in supporting pepper vines and poles of *Macaranga tanarius* has been used to make ladder in pepper harvesting in Southern Sumatra. *Macaranga* yields a high quality pulp and produces high quality particle board, cement bonded board and wood-wool board and good for plywood production. Besides that, it also provides good fuelwood. Some species produce

resin in the bark, pith or fruits which is called 'kino' or 'selaru' that can be used as glue. The bark of some species is being used in tanning fishing nets and in Papua New Guinea as twine for hut construction. In Malaysia a decoction of the root-bark of various species is drunk to treat diarrhoea, dysentery, fever and to clean wounds and applied after birth (Sosef *et al.*, 1998).

Macaranga yields a lightweight hardwood with a density of 270–500(–590) kg/m³ at 15% moisture content, but for *Macaranga involucrata* densities of over 830 kg/m³ and *Macaranga lowii* of 800–815 kg/m³ is reported. The heartwood is pale yellow-brown to pale brown or grey-brown, sometimes with a reddish tinge, not clearly separated from the sapwood. Shrinkage is moderate and in seasoning the wood is liable to sap-stain and subject to insect attack. The wood is soft to moderately hard and fairly weak. It is very easy to work with but very fibrous. The wood is non durable and permeable to pressure treatment (Sosef *et al.*, 1998).

It is moderately resistant to susceptible to dry-wood termite and the sapwood is susceptible to *Lyctus*. A few Macaranga species are either facultative or obligate myrmecophytes. Some species group provide specific nesting space, mainly hollow twigs, for ants of the genus *Crematogaster*, while the ant protect the plant from herbivour (Sosef *et al.*, 1998).

2.3.9 Eucalyptus hybrid

The eucalyptus can be found in a variety of sizes with some species being among the largest trees in the world; whereas, other members of the genus, may be

mere shrubs. It grows on the desert, swampland, valleys, and alpine regions. It finds nourishment in a complexity of soils and can survive in differing types of climate. The eucalyptus is an evergreen and many species grow very rapidly. Mostly erect in form, the tree is strong and usually slender. It is an aggressive plant whose leaves demand every vestige of sunlight, and its roots suck up all the moisture within their domain. The color of the wood varies from white to dark brown depending upon the species with the heartwood and sapwood being indistinguishable among species. The grain of this hardwood is similar to hickory or ash. Eucalyptus is generally very tough, and resists denting, tension, and torsion. Its' timber was used in the construction of ships, buildings, bridges, wharves, and railroad cars. It was used in the manufacturing of barrels, paving blocks, agriculture implements, and furniture. It was also cut for poles, posts, and pilings (Boas, 1947; Youngs, 1960).

2.3.10 Pelajau (*Pentaspadon motleyi* Hook.f.)

Pentaspadon consists of six species, distributed around Vietnam, Thailand, Malaysia, Sumatra, Borneo, New Guinea and the Solomon Islands. Refer as Plajau (Sumatra), White pelong tree, pelong licin (Peninsular Malaysia), empelanjau (Dayak, Sabah) and pelajau (Iban) (Lemmens *et al.*, 1995; Soepadmo, *et al.*, 1996).

The wood is used for flooring, interior construction, house posts, panelling, partitioning, mouldings, skirtings, planking, fence posts, plywood, boxes and crates, and artefacts. It is poor in durability thus all application should be under cover. Oil can be extracted from the trunk which is called 'minyak plang' in Peninsular Malaysia or 'minyak pelanjau' in Borneo. This black resin and its sediment are used

against skin eruptions. The fruits of *P. motleyi* are edible after boiling and the seed can be eaten more raw or boiled (Lemmens *et al.*, 1995).

It is a lightweight to medium weight to moderately hard wood. The heartwood is whitish-yellow or yellowish-green in colour to pale grey-pink and often is distinctly demarcated from the sapwood (greenish-white to pale yellow with a pink tinge). The density is 485–825 kg/m³ at 15% moisture content. The grain is straight to shallowly interlocked, the texture is moderately fine and even (Lemmens *et al.*, 1995).

Pelajau wood is rated moderately durable and not recommended to use outside in the tropic because it is susceptible to termite and powder-post beetle attacks. The wood has allergenic properties. Medicinal application of the black resin should be done in caution to prevent serious irritation (Lemmens *et al.*, 1995).

2.4 Damage to crops and timber

Some of the most important termite genera found in the Malaysian and Bornean forest are *Coptotermes*, *Heterotermes*, *Termitogeton*, *Prorhinotermes*, *Parrhinotermes* and *Schedorhinotermes* (Thapa, 1981).

There are numerous reports done on damage by termite in oil palm plantations. Sudharto *et al.* (1991) reported that there are two harmful termite on oil palm in Indonesia; *Coptotermes curvignathus* Holmgren which attacks the living tissue of the palm, while *Macrotermes gilvus* attacks on the rooting system, finally

killing the palm. While Wood (1968), Zulkefli *et al.* (2000) and Lim and Silek (2001) also reported the same attacks of *C. curvignathus* on young palms planted on deep peat.

The incidence of termite attacks on an oil palm plantation was closely related to the ecological conditions before planting such as previous situation whether after forest or it used to be cultivated area, types of soil for instance, peat soil, low land or highlands and the method of land preparation such as burning or land clearing. Attacks on peat soil were found to be most severe, even areas with good land clearing practices suffer the same fate but is slightly slowly (Sudharto *et al.*, 1991).

Many species of forest trees and crops that were attacked in the peat swamp forest: Anacardiaceae (*Campnosperma* spp.), Dipterocarpaceae (*Shorea* spp.), Sapotaceae (*Palaquium* spp.), coconut (*Cocos nucifera*) and some others (Sudharto *et al.*, 1991), *Acacia mangium* (Chey and Intachat, 2000), rubber (*Hevea brasiliensis*), mango (*Mangifera* spp.), papaya (*Carica papaya*) (Khoo *et al.*, 1991; Sudharto *et al.*, 1991).

There are many methods used to control termite infestation. The most popular method includes chemical control using organophosphate insecticide (Chlopyrifos, Alphamethrin and Aluminium phosphide), mechanical control by eradicating the queen and caste off the main nest, and biology control by using entomopathogenic fungi (*Beauveria* spp., *Pecilomyces* spp., and some strains of *Metarhizium anisopliae*). However, only biological control (Sudharto *et al.*, 1991) and termite baiting (Lim and Silek, 2001) seems to be able to avoid the damages

caused by *C. curvignathus* in oil palm plantation, especially in recently developed peat soil areas and deep peat.

2.5 Wood preference and feeding activities

There are very few researches being done on wood preference by subterranean termite; *Coptotermes curvignathus*. Ngee *et al.* (2004), have run an experiment on the wood preference of the species by using 15 kinds of Malaysian wood; rubber (*H. brasiliensis*), teak (*T. grandis*), pine (*Pinus caribae*), nyatoh (*Ganua* sp.), jelutong (*Dyera costulata*), angkana (*Pterocarpus indicus*), balan, white and red meranti (*Shorea* sp.), merbau (*Intsia palembanica*), membatu (*Parinari* sp.), terentang (*Camposperma auriculata*), medang (species of Lauracea), melunak (*Pentace* sp.) and perah (*Elateriospermum tapos*). While 15 kinds of Japanese heartwood; hiba (*Thujopsis dolabrata*), natural and planted hinoki (*Chamaecyparis obtusa*), ezomatsu (*Picea jezoensis*), todomatsu (*Abies sachaliensis*), katsura (*Cercidiphyllum japonica*), kuri (*Castanea crenata*), sugi (*Cryptomeria japonica*), keyaki (*Zelkova serrata*), kusunoki (*Cinnamomum camphora*), mizunara (*Quercus mongolica*), karamatsu (*Larix leptolepis*), akamatsu (*Pinus densiflora*), buna (*Fagus crenata*) and akagashi (*Quercus acuta*).

Ngee *et al.* (2004) found out that *C. curvignathus* showed a great preference for mizunara and pine but no significant difference was found between the two species. This was followed by jelutong, terentang, buna, nyatoh, rubber, karamatsu, red meranti and perah with no significant difference among them except between jelutong, red meranti and perah. In conclusion, they stated that, 3 Malaysian woods;

rubber, jelutong and terentang were shown great potential in baiting matrix and rubber wood is a better choice for detection of multiple termite species in monitoring stations in Malaysia. Besides, they had found in the experiment that *C. curvignathus* moderately prefer teak and hiba which is considered highly resistant wood and highly prefer buna which is considered moderately resistant to *Coptotermes formosanus* (Imamura, 2001).

In another feeding activities experiment on 2 kinds of Japanese subterranean *C. formosanus* Shiraki and *Reticulitermes speratus* as affected by moisture content of wood done by Nakayama *et al.*, (2005). In the discussion, it was found that the feeding preferences were in the middle moisture content (79–103%) between low moisture content (6–12%) and high moisture content (140–180%). Moreover in another test higher consumptions were generally obtained in water impregnation (moisture content 133–191%) and located nearest to the termite (bottom piece) out of the middle and top piece. Despite that, sign of attacked was seen in all of the feeding wood but the consumption was not significantly different. During the experiment it was also found that, almost all termites survived after 3 days in present experiment where moisture wood is used, compare to former experiment using air-dried wood at 25 °C and 70% relative humidity without water where most die off in the second and fourth day. It means that both species is able to extract water from the food even in a dry environment without water supply.

Using the same test subjects as above, another experiment was being done on the optimum temperature-humidity combination for the feeding activities of Japanese subterranean termites (Nakayama *et al.*, 2004). The daily consumption per

workers and survival were measured and the protozoan fauna in the hindgut were observed under 15 temperature-relative humidity (RH) combinations for 1 week. It was found out that, the activities of the samples are highest at around 30 °C for both species, and worker died at 40 °C within 5 days and 2 days for *C. formosanus* and *R. speratus* respectively. The optimum temperature-RH combinations for feeding activities were 30 °C at 90% RH for *C. formosanus* and 30 °C at 70–90% RH for *R. speratus*. In the current experiment, *C. formosanus* workers consumed rate were highest at 30–35 °C (ca. 0.12 mg/day/worker for 50% RH, ca. 0.14 mg/day/worker for 70% RH and ca. 0.27 mg/day/worker for 90 % RH) and it is significantly different between the consumption rate at highest (90%) and lowest (50%) RH. Additionally there has been reported *C. formosanus* workers consumed wood blocks best from 29–33 °C (100% RH). As for *R. speratus* no wood consumption was observed at 35 °C, 90% RH and over 40 °C. Wood consumption gradually increased with temperature from 20 °C (ca. 0.05 mg/day/worker), 30 °C (ca. 0.07 mg/day/worker) but drastically decreased when over 30 °C.

In an experiment done by Katsumata *et al.* (2006) about termite feeding preference to four wood species (sapwood of *Cryptomeria japonica* D. Don and heartwoods of *Pseudotsuga menziesii* (Mirbel) Franco, *Larix kaempferi* (Lambert) Carriere, and *Chamaecyparis obtusa* Endl) after gamma radiation. It was found that in a no choice test the consumption rates in *C. japonica* and *P. menziesii* were likely to increase in increases level in gamma radiation, whereas little effect is seen in *L. kaempferi* and *C. obtusa*. In a two-choice test, using *C. formosanus* with 100 kGy-irradiated *C. japonica* and *P. menziesii*, which lacks in anti-termite properties were consumed more than any other wood sample with or without irradiation. In

conclusion it was stated that *C. japonica* and *P. menziesii* which were less durable become more susceptible to termite attacks after gamma radiation. On other hand, no distinct effect was seen in heartwood of *L. kaempferi* and *C. obtusa* which are rather durable and contain antitermite property.

Chen and Henderson (1996) reported on the determination of feeding preference of Formosan subterranean termite (*Coptotermes formosanus* Shiraki) for some amino acid additives reveals that more filter paper treated with D-aspartic and L-glutamic acid are consumed compare to control (filter paper treated with water). Adding other amino acids such as L-proline, L-lysine or L-isoleucine into filter paper in a two choice test, slightly increase the consumption rate compare to filter paper treated with distilled, deionised water. Comparing all the amino acids in a multiple choice test, only D-aspartic and L-glutamic acids is significantly different than other while is not different among the two. In a no choice test, *C. formosanus* preferred filter paper treated with amino acids than treated with distilled, deionised water. This results suggested that, Formosan subterranean termite may feed on food high in nitrogen content to provide sufficient nitrogen supply to the nest. This also answered why heavy attacks was found in sugarcane plantation in south China (Dai and Luo, 1980; Chen and Hendreson, 1996) because D-aspartic, L-glutamic and alanine are 3 most common amino acids that can be found in sugarcane juice. However, no field testing was done to verify the data based on the no choice test and two choice tests.

A study was conducted by Morales Ramos and Rojas (2003), on the nutritional ecology, growth and survival of Formosan subterranean termite fed with

preferred wood species. It was found that colonies of *C. formosanus* fed on pecan (*Carya illinoensis* (Wangenh) and red gum (*Liquidambar styraciflua* L.) produce more progeny than other colonies fed on other 9 wood species. Progeny feeding on pecan and American ash (*Fraxinus americana* L.) had significantly higher survival rate than other colonies feeding on other wood species. Colonies feeding on nutritionally-supplemented cellulose based matrix showed similar fitness characteristic as colonies fed on the best wood treatment. It was also concluded that the colony fitness of *C. formosanus* can be partially explained with the nutritional value of food source. Colonies fed on loblolly pine (*Pinus taeda* L.) and ponderosa pine (*Pinus ponderosa* Laws.) had significantly lower survival and produced fewer worker and soldier than other colonies.

Zulkefli *et al.* (2006) had done a termite detection technique using rubber stake (rubber wood) in an oil palm plantation in Sessang at 3 different locations; deep peat (mature palm), medium deep peat (mature palm) and deep peat (younger palm). It was found out that, as time goes by, *C. curvignathus* dominated the rubstake which previously dominated by other species. In conclusion, rubber wood is recommended for detecting *C. curvignathus* as it is cheap and can reduce cost and time of management.

Other studies done by Indrayani *et al.* (2007) on feeding responses by dry-wood termite (*Incisitermes minor* (Hagen)) Isoptera: Kalotermitidae, against ten commercial timbers; 5 from Japan (*Larix leptolepis* Gord, *Cryptomeria japonica* D. Don, *Fagus crenata* Blume, *Chamaecyparis obtusa* Endl. and *Pinus densiflora* Sieb. Et Zucc.), 4 from The United States of America (*Pseudotsuga menziesii* Mirbel,

Thuja plicata Donn ex D. Don, *Tsuga heterophylla* Sarg. and *Picea abies* Karst) and 1 from Malaysia (*Hevea brasiliensis*) for their resistance against termite invasion. The survival rate in a choice test and no-choice test using both heartwood and sapwood are more than 70% and 75% after 3 months of incubation respectively. With regards to wood consumptions, either no-choice or choice test, Karamatsu (*Larix leptolepis* Gord), buna (*Fagus crenata* Blume) and Douglas fir (*Pseudotsuga menziesii* Mirbel) were considered “resistant” among the ten species. On the other hand, comparing heartwood in a no-choice and choice test buna, Karamatsu, Douglas fir, sugi (*Cryptomeria japonica*), akamatsu (*Pinus densiflora*) and western red cedar (*Thuja plicata*) were considered “resistant”. The ranking of the resistance of the timber was buna, karamatsu, sugi, western red cedar, Douglas fir, rubber, western hemlock, hinoki and lastly spruce.

CHAPTER 3

METHODOLOGY

3.1 *Coptotermes curvignathus* culture

Coptotermes curvignathus were collected from an infested rubber wood stake in an underground monitoring station in UPM Bintulu Campus. The termites were placed inside a plastic container lined with a piece of moist filter paper and incubated in the dark at 28 ± 2 °C and more than 85% RH for 24 hours prior to testing.

3.2 Wood blocks

Wood from ten species of planted forest timber trees were tested in a multiple choice test for termite feeding preferences as shown in Table 3.1. Wood logs from various species were cut into pieces before separating sapwood and heartwood. Wood block chips measuring approximately (1 x 1 x 2 cm) were cut from the heartwood and sapwood. These wood pieces were oven-dried for 24 hours at 105 °C. Initial weight was taken using an analytical balance before feeding to the termites. A preliminary test using rubber wood blocks was used to determine the behaviour and longevity of the termites.

Table 3.1: Species of planted forest trees for multiple choice test

Tree species	Common name	Parts of wood
<i>Acacia mangium</i>	Akasia (Indonesia), Mangium (Malaysia)	Heartwood and sapwood
<i>Acacia auriculiformis</i>	Northern Black Wattle (English), Akasia (Indonesia)	Heartwood and sapwood
<i>Acacia crassicarpa</i>	Northern Wattle, Red wattle (English)	Heartwood and sapwood
<i>Eucalyptus hybrid</i>	Eucalyptus (English)	Heartwood and sapwood
<i>Macaranga gigantea</i>	Mahang (Indonesia)	Heartwood and sapwood
<i>Gmelina arborea</i>	Yemane, Arborea	Heartwood and sapwood
<i>Tectona grandis</i>	Teak (English), Jati (Malaysia)	Heartwood and sapwood
<i>Azadirachta excelsa</i>	Sentang (Malaysia)	Heartwood and sapwood
<i>Hevea brasiliensis</i>	Rubber (English), Pokok getah (Malaysia)	Heartwood and sapwood
<i>Pentaspadon motleyi</i>	Pelajau (Malaysia)	Heartwood and sapwood

3.3 Experiment 1: Multiple choice feeding with oven-dried woods (heartwood and sapwood)

The design of the experiment apparatus was modified from Lim (2007). The apparatus consists of a 15 cm Petri dish and ten 9 cm Petri dishes. The 15 cm Petri dish which acted as a harbourage for the termite was punctured with 10 straw-size holes at the perimeter. It was filled with moist vermiculite to provide high humidity before being filled with 500 g autoclaved river sands distributed evenly within the dish.

The feeding chamber (FC) consisted of a 9 cm Petri dish punctured with a hole at the perimeter and filled with moist vermiculite and sand as base. Wood blocks (heartwood and sapwood) were put into the FC after the initial weight has been taken. The FC was arranged randomly around and connected to the harbourage via a bridge (plastic drinking straw) 8 cm long with 0.5 cm diameter (Figure 1). The control consisted of only rubber wood as food for the termite.

The ends of the straws at the holes were held in position with modelling clay. The clay also prevented the termites from escaping. A total of 500 workers and 5 soldiers were aspirated and placed in each harbourage for simultaneous foraging activities. All apparatus were incubated in the dark for 30 days at 28 ± 2 °C and more than 85% RH.

Daily assessments were made and irregularity was recorded. At the end of the experiment, wood blocks were collected and oven-dried for 24 hours at 105 °C before determining the final mass loss due to feeding by the termite. The total

consumption was calculated by adding mass loss in heartwood and sapwood. Each treatment was replicated 5 times and the experiment was replicated 3 times. The data in miligrams (mg) was subjected to analysis of variance (ANOVA) and the means are separated using DNMRT at $p < 0.05$.

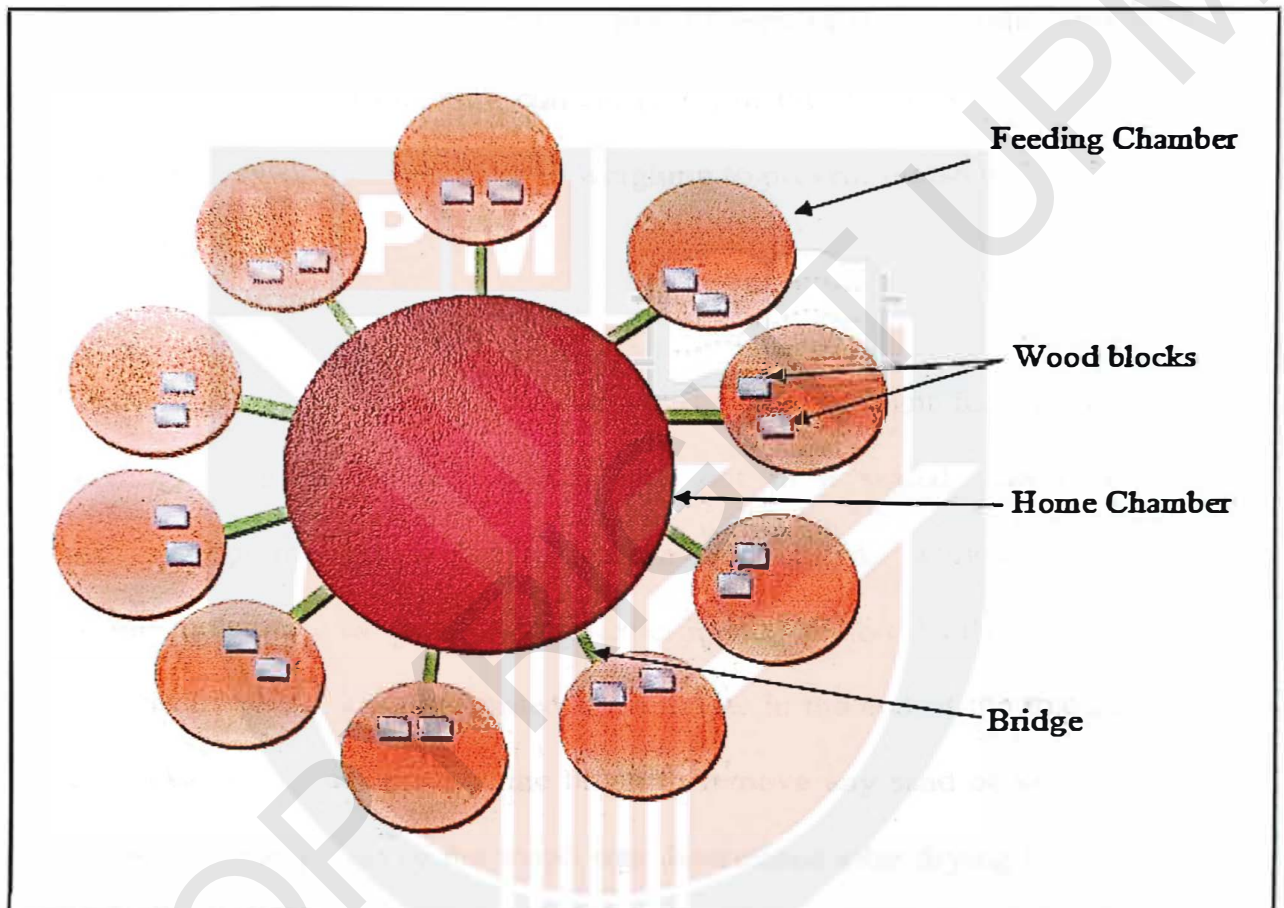


Figure 1: Multiple choice feeding test, apparatus setting.

3.4 Experiment 2: Multiple choice feeding test using fresh woods (heartwood and sapwood)

The same apparatus was used as in Experiment 1: Treatment consisted of fresh wood blocks. Four pieces of heartwood and sapwood in 3 replicates were randomly selected from each wood species and were weighed before putting into a 105 °C oven and dried for 24 hours or until the weight differences is negligible. This is to determine the average total moisture content (MC) in the wood. A dessicator was used to keep the oven-dried wood prior to weighing to prevent moisture from the air being absorbed into the wood blocks.

Fresh wood blocks were further sterilised with UV light for 30 minutes, before feeding. Balance of wood pieces was put in a sealed beaker in the refrigerator. A control was set up with fresh wood blocks without termite to determine the moisture change during the experimental period. Daily assessments were made and irregularity was recorded if available. In the end of the experiment the wood blocks were clean with a fine brush to remove any sand or vermiculite. The mass loss (consumption) of the wood was determined after drying in oven for 24 hours in 105 °C. The consumption was calculated using following formula:

Consumption in (mg) =	Initial fresh wood weight – total moisture content (%) – the weight of the feeding wood blocks after drying
------------------------------	--

The total wood consumption was calculated by adding the mass loss in both heartwood and sapwood.

The experiment was repeated 3 times and treatments replicated 5 times. The data were subjected to analysis of variance while the means are separated using DNMRT at $p < 0.05$.

3.5 Experiment 3: Force feeding test using oven-dried wood (heartwood and sapwood)

Nine centimetre Petri dishes were filled with moist soils (70% vermiculite and 30% autoclaved sand) which served as a base and water reservoir in this test. Wood blocks that have been oven-dried for 24 hours at 105 °C were put into the Petri dish after the initial weight was taken. One hundred workers and three soldiers were put into each Petri dish consisting of single piece heartwood and sapwood of each respective species. A control using rubber wood was set up to determine the mortality of the termite.

The Petri dish was then sealed before placed into the incubator at 28 ± 2 °C for 14 days at humidity $\geq 85\%$ in dark condition. At the end of the experiment period the wood blocks were cleaned with brush before drying in the oven at 105 °C for 24 hours and placed in the dessicator for few hours to stabilise it before taking the final weight. The total consumption in miligram was calculated.

3.6 Experiment 4: Multiple choice tests using oven-dried within a same container (heartwood and sapwood).

A 15 cm Petri dish was used as a harbourage for the termite and filled with moist soils (70% vermiculite and 30% autoclaved sand). The moist soils served as water reservoir for termite during the experiment period. Oven-dried wood was used in the test after drying for 24 hours at 105 °C.

One piece of heartwood and sapwood from all tree species was randomly placed within the Petri dish after the initial weight was taken. Two hundred fifty workers and five soldiers were used in the test for 21 days. The experiment was repeated twice with four replicates and put into an incubator at 28 ± 2 °C. A control was set up for comparing treatment and determines the mortality rate of the termite. At the end of the experiment the wood blocks were oven-dried for 24 hours at 105 °C. The total consumption in miligram was calculated by subtract the initial with the final weight.

CHAPTER 4

RESULTS

4.1 Multiple choice test using oven-dried wood (heartwood and sapwood).

The results for multiple choice test were shown (Table 4.1) that *Coptotermes curvignathus* highly preferred *Hevea brasiliensis* followed by *Pentaspadon motleyi*. However, there was no significant difference among the rest of the wood species (Appendix 1). Moreover, there was no significant difference between the heartwood and sapwood of all the species in terms of termite consumption (Table 4.2).

Table 4.1: Oven-dried wood consumption by *Coptotermes curvignathus* for multiple choice test

Wood species	Mean weight of wood consumed (mg)
<i>Hevea brasiliensis</i>	391.63 ^a
<i>Pentaspadon motleyi</i>	165.39 ^b
<i>Macaranga gigantea</i>	58.07 ^c
<i>Acacia crassicarpa</i>	49.92 ^c
<i>Eucalyptus hybrid</i>	22.92 ^c
<i>Azadirachta excelsa</i>	18.79 ^c
<i>Acacia mangium</i>	16.48 ^c
<i>Tectona grandis</i>	15.14 ^c
<i>Acacia auriculiformis</i>	10.93 ^c
<i>Gmelina arborea</i>	7.53 ^c

* The means with different superscripts within the column were significantly different at $p \leq 0.05$ (DNMRT).

Table 4.2: Comparison between parts of wood (oven-dried) of all tree species consumed by *Coptotermes curvignathus*

Parts of wood	Mean weight of wood consumed (mg)
Sapwood	83.73 ^a
Heartwood	67.63 ^a

* The means with different superscripts within the column were significantly different at $p \leq 0.05$ (DNMRT).

4.2 Multiple choice test using fresh wood (heartwood and sapwood).

In terms of fresh wood, *Coptotermes curvignathus* preferred *Hevea brasiliensis* to other wood species. The next preferred species were *Acacia crassicarpa* and *Pentaspadon motleyi*, and there was no significant difference between the two species. This was followed by the least preferred species where there was no significant difference among them (Table 4.3, Appendix 2). Moreover, in terms of parts of wood the *Coptotermes curvignathus* consumed significantly more sapwood than heartwood (Table 4.4). In comparison of each species, there was no difference in consumption between parts of wood in *A. auriculiformis*, *M. gigantea*, *E. hybrid* and *Gmelina arborea*. *Coptotermes curvignathus* significantly preferred sapwood of all species except *A. mangium* (Table 4.5).

Table 4.3: Fresh wood consumption by *Coptotermes curvignathus* from multiple choice test

Wood species	Mean weight of wood consumed (mg)
<i>Hevea brasiliensis</i>	554.97 ^a
<i>Acacia crassicarpa</i>	215.47 ^b
<i>Pentaspadon motleyi</i>	191.97 ^b
<i>Acacia auriculiformis</i>	88.78 ^c
<i>Acacia mangium</i>	75.49 ^c
<i>Macaranga gigantea</i>	54.25 ^c
<i>Eucalyptus hybrid</i>	39.63 ^c
<i>Azadirachta excelsa</i>	27.01 ^c
<i>Gmelina arborea</i>	17.57 ^c
<i>Tectona grandis</i>	8.69 ^c

* The means with different superscripts within the column were significantly different at $p \leq 0.05$ (DNMRT).

Table 4.4: Comparison between parts of wood (fresh) of all tree species consumed by *Coptotermes curvignathus*

Parts of wood	Mean weight of wood consumed (mg)
Sapwood	163.03 ^a
Heartwood	91.73 ^b

* The means with different superscripts within the column were significantly different at $p \leq 0.05$ (DNMRT).

Table 4.5: Comparison between fresh (sapwood and heartwood) of each wood species consumed by *Coptotermes curvignathus*

Wood species	T test ($P > t $)	Preference by <i>C. curvignathus</i>
<i>Hevea brasiliensis</i>	0.0020**	Sapwood
<i>Azadirachta excelsa</i>	0.0401*	Sapwood
<i>Acacia mangium</i>	0.0078**	Heartwood
<i>Acacia auriculiformis</i>	0.1807	No difference
<i>Acacia crassicarpa</i>	<0.0001**	Sapwood
<i>Macaranga gigantea</i>	0.9784	No difference
<i>Tectona grandis</i>	0.0326*	Sapwood
<i>Pentaspadon motleyi</i>	0.0347*	Sapwood
<i>Eucalyptus</i> hybrid	0.6516	No difference
<i>Gmelina arborea</i>	0.0959	No difference

* Significant at ($p \leq 0.05$)
** Significant at ($p \leq 0.01$)

4.3 Force feeding test using oven-dried wood (sapwood and heartwood).

In a force feeding test, consumption of *Hevea brasiliensis* by *C. curvignathus* was the highest when compared to other wood species. This was followed by *Pentaspadon motleyi*, *Acacia crassicarpa*, *Tectona grandis*, *Acacia mangium*, *Macaranga gigantea*, *Eucalyptus* hybrid, *Acacia auriculiformis*, *Gmelina arborea* in descending order of preference, with the least consumption being in *Azadirachta excelsa* (Table 4.6, Appendix 3). In terms of parts of wood consumed, there was significant difference in consumption between sapwood and heartwood, with higher

consumption in sapwood (Table 4.7). However there was no difference in consumption between parts of wood in *A. mangium* and *M. gigantea* (Table 4.8).

Table 4.6: Comparison of wood (oven-dried wood, sapwood and heartwood) consumed in a force feeding test.

Wood species	Mean weight of wood consumed (mg)
<i>Hevea brasiliensis</i>	179.78 ^a
<i>Pentaspadon motleyi</i>	146.07 ^b
<i>Acacia crassicarpa</i>	131.08 ^{bc}
<i>Tectona grandis</i>	120.33 ^{cd}
<i>Acacia mangium</i>	106.46 ^{de}
<i>Macaranga gigantea</i>	92.05 ^{ef}
<i>Eucalyptus</i> hybrid	74.17 ^{fg}
<i>Acacia auriculiformis</i>	71.19 ^g
<i>Gmelina arborea</i>	44.97 ^h
<i>Azadirachta excelsa</i>	22.01 ⁱ

* The means with different superscripts within the column were significantly different at $p \leq 0.05$ (DNMRT).

Table 4.7: Comparison between parts of wood (oven-dried) of all tree species consumed by *Coptotermes curvignathus*

Parts of wood	Mean weight of wood consumed (mg)
Sapwood	151.40 ^a
Heartwood	46.22 ^b

* The means with different superscripts within the column were significantly different at $p \leq 0.05$ (DNMRT).

Table 4.8: Comparison between oven-dried sapwood and heartwood of each wood species consumed by *Coptotermes curvignathus*

Wood species	T test ($Pr > t $)	Preference by <i>C. curvignathus</i>
<i>Hevea brasiliensis</i>	0.0017**	Sapwood
<i>Azadirachta excelsa</i>	0.0190*	Sapwood
<i>Acacia mangium</i>	0.1483	No difference
<i>Acacia auriculiformis</i>	0.0002**	Sapwood
<i>Acacia crassicarpa</i>	<0.0001**	Sapwood
<i>Macaranga gigantea</i>	0.7806	No difference
<i>Tectona grandis</i>	<0.0001**	Sapwood
<i>Pentaspadon motleyi</i>	0.0012**	Sapwood
<i>Eucalyptus hybrid</i>	<0.0001**	Sapwood
<i>Gmelina arborea</i>	<0.0001**	Sapwood

* Significant at ($p \leq 0.05$)

** Significant at ($p \leq 0.01$)

4.4 Multiple choice test without feeding chamber (sapwood and heartwood).

In a multiple choice test within a single harbourage, *C. curvignathus* exhibited the highest consumption of *Hevea brasiliensis* which was significantly higher than all the rest of the wood species. *Pentaspadon motleyi* was a distant second in terms of wood consumption, followed by *Acacia crassicarpa*, in descending order *Tectona grandis*, *Acacia auriculiformis*, *Eucalyptus hybrid*, *Acacia mangium*, *Azadirachta excelsa*, *Macaranga gigantea* and *Gmelina arborea* (Table 4.9, Appendix 4). In average of all the species, *C. curvignathus* significantly preferred sapwood than

heartwood (Table 4.10) except *A. mangium*, *M. gigantea*, *P. motleyi* and *G. arborea* where there was no difference between the parts (Table 4.11).

Table 4.9: Comparison of wood consumed (oven-dried wood, sapwood and heartwood) by *C. curvignathus* in a multiple choice test without feeding chamber

Wood species	Mean weight of wood consumed (mg)
<i>Hevea brasiliensis</i>	159.83 ^a
<i>Pentaspadon motleyi</i>	81.22 ^b
<i>Acacia crassicarpa</i>	36.83 ^c
<i>Macaranga gigantea</i>	36.21 ^c
<i>Tectona grandis</i>	13.78 ^d
<i>Eucalyptus hybrid</i>	12.13 ^d
<i>Acacia auriculiformis</i>	11.30 ^d
<i>Acacia mangium</i>	8.91 ^d
<i>Azadirachta excelsa</i>	6.88 ^d
<i>Gmelina arborea</i>	3.60 ^d

* The means with different superscripts within the column were significantly different at $p \leq 0.05$ (DNMRT).

Table 4.10: Comparison between parts of wood (oven-dried) of all tree species consumed by *Coptotermes curvignathus*

Parts of wood	Mean weight of wood consumed (mg)
Sapwood	51.49 ^a
Heartwood	22.85 ^b

* The means with different superscripts within the column were significantly different at $p \leq 0.05$ (DNMRT).

Table 4.11: Comparison between oven-dried sapwood and heartwood of each species consumed by *Coptotermes curvignathus*

Wood species	T test (Pr> t)	Preference by <i>C. curvignathus</i>
<i>Hevea brasiliensis</i>	0.0112*	Sapwood
<i>Azadirachta excelsa</i>	0.0480*	Sapwood
<i>Acacia mangium</i>	0.1030	No difference
<i>Acacia auriculiformis</i>	0.0005**	Sapwood
<i>Acacia crassicaarpa</i>	0.0036**	Sapwood
<i>Macaranga gigantea</i>	0.1185	No difference
<i>Tectona grandis</i>	<0.0001**	Sapwood
<i>Pentaspadon motleyi</i>	0.8169	No difference
<i>Eucalyptus</i> hybrid	0.0212*	Sapwood
<i>Gmelina arborea</i>	0.1194	No difference

* Significant at ($p \leq 0.05$)

** Significant at ($p \leq 0.01$)

CHAPTER 5

DISCUSSION

All feeding preference test on *Coptotermes curvignathus* showed that *Hevea brasiliensis* was the favourite choice of food that was significantly different from the other species. Ngee *et al.* (2004) had similar finding with *Hevea brasiliensis* which was the most preferred wood among 15 species of Malaysian wood, and suggested its use as a baiting matrix. In terms of building works, Lemmens *et al.* (1995) suggested that though rubber was a moderately durable wood it was not suitable for exterior design because of the wood's susceptibilities to *C. curvignathus*. In agriculture, rubber was one of the major crops under serious termite attack as reported by Khoo *et al.* (1991) and Sudharto *et al.* (1991). Indrayani *et al.* (2006) have reported rubber as non-resistant in both parts in a force feeding test and moderately resistant in both parts in choice feeding test when testing for feeding responses with western dry-wood termite *Incisitermes minor*. In a study done by Zulkefli *et al.* (2006) on detection of termite using rubber stake, it was found that *C. curvignathus* dominated the stake within one month in an oil palm plantation on peat.

The second most preferred wood species in the present study were *Pentaspadon motleyi* and *Acacia crassicarpa*. *Pentaspadon motleyi* was preferred by the termite probably because of the softness and the non-durability of the wood. It is cited as prone to termite and powder-post beetle attacks (Lemmens *et al.*, 1995). It is interesting to note that although all *Acacia* trees share certain characteristic, *Acacia*

crassicarpa was preferred by *C. curvignathus* unlike *A. mangium* and *A. auriculiformis* even in a force feeding condition or a multiple choice test using fresh wood. The consumption of *Acacia crassicarpa* was higher and significantly different than the other *Acacia* spp. In case of multiple choice tests using oven-dried wood and multiple choice tests without feeding chamber, there were no differences in consumptions of all *Acacias*. This was probably due to some content of the wood in fresh condition or the different degree of hardness of the wood that attracts the termite. There were reports about *C. curvignathus* attacks on *Acacia mangium* trees by Harris (1969) and Chey and Intachat (2000), but in the present study the trend was not seen in all four preference tests.

Macaranga gigantea was one of the less preferred species. Sosef *et al.* (1998) reported that, the wood was fairly soft and thus susceptible to attacks by *Lyctus*. However, *C. curvignathus* did not seem to prefer the wood suggesting that other than softness and moisture there were certain properties and qualities that the termites were attracted to.

The least preferred species were *Gmelina arborea*, *Azadirachta excelsa* and *Eucalyptus* hybrid. This was because even in a force feeding condition, these woods seem to be consumed the least. *Coptotermes curvignathus* appeared to wander around the wood but no obvious damage had been seen. They like to aggregate beneath the wood of *Eucalyptus* hybrid and *Gmelina arborea*. This may be due to the odour or fragrance of *Eucalyptus* hybrid and *Gmelina arborea*. *Azadirachta excelsa*'s seed was known to have insecticidal properties due to presence of azadirachtin (Butterworth and Morgan, 1986; Sompong and Rungnoi, 2000) and the

extracts of the plant was known to be antifeeding, insect growth inhibitory, antipyretic and many more (Cui, *et al.*, 1998). This could be the reason for the high mortality rate in the force feeding test in *Azadirachta excelsa* chamber. *Gmelina arborea* has been reported to be durable and resistant to insect attacks (Lemmens *et al.*, 1995).

Eucalyptus tree were reported to be notoriously susceptible to termite attack particularly *Coptotermes acinaciformis* (Froggatt), *Coptotermes frenchi* Hill and *Porotermes adamsoni* (Froggatt). However the susceptibility tested with *Macrotermes natalensis* can be varied with different types of *Eucalyptus* species and clones and even from different provenances (Atkinson *et al.*, 1992). Damage to the heartwood part by termite has been reported in Australia (Greaves, 1967; Elliot and Bashford, 1984). The trend however was not seen in the present study using *C. curvignathus*. It may be because of the sample was hybridise from the tolerant species or it was resistant to *C. curvignathus*.

Tectona grandis was another wood known for its hardness and extreme durability (Ti and Tangau, 1991; Kjaer *et al.*, 1999) but in Ngee, *et al.* (2004) reported that the subterranean termite (*Coptotermes* spp.) in Malaysia moderately preferred the wood more than the Japanese species, *Coptotermes formosanus*. It tallied with the results from the present force feeding study that *T. grandis* was one of the preferred species with no significant difference with *Acacia crassicarpa*. Nevertheless, if given a multiple choice test whether fresh or oven-dried *T. grandis* was never the preferred species.

The different parts of the wood also played an important role in *C. curvignathus* preferences for food and consumption. Generally *C. curvignathus* significantly preferred sapwood to heartwood. In all four feeding tests, the consumption of sapwood and heartwood appeared to be significantly different except in multiple choice test using oven-dried wood. It suggests that in fresh condition most of the alkaloids and chemical substances were stored in heartwood which may deter the termite from feeding on them. Scheffrahn (1991) stated that the resistance of wood to termite attack is mainly determined by the presence of chemicals in the lignocellulosic tissue (heartwood). On the other hand, the termite may prefer to feed on living tissue which was the sapwood as compared to the dead cells (lignin) of the heartwood.

It was observed that at times the termite like to aggregate in the small valley between the wood block species as in multiple choice test without feeding chamber or in the straw of the multiple choice test (fresh and oven-dried). This was probably due to the high humidity in the narrow environment which was conducive to termite survival. However the aggregation of termite did not affect the mass loss or the consumption of the wood involved in the former test.

CHAPTER 6

CONCLUSION

Among the planted species *H. brasiliensis* was significantly preferred by *C. curvignathus* in all preference tests with mean wood consumption of 554.97 mg (fresh), 391.63 mg (oven-dried) and 179.80 mg (force test). The potential ones beside *Hevea brasiliensis* was *Pentaspadon motleyi* with mean consumption of 215.47 mg (fresh), 165.39 mg (oven-dried) and 146.07 mg (force test) respectively. Thus these species can be used in plantation for termite bating purposes. The least preferred was *Azadirachta excelsa* and *Gmelina arborea* because of the azadirachtin properties and durabilities of respective species.

In all preference test except multiple choice test (oven-dried), *Coptotermes curvignathus* significantly preferred sapwood to heartwood. The mean consumption of the fresh ones was higher than the oven-dried ones. This indicates *C. curvignathus* highly preferred living tissue than dead tissue and fresh instead of oven-dried.

REFERENCE

- Ahmad, D. and L.H. Ang. 1993. Acacias for rural, industrial and environment development in Malaysia. In *Acacias for Rural, Industrial and Environmental Development*, ed. Kamis Awang and D.A. Taylor. pp. 46-49. Bangkok: Windrock-International and FAO.
- Appanah, S. and G. Weinland. 1993. Planting Quality Timber Trees in Peninsular Malaysia: A review. Kepong: Forest Research Institute Malaysia.
- Atkinson, P.R., K.M. Nixon and M.J.P. Shaw. 1992. On the susceptibility of *Eucalyptus* species and clones to attack by *Macrotermes natalensis* Haviland (Isoptera: termitidae). *Forest Ecology and Management* 48:15-30.
- Awang, K. and D.A. Taylor. ed. 1993. Acacias for Rural, Industrial and Environmental Development. Proceedings of the Second Meeting of the Consultative Group for Research and Development of Acacias (COGREDA). Bangkok, Thailand: Windrock-International and FAO. 258.
- Bhatt, B.P. and J.M.R. Tomar. 2002. Firewood properties of some Indian mountain tree and shrub species. *Biomass and Bioenergy* 23:257-256.
- Boas, I.H. 1947. The commercial timbers of Australia, the properties and uses. Commonwealth Sci. Indus. Res. Organ. pp. 344. Melbourne, Australia.
- Butterworth, J.H. and E.D. Morgan. 1968. Isolation of a substance that suppresses feeding in locusts. *Journal of Chemical Communication* 11:23-24.
- Chakraborty, R.N. and D. Chakraborty. 1989. Changes in soil properties under *Acacia auriculiformis* plantations in Tripura. *Indiana Forester* 115(4):272-273.
- Chen, J. and G. Henderson. 1996. Determination of feeding preference of Formosan subterranean termite (*Coptotermes formosanus* Shiraki) for some amino acid additives. *Journal of Chemical Ecology*. 22(12):2359-2369.
- Chey, V.K. and J. Intachat. 2000. Acacia plantation in Malaysia and their insect pests. *The Planter* 76(888)-2000, ISP K.L. 171 - 190.

- CSIRO, 1993. Collaborative research in regrowth forests of East Gippsland between CSIRO and the Victorian Department of Conservation and natural Resources. Regrowth Forests Program, CSIRO Division of Forestry. Second progress report, August. (unpublished report)
- Cui, B., H. Chai, H.L. Constant, T. Santisuk, V. Reutrakul, C.W.W. Beecher, N. R. Farnsworth, G.A. Cordell, J.M. Pezzuto, and A.D. Kinghorn. 1998. Limonoids from *Azadirachta excelsa*. *Phytochemistry* 47(7):1283-1287.
- Dai, Z.-R. and J.-Z. Luo. 1980. Preliminary observation on feeding of Formosan subterranean termites. *Kun Chong Zhi Shi* 17:74 – 76.
- Dela Cruz, L.U. and A.C. Luna. 1992. Effect of *Acacia auriculiformis* and *Gmelina arborea* on soil and microclimate of a degraded grassland in Nueva Ecija, Philippines. Paper presented at an international symposium on rehabilitation of degraded grassland held in Tsukuba, Japan.
- Eggleton, P. 2000. Global patterns of termite diversity. Kluwer Academic Publisher. Netherlands. Ed. Abe, T., D.E. Bignell and M. Higashi. In. Termites: Evolution, Sociality, Symbioses, Ecology.
- Elliott, H.J. and Bashford, R. 1984. Incidence and effects of the dampwood termite, *Porotermes adamsoni*, in two Tasmanian east coast eucalypt forests. *Austs. For.* 47: 11–15.
- Greaves, R. 1967. The influence of insects on the productive capacity of Australian forests. *Aust. For. Res.* 3:36–45.
- Imamura, Y. 2001. Anti-insect performance of wood and wood-based materials. In *Wood Preservation*, ed. Japan Wood Preserving Association, p. 108-111. Tokyo: Japan Wood Preserving Association (in Japanese).
- Indrayani Y., T. Yoshimura, Y. Yanase and Y. Imamura. 2007. Feeding responses of the western dry – wood termite *Incisitermes minor* (Hagen) (Isoptera: Kalotermitidae) against ten commercial timbers. *Journal of Wood Science.* 53:239-248.
- Katsumata, N., T. Yoshimura, K. Tsunoda and Y. Imamura. 2006. Termite feeding preference to four wood species after gamma radiation. *Journal of Wood Science.* 53(4)361-364.

- Khoo, K.C., P.A.C. Ooi and C.T. Ho. 1991. Crop pests and their management in Malaysia. Tropical Press, Kuala Lumpur, Malaysia.
- Kjaer, E.D., S. Kajornsrichon and E.B. Lauridsen. 1999. Heartwood, calcium and silica content in five provenances of Teak (*Tectona grandis*). *Silvae Genet.* 48:1-3.
- Kokutse, A.D., H. Bailleres, A. Stokes and K. Kokou. 2004. Proportion and quality of heartwood in Togolese teak (*Tectona grandis* L.f.). *Forest ecology and management* 189:37-48.
- Krishna, K. and F.M. Weesner. 1969. Biology of termite, volume 1. Academic Press, New York and London.
- Kushalapa, K.A. 1991. Performance of *Acacia auriculiformis* in India. In *Advances in Tropical Acacia Research*, ed. J.W. Turnbull. p. 189-193. Canberra: Australian Centre for International Agriculture Research.
- Lemmens, R.H.M.J., I. Soerianegara and W.C. Wong. 1995. Plant resources of South East Asia 5 – (2) Timber trees: Minor commercial timbers. Prosea – Bogor Indonesia.
- Ley S.V., A.A. Denholm and A. Wood. 1993. The chemistry of azadirachtin. *National Products Reports*. 109–157.
- Lim, G.M. 2007. Effects of Selected Residual Soil Termiticides On *Coptotermes curvignathus* Holmgren (Insecta: Isoptera: Rhinotermitidae) of Oil palm in Peat. B.BS thesis. Faculty of Agriculture and Food Science, UPM Bintulu Campus, Sarawak, Malaysia. (Unpublished).
- Lim, K. H. and Silek, B. 2001. Termite infestation on oil palms planted on deep peat in Sarawak: Tradewinds experience. Proceedings of the 2001 PIPOC International Palm Oil Congress (Agriculture).
- Mordue (Luntz) A.J. and A. Blackwell. 1993. Review- Azadirachtin: an update. *Journal of Insect Physiology*. 39(11):903–924.
- Morales Ramos, J.A. and M.G. Rojas. 2003. Nutritional ecology of Formosan subterranean termite (Isoptera: Rhinotermitidae): II. Growth and survival of

incipient colonies feeding on preferred wood species. *Journal of Economic Entomology*. (abstract).

- Nakayama, T., T. Yoshimura and Y. Imamura. 2005. Feeding activities of *Coptotermes formosanus* Shiraki and *Reticulitermes speratus* (Kolbe) as affected by moisture content of wood. *Journal of Wood Science*. 51:60 – 65.
- Nakayama, T., T. Yoshimura and Y. Imamura. 2004. The optimum temperature – humidity combination for the feeding activities of Japanese subterranean termites. *Journal of Wood Science*. 50:530 – 534.
- National Research Council. 1980. Firewood crops: Shrub and Tree Species for Energy Production. Volume 2, National Academy Press, Washington, D.C.
- Ngee, P.-S., A. Tashiro, T. Yoshimura, Z. Jaal and C.Y. Lee. 2004. Wood preference of selected Malaysian subterranean termites (Isoptera: Rhinotermitidae, Termitidae). *Sociobiology* 43(3):535-550.
- Pinyopusarek, K. 1990. *Acacia auriculiformis* – an annotated bibliography. Bangkok-Winrock International-F/FRED and ACIAR. 154.
- Scheffrahn, R.H. 1991. Allelochemical resistance of wood to termites. *Sociobiology* 19:257–281.
- Soepadmo, E., K. M. Wong and L.G. Saw. 1996. Tree Flora of Sabah and Sarawak-volume two. Forest Research Institute Malaysia. 67.
- Sompong, T., O. Rungnoi. 2000. Induction of somatic embryogenesis from leaves of Sadao Chang (*Azadirachta excelsa* (Jack) Jacobs). *Scientia Horticulturae* 86:311-321.
- Sosef, M.S.M., L.T. Hong, S. Prawirohatmodjo ed. 1998. Plant resources of South East Asia 5 – (3) Timber trees: Lesser-known timbers. Prosea – Bogor Indonesia.
- Sudharto, Ps., A. Sipayung and R. Desmier de Chenon. 1991. Termites – A new problem on oil palm plantations in Indonesia. PORIM International Palm Oil Conference.

Thapa, R.S. 1981. Termites of Sabah. Sabah Forest Department. Sandakan.

Thomson, L.A.J. 1987. Australian acacia for saline, alkaline soils in the hot, dry subtropics and tropics. In *Australian acacia in Developing Countries*, ed. J.W. Turnbull. p. 66-69. Queensland, Australia: Australian Centre for International Agricultural Research.

Ti, T.C. and W.M. Tangau. 1991. Cultivated and potential forest plantation tree species – with special reference to Sabah. Institute for Development Studies (Sabah).

Van Den Beldt, R.J. ed. 1993. Imperata grassland in Southeast Asia: Summary reports from the Philippines, Malaysia and Indonesia. Multipurpose Tree Species Research Network Report No. 18. Bangkok: Winrock- International. 52.

Wong, W. C. and K. C. Khoo. 1980. *Gmelina arborea*. A literature review. Forest Research Institute report No. 14.

Wood, B.J. 1968. Pests of oil palm in Malaysia and their control. The Incorporated Society of Planters.

Youngs, R.L. 1960. Physical, mechanical and other properties of five Hawaiian woods. U.S. Forest Product Laboratory Report 2191.

Zulkefli, M., K. Norman and A.S. Idris. 2000. Pengawalan penyakit dan perosak sawit. Seminar pekebun kecil dan penyelia ladang sawit peringkat negeri Sabah dan Sarawak. Sandakan, Sabah.

Zulkefli, M., K. Norman, B.W.Z.A. Mohd Basri and N. J. Kairul. 2006. Rubstake – rubber wood stake for detecting subterranean termites in peat soil. MPOB Malaysia.

APPENDICES

APPENDIX 1

ANOVA table in a multiple choice test with dry wood

Source	DF	Sum of squares	Mean square	F Value	Pr > F
Replicate	4	48126.64	12031.66	1.87	0.1371
Factor A (Species)	9	1.08727.83	145414.20	22.59	<.0001***
Error (a)	36	231697.00	6436.03	2.82	0.0008***
Factor B (Parts)	1	6480.25	6480.25	2.84	0.0996
A x B	9	33993.04	3777.00	1.66	0.1322
Error (b)	40	91171.88	2279.30		
Total	99	1720196.64			

$$r^2 = 0.946999$$

$$CV = 63.08402$$

*Significant at $p \leq 0.05$

**Significant at $p \leq 0.01$

***Significant at $p \leq 0.001$

APPENDIX 2

ANOVA table in a multiple choice test with fresh wood

Source	DF	Sum of squares	Mean square	F Value	Pr > F
Replicate	4	27354.90	6838.72	0.97	0.4342
Factor A (Species)	9	2482152.05	275794.67	39.25	<.0001***
Error (a)	36	252956.53	7026.57	1.23	0.2618
Factor B (Parts)	1	127085.12	127085.12	22.24	<.0001***
A x B	9	533860.38	59317.82	10.38	<.0001***
Error (b)	40	228613.58	5715.34		
Total	99	3652022.56			

$$r^2 = 0.937401$$

$$CV = 59.34847$$

*Significant at $p \leq 0.05$

**Significant at $p \leq 0.01$

***Significant at $p \leq 0.001$

APPENDIX 3

ANOVA table in a force test with dry wood

Source	DF	Sum of squares	Mean square	F Value	Pr > F
Replicate	4	0.00307847	0.00076962	1.64	0.1857
Factor A (Species)	9	0.20565311	0.02285035	48.67	<.0001***
Error (a)	36	0.01690178	0.00046949	0.50	0.9806
Factor B (Parts)	1	0.27656029	0.27656029	296.07	<.0001***
A x B	9	0.20112442	0.02234716	23.92	<.0001***
Error (b)	40	0.03736426	0.00093411		
Total	99	0.74068234			

$$r^2 = 0.949554$$

$$CV = 30.93092$$

*Significant at $p \leq 0.05$

**Significant at $p \leq 0.01$

***Significant at $p \leq 0.001$

APPENDIX 4

ANOVA table in a multiple choice in a single harbourage

Source	DF	Sum of squares	Mean square	F Value	Pr > F
Replicate	3	0.00177533	0.00059178	1.90	0.1538
Factor A (Species)	9	0.17295005	0.01921667	61.62	<.0001***
Error (a)	27	0.00842046	0.00031187	0.46	0.9774
Factor B (Parts)	1	0.01639640	0.01639640	24.22	<.0001***
A x B	9	0.06924127	0.00769347	11.37	<.0001***
Error (b)	30	0.02030558	0.00067685		
Total	79	0.28908909			

$$r^2 = 0.946999$$

$$CV = 63.08402$$

*Significant at $p \leq 0.05$

**Significant at $p \leq 0.01$

***Significant at $p \leq 0.001$

APPENDIX 5

Moisture test

Tree species	Part of wood	Moisture (%)
<i>Acacia mangium</i>	Sapwood	49.8486%
	Heartwood	52.0431%
<i>Acacia auriculiformis</i>	Sapwood	34.1077%
	Heartwood	35.3131%
<i>Acacia crassicaarpa</i>	Sapwood	43.0708%
	Heartwood	29.9104%
<i>Eucalyptus hybrid</i>	Sapwood	33.2990%
	Heartwood	30.2871%
<i>Macaranga gigantea</i>	Sapwood	41.9885%
	Heartwood	39.1924%

<i>Gmelina arborea</i>	Sapwood	50.6883%
------------------------	---------	----------

	Heartwood	50.4254%
--	-----------	----------

<i>Tectona grandis</i>	Sapwood	9.3165%
------------------------	---------	---------

	Heartwood	8.2619%
--	-----------	---------

<i>Azadirachta excelsa</i>	Sapwood	26.7390%
----------------------------	---------	----------

	Heartwood	26.6539%
--	-----------	----------

<i>Hevea brasiliensis</i>	Sapwood	37.6694%
---------------------------	---------	----------

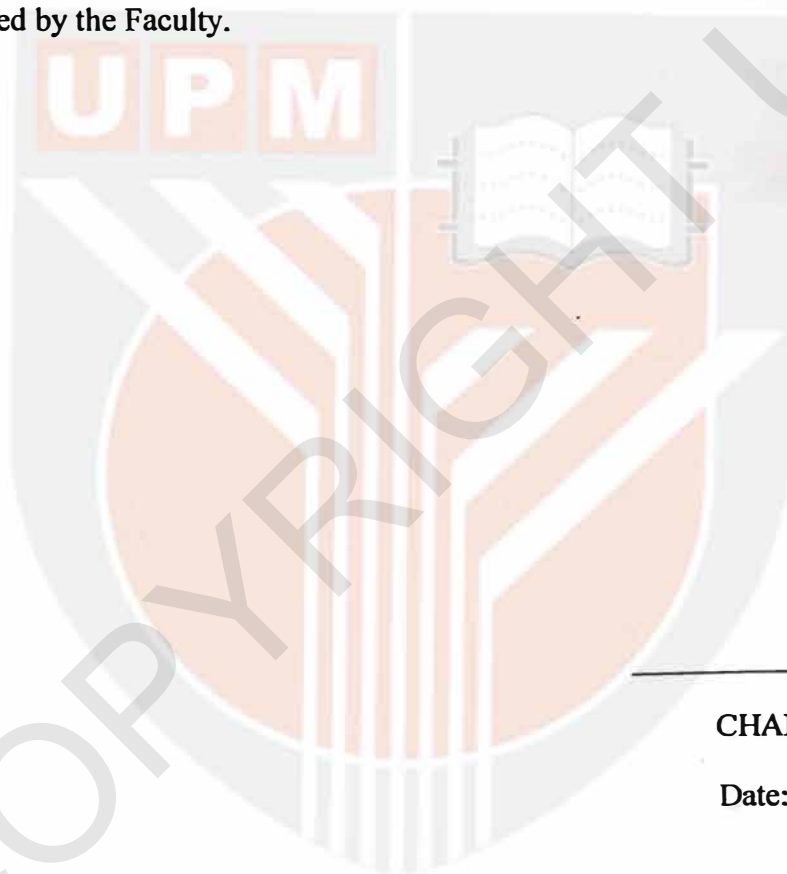
	Heartwood	34.4538%
--	-----------	----------

<i>Pentspadon motleyi</i>	Sapwood	46.4918%
---------------------------	---------	----------

	Heartwood	47.9022%
--	-----------	----------

PUBLICATION OF THE PROJECT UNDERTAKING

This is to certify that I have no objection to publish the project entitled "Feeding Preference of Subterranean Termite *Coptotermes curvignathus* Holmgren (Insecta: Isoptera: Rhinotermitidae) on Selected Timber Species" by the supervisor in a joint authorship. However, it has to be evaluated by the Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Campus and published in the form approved by the Faculty.



CHAN SEOW PHAN

Date: 20 APRIL 2008