



Faculty of Resource Science and Technology

**Termite Resistance of Selected Wood Species Treated using Various
Chemicals and Treatment Methods Exposed to *Coptotermes curvignathus***

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Termite Resistance of Selected Wood Species treated using Various
Chemicals and Treatment Methods Exposed to *Coptotermes curvignathus*

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A thesis submitted

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DECLARATION

I hereby declare that the Masters degree thesis is based on my original work excepts for quotations and citations, which have been duly acknowledged. This thesis has not been accepted for any degree and is not concurrently submitted in canditure for any other degree.

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ABSTRACT

Malaysian forests are blessed with diversity of wood species not only become a source of income to Malaysia in terms of timber trading but also provide its citizens with wood material for various uses. However, all untreated wood exposed to tropical condition is predisposed to high termite and decay hazard and therefore untreated wood needed to be protected using wood protective chemicals. The objectives of this study were to collect and identify termite genus that caused destructive damages to wood and wood products, to provide baseline data on selected basic wood properties and natural durability of selected wood species to termites. Besides that, it was essential to determine the wood protection of selected species using different treatment methods and wood protective chemicals (diesel and dead engine oil, Light organic solvent preservative (LOSP) and agro-insecticides). Treated wood was exposed to the aboveground termite test simulating Hazard Class 2 condition. Information on basic physical properties, extractive contents and natural durability of tested woods had been recorded. The natural durability study found out that a total of 11 out of 69 tested species were regarded as highly susceptible and visually rated 0. Examples of non-durable wood were *Aglaia borneensis*, *Dyera polyphylla*, *Neolamarckia cadamba*, *Adinandra borneensis* and *Hevea brasiliensis*. There were 25 out of 69 tested species were found to be moderately resistant to termite and these species were rated 6.5 to 8.9. Examples of these species were *Koompassia malaccensis*, *Canarium apertum*, *Azadirachta excelsa*, *Kokoona reflexa* and *Heritiera aurea*. There were 17 wood species considered resistant to termites (rating 9 – 9.4). Examples of these species were *Acacia mangium*, *Anisoptera grossivenia* and *Palaquium* spp. There were 12 out of 69 regarded as highly resistant to termite with rating (≥ 9.5). Examples of these species were *Artocarpus anisophyllus*, *Upuna borneensis* and *Eusideroxylon zwageri*. This study also confirmed

that the natural durability of *Dipterocarpus* spp. varies depending on the species tested. In experiment 3, *H. brasiliensis*, *A. mangium* and pine ply were dip-treated using diesel revealed that these woods dip-treated using diesel oil achieved good protection to wood (rating: 9.5 – 9.7). In experiment 4, *K. reflexa*, *A. borneensis* and *C. apertum* were dip-treated and vacuum pressure-treated using LOSP. It was found that vacuum pressure-treated wood using LOSP achieved good protection to wood (rating: 9.2 – 10). Dip-treated *H. brasiliensis*, *K. malaccensis* in experiment 5 and also *N. cadamba* in experiment 6 using 6.3 and 12.5% chlorpyrifos, 1.68 and 3.35% cypermethrin as well as 3.38 and 6.75% permethrin were found completely protecting the wood from termites (rating: 10). In experiment 7, *H. brasiliensis* and *N. cadamba* were vacuum pressure-treated to target retentions of different agro-insecticides. Wood vacuum pressure-treated to target retentions of 0.1% m/m cypermethrin were well protected from termites (rating: 9.5 – 10). Good protection (rating: 9.3 – 9.5) had been achieved in wood vacuum pressure-treated to target retentions of 0.0051% m/m deltamethrin. In conclusion, genus *Coptotermes* proven to be prevalent insect pest. Besides that, baseline data of wood physical properties, extractive contents and natural durability of tested wood species had been documented. Diesel and LOSP treatment can be effectively use in wood protection. For dipping treatment, 6.3 and 12.5% chlorpyrifos, 1.68 and 3.35% cypermethrin, 3.38 and 6.75% permethrin were found completely protecting the wood. It was also proven that target retentions used in other countries may not applicable to be used in tropical region.

Keywords: Natural durability, termites, LOSP, agro-insecticides, dipping treatment, vacuum pressure treatment

Ketahanan Terhadap Anai-Anai Spesies Kayu Terpilih yang Dirawat dengan Berbagai Bahan Kimia dan Kaedah Pengawetan Didedahkan kepada Coptotermes curvignathus

ABSTRAK

Hutan di Malaysia bukan sekadar menjadi sumber pendapatan kepada negara dari segi penjualan kayu-kayan namun membekalkan rakyatnya dengan bahan kayu untuk pelbagai kegunaan. Kayu yang digunakan di persekitaran tropika tanpa diawet akan mengalami serangan biologi (anai-anai dan kulat) maka kayu perlu dirawat dengan bahan kimia. Objektif kajian ini adalah untuk mengenalpasti genus anai-anai yang menyerang kayu dan produk kayu. Selain itu, untuk menyediakan data asas bagi spesies kayu yang diuji dari segi ciri-ciri fizikal, kandungan ekstrakatif dan daya ketahanan semula jadi terhadap anai-anai. Selain itu, maklumat mengenai perlindungan spesies kayu menggunakan berbagai rawatan kimia (diesel, pengawet pelarut organik (LOSP) dan racun serangga perosak) serta kaedah perawatan yang berbeza perlu diketahui. Spesies kayu yang dirawat telah didedahkan kepada anai-anai di ujian lapangan menyerupai keadaan Hazard Class 2. Untuk daya ketahanan semula jadi terhadap anai-anai, dilaporkan 11 daripada 69 spesies kayu yang diuji adalah tidak tahan terhadap serangan anai-anai. Contoh-contoh spesies kayu tersebut adalah Aglaia borneensis, Dyera polyphylla, Neolamarckia cadamba, Adinandra borneensis dan Hevea brasiliensis. Terdapat 25 spesies kayu yang sederhana tahan terhadap anai-anai dengan kadar visual 6.5 hingga 8.9. Contoh-contoh spesies kayu tersebut adalah Koompassia malaccensis, Canarium apertum, Azadirachta excelsa, Kokoona reflexa dan Heritiera aurea. Didapati 17 spesies kayu yang tahan terhadap serangan anai-anai (kadar visual: 9 – 9.4). Contoh-contoh spesies kayu tersebut adalah Acacia mangium, Anisoptera grossivenia dan Palaquium spp. Terdapat 12 spesies kayu yang sangat tahan terhadap anai-anai dengan kadar visual lebih daripada 9.5. Contoh-

contoh spesies kayu tersebut adalah Artocarpus anisophyllus, Upuna borneensis dan Eusideroxylon zwageri. Kajian ini juga telah mengesahkan bahawa daya ketahanan semula jadi Dipterocarpus spp. terhadap anai-anai adalah berbeza mengikut spesies keruing yang diuji. Dalam eksperimen 3, H. brasiliensis, A. mangium dan papan lapis pine yang dirawat dengan diesel secara rendaman mendapat perlindungan yang baik (kadar visual: 9.5 – 9.7). Dalam eksperimen 4, K. reflexa, A. borneensis dan C. apertum telah diawet dengan LOSP dan didapati menggunakan kaedah tekanan vakum juga memberikan perlindungan yang baik (kadar visual: 9.2 – 10). Kajian ini juga mendapati H. brasiliensis, K. malaccensis dalam eksperimen 5 dan N. cadamba dalam eksperimen 6 diawet dengan 6.3 dan 12.5% chlorpyrifos, 1.68 dan 3.35% cypermethrin, 3.38 dan 6.75% permethrin dengan kaedah rendaman mendapat perlindungan yang sempurna (kadar visual: 10). Dalam eksperimen 7, H. brasiliensis dan N. cadamba yang dirawat secara tekanan vakum sehingga mencecah kadar pengekal untuk setiap jenis racun serangga perosak. Kayu H. brasiliensis dan N. cadamba yang dirawat mencecah kadar pengekal 0.1% m/m cypermethrin dan 0.0051% m/m deltamethrin dalam kayu telah mendapat perlindungan yang baik. Kesimpulannya, genus Coptotermes dikenalpasti sebagai serangga perosak yang lazim. Selain itu, maklumat asas untuk spesies kayu yang diuji telah didokumentasikan. Rawatan kayu menggunakan diesel, LOSP dan racun serangga perosak dengan kepekatan yang tinggi juga memberikan perlindungan yang baik kepada kayu. Kayu yang dirawat mencecah kadar pengekal yang disyorkan untuk negara lain tidak dijamin dapat memberikan perlindungan sepenuhnya kepada kayu.

Kata kunci: Ketahanan semulajadi, anai-anai, LOSP, racun serangga perosak, rawatan rendaman, rawatan tekanan vakum

LIST OF CONTENTS

	Page
DECLARATION	i
AKNOWLEDGEMENT	ii
ABSTRACT	iii
ABSTRAK	v
LIST OF CONTENTS	vii
LIST OF TABLES	xiv
LIST OF FIGURES	xvii
CHAPTER 1: INTRODUCTION	1
1.1 Problem statements	3
1.2 Objectives	4
CHAPTER 2: LITERATURE REVIEW	5
2.1 Tropical timber	5
2.1.1 Acacia (<i>Acacia mangium</i>)	7
2.1.2 Bajan (<i>Kokoona reflexa</i>)	7
2.1.3 Kelempayan (<i>Neolamarckia cadamba</i>)	8
2.1.4 Kempas (<i>Koompassia malacensis</i>)	8
2.1.5 Keruing (<i>Dipterocarpus</i> spp.)	9
2.1.6 Legai (<i>Adinandra borneensis</i>)	9
2.1.7 Rubberwood (<i>Hevea brasiliensis</i>)	10
2.1.8 Seladah (<i>Canarium apertum</i>)	10

2.1.9 Other timber species used	11
2.2 Wood physical and mechanical properties	17
2.2.1 Density	17
2.2.2 Mechanical properties	18
2.2.3 Water permeability	19
2.3 Wood Extractives	20
2.4 Subterranean Termites	21
2.4.1 General characteristics of termites	21
2.4.2 Damages done by termites from genus <i>Coptotermes</i>	22
2.5 Types of preservatives	24
2.5.1 Oil-borne preservatives	24
2.5.2 Waterborne preservatives	25
2.5.2.1 CCA preservative	26
2.5.2.2 Borate preservatives	27
2.5.2.3 Chlorpyrifos	29
2.5.2.4 Cypermethrin	30
2.5.2.5 Deltamethrin	30
2.5.2.6 Permethrin	31
2.5.3 Light organic solvent preservative	32
2.6 Treatment methods	33
2.6.1 Dipping treatment	33
2.6.2 Vacuum pressure treatment	34

CHAPTER 3: MATERIALS AND METHODS	35
3.1 Study sites	35
3.2 Termite collections	35
3.3 Experiment 1: Basic physical properties, extractive contents and natural termite resistance of tested species	36
3.3.1 Wood samples	36
3.3.2 Wood density	38
3.3.3 Hardness test	39
3.3.4 Compression parallel to grain test	40
3.3.5 Water permeability	41
3.3.6 Extractive content	41
3.3.6.1 Preparation of sawdust	41
3.3.6.2 Cold water extraction	42
3.3.6.3 Hot water extraction	42
3.3.6.4 Methanol extraction	43
3.3.6.5 Extractive content calculation	43
3.3.7 Natural termite Resistance	44
3.4 Experiment 2: Natural termite resistance of <i>Dipterocarpus</i> spp. and <i>Acacia mangium</i>	45
3.5 Experiment 3: Termite resistance of <i>Acacia mangium</i> , <i>Hevea brasiliensis</i> and pine ply dip-treated with diesel, dead engine oil and combination of both oils	46

3.6 Experiment 4: Termite resistance of light organic solvent preservative treated <i>Kokoona reflexa</i> , <i>Adinandra borneensis</i> and <i>Canarium apertum</i> using dipping and vacuum pressure treatment	47
3.6.1 Dipping treatment	48
3.6.2 Vacuum pressure treatment	48
3.7 Experiment 5: Termite resistance of <i>Koompassia malaccensis</i> and <i>Hevea brasiliensis</i> dip-treated using chlorpyrifos, cypermethrin and permethrin	49
3.8 Experiment 6: Termite resistance of <i>Neolamarckia cadamba</i> and <i>Hevea brasiliensis</i> dip-treated using chlorpyrifos, cypermethrin and permethrin	51
3.9 Experiment 7: Termite resistance of <i>Neolamarckia cadamba</i> and <i>Hevea brasiliensis</i> vacuum pressure-treated with chlorpyrifos, cypermethrin, deltamethrin and permethrin	52
3.10 Data Analysis	54
CHAPTER 4: RESULTS	55
4.1 Termite collections	55
4.2 Experiment 1: Basic physical properties, extractive contents and natural termite resistance of tested species	58
4.2.1 Basic physical properties	58
4.2.2 Extractive contents	65
4.2.3 Natural termite resistance	73

4.3 Experiment 2: Natural termite resistance of <i>Dipterocarpus</i> spp. and <i>Acacia mangium</i>	78
4.4 Experiment 3: Termite resistance of <i>Acacia mangium</i> , <i>Hevea brasiliensis</i> and pine ply dip-treated with diesel, dead engine oil and combination of both oils	80
4.5 Experiment 4: Termite resistance of light organic solvent preservative treated <i>Kokoona reflexa</i> , <i>Adinandra borneensis</i> and <i>Canarium apertum</i> using dipping and vacuum pressure treatment	82
4.6 Experiment 5: Termite resistance of <i>Koompassia malaccensis</i> and <i>Hevea brasiliensis</i> dip-treated using chlorpyrifos, cypermethrin and permethrin	85
4.6.1 Low humidity exposure	85
4.6.1.1 Chlorpyrifos	85
4.6.1.2 Cypermethrin	87
4.6.1.3 Permethrin	89
4.6.2 High humidity exposure	93
4.6.2.1 Chlorpyrifos	93
4.6.2.2 Cypermethrin	95
4.6.2.3 Permethrin	97
4.7 Experiment 6: Termite resistance of <i>Neolamarckia cadamba</i> and <i>Hevea brasiliensis</i> dip-treated using chlorpyrifos, cypermethrin and permethrin	105
4.7.1 Chlorpyrifos	105
4.7.2 Cypermethrin	107

4.7.3 Permethrin	109
4.8 Experiment 7: Termite resistance of <i>Neolamarckia cadamba</i> and <i>Hevea brasiliensis</i> vacuum pressure-treated with chlorpyrifos, cypermethrin, deltamethrin and permethrin	113
4.8.1 Chlorpyrifos	113
4.8.2 Cypermethrin	115
4.8.3 Deltamethrin	117
4.8.4 Permethrin	119
CHAPTER 5: DISCUSSION	122
5.1 Termite collections	122
5.2 Basic physical properties, extractive contents and natural termite resistance of tested species	124
5.3 Natural termite resistance of <i>Dipterocarpus</i> spp. and <i>Acacia mangium</i>	131
5.4 Termite resistance of <i>Acacia mangium</i> , <i>Hevea brasiliensis</i> and pine ply dip-treated with diesel, dead engine oil and combination of both oils	132
5.5 Termite resistance of light organic solvent preservative treated <i>Kokoona reflexa</i> , <i>Adinandra borneensis</i> and <i>Canarium apertum</i> using dipping and vacuum pressure treatment	134
5.6 Termite resistance of <i>Koompassia malaccensis</i> and <i>Hevea brasiliensis</i> dip-treated using chlorpyrifos, cypermethrin and permethrin	135

5.7 Termite resistance of <i>Neolamarckia cadamba</i> and <i>Hevea brasiliensis</i> dip-treated using chlorpyrifos, cypermethrin and permethrin	138
5.8 Termite resistance of <i>Neolamarckia cadamba</i> and <i>Hevea brasiliensis</i> vacuum pressure-treated with chlorpyrifos, cypermethrin, deltamethrin and permethrin	140
CHAPTER 6: CONCLUSION AND RECOMMENDATIONS	143
REFERENCES	145
APPENDICES	161

LISTS OF TABLES

		Page
Table 2.1	Species descriptions of tested wood	14
Table 3.1	List of wood species used	36
Table 3.2	AWPA E7-07 termite rating scheme (AWPA 2008)	45
Table 3.3	List of <i>Dipterocarpus</i> spp. and <i>Acacia mangium</i>	45
Table 3.4	Concentrations used for wood treatment using dipping treatment	50
Table 3.5	Working concentrations used to vacuum pressure-treat wood to the target retentions (% m/m) of each insecticide	53
Table 4.1	Number of collected termite specimens based on genus and species	55
Table 4.2	Basic physical properties of tested wood species	60
Table 4.3	Extractive contents of tested wood species	67
Table 4.4	Mean percentage mass loss, absolute mass loss and termite rating of tested wood species	74
Table 4.5	Mean percentage mass loss, absolute mass loss and termite rating of <i>Dipterocarpus</i> spp. and <i>Acacia mangium</i>	79
Table 4.6	Mean percentage mass loss, absolute mass loss and termite rating of oil treated <i>Acacia mangium</i> , <i>Hevea brasiliensis</i> and pine plywood	81
Table 4.7	Mean percentage mass loss, absolute mass loss and termite rating of LOSP treated <i>Kokoona reflexa</i> , <i>Adinandra borneensis</i> and <i>Canarium apertum</i>	82
Table 4.8	Mean actual retention of treated wood treated using different treatment methods	83
Table 4.9	Mean percentage mass loss, absolute mass loss and termite rating of chlorpyrifos treated wood exposed to low humidity exposure	86
Table 4.10	Mean percentage mass loss, absolute mass loss and termite rating of cypermethrin treated wood exposed to low humidity exposure	88

Table 4.11	Mean percentage mass loss, absolute mass loss and termite rating of permethrin treated wood exposed to low humidity exposure	90
Table 4.12	Mean actual retentions of active ingredients in treated wood (low humidity exposure)	91
Table 4.13	Mean percentage mass loss, absolute mass loss and termite rating of chlorpyrifos treated wood exposed to high humidity exposure	94
Table 4.14	Mean percentage mass loss, absolute mass loss and termite rating of cypermethrin treated wood exposed to high humidity exposure	96
Table 4.15	Mean percentage mass loss, absolute mass loss and termite rating of treated wood dip-treated using different concentrations of Permethrin comparing different dipping times exposed to high humidity exposure	99
Table 4.16	Mean actual retentions of active ingredients in treated wood (high humidity exposure)	103
Table 4.17	Mean percentage mass loss, absolute mass loss and termite rating of <i>H. brasiliensis</i> and <i>N. cadamba</i> dip-treated using different concentrations of Chlorpyrifos	106
Table 4.18	Mean percentage mass loss, absolute mass loss and termite rating of <i>H. brasiliensis</i> and <i>N. cadamba</i> dip-treated using different concentrations of Cypermethrin	108
Table 4.19	Mean percentage mass loss, absolute mass loss and termite rating of <i>H. brasiliensis</i> and <i>N. cadamba</i> dip-treated using different concentrations of Permethrin	110
Table 4.20	Mean actual retentions of particular chemicals' active ingredients in woods	112
Table 4.21	Mean percentage mass loss, absolute mass loss and termite rating of <i>H. brasiliensis</i> and <i>N. cadamba</i> vacuum pressure-treated to different target retentions of Chlorpyrifos	113
Table 4.22	Mean percentage mass loss, absolute mass loss and termite rating of tested species	115
Table 4.23	Mean percentage mass loss, absolute mass loss and termite rating of <i>H. brasiliensis</i> and <i>N. cadamba</i> vacuum pressure-treated to different target retentions of Cypermethrin	116
Table 4.24	Mean percentage mass loss and termite rating of treated wood vacuum pressure-treated to different target retentions of Cypermethrin	117

Table 4.25	Mean percentage mass loss, absolute mass loss and termite rating of <i>H. brasiliensis</i> and <i>N. cadamba</i> vacuum pressure-treated to different target retentions of Deltamethrin	118
Table 4.26	Mean percentage mass loss and termite rating of treated wood vacuum pressure-treated to different target retentions of Deltamethrin	119
Table 4.27	Mean percentage mass loss, absolute mass loss and termite rating of <i>H. brasiliensis</i> and <i>N. cadamba</i> vacuum pressure-treated to different target retentions of Permethrin	120
Table 4.28	Mean actual retentions of active ingredients in treated wood	121

LISTS OF FIGURES

		Page
Figure 3.1	Compression parallel to grain test	40

CHAPTER 1

INTRODUCTION

Malaysian forests are well-diverse with timber species that continuously provide the citizens with wood to be used as materials for wood products manufacturing which can be used under H2 biological hazard class specified in the Malaysian wood protection Standard (Wong, 2004; 2005). According to Wong (2004), Malaysian hazard class selection guideline would make it easier to select preservative treatment system and specification to protect wood under assigned hazard class. H2 hazard class meant for wood used particularly indoor aboveground not subjected to wetting or leaching. Besides that, some timbers harvested from Malaysian forests also known to have commercial values in timber trading. For instance, Sarawak had exported about 2 million m³ of logs worth approximately RM1.1 billion from January to October 2016 (STA Review, 2016).

Timber species from Malaysian forests have a wide range of natural durability. Natural durability is defined as the ability of timber to withstand attack by wood destroying organisms (Azrieda *et al.*, 2016). Use of naturally high durable or termite resistant wood species often preferred for utilization that their service life is expected to last longer, but over the years these species if without treatment would eventually deteriorate biologically. Although wood is well known for its vast functionality, due to its biological nature, wood is readily degraded by bacteria, fungi and termites (Walker, 1993). In the tropical region, untreated wood is predisposed to high decay and termite hazard (Wong, 2004).

Termite is an important wood bioteriorating insect which feeds mainly on cellulosic materials. For instance, termites feed on papers, wooden buildings and trees. It was reported that there are over 2500 termite species known today while *Reticulitermes* and

Coptotermes are the major destructive pest of America, Europe and Asia (Pearce, 1997). Kirton and Wong (2001), reported that termites as economically important structural pests in tropical countries and their destructive significance to wood products seem more serious than that of tropical decay fungi. Genus *Coptotermes* causes more widespread and serious damage to mature trees. It was also reported that *Coptotermes* responsible for more than 90 percent of the total infestations in buildings in West Malaysia. Lee (2004), also reported that in the year of 2003, the cost to control termites in Malaysia amounted USD 10-12 million. So far successful termite control measures in agriculture and wood buildings depend largely on the pest controls and wood preservation industries by applying chemically persistent wood preservatives.

In the past, most woods were treated using chromated copper arsenate (CCA) as it is the most effective wood preservative meant to protect wood from decay fungi and wood attacking insects (Walker, 1993). CCA has been preferably used by the timber industry to treat wood because of its cost effectiveness besides that CCA not only kill insects (due to arsenical compound) but also inhibit fungal attack (due to the presence of copper). CCA treated wood is odourless and paintable (Walker, 1993). CCA previously was widely used throughout the world including Malaysia for both indoor and outdoor use complying with Malaysian Standard MS360:1991 (Wong *et al.*, 1997). In Malaysia, CCA mainly used to treat roof trusses, ceiling joists of residential houses (Wong *et al.*, 2011). However, CCA is not environmental friendly, harmful to workers and the environment. The dangers posed to wood treatment workers by CCA preservative and environmental degradation becoming major concerns from various environmental protection agencies worldwide.

1.1 Problem statements

Many people tend to have the propensity to assume timber quality and durability based on casual observations (Wong & Ling, 2009). It is often assumed that refractory timbers and all dense, dark coloured timbers are durable while all less dense and light coloured timber are non-durable. Besides that, the trade names used in timber trading often confined to multi-species groups that the same trade name may comprises of different species (Wong, 2002). For instance, there are many species under the trade name Keruing. Many local people tend to assume that species with trade name keruing is resistance to termite. However, in actual fact, different species of keruing have different natural durability ranging from moderately durable to non-durable (Wong, 2002; Wong & Ling, 2009). It would be very important to come out with the baseline data in order to provide people with concrete information about the wood instead by assuming the timber quality and durability based on assumption. It can be rather dangerous to assume that termite resistant wood species does not need to be chemically protected.

Every wood species including those naturally resistant to termite need to be protected using chemical preservatives. Since CCA is regarded as harmful wood preservative to the wood treatment workers and the environment. Other part of the world, people use diesel and dead engine oil to preserve the wood (Akutse *et al.*, 2012; Pereira *et al.*, 2015). There are many studies also demonstrate that wood treatment using organophosphate or synthetic pyrethroids including LOSP can provide protection to wood against wood biodeteriogens (Sornnuwat *et al.*, 1994; Messaoudi *et al.*, 2018). Hence, other alternatives of using various chemicals like diesel or dead engine oil, light organic solvent preservatives and agro-insecticides containing organophosphate or synthetic pyrethroids should be considered to protect tropical hardwoods. However, baseline data (especially on aboveground termite test)

of tested wood species are rather limited (Wong, 2005; Kadir & Masseat, 2017). Besides that, the information on the preservation of Malaysian hardwoods using various chemicals such as diesel or dead engine oil, LOSP and synthetic agro-insecticides are very limited.

1.2 Objectives

- i. To identify termite genus and species that caused destructive damages to wood and wood products.
- ii. To establish baseline data on basic wood properties and natural durability of selected wood species against termites (*Coptotermes curvignathus*).
- iii. To determine termite resistance of selected wood species using oil-based and solvent-based wood preservative.
- iv. To compare termite resistance of waterborne preservative-treated wood using dipping and vacuum pressure treatment.

CHAPTER 2

LITERATURE REVIEW

2.1 Tropical timber

Many timbers are used on a large scale for various purposes such as in construction sectors, furniture manufacturing industries, pulp and paper and more. The high demand for tropical timber forces the wood industries to utilize secondary timbers, imported timbers and plantation timbers from indigenous and exotic trees (Remadevi & Muthukrishnan, 2007). In Sarawak, the government had initiated the planting programme of fast-growing timber species to sustain the existing natural forests. Jusoh *et al.* (2014), stated that although *Acacia mangium* is the main species planted in Sarawak, other tree species such as *Neolamarckia cadamba*, *Paraserianthes falcataria* and *Eucalyptus* spp. also being planted. According to Remadevi and Muthukrishnan (2007), most of the exotic timber species are fast-growing and yield marketable sized timber in a shorter time. Besides that, exotic trees such as *Eucalyptus* and *Acacia* yield quality timber. Tropical timber logs, sawn timber and plywood are widely commercialized in the international timber trade. In 2016 alone, Sarawak had exported approximately 2 million m³ logs (STA Review, 2016). Examples of timber logs being traded were *Acacia mangium*, kapur, keruing, meranti, resak, selangan batu and other timber species (STA Review, 2016). End-users often prefer wood in terms of good natural durability, strength and appearance of timber for various end-uses (Wong *et al.*, 2005).

Malaysian hardwoods are classified according to the timber classification and strength groups. For timber classification, Malaysian Grading Rules (Anonymous, 1984) was used which categorized hardwoods into four broad groups. The four groups are Light hardwood

(density range of 400 to 720 kg/m³), Medium hardwood (720 to 880 kg/m³), Heavy hardwood (800 to 1120 kg/m³) and softwood based on botanical distinction. As for the strength grouping, the grouping was done according to Burgess (1958), which divides the timber into four strength grouping. Group A (Extremely strong, green compressive strength > 55.2 MPa), Group B (Very strong, green compressive strength between 41.4 to 55.2 MPa), Group C (Strong, green compressive strength between 27.6 to 41.4 MPa) and Group D (Weak, green compressive strength between < 27.6 MPa). Besides that, other wood physical, mechanical and chemical properties are also used to evaluate wood quality. The lack of information on basic wood properties, extractive contents and natural termite resistance on wood species often leads to the impressions of timber quality and durability based on casual observations by end-users. It is commonly assumed that refractory timbers, as well as all dense and dark coloured timbers, are durable while all less dense and light coloured timber are non-durable (Wong and Ling, 2009). Besides that, wood traders often use the trade names in timber trading that usually confined to multi-species groups that the same trade name may comprises of different species (Wong, 2002). However, in timber trading, it is not practical to treat all the available species as individual entries as it will cause confusion in large number of timbers traded. For example, there are many wood species under the trade name Keruing. Many people assume that species with trade name keruing is resistance to termite. However, in reality, different species of keruing possess different natural durability ranging from moderately durable to non-durable (Wong, 2002; Wong & Ling, 2009). Thus, these issues needed to be addressed properly.

Examples of tropical timbers used in this research were Acacia (*Acacia mangium*), bayan (*Kokoona reflexa*), kelempayan (*Neolamarckia cadamba*), kempas (*Koompassia malacensis*), keruing (*Dipterocarpus* spp.), legai (*Adinandra borneensis*), rubberwood

(*Hevea brasiliensis*) and seladah (*Canarium apertum*). Other timber species also were used in this research.

2.1.1 Acacia (*Acacia mangium*)

Acacia is a light hardwood belonged to the family Leguminosae and has air-dry density of 290 to 580 kg/m³ and the density varies with the age of Acacia (Wong, 2002). This wood is moderately strong under strength group C. Acacia is reported non-durable when exposed to extreme conditions (Wong, 2002; Wong & Ling, 2009). Acacia can be used as light construction works, veneer, plywood, furniture and cabinets.

2.1.2 Bajan (*Kokoona reflexa*)

Bajan is a medium hardwood from the family Celastraceae. Its sapwood ranges from cream to light yellow brown whereas its heartwood ranges from pink brown to red brown, dark red-brown or dark brown. Its texture is moderately fine but uneven. Other distinct features include feathery tracery can be seen on flat sawn surface and fine streaks which visible on quarter sawn surface. The basic density of this wood is about 737 kg/m³ (Forest Department Sarawak, 1999). It was reported that bajan is non-durable in its natural durability. It is also highly susceptible powder post beetle and its treatability is easy to treat. Bajan is very strong and assigned as Strength Group A (Forest Department Sarawak, 1999; Wong, 2002) that makes it suitable for medium and heavy construction materials, heavy duty flooring, door and window frames.

2.1.3 Kelempayan (*Neolamarckia cadamba*)

Neolamarckia cadamba (Roxb.) belongs to the family Rubiaceae. It is also known as Kelampayan. *Neolamarckia cadamba* possess a broad crown and straight cylindrical bole which is useful for the timber industry. The tree itself may reach a height of 45 meters and a trunk diameter of 100 to 160 centimeter. The wood has a density of 290 to 560 kg/m³ (Wong, 2002). It has a very good surface give it easy to nail. Kelempayan is weak (Strength Group D) and reputedly known as non-durable wood (Wong, 2002; Tawi & Wong, 2016). The timber is suitable for the production of plywood, boxes, crates, furniture components, pulp and paper.

2.1.4 Kempas (*Koompassia malacensis*)

Kempas or menggris is a medium hardwood come from the family of Fabaceae. Its sapwood is either cream white to light yellowish colour while its heartwood is usually brick red, reddish brown, orange red brown or dark red brown. As for the wood texture, it is coarse but even. The basic density of this wood is 794 kg/m³ (Forest Department Sarawak, 1999). As for natural durability, kempas heartwood is categorized as moderately durable. Kempas sapwood is highly susceptible to powder post beetle and heartwood moderate to highly susceptible to termites. The heartwood is moderately difficult to treat. Kempas is very strong (Strength Group A) (Forest Department Sarawak, 1999; Wong, 2002). However, kempas is known to be moderately to highly susceptible to termite attack (Forest Department Sarawak, 1999; Wong, 2002). Kempas is suitable for heavy construction, telecommunication poles and medium to heavy duty floor.

2.1.5 Keruing (*Dipterocarpus* spp.)

Keruing is a medium hardwood comes from the family Dipterocarpaceae. Its sapwood is light grey-brown in colour while its heartwood ranges pinkish brown, reddish brown, purple red-brown or brown in colour. The texture of the wood is moderately coarse to coarse and even. Another distinct feature is that they possess patches of oleo-resin often visible on cross sectional surfaces. Keruing also has a distinctive resinous smell when freshly cut. The basic density of keruing is about 635 kg/m³ (Forest Department Sarawak, 1999). Keruing is generally strong (Strength Group B) (Forest Department Sarawak, 1999) but there are some keruing which are extremely strong (Strength Group A) (Wong, 2002). For its natural durability, keruing heartwood is moderately durable to durable. Keruing heartwood (depending on species) is moderate to highly susceptible to termites depending on species (Forest Department Sarawak, 1999). Keruing is suitable for heavy construction posts, beams, columns, window frames and even plywood manufactures.

2.1.6 Legai (*Adinandra borneensis*)

Legai in Sarawak or Samak in Peninsular Malaysia comes from the family of Theaceae. The timber is moderately hard and moderately heavy with a density of 530 to 920 kg/m³ (Wong, 2002). The sapwood is lighter in colour and not clearly defined from the heartwood which is grey-brown. The texture is rather fine and even. The timber is strong (Strength Group B). The heartwood is known to be non-durable and easy to impregnate with preservatives. Legai is suitable for flooring, panelling, door and window frames and even plywood manufactures.

2.1.7 Rubberwood (*Hevea brasiliensis*)

Hevea brasiliensis or rubberwood belongs to the family of Euphorbiaceae. Rubberwood is fine, straight grained and light yellowish to white in colour (Akhter, 2005). It is widely used in furniture manufacture and various applications (Sujan *et al.*, 1980; Akhter, 2005). Rubberwood has low durability and very susceptible to fungi and insect infestations (Akhter, 2005). According to Akhter (2005), rubberwood itself has a high content of starch which attracts wood degrading agents. Hidayat *et al.* (2018), also reported that *Coptotermes curvignathus* are closely related to rubber tree which this termite species is considered as rubber termite due to their economic significance in rubber plantations. *C. curvignathus* found highly destructive of rubberwood as compared to teak, casuarina pine, acacia and other exotic wood (Wong *et al.*, 1998).

2.1.8 Seladah (*Canarium apertum*)

Seladah is a light hardwood from the family of Burseraceae. The sapwood of seladah varies from whitish-yellowish or light yellow to light pink-brown, pink-brown, light-grey brown or light red-brown. The heartwood is light yellow-brown, pink-brown, pinkish grey-brown to red-brown. Its texture is moderately fine to moderately coarse or even. The basic density of this wood is about 547 kg/m³ (Forest Department Sarawak, 1999). Seladah wood is fairly strong (Strength Group C) (Forest Department Sarawak, 1999; Wong, 2002). The natural durability of the heartwood ranges from non-durable to durable. Seladah is suitable to be used as joists, light to medium flooring, boxes and crates.

2.1.9 Other timber species used

The wood species used in experiment 1 encompassed of light hardwood, medium hardwood, heavy hardwood and softwood timbers (temperate and tropical) from various plant families.

Some of the wood species used are from family Dipterocarpaceae can also be assigned to their specific groups such as Kapur (*Dryobalanops*) group and Balau group. Kapur (*Dryobalanops* spp.), kapur bukit (*Dryobalanops beccarii*) and kapur kelansau (*Dryobalanops oblongifolia*) are examples of wood species under Kapur (*Dryobalanops*) group. These species belonged to family Dipterocarpaceae. These wood species are medium hardwoods with air-dry density range of 580 to 820 kg/m³. Kapur wood is strong and assigned as Strength Group B. The durability of kapur can range from very durable to non-durable depending on the kapur species (Wong, 2002). However, according to the documentation by Forest Department Sarawak (1999), the durability of kapur is durable to moderately durable. Wong and Ling (2009), also found out that some kapur can last up to 5 to 10 years (durable) but mostly last up to 2 to 5 years (moderately durable) exposed to in-ground stake test.

Kumus (*Shorea laevis*), red balau (*Shorea* spp.), selangan batu (*Shorea* spp.), selangan batu (*S. pluriscostata*) and selangan batu kuning (*S. flava*) are wood species classified under selangan batu group. These species are heavy hardwoods from the family Dipterocarpaceae with air-dry density 850 – 1155 kg/m³. Wood species from this group is very strong (Strength Group A). The durability of these timbers varies from durable to very durable depending on the species.

Wood species used in this experiment can also be reviewed in terms of types of timber (Light hardwoods, medium hardwoods, heavy hardwoods and tropical softwoods).

Examples of light hardwoods used were medang luis kasar (*Alseodaphne insignis*), bintangor (*Calophyllum incrassatum*), tekalong (*Artocarpus odoratissimus*), benuah (*Macaranga pearsonii*) and jelutong (*Dyera polyphylla*). Medang luis kasar is a light hardwood from the family of Lauraceae. Medang luis kasar has a range of air-dry density of 350 to 880 kg/m³. Medang is considerably strong under Strength Group C. Wong (2002), reported that medang, on the whole, is non-durable but Forest Department Sarawak (1999), categorized it as moderately durable to non-durable depending on the species. Bintangor comes from the family Guttiferae. Bintangor is the standard Malaysian name for timber species from *Calophyllum* spp. This timber is a light hardwood with air-dry density of 465 to 865 kg/m³. Bintangor is only moderately strong under Strength Group C. The timber is moderately durable to non-durable (Forest Department Sarawak, 1999; Wong, 2002). Tekalong is from the family Moraceae. Tekalong or terap is a light hardwood with air-dry density of 400 to 560 kg/m³. It is classified under strength group D. This timber is non-durable. Benuah or Mahang is from the family of Euphorbiaceae. Mahang is the standard Malaysian name for timber species from *Macaranga* spp. The timber has a density of 270 to 495 kg/m³ and reputed to be non-durable. Jelutong comes from family Apocynaceae. Jelutong is a light hardwood with air-dry density of 420 to 500 kg/m³ with strength group D. This timber is highly perishable.

Examples of medium hardwoods used in this experiment were leban (*Vitex pubescens*), teruntum (*Lumnitzera littorea*), rambai (*Baccaurea polyneura*), bintawak (*Artocarpus anisophyllus*) and mergasing (*Mesua macrantha*). Leban is a medium hardwood from the family Verbenaceae and has an air-dry density of 705 to 880 kg/m³. Leban is considered durable even inground contact. Teruntum is medium hardwood from the family Combretaceae with air-dry density of 755 – 835 kg/m³. The timber is moderately durable

and subjected to termite attacks. As for rambai, the standard Malaysian name for *Baccaurea* spp. is tampoi from the family Euphorbiaceae. This timber is a medium hardwood with air-dry density of 630 to 950 kg/m³. Interestingly Wong (2002), reported that species from tampoi is durable but Forest Department Sarawak (1999), reported that tampoi is non-durable. Bintawak or keledang is a medium hardwood from the family Moraceae with air-dry density of 495 to 945 kg/m³. The timber is moderately durable to non-durable. As for mergasing, the standard Malaysian name for mergasing is Penaga tikus. The timber is a medium hardwood from the family of Guttiferae with air-dry density of 705 to 880 kg/m³. The timber is non-durable and infrequently used (Wong, 2002).

Examples of heavy hardwoods used in this experiment were belian (*Eusideroxylon zwageri*), penyau (*Upuna borneensis*), tembusu (*Fagraea fragrans*), keranji (*Dialium* spp.) and bedaru (*Cantleya corniculata*). Belian is exceptionally hard and classified under heavy hardwood from the family Lauraceae. This timber is very strong (Strength Group A) and known to be the most durable timber in the world. Penyau is a heavy hardwood from the family of Dipterocarpaceae. The air-dry density of this wood is 945 to 1040 kg/m³. Penyau wood known to be very durable (Forest Department Sarawak, 1999; Wong, 2002). Next, Tembusu is a heavy hardwood from the family of Longaniaceae. It has a range of air-dry density of 640 to 1075 kg/m³. The timber is strong and assigned as Strength Group B. Tembusu is durable. Keranji is a heavy hardwood from the family of Leguminosae. It has a range of air-dry density from 755 to 1250 kg/m³. The timber is very strong (strength group A). Keranji is known to be moderately durable (Forest Department Sarawak, 1999; Wong, 2002). Bedaru or dedaru belonged to family Icacinaceae. The timber is a heavy hardwood with air-dry density 1105 to 1140 kg/m³. This timber is very strong and assigned as Strength Group A but bedaru is moderately durable (Wong, 2002; Wong & Ling, 2009).

Examples of tropical softwoods used in this experiment were bindang (*Agathis borneensis*), kayu cina (*Podocarpus micropedunculatus*) and sempilor (*Dacrydium elatum*). Bindang is a softwood timber with air-dry density of 360 to 660 kg/m³. The timber is weak and assigned to Strength Group D while Kayu cina or podo is a softwood with air density range of 380 to 920 kg/m³. The timber is fairly strong (Strength Group C). Sempilor has an air-dry density of 435 to 705 kg/m³. All of these tropical softwoods are non-durable when exposed to extreme condition. Other timber species used have been reviewed and were described in Table 2.1.

Table 2.1: Species descriptions of tested wood

Common Name (Scientific Name)	Family	Timber Group	Strength Group	Durability Classes
Bedaru (<i>Cantleya corniculata</i>)	Icacinaceae	HHW	A ^a	3 ^{a,b}
Belian (<i>Eusideroxylon zwageri</i>)	Lauraceae	HHW	A ^{a,c}	1 ^{a,b,c}
Bengang (<i>Neesia borneensis</i>)	Bombacaceae	LHW	B – C ^a	4 ^{a,b}
Benuah (<i>Macaranga pearsonii</i>)	Euphorbiaceae	LHW	?	4 ^{a,b}
Bindang (<i>Agathis borneensis</i>)	Araucariaceae	Softwood	D ^{a,c}	4 ^{a,b,c}
Bintangor (<i>Calophyllum incrassatum</i>)	Guttiferae	LHW	C ^{a,c}	3 – 4 ^{a,b,c}
Bintawak (<i>Artocarpus anisophyllus</i>)	Moraceae	MHW	A – B ^a	3 – 4 ^{a,b}
Binuang (<i>Octomeles sumatrana</i>)	Datiscaceae	LHW	D ^a	4 ^{a,b}
Casuarina (<i>Casuarina equisetifolia</i>)	Casuarinaceae	HHW	B ^a	3 ^a
Chengal (<i>Neobalanocarpus heimii</i>)	Dipterocarpaceae	HHW	A ^a	1 ^a
Chengal pasir (<i>Hopea beccariana</i>)	Dipterocarpaceae	MHW	B ^a	3 ^{a,b}
Douglas fir (<i>Pseudotsuga menziesii</i>)	Pinaceae	Softwood	D ^d	4 ^e

Table 2.1 continued

Common Name (Scientific Name)	Family	Timber Group	Strength Group	Durability Classes
Engkabang jantung (<i>Shorea macrophylla</i>)	Dipterocarpaceae	LHW	C ^a	4 ^{a,b}
Entuyut (<i>Tetramerista glabra</i>)	Tetrameristaceae	MHW	A ^a	3 – 4 ^{a,b}
Jelawei mempelam babi (<i>Terminalia phellocarpa</i>)	Combretaceae	LHW	?	4 ^{a,b}
Jelutong paya (<i>Dyera polyphylla</i>)	Apocynaceae	LHW	D ^a	4 ^{a,b,c}
Kapur (<i>Dryobalanops</i> spp.)	Dipterocarpaceae	MHW	B ^a	2 – 3 ^{b,c}
Kapur bukit (<i>Dryobalanops beccarii</i>)	Dipterocarpaceae	MHW	B ^a	2 – 3 ^{b,c}
Kapur kelansau (<i>Dryobalanops oblongifolia</i>)	Dipterocarpaceae	MHW	B ^a	2 – 4 ^{a,b}
Kayu cina (<i>Podocarpus micropedunculatus</i>)	Podocarpaceae	Softwood	C ^a	4 ^{a,b}
Kelat (<i>Syzygium</i> spp.)	Myrtaceae	MHW	B ^a	3 ^a
KerANJI (<i>Dialium</i> spp.)	Leguminosae	HHW	A ^{a,c}	3 ^{a,b,c}
Kulim (<i>Scorodocarpus borneensis</i>)	Olacaceae	MHW	A ^a	3 ^a
Kumpang (<i>Myristica maxima</i>)	Myristicaceae	LHW	C ^{a,c}	4 ^{a,b,c}
Kumus (<i>Shorea laevis</i>)	Dipterocarpaceae	HHW	A ^a	2 ^{a,b}
Leban (<i>Vitex pubescens</i>)	Verbenaceae	MHW	?	2 – 3 ^{a,b}
Lun siput daun besar (<i>Shorea iliasii</i>)	Dipterocarpaceae	LHW	B – C ^a	3 ^{a,b}
Mata ulat (<i>Kokoona</i> spp.)	Celastraceae	MHW	A ^a	3 ^a
Medang luis kasar (<i>Alseodaphne insignis</i>)	Lauraceae	LHW	C ^{a,c}	2 – 4 ^{a,b,c}
Mempening (<i>Lithocarpus</i> spp.)	Fagaceae	MHW	B ^c	3 ^{a,c}
Mengkulang (<i>Heritiera aurea</i>)	Sterculiaceae	MHW	B ^{a,c}	3 – 4 ^{a,b,c}

Table 2.1 continued

Common Name (Scientific Name)	Family	Timber Group	Strength Group	Durability Classes
Meranti buaya (<i>Shorea uliginosa</i>)	Dipterocarpaceae	LHW	C ^a	3 ^{a,b}
Meranti luang (<i>Shorea ovalis</i>)	Dipterocarpaceae	LHW	C ^a	4 ^{a,b}
Mergasing (<i>Mesua macrantha</i>)	Guttiferae	MHW	?	3 – 4 ^{a,b}
Mersawa kunyit (<i>Anisoptera grossivenia</i>)	Dipterocarpaceae	LHW	C ^{a,c}	3 ^{a,b}
Nyato (<i>Palaquium</i> spp.)	Sapotaceae	LHW	C ^c	2 – 3 ^c
Oil palm stem (non-wood) (<i>Elaeis guineensis</i>)	Arecaceae	Non wood	?	4
Pajang / Asam (<i>Mangifera pajang</i>)	Anacardiaceae	LHW	C ^{a,c}	3 – 4 ^{a,b,c}
Pelong / Plajau (<i>Pentaspadon motleyi</i>)	Anacardiaceae	LHW	D ^a	3 ^{a,b}
Penyau (<i>Upuna borneensis</i>)	Dipterocarpaceae	HHW	A ^{a,c}	1 ^{a,b,c}
Pulai (<i>Alstonia</i> spp.)	Apocynaceae	LHW	D ^{a,c}	4 ^{a,c}
Radiata pine (<i>Pinus radiata</i>)	Pinaceae	Softwood	D ^d	4 ^e
Rambai / Tampoi (<i>Baccaurea polyneura</i>)	Euphorbiaceae	MHW	B ^c	2 – 4 ^{a,b,c}
Red Balau (<i>Shorea</i> spp.)	Dipterocarpaceae	HHW	A – B ^a	3 ^a
Red Meranti (<i>Shorea carapace</i>)	Dipterocarpaceae	LHW	C ^{a,c}	3 ^b
Rengas (<i>Gluta</i> spp. / <i>Melanochyla</i> spp.)	Anacardiaceae	MHW	B ^{a,c}	3 ^{a,c}
Sawih (<i>Duabanga moluccana</i>)	Sonneratiaceae	LHW	C ^a	4 ^{a,b}
Segera (<i>Aglaia borneensis</i>)	Meliaceae	MHW	B ^a	4 ^b
Selangan batu (<i>Shorea pluriscostata</i>)	Dipterocarpaceae	HHW	A ^c	1 ^b
Selangan batu (<i>Shorea</i> spp.)	Dipterocarpaceae	HHW	A ^c	3 ^b
Selangan batu kuning (<i>Shorea flava</i>)	Dipterocarpaceae	HHW	A ^c	3 ^b

Table 2.1 continued

Common Name (Scientific Name)	Family	Timber Group	Strength Group	Durability Classes
Selangan merah (<i>Shorea kunstleri</i>)	Dipterocarpaceae	HHW	A – B ^a	3 ^{a,b}
Sempilor (<i>Dacrydium elatum</i>)	Podocarpaceae	Softwood	?	3 – 4 ^{a,b}
Sentang (<i>Azadirachta excelsa</i>)	Meliaceae	LHW	C ^a	3 – 4 ^{a,b}
Teak (Malaysia) (<i>Tectona grandis</i>)	Verbenaceae	MHW	?	1 – 2 ^a
Teak (Myanmar) (<i>Tectona grandis</i>)	Verbenaceae	MHW	?	1 – 2 ^a
Tekalong (<i>Artocarpus odoratissimus</i>)	Moraceae	LHW	C – D ^a	4 ^{a,b}
Tembusu (<i>Fagraea fragrans</i>)	Longaniaceae	HHW	B ^a	2 ^a
Teruntum merah (<i>Lumnitzera littorea</i>)	Combretaceae	MHW	?	3 ^{a,b}
Ubah urat (<i>Syzygium sarawakensis</i>)	Myrtaceae	MHW	B ^{a,c}	4 ^{b,c}
Yellow meranti (<i>Shorea</i> spp.)	Dipterocarpaceae	LHW	C ^{a,c}	3 – 4 ^{a,c}

Notes: Malaysian in-ground natural durability class: 1 (very durable): >10 years; 2 (durable): 5-10 years; 3 (moderately durable): 2-5 years; 4 (nondurable): <2 years; Malaysian timber strength group (based on Green Compressive Stress): A (extremely strong), B (very strong), C (strong), D (weak,); Timber group: LHW (Light hardwood), MHW (Medium hardwood), HHW (Heavy Hardwood), ?: Assumed strength group as no data available.

References: a (Wong, 2002); b (Wong & Ling, 2009); c (Forest Department Sarawak, 1999), d (Krestchmann, 2012); e (Australian Standard, 2005)

2.2 Wood physical and mechanical properties

2.2.1 Density

Wood density of material can be defined as the mass over unit volume (kg/m^3). There are three conditions whereby to calculate wood density which include basic density, air-dry density and green density (Walker, 1993). Air-dry density is measured after the wood had been left to dry in an open space and had achieved a moisture content which influenced by

the atmospheric equilibrium (particularly temperature and humidity). Green density applied to freshly logged timber or sawn timbers which still in green (wet) condition. Green density is also age and species dependent. Basic density measures the oven-dry mass of wood per green volume of wood. Within a species or within a tree, there is usually a negative correlation between basic density and moisture content which implies that higher moisture content result in lower basic density (Walker, 1993). Wood extractives somehow contributed to wood density as wood extractives deposited in wood cells. The previous study also found that wood extractives influence density appreciably and thus play roles in wood characteristics including durability (Wong *et al.*, 1983; Ona *et al.*, 1997; Antwi-Boasiako & Pitman, 2009; Kadir & Hale, 2012; Amusant *et al.*, 2014).

2.2.2 Mechanical properties

Wood strength is defined as the ability of wood to sustain a load. The magnitudes of the load that can be sustained differ with the shape and size of test specimens. Strength in another term expressed as stress, which is the load per unit area. All wood will fail or break when they achieve their critical stress (also known as failure stress) vary in terms of species (Walker, 1993). Wood less than its critical stress undergoes compression, stretched or bend. The load can be applied in terms of tension, compression and shear. Since wood is anisotropic, it is to determine the direction of stress with respect to the grain of the wood. According to Walker (1993), wood tested in tension or compression and loaded in parallel to grain direction sustained more stress than when loaded perpendicular to the grain but it is in reverse for shear. It is important to note down these parameters as it can represent a population of tested timber species which will give us a better idea of its mechanical properties. According to Zabel and Morrel (1992), in decay testing, MOR, impact bending,

crushing strength, tensile parallel to grain, compression perpendicular to grain, toughness, hardness and shear strength are among strength testing that usually being conducted. Similarly, hardness, as well as lignin bioactive ingredients, also contributed to higher wood resistance.

2.2.3 Water permeability

Wood permeability is the ability of liquid or gas to enter wood. Air-free waterlogged fibers dry the moisture content of the timber will drop below the fiber saturation point and the water interface will evaporate from the surface. The absorbed water in the air-free, saturated lumen may under tension whereby water is being stretched and pulled onto cell walls. As timber is permeable, the displaced sap can flow from the drained fiber through interconnecting saturated lumens via unspirated pits. As for impermeable timber, the absorbed water is tougher to displace as the pits may be completely blocked. There could be no mass flow and displaced sap must diffuse through numerous cell walls (Walker, 1993). There are other factors influencing water permeability whereby water uptake behaviour mainly affected by the microstructure of wood and the presence of extractives (Michalec & Niklasová, 2006). The presence of fats and wax in wood properties could also influence water permeability (Barnett & Jeronimidis, 2003). The difference in the rate of water permeability varies among wood species mainly due to the rate of diffusion of both water vapour and bound water between macroscopic surface and the core of the specimen and the relaxation of the swelling and/or temperature (Engelund *et al.*, 2013). Another factor that will result in higher uptake or absorptions and penetration of the solution is by increasing the dipping times (Humar & Lesar, 2009; Ma *et al.*, 2013).

2.3 Wood Extractives

Wood extractives are secondary metabolites found in the heartwood of some tree species. Wood extractives are compounds that can be extracted from wood using polar or non-polar solvents. Amount of extractives existing naturally in wood are important in wood utilization. Extractive content in wood generally can range from 1 to 20% depending mainly on the wood species and their position within a tree (Walker, 1993). Usually, carbohydrates in extractives can be extracted using water extraction method while resinous extractives usually can be extracted using solvents. Types of compounds isolated mainly rely on the polarity of the solvents used during the extraction. Yamamoto & Hong (1988), reported that cold water extraction method extracted the least extractives from chengal (1.8 – 3.6%), methanol extracted the most extractives from chengal (10.9 – 23.4%) and hot water extraction yielded 5.9 to 10.7%.

Wood extractives vary naturally between or within species. Within trees, extractive contents decrease as the height increased. While as for softwoods and hardwoods, extractives are more abundant in heartwood compared to sapwood. Lukmandaru (2011), revealed that the average of methanol extractive contents of heartwood was between 3.5 to 5% as compared to only 2 to 2.9% in sapwood. According to Walker (1993), wood extractives exist in the form of low molecular weight compounds like triterpenes and sterols, hydrocarbons or even polyphenolic structures.

Extractives are important in determining wood durability. Previous studies had shown that wood extractives extracted from durable wood are able to protect non-resistant wood. Brocco *et al.* (2015), reported that pinus treated with teak hardwood extractives extracted using absolute ethanol had the lowest percentage mass loss (3.35%) caused by *Nasutitermes corniger* compared to controls (9.76% mass loss). Kadir *et al.* (2014),

observed that the antitermitic properties of chemical compounds increased as the concentrations increased. It was also found that the chemical compounds extracted from bark and heartwood of *Neobalanocarpus heimii* was more potent compared to those extracted from *Madhuca utilis*. At the end of 14 days termite test, the consumptions of paper discs were lower than the controls (Kadir *et al.*, 2014). On the other hand, extracted chengal was found to be susceptible to wood destroying agent and thus it can be concluded that its extractive indeed contains toxic compound that prevents organisms from infesting it.

2.4 Subterranean termites

2.4.1 General characteristics of termites

Termites are insects from the order Isoptera, there are approximately 2761 known species in 282 genera worldwide and about 30 species of termite causing damage to wood and wood products (Baker, 2005). Termites live as a colony and they are divided into three castes i.e. reproductive caste, worker caste and soldier caste (Arthur, 2002; Baker, 2005). These three castes undergo different types of life cycle and development, thus they behave differently. Reproductive caste consists of a king and a queen where they perform the reproductive function, function of the worker caste is to carry on all aspects of colony maintenance such as care for the egg, construct and repair tunnels, clean, provide food and help soldier in defending the colony from enemies.

According to Pearce (1997), since termites live in the dark, they utilize sensory and chemical communication. Termites can distinguish odours using their peg-like sensilla mainly found on their antennae and other parts of the mouthparts which are used in the detection of chemicals like sex and trail pheromones. Foraging, defence, nest building and alarm trails involve pheromones at different concentrations. As for feeding mechanisms,

termites use trophallaxis which involves the exchange of secretion or liquid food between individual termites. Termites can pass partially digested semi-liquid food through secretions by mouth or receive from the anus of another termite. This is important when the food source is scarce. Subterranean termites need high moisture level. The difference between subterranean termites and damp wood termites are subterranean termites live in the soil (Arthur, 2002; Baker, 2005). They attack most of the wood structure (Arthur, 2002) by building a tunnel from ground to the crack at the wood structure such as small crack at the building. Formosan subterranean termites feed on more than 50 living tree species such as white oak and pecan (Roger *et al.*, 2010). The infestation can be determined by swarming behaviour and the presence of long tube that make from mud and fecal material on the structure such as building wall (Arthur, 2002; Dini, 2010). According to Dini (2010), subterranean termites can be controlled by using soil treatment, wood treatment and termites bait.

2.4.2 Damages done by termites from genus *Coptotermes*

According to Pearce (1997), cities tend to be prone to termite attack. It is important not to reuse timber that might contain termites. Land clearing for buildings and agriculture plantation caused termites loss their natural food source which eventually led subterranean to adapt and survive better. *Coptotermes* originally a damp forest genus become a serious urban pest with wide distribution (Pearce, 1997). Plantations which are close to cities provide a constant source of alates of building pests. External woods used in houses are less protected after weathering, therefore vulnerable to termites. Few common species of termite that infest building and structure include *Coptotermes*, *Schedorhinothermes*, *Microcerotermes*, *Nasutitermes*, *Globitermes* and *Odontotermes* were observed in

Malaysia and Singapore by Lee *et al.* (2005), and *Coptotermes* (85%) was found economically important species infesting building structures. *C. gestroi* mainly infests houses in rural area in Thailand (Lee *et al.*, 2005).

Termites from genus *Coptotermes* caused many problems to the tree plantation. Based on Stone (1991), it was observed that *C. acinaciformis* and *C. frenchi* are types of termites mostly hosting in *Eucalyptus pilularis* whereas *C. curvignathus* usually attack plantation such as *Araucacia* spp. and *Pinus* spp. Jasmi and Ahmad (2011), stated that *Araucacia* spp. and *Pinus* spp. plantation in Malaysia was known to have been 100% infested by *Coptotermes* spp. Jasmi and Ahmad (2011), observed that those infected trees are often left as a thin shell with honeycomb. Lenz (2005), observed and reported that out of 6 genera found in *Araucaria* plantation in Teluk Bahang, Penang, *C. curvignathus* was found to be the most dominant species in standing *Araucaria* trees while *Schedorhinotermes* was mainly found in fallen logs and dead stumps. Tho and Kirton (1998), observed that high incidence of *C. curvignathus* attack in conifer plantation in Bahau. The most preferred conifer species that *C. curvignathus* tend to attack was *Araucaria cunninghamii* (7.72%) and *A. hunsteinii* (6.65%). There was another case whereby *Coptotermes* attacked dead portion and living heartwood of Acacia in *Acacia mangium* plantation with high cost was incurred to overcome this termite problem (Kirton, 1999). Termite from this genus also a major structural pest that they tend to infest wood products in buildings and houses. The common locations of termite infestations within building usually can be found in door or window frame, skirting area, built-in cabinet, parquet flooring and others (Lee, 2000) Termite attacks causing economic loss. Jasmi and Ahmad (2011), stated that in 2003, the cost in controlling termites in Malaysia was approximately USD10-12 million. Large

economical losses could be due to the high cost in termite management in tree plantations as well as repairs of the damaging wooden structures imposed by termites.

2.5 Types of preservatives

There are many types of wood preservatives (from oil-borne, waterborne, organic solvent based preservative etc.) available in the market for various level of protections. It is to consider wisely in selecting preservative that likely to achieve maximum function and permanence in the wood as to provide full protection when the woods are for commercial uses. As for health concern, classical wood preservatives like DDT, lindane or pentachlorophenol had been banned (Wörle *et al.*, 2012). Barnes (2002), also mentioned that pentachlorophenol used to treat wood would cause toxicity to aquatic organisms. The types of preservative can be categorized as oil-borne preservatives, waterborne preservatives and light organic solvent preservatives.

2.5.1 Oil-borne preservatives

According to Zabel and Morell (1992), few oil-borne preservatives have been widely used in the United States. This oil-borne preservative is used for pressure treatment of wood. These chemicals are creosote, pentachlorophenol, copper naphthenate, tributyltin oxide and copper-8-quinolinolate. Among all the mentioned oil-borne preservatives, creosote was once widely used. The composition of creosote varies depending on the distillation ranges used. This preservative had been proven to be the most effective toxic component that can protect wood against biodeteriorating agents (e.g. fungi, borers, termites etc). The toxicity of creosote has never been fully understood due to the complexity of the chemical itself. In some countries due to health concern and environmental safety, creosote application had

been minimized especially the application where direct human contact. However, the usage of creosote and petroleum blend still be used to protect railroad ties and bridges timber (Zabel & Morell, 1992). Owoyemi *et al.* (2016), revealed that five Nigerian wood species dip-treated using bitumen and creosote (70:30 ratio) and left for 24 hours had tremendously increased wood protection to the Nigerian wood. For termite resistance, the weight loss of the treated wood samples had a range between 0.58 - 32.97% while untreated wood samples sustained mass loss ranged between 14.05 - 100%. In some part of the world, farmers tend to use diesel and kerosene as remedy to kill termites (Akutse *et al.*, 2012). Besides that, used engine oil also proven to provide protection to wood (Olaniran *et al.*, 2010; Pereira *et al.*, 2015). Diesel and dead engine oil is a remedy recommended on the internet for homeowners to kill termites. Since diesel and dead engine oil can be obtained cheaply from the petrol stations and automobile workshops, a lot of the homeowners would buy these oils, mixed them themselves to do a “Do It Yourself” termiticide and apply it (spray or brush-treat) the affected area.

2.5.2 Waterborne preservatives

Waterborne preservatives are regarded as aqueous solutions of toxic salts (Eaton & Hale, 1993). There are wide ranges of waterborne preservatives available in the market. Waterborne preservatives are less odour, leaving the wood clean for handling, it can be in the form of pastes or powders to be diluted on site, treated wood using waterborne preservative is paintable. Some known waterborne preservatives include CCA preservative, borate preservative, organophosphate (e.g. chlorpyrifos) and synthetic pyrethroid based (e.g. cypermethrin, deltamethrin and permethrin), usually used as emulsifiable concentrates or suspension concentrates.

2.5.2.1 CCA preservative

Prior to the invention of environmental friendly insecticides (e.g. synthetic pyrethroids) Chromated Copper Arsenate or simply called CCA has been widely used as wood preservative to treat wood for its renown toxicity and efficacy against wood decay fungi and wood destroying insects. There are three formulations of CCA available which is CCA-Type A, B and C. CCA-Type C has been primarily used and was found to have the optimum combination of efficacy and leaching resistance (Lebow, 2010). The composition of CCA-Type C is 47.5% chromium trioxide, 34% arsenic pentoxide and 18.5% copper oxide. In CCA, copper is the primary ingredient for its fungicidal properties, arsenic is toxic to insects while chromium act as a carrier. CCA has been preferably used by timber industry to treat wood because of its cost effectiveness, CCA treated wood is odourless and paintable (Walker, 1993). CCA is used widely throughout the world including Malaysia for both indoor and outdoor use complying to Malaysian Standard MS360:1991 (Wong *et al.*, 1997). In Malaysia, CCA mainly used to treat roof trusses, ceiling joists of residential houses (Wong *et al.*, 2011). CCA has been reported to be the most effective wood preservative. For instance, Grace (1998), reported that CCA treated southern yellow pine wafers exposed to *Coptotermes acinaciformis* sustained minimal mass losses (0.62 – 1.82%) compared to the untreated control which sustained 35.61 – 37.42% mass loss. He also reported that CCA treated radiata pine sustained minimal mass losses (2.5 – 3%) compared to the control which sustained 80.3% mass loss. 100% termite mortality also observed in the 4 weeks no choice test. Ling and Wong (2005), reported that although CCA had been reported to be most effective preservative, their study revealed that the efficacy of CCA depending much on the retention level permitted, treatability of wood species used as well as environmental condition (e.g. wetness causes leaching). All the

tested wood was pressure-treated at minimum retention of 16 kg/m³ CCA salt basis. Initially during the 5th year of exposure CCA treated specimens were still sound however down the line to the 20th years, none of the CCA products were able to completely protect the wood (mean 5-point scale of decay/termite visual rating 4.2 – 8, whereby 10 is sound and 0 is destroyed). Due to environmental concerns about CCA, it was banned in certain countries like North America, EU, Australia and South Africa (Wong *et al.*, 2011). Although CCA is believed to be leaching resistant, to an extent leachates from CCA treated wood could possibly contaminate the soil, its adjacent surrounding and groundwater. Wong and Chong (2014), found that certain amounts (not all) of the heavy metal compounds did leach out to different types of soil tested apparently in the long term will affect the environment. Chen and Olsen (2016), reviewed that arsenic from CCA treated wood contributed to the cause of arsenic intoxication with the focus on dermatologic manifestation. Although CCA is effective in protecting the wood, its potential health hazard poses to the environment must not be neglected.

2.5.2.2 Borate preservatives

Borate preservatives are soluble in water, highly leachable and therefore should only be used in aboveground condition whereby wood is sheltered from wetting (Walker, 1993). Borate preservative usually used to treat framing, interior finishing and flooring. These preservatives not only can be used to pressure treat wood, but borate preservatives are also commonly sprayed, brushed or injected to treat wood (Lebow, 2010). This preservative easily diffuses into the wood that is wet and therefore often used as a remedial treatment. Examples of borate preservatives are sodium tetraborate, sodium pentaborate, boric acid and as well as disodium octaborate tetrahydrate (DOT). Such preservatives are effective

against decay and wood destroying insects (e.g. termites, carpenter ants and wood boring beetles). Wong and Grace (2004), reported that boric acid clearly improved the resistance of rubberwood chipboard against *Coptotermes formosanus*. In their no choice and two choice test, borate-treated rubberwood chipboard sustained only slight to trace attack (mean visual rating 9 – 9.8) with 100% termite mortality. Gentz and Grace (2007), also found that aspen composite particleboard treated with six different boron formulations (0.18% and 0.88% zinc borate, zinc borate with disodium octaborate tetrahydrate (ZB/DOT): 60/40 ZB/DOT and 80/20 ZB/DOT, zinc borate with anhydrous boric acid (ZB/B₂O₃): 60/40 ZB/B₂O₃ and 80/20 ZB/B₂O₃), untreated particleboard and Douglas fir as control were used in this experiment. Obviously, aspen composite particleboard treated with different boron formulations had the least wood consumptions (range: 0.860 – 1.550 mg/termite) after 4 weeks by *Coptotermes formosanus* compared to Douglas fir (4.919 mg/termite) and untreated particleboard (7.657 mg/termite). Zaidon *et al.* (2008), also reported that exposure of rubberwood particleboard, EFB (Empty Fruit Bunch) particleboard and Rubberwood-EFB particleboard sprayed using Timberlife®, Stoprot®, Cislin® and boric acid to *Coptotermes curvignathus* had lower percentage weight loss as compared to the untreated controls. Usta *et al.* (2009), also found out that MDF treated using four concentrations (1, 1.5, 2 & 2.5%) of boric acid, borax, zinc borate and sodium perborate tetrahydrate caused 100% mortality to *C. formosanus* in their laboratory termite test. The test was conducted for three weeks and it was found termite mortality in MDF treated with boric acid (1.5 – 2.5%), sodium perborate tetrahydrate (1.5 – 2.5%) died completely in week 2 whereas 100% termite mortality achieved on week 3 in MDF treated with zinc borate at 2 to 2.5% and in all borax concentrations. Only 18.8% termite mortality observed in control.

2.5.2.3 Chlorpyrifos

Chlorpyrifos is an organophosphate insecticide which has been utilized widely at home and on the farm. Chlorpyrifos is a white crystal-like solid with a strong smell (Risher & Navarro, 1997; NPIC, 2010). It is partially soluble in water, so usually, Chlorpyrifos is mixed using oily liquids before applied to crops and animals. The application of Chlorpyrifos at home is to control vectors such as cockroaches, fleas and termites (Risher & Navarro, 1997). Based on Risher and Navarro (1997), chlorpyrifos is used to control ticks on cattle and act as pesticide to repel crop pest in the farms. Chlorpyrifos was first registered as insecticide in 1965 and US EPA re-registered it in 2006. Commercial pesticides such as Dursban and Lorsban also contain Chlorpyrifos as their active ingredients. In wood industry, Chlorpyrifos is widely used as wood preservative to prevent wood-infesting insects such as beetles, Carpenter ants, Carpenter bees and termites (Nufarm Chlorpyrifos SPC 2 Insecticide, 2010). According to Nufarm Chlorpyrifos SPC 2 Insecticide (2010), to control the manifestation of wood-infesting ants, Chlorpyrifos is applied around cracks or crevices and areas where ants can enter or hide. For termites' controls, Chlorpyrifos will kill the worker termites. Chlorpyrifos has served as one of the widely used wood preservatives in Japan for the past few years (Kurata *et al.*, 2005). Laks *et al.*'s study (as cited in Tolley *et al.*, 1998), predicted that target retentions of 0.014 to 0.015 kg/m³ chlorpyrifos could provide 99% mortality of *Coptotermes formosanus* in laboratory bioassay.

2.5.2.4 Cypermethrin

Cypermethrin is an insecticide which belongs to the pyrethroid family. It was first commercialized in 1977. The common products which contain Cypermethrin as active ingredient are Demon, Cymbush, Ammo and Cynoff. Most of the Cypermethrin is used in cotton industry. It is mainly used to kill insects on cotton. According to Cox (1996), Cypermethrin also used to kill pests like cockroaches and termites. Cypermethrin is a contact poison. It kills insects by disrupting the normal function of the nervous system. Cypermethrin also believed to cause convulsion and excitability (Cox, 1996). It also affects the functionality of certain neuro enzymes such as monoamine oxidase which breaks down neurotransmitters. Cypermethrin is an insecticide which also applicable used as wood preservative. Most of the Cypermethrin is used in preventive and remedial treatment (Cypermethrin, 2012). Cypermethrin is effective in controlling *Hylotrypes bajulus* (furniture beetle), *Anobium punctatum* (house longhorn beetle) and *Reticulitermes santonesis* (termites) (Cypermethrin, 2012). Van Acker *et al.* (1990), found that Organic insecticides such as lindane or cypermethrin gave the best results, with no attack of *Lyctus africanus* (wood-boring beetle) on treated plywood. It proves that cypermethrin is indeed a good preservative use to control insects. Sornnuwat *et al.* (1994), reported that rubberwood brushed or dipped for 5 minutes using cypermethrin (0.125 – 0.5%) and permethrin (0.5 – 2%) and chlorpyrifos (1 – 2%) yielded good results (0 – 10% weight loss) against *Coptotermes gestroi*.

2.5.2.5 Deltamethrin

Deltamethrin like other synthetic pyrethroids (e.g. cypermethrin and permethrin) also a very powerful knockdown insecticide. Deltamethrin has low mammalian toxicity and thus

is widely used (Barry, 1993; Eaton & Hale, 1993). Deltamethrin is also employed for general insect controls and it can give long term protection or eradication against wood borers and termites. Hanh and Huyen (2016), observed the quantity of fecal material reduced after 5 days of treatment using Cislin (deltamethrin) but the drywood termite colony was not eliminated. While for the injecting, covering and binding treatment (Permethrin and Deltamethrin), it achieved 100% efficacy after 5 days.

2.5.2.6 Permethrin

Permethrin is an insecticide which contains pyrethroid compound (Imgrund, 2003; Beyond Pesticides, 2004). It is also a non-systemic and broad-spectrum insecticide. According to Imgrund (2003), Permethrin is mainly used as insecticide, termiticide and some wood preservatives. Permethrin was registered with US EPA and was commercialized in the year 1977 (NPTN, 1997). It is also commonly used at home and garden as insecticide and treatment for ectoparasites such as fleas and lice (Beyond Pesticides, 2004). Permethrin is very efficient in killing pests. According to Imgrund (2003), Permethrin is a contact poison which dependent on disturbance of axonic nerve impulse conduction, causing immediate paralysis and death. According to NPTN (1997), Permethrin kills insects when having direct contact with it besides it is believed to have a repellent effect. Permethrin also believed to be very effective against the growth stages of insects especially larvae (NPTN, 1997). Commercial products such as Nix, Elimite, Prelude, Combat, Ambush, Dragnet, Outflank and Pethrine contain Permethrin as their active ingredients (Beyond Pesticides, 2004). Permethrin can be in many forms such as dusts, fogs, sprays and emulsifiable concentrates and creams. Fadillah *et al.* (2014), reported that soaking and brushing of mahogany wood using permethrin was very useful in enhancing the wood resistance

toward *Coptotermes curvignathus* with 100% termite mortality. Pinniger and Child (1996), found that Permethrin and Cypermethrin is the active ingredient in most insecticides which are used to treat *Anobium punctatum* (furniture beetle). Permethrin has relatively low mammalian toxicity with high insecticidal properties which only little dosage is required for the treatment. Treatments against woodborers are carried out by applying insecticide diluted to the treatment surface (Pinniger & Child, 1996).

2.5.3 Light organic solvent preservative

Organic solvent preservatives were introduced in between the 1920s to 1930s. They are composed of biocidal compounds (insecticides or fungicides) which dissolved in a volatile or non-volatile, non-polar organic solvent. According to Eaton and Hale (1993), organic solvent preservatives can be prepared with three types of solvent carrier which is oily type (e.g. heavy fuel oil), medium-heavy type (e.g. kerosene or petrol) and light type (white spirit). Light organic solvent preservatives (LOSP) can be applied by dipping, brushing, spraying or double vacuum. Due to their absorptive capability, LOSP is widely used in the remedial treatment of wood in buildings where fungal or termite infestations are known. There are advantages of using LOSP which is the wood dries faster after treated; the active ingredient (e.g. permethrin, tebuconazole, propiconazole etc) is less insoluble in water therefore not readily leached, paintable and glue-able if a suitable solvent is used. In Light Organic Solvent Preservatives (LOSP), Permethrin is usually used as active ingredient (a.i.). Usually, the proportion of permethrin in LOSP is less than 0.1 % w/w. (Koppers Arch Wood Protection, 2007). LOSP treatment is used to protect timber from attack by termites, insects and fungal decay. Most of the timber is used for exterior foundation and structural application above the grounds (Koppers Arch Wood Protection, 2007). In the

Northern Territory trial, untreated controls (radiata pine and slash pine) sustained moderate-severe to severe attack from *C. acinaciformis*. Enveloped, Tanalith T solvent failed to protect radiata pine and slash pine which sustained slight to moderate damage. However, enveloped, 0.002% m/m deltamethrin; enveloped, 0.02% m/m permethrin and LOSP 0.02% m/m permethrin successfully protected radiata pine and slash pine with a mean rating of 1.0 to 1.2, whereby 1 is sound. In Queensland trial, untreated controls (radiata pine heartwood, slash pine sapwood and slash pine heartwood) failed the test as high mass loss was obtained (> 45.0g). Enveloped, 0.002% m/m deltamethrin; enveloped, 0.02% m/m permethrin as well as LOSP 0.02% m/m permethrin successfully protected all the treated radiata pine and slash pine (sapwood and heartwood) (Peters & Creffield, 2003).

2.6 Treatment methods

After the right selection of preservatives to be used for treatment, it is then to decide the right treatment methods as to achieve the desired retention and penetration within the treated wood to maximize the protection on the wood. There are common methods which involve pressure or non-pressure treatment.

2.6.1 Dipping treatment

There are many non-pressure or superficial treatments used in commercial practice for treating the wood. The use of brush and spray application perhaps the easiest and most common methods known to householder (Barry, 1993). Dipping or immersion is another form of superficial treatment. The use of simple low viscosity preservative for dipping will penetrate quickly into the wood as soon as possible. According to Barry (1993), immersion of wood in preservative for up to 10 minutes is usually considered as dipping whereas

longer immersion is known as steeping. It will take longer time to achieved desired retention using dipping thus the only way to achieve that is by extending the dipping times. The advantages of using dipping is that it is simple, involve low capital cost and could achieved excellent penetration and preservative loading provided the dipping time is adequate. Dipping would achieve deeper penetration provided the wood is dry.

2.6.2 Vacuum pressure treatment

For long reliable service in decay or termite hazard conditions, pressure treatment with effective preservative is mandatory. When pressure treatment is performed correctly, it will result in deeper and more uniform treatment in the entire wood (Zabel & Morell, 1992). Wood is immersed in the treating solution in a treating chamber. The vacuum then is applied to remove air as much as possible within the wood. Once vacuum treatment is complete, vacuum is released and atmospheric pressure or higher pressure is applied to press the treating solution into the wood. Maximum uptake, deeper penetration and retention of preservative can be achieved using this method and thus excellent protection could be achieved. Adaptations of approved target retentions in wood used in other countries (e.g. non tropical countries) may not necessarily applicable to be used in our tropical condition to control our tropical termites.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study sites

This study mainly was carried out in an active termite test site heavily infested by *Coptotermes curvignathus* at Timber Research and Technical Training Centre (TRTTC), Sarawak Forestry Corporation, Kota Sentosa, Kuching. The grinding of wood chips into sawdust, compression parallel to grain and hardness test was done in TRTTC. All of the laboratory analysis and wood treatment was done in Wood Biodeterioration Laboratory of Faculty of Resource Science and Technology, University Malaysia Sarawak (UNIMAS).

3.2 Termite collections

Termites were collected from infested wood, termite mounds and specimens provided by local pest control companies. Termites were mainly collected around UNIMAS campus and Kuching area. Locations and general observation of termite attacks were also recorded. Termite specimens (particularly termite soldier) were collected, put inside a vial filled with 70% ethanol and sent to Forest Research Institute Malaysia (FRIM), Kepong to be identified using morphometry analysis (e.g. head sizes, shapes of mandibles etc.) by officers there. A reference copy of termite specimens were both kept in Wood Biodeterioration Laboratory of Faculty Resource Science and Technology, UNIMAS and Forest Research Institute Malaysia, Kepong.

3.3 Experiment 1: Basic physical properties, extractive contents and natural termite resistance of tested species

3.3.1 Wood samples

Different number of wood species were used in the comparison of basic wood physical properties, extractive contents and natural termite resistance. Heartwood of commercial timber, Sarawak authenticated timber and exotic timber species were used in this experiment as shown in Table 3.1. All of these wood species materials were obtained from Wood Biodeterioration Laboratory, FRST, UNIMAS and hence the locality, age of the collected wood species were not known.

Table 3.1: List of wood species used

No.	Code	Common Name	Scientific Name
1	A	Akasia	<i>Acacia mangium</i>
2	BJ	Bajan	<i>Kokoona reflexa</i>
3	BD	Bedaru	<i>Cantleya corniculata</i>
4	GG	Belian	<i>Eusideroxylon zwageri</i>
5	BG	Bengang	<i>Neesia borneensis</i>
6	BH	Benuah	<i>Macaranga pearsonii</i>
7	AB	Bindang	<i>Agathis borneensis</i>
8	BR	Bintangor	<i>Calophyllum incrassatum</i>
9	BW	Bintawak	<i>Artocarpus anisophyllus</i>
10	B	Binuang	<i>Octomeles sumatrana</i>
11	CA	Casuarina	<i>Casuarina equisetifolia</i>
12	D	Chengal	<i>Neobalanocarpus heimii</i>
13	CP	Chengal pasir	<i>Hopea beccariana</i>
14	DF	Douglas fir	<i>Pseudotsuga menziesii</i>
15	E	Engkabang jantung	<i>Shorea macrophyla</i>
16	ET	Entuyut	<i>Tetramerista glabra</i>
17	JW	Jelawei mempalam babi	<i>Terminallia phellocarpa</i>
18	J	Jelutong paya	<i>Dyera polyphylla</i>
19	I	Kapur	<i>Dryobalanops</i> spp.
20	KB	Kapur bukit	<i>Dryobalanops beccarii</i>
21	KK	Kapur kelansau	<i>Dryobalanops oblongifolia</i>
22	KC	Kayu cina	<i>Podocarpus micropedunculatus</i>
23	KL	Kelat	<i>Syzygium</i> spp.
24	KY	Kelempayan	<i>Neolamarckia cadamba</i>

Table 3.1 continued

No.	Code	Common Name	Scientific Name
25	KP	Kempas	<i>Koompassia malaccensis</i>
26	KE	KerANJI	<i>Dialium</i> spp.
27	L	Keruing	<i>Dipterocarpus</i> spp.
28	KU	Kulim	<i>Scorodocarpus borneensis</i>
29	KG	Kumpang	<i>Myristica maxima</i>
30	KM	Kumus	<i>Shorea laevis</i>
31	LB	Leban	<i>Vitex pubescens</i>
32	LG	Legai	<i>Adinandra borneensis</i>
33	LN	Lun siput daun besar	<i>Shorea iliasii</i>
34	P	Mata ulat	<i>Kokoona</i> spp.
35	ME	Medang luis kasar	<i>Alseodaphne insignis</i>
36	MP	Mempening	<i>Lithocarpus</i> spp.
37	MK	Mengkulang	<i>Heritiera aurea</i>
38	MB	Meranti buaya	<i>Shorea uliginosa</i>
39	ML	Meranti luang	<i>Shorea ovalis</i>
40	MG	Mergasing	<i>Mesua macrantha</i>
41	MS	Mersawa kunyit	<i>Anisoptera grossivenia</i>
42	LL	NyatoH	<i>Palaquium</i> spp.
43	BB	Oil palm stem (non-wood)	<i>Elaeis guineensis</i>
44	PJ	Pajang / Asam	<i>Mangifera pajang</i>
45	PE	Pelong / Plajau	<i>Pentaspadon motleyi</i>
46	PY	Penyau	<i>Upuna borneensis</i>
47	PL	Pulai	<i>Alstonia</i> spp.
48	RP	Radiata pine	<i>Pinus radiata</i>
49	RU	Rambai / Tampoi	<i>Baccaurea polyneura</i>
50	BM	Red Balau	<i>Shorea</i> spp.
51	MM	Red Meranti	<i>Shorea carapace</i>
52	RG	Rengas	<i>Gluta</i> spp. or <i>Melanochyla</i> spp.
53	R	Rubberwood	<i>Hevea brasiliensis</i>
54	SH	Sawih	<i>Duabanga moluccana</i>
55	SG	Segera	<i>Aglaia borneensis</i>
56	SD	Seladah	<i>Canarium apertum</i>
57	SB2	Selangan batu	<i>Shorea pluriscostata</i>
58	SB1	Selangan batu	<i>Shorea</i> spp.
59	SB3	Selangan batu kuning	<i>Shorea flava</i>
60	SM	Selangan merah	<i>Shorea kunstleri</i>
61	SP	Sempilor	<i>Dacrydium elatum</i>
62	S	Sentang	<i>Azadirachta excelsa</i>
63	JM	Teak (Malaysia)	<i>Tectona grandis</i>
64	JB	Teak (Myanmar)	<i>Tectona grandis</i>
65	TK	Tekalong	<i>Artocarpus odoratissimus</i>
66	HH	Tembusu	<i>Fagraea fragrans</i>
67	TM	Teruntum merah	<i>Lumnitzera littorea</i>
68	UB	Ubah urat	<i>Syzygium sarawakensis</i>
69	YM	Yellow meranti	<i>Shorea</i> spp.

Due to the lack of wood resources, the number of species used varies among the tested parameters and experiments as different parameters required different wood dimension. Therefore, 67 wood species were tested for density, water permeability and extractive contents. For the compression parallel to grain test, only 58 wood species were tested, while 66 wood species tested for wood hardness. As for natural termite resistance, 69 wood species were tested.

3.3.2 Wood density

For wood density, 67 wood species were tested. These wood species had been air-dried in the laboratory. Upon testing, wood dimension of 20 mm length x 10 mm width x 10 mm height was prepared. Three replicates of each species were tested. Volumes of wood samples were then determined by the water displacement method. The wood sample was pricked using a sewing needle and the whole sample block was immersed in 200 ml beaker placed on a weighing balance. Weight increased shown on the weighing balance showed the volume of water displaced. Volumes (cm³) obtained were used to determine the wood density. Wood samples were then oven-dried for 48 hours at 105°C. After 48 hours, oven-dried weights (g) of the wood were obtained. The wood density was then determined using the following formula:

$$\text{Wood density} = \frac{\text{Oven-dried weight (g)}}{\text{Volume (cm}^3\text{)}}$$

3.3.3 Hardness test

A total of 66 wood species were tested for hardness testing using 807 tubular impact tester. Wood samples were cut into 20 mm length x 20 mm width x 20 mm height square blocks. Three replicates of each species were tested. Cross sectional face of the wood blocks was adjusted upright where 1kg load was released and directly impact on the cross sectional face. The depth of depression caused by the fallen impact was measured using an optical micrometer. The depth measurement was used in the formula below to determine the Brinell Hardness Number.

$$\text{BHN} = \frac{2P}{\pi D [D - \sqrt{D^2 - d^2}]} \times 0.102$$

Where P is load, D is steel ball diameter, and d is the depth of depression.

3.3.4 Compression parallel to grain test

A total of 58 wood species were available for compression test using Instron Universal Testing Machine (Figure 3.1). For compression parallel to grain test, British Standard 373: 1957 methods of testing small clear specimens of timber was adopted with modification. The dimension of wood sample used was 50 mm length x 20 mm width x 20 mm height. Three replicates of each species were tested. The test sample then subjected to compression test at a rate of 6.0 mm/min, the maximum load (N) and maximum stress (Nmm^{-2}) were recorded for each test species.



Figure 3.1: Compression parallel to grain test.

3.3.5 Water permeability

A total of 67 wood species were available and tested for their water permeability. This methodology was adapted from Mori *et al.* (2014), with modification. Wood samples of 20 mm length x 5 mm width x 5 mm height size were prepared. Three replicates of each species were tested. Wood samples were then end-sealed using coating. Air-dried mass was recorded to determine the weights of the coating. After coating, wood samples were then oven-dried for 48 hours at 105°C. After 48 hours, oven-dried mass were recorded. For water permeability testing, the initial weights of wood samples were recorded. Wood samples were put in a mesh and weights were tied with the mesh so that wood samples would not float. The mesh filled with wood samples then submerged in a beaker filled with distilled water and placed in water bath for 4 hours at 30°C. After 4 hours, wood samples were taken out and the final weights after submerged were measured immediately. The permeability index was then determined using the following formula:

$$\text{Water permeability index} = \frac{\text{Uptake (Final weight} - \text{Initial weight)(g)}}{\text{Volume (cm}^3\text{) X Number of hours submerged}}$$

3.3.6 Extractive content

3.3.6.1 Preparation of sawdust

As many as 67 wood species were tested for their extractive contents. All the species were prepared of about match sticks size grounded using a sawdust grinder at TRTTC sieved through 1mm particle size. The grinder was cleaned each time after a wood sample was grounded to avoid contamination. Grounded sawdust was individually put into labelled plastic bags and brought back to the laboratory for further experiment.

3.3.6.2 Cold water extraction

For cold water extraction, TAPPI T 207 cm-99 (1999) was used with modification. About 1 gram of sawdust was oven-dried at 105°C for 48 hours. Three replicates of each species were tested. After oven-dried, the weight of sawdust was immediately recorded (W1). Sawdust was then poured carefully into round cylindrical medicine bottle to avoid sawdust lose. 75ml of distilled water was then poured into the bottle and the samples were stand for 48 hours with constant stirring. After 48 hours, the samples were filtered through filtering crucible porosity number 2. The filtered sawdust then oven-dried again for 48 hours to obtain weight after extraction (W2).

3.3.6.3 Hot water extraction

As for hot water extraction, TAPPI T 207 cm-99 was used with modification. 1 gram of sawdust was oven-dried at 105°C for 48 hours. Three replicates of each species were tested. After oven-dried, the weight of the sawdust was immediately recorded (W1). Sawdust was then transferred carefully into a 250ml conical flask to avoid sawdust lose. 200ml of distilled water was then poured into the conical flask and sealed using aluminium foil. Instead of using reflux condenser in accordance with TAPPI T 207 cm-99, samples were autoclaved for 4 hours at 121°C and 15 psi. After 4 hours autoclaving, pressure in the autoclave was released and the samples were left to cool down before filtration made. The samples were then filtered through filtering crucible porosity number 2. The filtered sawdust then oven-dried again for another 48 hours to obtain the weight after extraction (W2).

3.3.6.4 Methanol extraction

One gram of sawdust was oven-dried at 105°C for 48 hours. Three replicates of each species were tested. After oven-dried, the weight of sawdust was immediately recorded (W1). Sawdust was then poured carefully into 250ml conical flask to avoid sawdust lose. 70ml of analytical graded methanol was then poured into the conical flask and sealed using aluminium foil. The samples were placed in a water bath and was heated at 55°C (less than the boiling point of methanol) using a hot plate stirrer for 6 hours. After 6 hours, the samples were left to cool down before filtration made. The samples were then filtered through filtering crucible porosity number 2. The filtered sawdust then oven-dried again for 48 hours to obtain weight after extraction (W2).

3.3.6.5 Extractive content calculation

The extractive contents were then calculated using the following formula:

$$\text{Extractive content (\%)} = \frac{W1 - W2}{W1} \times 100\%$$

Where W1 was the weight of sawdust before extraction and W2 was the weight of sawdust after extraction. For cold water and hot water extractives, pH values were taken using Mettler Toledo pH meter.

3.3.7 Natural termite resistance

A total of 69 wood species were tested for natural termite resistance to *Coptotermes curvignathus* simulating H2 aboveground termite field test. Wood samples of 20 mm length x 20 mm width x 20 mm height were prepared using METABO Bandsaw and sanded using sand paper. Four replicates of each species were used in this study to determine termite resistance of tested species. Wood blocks were oven-dried for 48 hours at 105°C and the oven-dry masses (ODM1) were recorded for all the blocks. The termite test protocol used in this study was previously employed by Wong (2005).

Wood blocks were arranged randomly on a perforated aluminium tray alongside with corrugated cardboard and softwood blocks then exposed to an aboveground H2 hazard class test assembly. The H2 hazard class test assembly was sheltered from rain and non-wetting internal environment except humidity (Wong, 2005), positioned above a stack of keruing sawn timbers infested with *Coptotermes curvignathus* for 6 months. In the test assembly, perforated aluminium trays were placed on additional softwood blocks or untreated rubberwood blocks to lure termite from infested keruing stakes to attack the test blocks from underneath. The top region of the perforated aluminium trays were supplemented with corrugated cardboards to provide insulation for termite activity. After 6 months, wood samples were harvested and debris was cleaned, then oven-dried for 48 hours at 105°C to determine the final mass (ODM2) of attacked wood. Percentage and absolute mass losses were then calculated. Test blocks that remain at the end of test exposure were visually evaluated based on AWP A E7-07 termite rating scales (Table 3.2) to rate the severity of termite attack done to test samples. The AWP A E7 test was well used basically comprises of a range of different stake sizes and allowing testings to be

done in different geographic locations (International Research Group on Wood Protection, n.d.).

Table 3.2: AWP A E7-07 termite rating scheme (AWPA, 2008)

Rating	Description
10	Sound
9.5	Trace, surface nibbles permitted
9	Slight attack, $\leq 3\%$ of cross sectional area affected
8	Moderate attack, 3-10% cross sectional area affected
7	Moderately severe attack and penetration, 10-30% of cross sectional area affected
6	Severe attack, 30-50% of cross sectional area affected
4	Very severe attack, 50-75% of cross sectional area affected
0	Failure (destroyed)

3.4 Experiment 2: Natural termite resistance of *Dipterocarpus* spp. and *Acacia mangium*

Table 3.3 shows the common names, scientific names, dimensions and coding of keruing (predetermined dimension) and *Acacia*.

Table 3.3: Lists of *Dipterocarpus* spp. and *Acacia mangium*.

Code	Common name (Scientific name)	Sample dimension (cm) (Width x Length x Height)
ASP	<i>Acacia</i> (<i>Acacia mangium</i>)	3.0 x 5.0 x 1.0
A	<i>Acacia</i> (<i>Acacia mangium</i>)	2.5 x 5.0 x 1.5
KM	Keruing Mempelas (<i>Dipterocarpus crinitus</i>)	2.5 x 5.0 x 1.5
KS	Keruing (<i>Dipterocarpus</i> spp.)	2.0 x 5.0 x 1.0
KSP	Keruing Sol Padi (<i>Dipterocarpus pachyphyllus</i>)	2.5 x 5.0 x 1.5
L	Keruing braceply (<i>Dipterocarpus</i> spp.)	2.5 x 5.0 x 1.0
KG	Keruing Gondol (<i>Dipterocarpus kerrii</i>)	2.5 x 4.5 x 1.5
P	Keruing plywood (<i>Dipterocarpus</i> spp.)	2.5 x 5.0 x 1.0
KK	Keruing Kobis (<i>Dipterocarpus confertus</i>)	2.5 x 4.5 x 1.0
UK	Keruing Utap (<i>Dipterocarpus rigidus</i>)	2.0 x 4.5 x 1.0
KB	Keruing Baran (<i>Dipterocarpus eurynchus</i>)	2.0 x 5.0 x 1.5

A total of nine *Dipterocarpus* spp. and *Acacia mangium* were tested for its natural durability against *C. curvignathus*. Six replicates of each species were used in this study. Wood blocks were oven-dried for 48 hours at 105°C and the oven-dry masses (ODM1) were recorded for all the blocks then exposed to test assembly. Wood samples were sandwiched together with bait wood materials in the test assembly simulating H2 hazard class sheltered from rain and non-wetting internal environment except humidity (Wong, 2005), positioned above a stack of keruing sawn timbers infested with *C. curvignathus* for 4 months. After 4 months, wood samples were harvested, debris cleaned and harvested wood samples were oven-dried for 48 hours at 105°C to determine the final mass (ODM2) of attacked wood. Percentage and absolute mass losses were then calculated. Test blocks that retrieved were visually evaluated based on AWPA E7-07 termite rating scales (refer Table 3.2) to rate the severity of termite attack done to test samples.

3.5 Experiment 3: Termite resistance of *Acacia mangium*, *Hevea brasiliensis* and pine ply dip-treated with diesel, dead engine oil and combination of both oils

Six replicates of 20 mm length x 20 mm width x 20 mm height of *A. mangium*, *H. brasiliensis* and pine plywood wood blocks were prepared for each treatment. Wood blocks were dip-treated at duration of 1 minute using diesel, dead engine oil and combination of diesel and dead engine oil at 1:1 ratio. The reason for mixing the dead engine oil with diesel is to make it less viscous. Untreated controls for each species were also included. Wood blocks were oven-dried for 48 hours at 105°C and the oven-dry masses (ODM1) were recorded for all the blocks. Prior to dipping treatment, the air-dry mass of the wood samples were recorded. Two weeks of conditioning in dark condition

were done immediately after wood samples were dip-treated using the oils. Treated wood samples were arranged in a perforated aluminium tray supplemented with bait wood materials exposed to aboveground H2 hazard class test assembly sheltered from rain and non-wetting internal environment except humidity (Wong, 2005), positioned above a stack of keruing sawn timbers infested with *C. curvignathus* for 6 months.

In the test assembly, perforated aluminium trays were placed on additional softwood blocks or untreated rubberwood blocks to lure termite from infested keruing stakes to attack the test blocks from underneath. Top region of the perforated aluminium trays were supplemented with corrugated cardboards to provide insulation for termite activity. After 6 months, wood samples were retrieved and debris was removed. Retrieved wood samples were then oven-dried for 48 hours at 105°C to determine the final mass (ODM2) of attacked wood. Percentage and absolute mass losses were then calculated. Test blocks were visually evaluated based on AWP A E7-07 termite rating scales (refer Table 3.2) to rate the severity of termite attack done to test samples.

3.6 Experiment 4: Termite resistance of light organic solvent preservative treated *Kokoona reflexa*, *Adinandra borneensis* and *Canarium apertum* using dipping and vacuum pressure treatment

Wood species of *K. reflexa*, *A. borneensis* and *C. apertum* was used in this experiment. The LOSP solution was made by mixing the concentrate in white spirit of 1 to 6. The diluted LOSP contain 0.186 to 0.2% w/w permethrin, 0.14 to 0.15% propiconazole and as well as tebuconazole. Wood samples were treated with LOSP solution using dipping and vacuum pressure treatment. Total of 24 wood blocks dimension of 100 mm length x 20 mm width x 20 mm height were prepared for each species. Six replicates of wood blocks

were tested for each treatment. Six wood blocks of each species were sent to Klang for vacuum pressure treatment using industrial treatment plant in Klang. Another 12 wood blocks (6 for dipping and 6 for vacuum pressure treatment) were treated in wood biodeterioration lab FRST by using dipping and vacuum pressure treatment. Untreated controls were also included for comparison.

3.6.1 Dipping treatment

Wood blocks were first oven-dried for 48 hours at 105°C and the oven-dry masses (ODM1) were recorded for all the blocks. Prior to dipping treatment, the air-dry mass of the wood samples were recorded. Wood samples were then dipped individually in LOSP solution for 10 minutes. After 10 minutes, wood blocks were taken out and wet weights were recorded. Chemical uptakes were calculated. After treatment, wood samples were conditioned in dark condition for 14 days before exposing them in termite field test according to termite test protocol by Wong, (2005).

3.6.2 Vacuum pressure treatment

Wood blocks were initially oven-dried for 48 hours at 105°C and the oven-dry masses (ODM1) were recorded for all the blocks. Prior to pressure treatment, the air-dry mass of the wood samples were recorded. Wood samples were then immersed in prepared solution together with loads to prevent from floating. The samples then subjected to impregnation under vacuum condition of 27 InHg for 30 minutes. After 30 minutes, the vacuum was released and the samples were allowed to stand in the solution for 1 hour before wet weights were recorded. The chemical uptakes were calculated based on the wet weight.

Treated samples were then conditioned in a dark condition for 14 days before exposed to termites in the field in accordance with termite test protocol by Wong, (2005).

Dip-treated and vacuum pressure-treated wood blocks were arranged in the test assembly whereby the treated samples sandwiched together with bait wood materials in the test assembly simulating H2 hazard class sheltered from rain and non-wetting internal environment except humidity (Wong, 2005), positioned above a stack of keruing sawn timbers infested with *C. curvignathus* for 4 months. After 4 months, wood samples were harvested, debris cleaned and all the retrieved wood samples were then oven-dried for 48 hours at 105°C to determine the final mass (ODM2) of attacked wood. Percentage and absolute mass losses were then calculated. Harvested test blocks were visually evaluated based on AWP A E7-07 termite rating scales (refer Table 3.2) to rate the severity of termite attack done to test samples.

3.7 Experiment 5: Termite resistance of *Koompassia malaccensis* and *Hevea brasiliensis* dip-treated using chlorpyrifos, cypermethrin and permethrin

The concentrations used for testing was adapted from the prescribed concentrations of each product and employing concentrations used by Sornnuwat *et al.*, (1994). Additional 2 concentrations 2 fold higher than the highest concentrations used by Sornnuwat *et al.* (1994), also being included for testing. Samples of agro-insecticides were sent to Universiti Sains Malaysia for actual active ingredient (a.i) concentrations and it was found out that the actual a.i concentrations were different from the nominal a.i stated on the bottle. Since the working concentrations used were calculated based on nominal a.i concentrations, the calculations were back-calculated using actual a.i concentrations and thus concentrations

used for testing were shown in Table 3.4. The dipping time (3 seconds versus 60 seconds) was compared whereby 3 seconds resembling spraying while 60 seconds resembling dipping (Tawi & Wong, 2016).

Table 3.4: Concentrations used for wood treatment using dipping treatment

Agro-insecticides	Nominal a.i concentrations (% m/m)	Actual a.i concentrations (% m/m)	Concentrations used for testing (%)
Chlorpyrifos	21.2%	33.2%	0.04, 0.08, 0.16, 0.32 ,0.4, 0.8, 1.6, 3.1, 6.3, 12.5
Cypermethrin	5.5%	9.2%	0.0023, 0.0046, 0.0092, 0.053, 0.105, 0.21, 0.42, 0.84, 1.68, 3.35
Permethrin	26.3%	22.2%	0.0011, 0.0022, 0.0044, 0.008, 0.017, 0.021, 0.042, 0.084, 0.17, 0.42, 0.85, 1.69 , 3.38, 6.75

Four replicates of 20 mm length x 20 mm width x 20 mm height *K. malaccensis* and *H. brasiliensis* wood blocks were used for each concentration in this study. Untreated controls for each species were also included. Wood blocks were oven-dried for 48 hours at 105°C and the oven-dry masses (ODM1) were recorded for all the blocks. Prior to dipping treatment, the air-dry mass of the wood samples were recorded. Wood blocks were dipped in agro-insecticides as in Table 3.4 for both 3 seconds and 60 seconds. Weight after the wood samples were dipped also recorded to determine the uptake of the solution. Two weeks of conditioning in dark condition were done immediately after wood samples were dipped-treated using the chemicals. All the treated wood samples together with the untreated control were arranged in a perforated aluminium tray supplemented with bait wood materials and exposed to two exposures (low and high humidity) of Malaysian H2 condition. For low humidity exposure, the perforated aluminium trays together with treated

samples were placed in the H2 hazard class test assembly was sheltered from rain and non-wetting internal environment except humidity (Wong, 2005), positioned above a stack of keruing sawn timbers infested with *C. curvignathus*. For high humidity exposure, the perforated aluminium trays together with treated samples were placed inside rectangular aluminium drums sheltered from rain and non-wetting internal environment just above the ground. After 6 months, wood samples were harvested and debris was cleaned, then oven-dried for 48 hours at 105°C to determine the final mass (ODM2) of attacked wood. Percentage and absolute mass losses were then calculated. All the harvested test blocks were visually evaluated based on AWPA E7-07 termite rating scales (refer Table 3.2) to rate the severity of termite attack done to test samples.

3.8 Experiment 6: Termite resistance of *Neolamarckia cadamba* and *Hevea brasiliensis* dip-treated using chlorpyrifos, cypermethrin and permethrin

Dimension of 20 mm lengths x 20 mm width x 20 mm height *N. cadamba* and *H. brasiliensis* wood blocks were used in this study. Both *N. cadamba* and *H. brasiliensis* were treated using various concentrations of different agro-insecticides listed in Table 3.4 and four replicates of wood samples were used for each concentration. Untreated controls for each species were also included. Wood blocks were oven-dried for 48 hours at 105°C and the oven-dry masses (ODM1) were recorded for all the blocks. Prior to dipping treatment, the air-dry mass of the wood samples were recorded. Weight after the wood samples were dipped also recorded to determine the uptake of the solution. Conditioning in dark condition was done immediately for 2 weeks after wood samples were dipped-treated using the chemicals.

Wood samples were arranged in a perforated aluminium tray filled with bait wood materials then exposed to aboveground H2 hazard class test assembly sheltered from rain and non-wetting internal environment except humidity (Wong, 2005), positioned above a stack of keruing sawn timbers infested with *C. curvignathus* for 6 months. In the test assembly, perforated aluminium trays were placed on additional softwood blocks or untreated rubberwood blocks to lure termite from infested keruing stakes to attack the test blocks from underneath. Top part of the perforated aluminium trays were supplemented with corrugated cardboards to provide insulation for termite activity. After 6 months, wood samples were harvested and debris was cleaned. The retrieved samples were oven-dried for 48 hours at 105°C to determine the final mass (ODM2) of attacked wood.

Percentage and absolute mass losses were then calculated. Retrieved test blocks were visually evaluated based on AWPA E7-07 termite rating scales (refer Table 3.2) to rate the severity of termite attack done to test samples.

3.9 Experiment 7: Termite resistance of *Neolamarckia cadamba* and *Hevea brasiliensis* vacuum pressure-treated with chlorpyrifos, cypermethrin, deltamethrin and permethrin

The target retentions used for cypermethrin, deltamethrin and permethrin were adapted from the Approved preservative treatments for H level H2 and H3 (AS1604.1, 2000) while the target retentions for chlorpyrifos was adapted from Laks *et al.*'s study (as cited in Tolley *et al.*, 1998). Water uptake test was carried out for both *N. cadamba* and *H. brasiliensis*. This led to the determination of respective working concentrations of all agro-insecticides required to achieve respective target retention in wood blocks. Since the working concentrations used were calculated based on nominal a.i concentrations to

achieve the required target retentions in wood, the calculations were back-calculated using actual a.i concentrations and thus target retentions needed to be achieved in wood blocks were higher than the recommended target retentions in the literature for testing were shown in Table 3.5.

Wood blocks of 20 mm lengths x 20 mm width x 20 mm height were cut from *N. cadamba* and *H. brasiliensis* using Metabo bandsaw. The working concentrations of each agro-insecticide for each wood species as shown in Table 3.5 were prepared to achieve the desired target retentions. Four replicates of wood samples were used for each concentrations. Untreated controls were also included for comparison purpose.

Table 3.5: Working concentrations used to vacuum pressure-treat wood to the target retentions (% m/m) of each insecticide

Agro-insecticides	Actual a.i concentrations (% m/m)	Working concentrations (%)	Target Retention (% m/m)
Chlorpyrifos	33.2	RW: 0.00205, 0.0041, 0.0082 KY: 0.0008, 0.0016, 0.0032	0.002, 0.004, 0.008
Cypermethrin	9.2	RW: 0.02625, 0.0525, 0.105 KY: 0.0105, 0.021, 0.042	0.025, 0.05, 0.1
Deltamethrin	3.5	RW: 0.001325, 0.00265, 0.0053 KY: 0.0005, 0.001, 0.002	0.0013, 0.0025, 0.0051
Permethrin	22.2	RW: 0.00885, 0.0177, 0.0354 KY: 0.00337, 0.00674, 0.1348	0.008, 0.017, 0.034

RW = *H. brasiliensis*, KY = *N. cadamba*.

Wood blocks were oven-dried for 48 hours at 105°C and the oven-dry masses (ODM1) were recorded for all the blocks. Prior to pressure treatment, the air-dry mass of the wood samples were recorded. Wood samples were then immersed in prepared solution together with weights to prevent from floating. The samples then subjected to impregnation under vacuum condition of 27 InHg for 30 minutes. After 30 minutes, the vacuum was released

and the samples were allowed to stand in the solution for 1 hour before wet weights were recorded. The chemical uptakes were calculated based on the wet weight. The treated samples were then conditioned in a dark condition for two weeks before exposed to termites in the field. Wood samples were arranged randomly in perforated aluminium trays supplemented with bait wood materials then exposed to aboveground H2 hazard class test assembly sheltered from rain and non-wetting internal environment except humidity (Wong, 2005), positioned above a stack of keruing sawn timbers infested with *C. curvignathus* for 6 months. In the test assembly, perforated aluminium trays were placed on additional softwood blocks or untreated rubberwood blocks to lure termite from infested keruing stakes to attack the trays from underneath. Top region of the perforated aluminium trays were supplemented with corrugated cardboards to provide insulation for termite activity. After 6 months, wood samples were harvested and debris was removed. All of the retrieved samples were then oven-dried for 48 hours at 105°C to determine the final mass (ODM2) of attacked wood. Percentage and absolute mass losses were then calculated. All the retrieved test blocks were visually evaluated based on AWPA E7-07 termite rating scales (refer Table 3.2) to rate the severity of termite attack done to test samples.

3.10 Data Analysis

All the data collected were analysed using Microsoft Excel and Minitab 14. One-way, two-way and General Linear Model were used based on the specific requirement of each experiment. One-way ANOVA was used to compare among treatments whereas two-way ANOVA and General Linear Model were used to compare among 2 or more treatments. Post Hoc test Least Significant Difference (LSD) was carried out when the ANOVA was significant.

CHAPTER 4

RESULTS

4.1 Termite collections

Total of 53 termite specimens (Table 4.1) particularly termite soldiers were collected and identified based on morphometric analyses (e.g. head sizes, shapes of mandibles etc.).

Table 4.1: Number of collected termite specimens based on genus and species

Genus (total number) / Species	Number of collected termite specimens
<i>Nasutitermes</i> (6)	
<i>Nasutitermes</i> sp.	2
<i>N. matangensis</i>	1
<i>N. havilandii</i>	1
<i>N. matangensisformis</i>	1
<i>N. regularis</i>	1
<i>Schedorhinotermes</i> (11)	
<i>S. sarawakensis</i>	1
<i>S. medioobscurus</i>	2
<i>S. tarakanensis</i>	2
<i>Schedorhinotermes</i> sp.	5
<i>S. malacensis</i>	1
<i>Coptotermes</i> (22)	
<i>C. curvignathus</i>	17
<i>C. sepangensis</i>	5
<i>Macrotermes</i> (8)	
<i>M. gilvus</i>	6
<i>Macrotermes</i> sp.	2
Others (6)	
<i>Procapritermes</i> sp.	2
<i>Globitermes globosus</i>	1
<i>Hospitalitermes bicolor</i>	1
<i>Bulbitermes</i> sp.	1
<i>Pericapritermes</i> sp.	1
Grand total	53

Based on Table 4.1, there were 22 identified specimens belonged to genus *Coptotermes* contributed to 41.51% to the overall collection. Out of these 22 collected specimens, *C. curvignathus* was found to be the most dominant species collected comprised of 17 cases (32.08%). Out of these 17 cases of *C. curvignathus*, there were 11 cases found to attack trees and 6 cases attacked wood products including the built-in cabinet, door frame, skirting (wall), laminated flooring, roof trusses and store room. Another *Coptotermes* species identified was *C. sepangensis* comprised of 5 cases (9.43%). Out of these 5 cases of *C. sepangensis*, there were 2 cases of *C. sepangensis* attacked trees and 3 cases attacked wood products.

Genus *Schedorhinotermes* comprised of 20.75% (11 specimens) of the total statistic. Out of these 11 collected specimens, there were 5 specimens identified as *Schedorhinotermes* sp. followed by 2 specimens each for *S. medioobscurus* and *S. tarakanensis*. Other species identified from this genus also include *S. sarawakensis* and *S. malacensis* with 1 specimen each species. In this survey, there were 6 cases [*Schedorhinotermes* sp. (4 cases); *S. tarakanensis* (2 cases)] of this genus found to attack wood products particularly L-joints in the test site. Genus *Schedorhinotermes* also found to attack living and dead trees for instance [*S. medioobscurus* (2 cases); *Schedorhinotermes* sp. (1 case)]. Both *S. sarawakensis* and *S. malacensis* were also observed crawling on the soil.

Genus *Macrotermes* contributed 15.09% (8 specimens) to the overall statistics. Out of 8 collected specimens, *M. gilvus* comprised of 6 specimens while another 2 specimens were identified as *Macrotermes* sp.. Termite from genus *Macrotermes* are mound-building termites and *Macrotermes*'s mounds usually form besides a living tree. There was no observation that this termite foraging from the living tree. However, this termite is believed to have symbiotic relationship with the living host by cultivating fungus comb. There were

4 cases of *M. gilvus* and 1 case of *Macrotermes* sp. mounds spotted beside a living tree. There were 3 cases of *M. gilvus* mounds were spotted as stand-alone mound.

Only 11.32% (6 specimens) of total termite collected belonging to the genus *Nasutitermes*. Out of 6 collected specimens, there were 2 specimens identified as *Nasutitermes* sp. followed by *N. matangensis*, *N. havilandii*, *N. matangensisformis* and *N. regularis*. All of the *Nasutitermes* termites were collected near the forest area. In the forest, *Nasutitermes* tend to forage on living trees, but in some cases they too attack wood products. In this survey, 2 cases of *Nasutitermes* termites were found to attack wood products (roof truss and hand rail) which were *Nasutitermes* sp. and *N. matangensisformis*. The rest of the collected termites of this genus were found to attack living trees.

Other termite species like *Procapritermes* sp. (3.77%; 2 specimens), *Globitermes globosus* (1.89%, 1 specimen), *Hospitalitermes bicolor* (1.89%, 1 specimen), *Bulbitermes* sp. (1.89%; 1 specimen) and *Pericapritermes* sp. (1.89%; 1 specimen) also contributed to the total statistic. All of these mentioned termite species were found attacking living and dead trees except for *Pericapritermes* sp. which was captured crawling on the soil.

4.2 Experiment 1: Basic physical properties, extractive contents and natural termite resistance of tested species

4.2.1 Basic physical properties

One-way ANOVA (refer Appendix B Table 1 to 4) shows that there was a significant difference ($P < 0.05$) among density, Brinell Hardness Number, Compression parallel to grain and water permeability index of tested wood.

For density, *Alstonia* spp. recorded the lowest density which was 0.247 g/cm^3 while densest wood recorded was *Shorea pluriscostata* with density of 0.919 g/cm^3 shown in Table 4.2.

Alstonia spp., *Shorea macrophylla*, *Duabanga moluccana*, *Macaranga pearsonii*, *Shorea ovalis* and *Neolamarckia cadamba* were some examples of Light Hardwood (LHW) which also concurred with Malaysia Grading Rule ($\text{LHW} = < 720 \text{ kg/m}^3$). *Lithocarpus* spp., *Fagraea fragrans*, *Anisoptera grossivenia*, *Syzygium* spp. and *Shorea kunstleri* were some examples of Medium Hardwood (MHW) in accordance with Malaysian Grading Rule ($\text{MHW} = 720 - 880 \text{ kg/m}^3$) while *Kokoona* spp., *Eusideroxylon zwageri* and *Shorea flava* were examples of Heavy Hardwood (HHW) based on Malaysian Grading Rule ($\text{HHW} = > 880 \text{ kg/m}^3$).

As for Brinell Hardness Number (BHN), wood species with higher BHN exhibit harder wood feature. It can be observed that wood species with low BHN tend to break apart and larger steel ball diameter also observed on the wood surface which happened on wood species with smaller BHN. On the contrary, wood species with higher BHN underwent checkings and smaller steel ball diameter observed when the load is applied. Although density may somehow influence the wood hardness, it does not necessarily that high density wood reflect harder wood. For instance, *Dialium* spp. with density of 0.863 g/cm^3

recorded the highest BHN which was 0.0464 while *S. pluriscostata* the densest wood recorded in this study (0.919 g/cm^3) only had BHN of 0.0122. On the contrary, *Alstonia* spp, (0.247 g/cm^3) and *D. moluccana* (0.307 g/cm^3) had the lowest BHN which was 0.0067. Based on Table 4.2, wood species with the lowest compressive stress was *D. moluccana* (28.51 Nmm^{-2}) while *Cantleya corniculata* recorded the highest compressive stress (111.51 Nmm^{-2}). Generally, among hardwoods, compressive stress was found to be lower in LHW [e.g. *D. moluccana* (28.51 Nmm^{-2}), *Macaranga pearsonii* (36.26 Nmm^{-2}) and *N. cadamba* (42.85 Nmm^{-2}) as compared to MHW [e.g. *A. grossivenia* (59.83 Nmm^{-2}), *Dipterocarpus* spp. (66.61 Nmm^{-2}) and *Koompassia malaccensis* (79.96 Nmm^{-2})] and HHW [e.g. *S. pluricostata* (95.27 Nmm^{-2}), *Kokoona* spp. (98.93 Nmm^{-2}) and *C. corniculata* (111.51 Nmm^{-2})]. Among softwoods, the compressive stress was rather low [e.g. *Dacrydium elatum* (44.60 Nmm^{-2}) and *Podocarpus micropedunculatus* (37.83 Nmm^{-2})]. For water permeability of tested wood species, *Hevea brasiliensis* had the highest water permeability ($0.090 \text{ gcm}^{-3}\text{h}^{-1}$) while belian had the lowest water permeability ($0.023 \text{ gcm}^{-3}\text{h}^{-1}$). Generally, for water permeability, LHW exhibit higher capability to absorb water and hence recorded higher water permeability index [e.g. *Dyera polyphylla* ($0.067 \text{ gcm}^{-3}\text{h}^{-1}$), *Mangifera pajang* ($0.076 \text{ gcm}^{-3}\text{h}^{-1}$) and *N. cadamba* ($0.087 \text{ gcm}^{-3}\text{h}^{-1}$)]. In contrast, MHW [e.g. *Vitex pubescens* ($0.033 \text{ gcm}^{-3}\text{h}^{-1}$), Burma-grown *Tectona grandis* ($0.034 \text{ gcm}^{-3}\text{h}^{-1}$) and *Syzygium sarawakensis* ($0.040 \text{ gcm}^{-3}\text{h}^{-1}$)] while HHW [e.g. *E. zwageri* ($0.023 \text{ gcm}^{-3}\text{h}^{-1}$), *Shorea laevis* ($0.024 \text{ gcm}^{-3}\text{h}^{-1}$) and *Upuna borneensis* ($0.028 \text{ gcm}^{-3}\text{h}^{-1}$)] absorbed less water. Among softwoods, *Pseudotsuga menziesii* has the highest water permeability ($0.051 \text{ gcm}^{-3}\text{h}^{-1}$) as compared to *D. elatum* ($0.035 \text{ gcm}^{-3}\text{h}^{-1}$) and *P. micropedunculatus* ($0.033 \text{ gcm}^{-3}\text{h}^{-1}$). Table 4.2 shows the overall results of basic physical properties of tested wood.

Table 4.2: Basic physical properties of tested wood species

Wood Samples	Wood density (gcm ⁻³)	Hardness (BHN)	Compressive stress (Nmm ⁻²)	Water Permeability (gcm ⁻³ h ⁻¹)
Akasia (<i>Acacia mangium</i>)	0.654 (0.030) <i>qrstu</i>	0.0105 (0.0006) <i>jklmnop</i>	63.53 (7.43) <i>mnopq</i>	0.028 (0.001) <i>abcd</i>
Bajan (<i>Kokoona reflexa</i>)	0.869 (0.020) <i>BCD</i>	0.0153 (0.0007) <i>yz</i>	83.86 (2.20) <i>vw</i>	0.040 (0.002) <i>ghijk</i>
Bedaru (<i>Cantleya corniculata</i>)	0.826 (0.034) <i>yzA</i>	0.0153 (0.0010) <i>yz</i>	111.51 (19.47) <i>B</i>	0.031 (0.003) <i>abcde</i>
Belian (<i>Eusideroxylon zwageri</i>)	0.901 (0.017) <i>DE</i>	0.0135 (0.0013) <i>tuvwx</i>	78.65 (9.44) <i>stuvw</i>	0.023 (0.002) <i>a</i>
Bengang (<i>Neesia borneensis</i>)	0.485 (0.012) <i>hij</i>	0.0088 (0.0001) <i>cdefghi</i>	49.46 (1.33) <i>defghijkl</i>	0.058 (0.002) <i>op</i>
Benuah (<i>Macaranga pearsonii</i>)	0.321 (0.008) <i>b</i>	0.0077 (0.0002) <i>bcde</i>	36.26 (3.55) <i>ab</i>	0.038 (0.004) <i>efghi</i>
Bindang (<i>Agathis borneensis</i>)	0.515 (0.017) <i>ijklm</i>	-	-	0.028 (0.003) <i>abcd</i>
Bintangor (<i>Calophyllum incrassatum</i>)	0.445 (0.006) <i>defg</i>	0.0088 (0.0004) <i>cdefghi</i>	46.14 (9.37) <i>bcdefghi</i>	0.041 (0.006) <i>ghijk</i>
Bintawak (<i>Artocarpus anisophyllus</i>)	0.662 (0.088) <i>qrstu</i>	0.0110 (0.0002) <i>lmnopqr</i>	73.24 (5.13) <i>qrstuv</i>	0.039 (0.002) <i>efghij</i>
Binuang (<i>Octomeles sumatrana</i>)	0.681 (0.013) <i>tuv</i>	0.0122 (0.0006) <i>qrstuv</i>	72.31 (5.33) <i>qrstu</i>	0.044 (0.005) <i>hijkl</i>
Casuarina (<i>Casuarina equisetifolia</i>)	0.835 (0.023) <i>zAB</i>	0.0138 (0.0010) <i>vwxy</i>	-	0.048 (0.003) <i>klmn</i>
Chengal (<i>Neobalanocarpus heimii</i>)	0.869 (0.017) <i>BCD</i>	0.0241 (0.0041) <i>B</i>	80.88 (6.29) <i>uvw</i>	0.028 (0.003) <i>abcd</i>
Chengal pasir (<i>Hopea beccariana</i>)	0.574 (0.006) <i>o</i>	0.0093 (0.0002) <i>efghijk</i>	59.19 (5.78) <i>jklmnop</i>	0.039 (0.007) <i>efghij</i>
Douglas fir (<i>Pseudotsuga menziesii</i>)	0.510 (0.002) <i>ijklm</i>	0.0097 (0.0001) <i>ghijklm</i>	53.20 (17.22) <i>ghijklm</i>	0.051 (0.003) <i>lmno</i>

Table 4.2 continued

Wood Samples	Wood density (gcm ⁻³)	Hardness (BHN)	Compressive stress (Nmm ⁻²)	Water Permeability (gcm ⁻³ h ⁻¹)
Engkabang jantung (<i>Shorea macrophylla</i>)	0.299 (0.009) <i>b</i>	0.0110 (0.0006) <i>lmnopqr</i>	39.84 (8.24) <i>abcd</i>	0.035 (0.002) <i>defg</i>
Entuyut (<i>Tetramerista glabra</i>)	0.637 (0.011) <i>pqrs</i>	0.0135 (0.0006) <i>tuvwx</i>	74.81 (6.95) <i>qrstuvw</i>	0.055 (0.007) <i>mnop</i>
Jelawei mempelam babi (<i>Terminalia phellocarpa</i>)	0.500 (0.014) <i>hijkl</i>	0.0091 (0.0007) <i>efghij</i>	49.60 (2.53) <i>defghijkl</i>	0.070 (0.006) <i>rs</i>
Jelutong paya (<i>Dyera polyphylla</i>)	0.434 (0.026) <i>de</i>	0.0081 (0.0004) <i>bcdefg</i>	37.26 (0.50) <i>ab</i>	0.067 (0.002) <i>qr</i>
Kapur (<i>Dryobalanops</i> spp.)	0.665 (0.013) <i>rstu</i>	0.0110 (0.009) <i>lmnopqr</i>	-	0.036 (0.002) <i>defgh</i>
Kapur bukit (<i>Dryobalanops beccarii</i>)	0.688 (0.006) <i>uv</i>	0.0091 (0.0002) <i>efghij</i>	48.62 (5.74) <i>cdefghij</i>	0.048 (0.002) <i>klmn</i>
Kapur kelansau (<i>Dryobalanops oblongifolia</i>)	-	-	-	-
Kayu cina (<i>Podocarpus micropedunculatus</i>)	0.468 (0.005) <i>efgh</i>	0.0085 (0.0008) <i>cdefg</i>	37.83 (8.11) <i>abc</i>	0.033 (0.003) <i>bcdef</i>
Kelat (<i>Syzygium</i> spp.)	0.796 (0.031) <i>y</i>	0.0131 (0.0002) <i>stuvwx</i>	66.37 (1.81) <i>nopq</i>	0.038 (0.002) <i>efghi</i>
Kelempayan (<i>Neolamarckia cadamba</i>)	0.387 (0.022) <i>c</i>	0.0073 (0.0002) <i>bc</i>	42.85 (2.91) <i>bcdefgh</i>	0.087 (0.018) <i>t</i>
Kempas (<i>Koompassia malaccensis</i>)	0.810 (0.016) <i>yzA</i>	0.0155 (0.0008) <i>z</i>	79.96 (16.25) <i>uvw</i>	0.057 (0.003) <i>op</i>
KerANJI (<i>Dialium</i> spp.)	0.863 (0.007) <i>BC</i>	0.0464 (0.0037) <i>C</i>	91.31 (3.69) <i>xyz</i>	0.033 (0.002) <i>bcdef</i>
Keruing (<i>Dipterocarpus</i> spp.)	0.759 (0.006) <i>x</i>	0.0145 (0.0004) <i>xyz</i>	66.61 (5.65) <i>nopq</i>	0.026 (0.002) <i>abc</i>
Kulim (<i>Scorodocarpus borneensis</i>)	0.649 (0.006) <i>pqrst</i>	0.0134 (0.0001) <i>tuvwx</i>	-	0.036 (0) <i>defgh</i>

Table 4.2 continued

Wood Samples	Wood density (gcm ⁻³)	Hardness (BHN)	Compressive stress (Nmm ⁻²)	Water Permeability (gcm ⁻³ h ⁻¹)
Kumpang (<i>Myristica maxima</i>)	0.473 (0.018) <i>fgh</i>	0.0085 (0.0002) <i>cdefg</i>	51.48 (1.53) <i>efghijkl</i>	0.043 (0.004) <i>ghijkl</i>
Kumus (<i>Shorea laevis</i>)	0.838 (0.013) <i>AB</i>	0.0138 (0.0003) <i>vwxy</i>	85.91 (4.11) <i>wxy</i>	0.024 (0.002) <i>a</i>
Leban (<i>Vitex pubescens</i>)	0.649 (0.020) <i>pqrst</i>	0.0086 (0.0002) <i>cdefgh</i>	59.93 (7.80) <i>jklmnop</i>	0.033 (0.001) <i>bcdef</i>
Legai (<i>Adinandra borneensis</i>)	0.555 (0.019) <i>no</i>	0.0103 (0.0002) <i>ijklmn</i>	40.71 (1.93) <i>bcde</i>	0.069 (0.014) <i>rs</i>
Lun siput daun besar (<i>Shorea iliasii</i>)	0.487 (0.027) <i>hijk</i>	0.0085 (0.0003) <i>cdefg</i>	53.85 (6.41) <i>hijklm</i>	0.035 (0.001) <i>defg</i>
Mata ulat (<i>Kokoona</i> spp.)	0.898 (0.016) <i>CDE</i>	0.0173 (0.0010) <i>A</i>	98.93 (5.34) <i>zA</i>	0.035 (0.005) <i>defg</i>
Medang luis kasar (<i>Alseodaphne insignis</i>)	0.479 (0.004) <i>ghi</i>	0.0093 (0.0006) <i>efghijk</i>	48.99 (1.78) <i>cdefghijk</i>	0.026 (0.002) <i>abc</i>
Mempening (<i>Lithocarpus</i> spp.)	0.743 (0.018) <i>wx</i>	0.0135 (0.0009) <i>tuvwx</i>	81.95 (0.98) <i>uvwxy</i>	0.047 (0.003) <i>jklm</i>
Mengkulang (<i>Heritiera aurea</i>)	0.627 (0.041) <i>pq</i>	0.0121 (0.0001) <i>pqrst</i>	66.27 (0.70) <i>nopq</i>	0.035 (0.003) <i>defg</i>
Meranti buaya (<i>Shorea uliginosa</i>)	0.544 (0.023) <i>mno</i>	0.0106 (0.0007) <i>jklmnopq</i>	60.03 (4.14) <i>klmnop</i>	0.040 (0.005) <i>fghijk</i>
Meranti luang (<i>Shorea ovalis</i>)	0.377 (0.005) <i>c</i>	0.0083 (0.0002) <i>bcdefg</i>	34.84 (0.59) <i>ab</i>	0.060 (0.008) <i>pq</i>
Mergasing (<i>Mesua macrantha</i>)	0.660 (0.007) <i>qrstu</i>	0.0120 (0.0003) <i>opqrst</i>	72.37 (5.75) <i>qrstu</i>	0.044 (0.009) <i>hijkl</i>
Mersawa kunyit (<i>Anisoptera grossivenia</i>)	0.752 (0.011) <i>x</i>	0.0105 (0.0002) <i>jklmnop</i>	59.83 (3.01) <i>jklmnop</i>	0.046 (0.006) <i>ijkl</i>
Nyatoh (<i>Palaquium</i> spp.)	0.557 (0.006) <i>no</i>	0.0094 (0.0003) <i>fghijkl</i>	-	0.039 (0.002) <i>efghij</i>

Table 4.2 continued

Wood Samples	Wood density (gcm ⁻³)	Hardness (BHN)	Compressive stress (Nmm ⁻²)	Water Permeability (gcm ⁻³ h ⁻¹)
Oil palm (non-wood) (<i>Elaeis guineensis</i>)	0.820 (0.036) <i>yzA</i>	0.0045 (0.0017) <i>a</i>	-	0.179 (0.013) <i>u</i>
Pajang / Asam (<i>Mangifera pajang</i>)	0.634 (0.015) <i>pqr</i>	0.0104 (0.0006) <i>ijklmno</i>	55.47 (8.67) <i>ijklmn</i>	0.076 (0.008) <i>s</i>
Pelong / Plajau (<i>Pentaspadon motleyi</i>)	0.616 (0.027) <i>p</i>	0.0092 (0.0002) <i>efghij</i>	49.62 (7.94) <i>defghijkl</i>	0.047 (0.004) <i>jklm</i>
Penyau (<i>Upuna borneensis</i>)	0.796 (0.012) <i>y</i>	0.0115 (0.0004) <i>nopqrs</i>	60.51 (1.34) <i>lmnop</i>	0.028 (0.002) <i>abcd</i>
Pulai (<i>Alstonia</i> spp.)	0.247 (0.027) <i>a</i>	0.0067 (0.0019) <i>b</i>	78.16 (1.59) <i>rstuvw</i>	0.075 (0.005) <i>rs</i>
Radiata pine (<i>Pinus radiata</i>)	0.429 (0.004) <i>d</i>	0.0102 (0.0022) <i>hijklmn</i>	44.04 (3.44) <i>bcdefgh</i>	0.046 (0.002) <i>ijkl</i>
Rambai / Tampoi (<i>Baccaurea polyneura</i>)	0.714 (0.007) <i>vw</i>	0.0126 (0.0010) <i>rstuvw</i>	64.10 (6.13) <i>mnopq</i>	0.034 (0.001) <i>cdef</i>
Red Balau (<i>Shorea</i> spp.)	0.685 (0.028) <i>tuv</i>	0.0106 (0.0004) <i>ijklmnopq</i>	69.37 (0.97) <i>pqrst</i>	0.038 (0.003) <i>efghi</i>
Red Meranti (<i>Shorea carapace</i>)	0.631 (0.024) <i>pqr</i>	0.0074 (0.0002) <i>bcd</i>	55.86 (7.83) <i>ijklmno</i>	0.036 (0.002) <i>defgh</i>
Rengas (<i>Gluta</i> spp. / <i>Melanochyla</i> spp.)	0.813 (0.011) <i>yzA</i>	0.0137 (0.0004) <i>uvwxy</i>	-	0.040 (0.003) <i>fghijk</i>
Rubberwood (<i>Hevea brasilliensis</i>)	0.639 (0.014) <i>pqrs</i>	0.0111 (0.0007) <i>mnopqr</i>	46.10 (16.42) <i>bcdefghi</i>	0.090 (0.003) <i>t</i>
Sawih (<i>Duabanga moluccana</i>)	0.307 (0.012) <i>b</i>	0.0067 (0.0001) <i>b</i>	28.51 (1.15) <i>a</i>	0.040 (0.001) <i>fghijk</i>
Segera (<i>Aglaia borneensis</i>)	0.430 (0.002) <i>d</i>	0.0073 (0.0005) <i>bc</i>	36.87 (5.70) <i>ab</i>	0.076 (0.008) <i>s</i>
Seladah (<i>Canarium apertum</i>)	0.535 (0.003) <i>lmn</i>	0.0080 (0.0002) <i>bcdef</i>	49.65 (0.43) <i>defghijkl</i>	0.050 (0.001) <i>lmno</i>

Table 4.2 continued

Wood Samples	Wood density (gcm ⁻³)	Hardness (BHN)	Compressive stress (Nmm ⁻²)	Water Permeability (gcm ⁻³ h ⁻¹)
Selangan batu (<i>Shorea pluriscostata</i>)	0.919 (0.020) <i>E</i>	0.0122 (0.0015) <i>qrstuv</i>	95.27 (4.01) <i>yzA</i>	0.026 (0.002) <i>abc</i>
Selangan batu (<i>Shorea</i> spp.)	-	-	-	-
Selangan batu kuning (<i>Shorea flava</i>)	0.843 (0.003) <i>AB</i>	0.0139 (0.0002) <i>wxyz</i>	103.58 (5.84) <i>AB</i>	0.025 (0.001) <i>ab</i>
Selangan merah (<i>Shorea kunstleri</i>)	0.800 (0.006) <i>yz</i>	0.0105 (0.0007) <i>klmnop</i>	67.78 (1.44) <i>pqrs</i>	0.040 (0.002) <i>ghijk</i>
Sempilor (<i>Dacrydium elatum</i>)	0.441 (0.004) <i>def</i>	0.0091 (0.0004) <i>efghij</i>	44.60 (4.51) <i>bcdefghi</i>	0.035 (0.006) <i>defg</i>
Sentang (<i>Azadirachta excelsa</i>)	0.518 (0.013) <i>klm</i>	0.0090 (0.0019) <i>defghij</i>	42.42 (4.99) <i>bcdefg</i>	0.043 (0.007) <i>ghijkl</i>
Teak (Malaysia) (<i>Tectona grandis</i>)	0.579 (0.061) <i>o</i>	0.0109 (0.0001) <i>klmnopq</i>	-	0.028 (0.002) <i>abcd</i>
Teak (Myanmar) (<i>Tectona grandis</i>)	0.522 (0.038) <i>klmn</i>	0.0094 (0.0003) <i>fghijkl</i>	60.03 (4.74) <i>klmnop</i>	0.034 (0.004) <i>cdef</i>
Tekalong (<i>Artocarpus odoratissimus</i>)	0.427 (0.038) <i>d</i>	0.0084 (0.0003) <i>cdefg</i>	49.25 (8.94) <i>defghijkl</i>	0.056 (0.004) <i>nop</i>
Tembusu (<i>Fagraea fragrans</i>)	0.750 (0.013) <i>wx</i>	0.0133 (0.0007) <i>tuvwx</i>	-	0.031 (0.003) <i>abcde</i>
Teruntum merah (<i>Lumnitzera littorea</i>)	0.673 (0.006) <i>stu</i>	0.0104 (0.0010) <i>ijklmno</i>	53.06 (7.17) <i>fghijklm</i>	0.070 (0.002) <i>rs</i>
Ubah urat (<i>Syzygium sarawakensis</i>)	0.837 (0.011) <i>AB</i>	0.0111 (0.0002) <i>mnopqr</i>	66.91 (12.78) <i>opqr</i>	0.040 (0.003) <i>fghijk</i>
Yellow meranti (<i>Shorea</i> spp.)	0.442 (0.025) <i>def</i>	0.0091 (0.0007) <i>efghij</i>	41.86 (2.21) <i>bcdef</i>	0.043 (0.004) <i>ghijkl</i>

“-” denotes sample not tested due to unavailable resource. (...) = standard deviation, n= 3
 Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD density= 0.036 gcm⁻³; LSD BHN= 0.0016; LSD compressive strength= 11.33 Nmm⁻²;
 LSD water permeability index= 0.008 gcm⁻³h⁻¹

4.2.2 Extractive contents

One-way ANOVA (refer Appendix B Table 5 & 6) shows that there was a significant difference ($P < 0.05$) among cold water extractive contents and cold water extractive pH of tested wood. The ranges of extractive contents extracted using cold water method was 0.8 to 14.6% as shown in Table 4.3. Wood species recorded the highest cold water extractive content was *Dryobalanops beccarii* which was 14.6% followed by *S. pluriscostata* (11%) and *U. borneensis* (10%). As for the wood species that had the lowest cold water extractive content was *Octomeles sumatrana* (0.8%). There were a few other species that recorded rather low extractive contents within the range of 1.1 to 1.9%. As for cold water extractive pH, *S. ovalis* extracted the most acidic extractive with pH of 3.75 while *Aglaia borneensis* extracted extractive that is almost neutral (pH 6.96).

According to one-way ANOVA (refer Appendix B Table 7 & 8), there was a significant difference ($P < 0.05$) among the hot water extractive contents of tested wood. Extractive contents extracted using hot water method had ranged from 2.9 to 18.5% as shown in Table 4.3. Wood species with the highest hot water extractive content was *S. pluricostata* which was 18.5% followed by *U. borneensis* (17.7%) and rengas (17.4%). On the contrary, wood species that had the lowest hot water extractive content was *P. micropedunculatus* (2.9%). The most acidic hot water extractive was extracted from *S. pluricostata* with pH of 3.74. Highest pH of hot water extractive was found slightly acidic. *Tetramerista glabra* yielded the highest pH for its extractive which was pH 6.03.

Based on one-way ANOVA (refer Appendix B Table 9), methanol extractive content was found to be significantly different ($P < 0.05$). In Table 4.3, the ranges of extractive content extracted using methanol were 1.6 to 23.3%. It was found that, the lowest methanol extractive content was extracted from *K. malaccensis* which was only 1.6% while the

highest methanol extractive content was extracted from *U. borneensis* content which was 23.3%.

Table 4.3: Extractive contents of tested wood species

Wood Samples	Cold water		Hot water		Methanol Extractive (%)
	Extractive (%)	pH	Extractive (%)	pH	
Akasia (<i>Acacia mangium</i>)	2.2 (0.1) <i>bcdef</i>	5.05 (1.07) <i>jklmnopq</i>	10.0 (0.1) <i>pqrst</i>	4.26 (0.03) <i>mn</i>	8.5 (0.3) <i>st</i>
Bajan (<i>Kokoona reflexa</i>)	3.7 (0.5) <i>klmn</i>	6.04 (0.32) <i>ABCDEFGH</i>	10.6 (0.3) <i>stu</i>	4.87 (0.15) <i>stu</i>	6.6 (0.5) <i>op</i>
Bedaru (<i>Cantleya corniculata</i>)	4.6 (0.3) <i>opqrst</i>	5.08 (0.08) <i>klmnopq</i>	11.4 (0.2) <i>vw</i>	4.54 (0) <i>pqr</i>	9.1 (0.1) <i>tu</i>
Belian (<i>Eusideroxylon zwageri</i>)	4.5 (0.4) <i>opqrs</i>	4.18 (0.16) <i>abcd</i>	11.4 (0.2) <i>vw</i>	3.99 (0.07) <i>def</i>	13.4 (0.4) <i>yz</i>
Bengang (<i>Nesia borneensis</i>)	2.7 (0.4) <i>defghi</i>	6.07 (0.16) <i>CDEFGHI</i>	3.4 (0.4) <i>ab</i>	5.39 (0.02) <i>AB</i>	2.4 (0.2) <i>bcd</i>
Benuah (<i>Macaranga pearsonii</i>)	2.1 (0.3) <i>bcde</i>	6.61 (0.02) <i>JKLMN</i>	6.1 (0.4) <i>fg</i>	4.94 (0.03) <i>tuv</i>	2.7 (0.3) <i>cde</i>
Bindang (<i>Agathis borneensis</i>)	3.9 (0.2) <i>lmno</i>	5.04 (0.02) <i>ijklmnopq</i>	8.5 (0.3) <i>mn</i>	4.18 (0.05) <i>ijklm</i>	4.7 (0.3) <i>l</i>
Bintangor (<i>Calophyllum incrassatum</i>)	1.1 (0) <i>a</i>	5.19 (0.19) <i>mnopqrs</i>	4.5 (0.3) <i>cd</i>	4.60 (0.02) <i>qr</i>	3.4 (0.3) <i>fgh</i>
Bintawak (<i>Artocarpus anisophyllus</i>)	1.5 (0.6) <i>ab</i>	6.69 (0.04) <i>JKLMN</i>	7.6 (0.3) <i>jkl</i>	4.87 (0.02) <i>stu</i>	6.6 (0.2) <i>op</i>
Binuang (<i>Octomeles sumatrana</i>)	0.8 (0.5) <i>a</i>	5.66 (0.43) <i>tuvwxyzABC</i>	5.6 (0.6) <i>ef</i>	4.08 (0.03) <i>efghij</i>	3.4 (0.2) <i>fgh</i>
Casuarina (<i>Casuarina equisetifolia</i>)	4.7 (0.7) <i>pqrst</i>	6.58 (0.13) <i>JKLMN</i>	3.9 (0.6) <i>bc</i>	5.52 (0.02) <i>BC</i>	3.6 (0.1) <i>ghi</i>
Chengal (<i>Neobalanocarpus heimii</i>)	7.0 (0.5) <i>CDEF</i>	4.61 (0.06) <i>defghij</i>	16.9 (0.2) <i>AB</i>	4.21 (0.01) <i>jklm</i>	13.6 (0.4) <i>zA</i>

Table 4.3 continued

Wood Samples	Cold water		Hot water		Methanol
	Extractive (%)	pH	Extractive (%)	pH	Extractive (%)
Chengal pasir (<i>Hopea beccariana</i>)	6.0 (0.5) <i>yzAB</i>	4.05 (0.17) <i>abc</i>	16.2 (0) <i>zA</i>	3.89 (0.03) <i>bcd</i>	15.5 (0.4) <i>D</i>
Douglas fir (<i>Pseudotsuga menziesii</i>)	2.0 (0.2) <i>bcd</i>	5.64 (0.05) <i>stuvwxyzABC</i>	9.7 (0.2) <i>opq</i>	4.42 (0.08) <i>op</i>	2.0 (0.2) <i>ab</i>
Engkabang jantung (<i>Shorea macrophylla</i>)	2.1 (0.1) <i>bcde</i>	5.29 (0.01) <i>nopqrstuv</i>	10.5 (0.3) <i>rstu</i>	4.54 (0.01) <i>pqr</i>	3.3 (0.4) <i>efg</i>
Entuyut (<i>Tetramerista glabra</i>)	3.9 (0.6) <i>lmno</i>	7.02 (0.02) <i>N</i>	10.0 (0.6) <i>pqrst</i>	6.03 (0.02) <i>E</i>	4.7 (0.6) <i>l</i>
Jelawei mempelam babi (<i>Terminalia phellocarpa</i>)	5.5 (1.0) <i>vwxy</i>	5.93 (0.18) <i>yzABCDEFGF</i>	6.5 (0.3) <i>ghi</i>	4.59 (0.02) <i>qr</i>	2.1 (0.3) <i>abc</i>
Jelutong paya (<i>Dyera polyphylla</i>)	5.3 (0.3) <i>tuvwxyz</i>	4.77 (0.21) <i>fghijklm</i>	13.7 (0.7) <i>y</i>	4.20 (0.03) <i>ijklm</i>	7.9 (0.2) <i>rs</i>
Kapur (<i>Dryobalanops</i> spp.)	5.5 (0.1) <i>vwxy</i>	4.02 (0.05) <i>abc</i>	11.8 (0.2) <i>wx</i>	3.89 (0.01) <i>bcd</i>	8.7 (0.3) <i>t</i>
Kapur bukit (<i>Dryobalanops beccarii</i>)	14.6 (0.4) <i>I</i>	3.91 (0.06) <i>ab</i>	16.2 (0.5) <i>zA</i>	3.78 (0.01) <i>ab</i>	14.1 (0.7) <i>ABC</i>
Kapur kelansau (<i>Dryobalanops oblongifolia</i>)	-	-	-	-	-
Kayu cina (<i>Podocarpus micropedunculatus</i>)	1.1 (0) <i>a</i>	6.38 (0.14) <i>FGHIJKL</i>	2.9 (0.4) <i>a</i>	5.48 (0.01) <i>BC</i>	4.0 (0.2) <i>hijk</i>
Kelat (<i>Syzygium</i> spp.)	5.3 (0.5) <i>tuvwxyz</i>	5.57 (0.36) <i>rstuvwxyz</i>	10.4 (0.4) <i>qrstu</i>	5.20 (0.02) <i>xyz</i>	7.8 (0.6) <i>r</i>
Kelempayan (<i>Neolamarckia cadamba</i>)	6.0 (0.3) <i>yzAB</i>	5.78 (0.05) <i>wxyzABCD</i>	12.3 (0.6) <i>x</i>	4.45 (0.02) <i>op</i>	3.5 (0.3) <i>fgh</i>

Table 4.3 continued

Wood Samples	Cold water		Hot water		Methanol
	Extractive (%)	pH	Extractive (%)	pH	Extractive (%)
Kempas (<i>Koompassia malaccensis</i>)	1.5 (0.6) <i>ab</i>	4.44 (0.63) <i>cdefgh</i>	5.6 (0.7) <i>ef</i>	3.83 (0.25) <i>abc</i>	1.6 (0.2) <i>a</i>
KerANJI (<i>Dialium</i> spp.)	3.5 (0.2) <i>jklm</i>	4.38 (0.05) <i>cdefg</i>	8.7 (0.3) <i>mn</i>	3.80 (0.05) <i>ab</i>	6.0 (0.2) <i>mn</i>
Keruing (<i>Dipterocarpus</i> spp.)	3.7 (0.6) <i>klmn</i>	4.58 (0.05) <i>defghi</i>	11.8 (0.2) <i>wx</i>	3.95 (0.04) <i>cde</i>	5.9 (0.3) <i>mn</i>
Kulim (<i>Scorodocarpus borneensis</i>)	3.3 (0.1) <i>hijklm</i>	4.17 (0.12) <i>abcd</i>	4.5 (0.4) <i>cd</i>	4.23 (0.01) <i>klm</i>	14.4 (0.4) <i>C</i>
Kumpang (<i>Myristica maxima</i>)	5.6 (0.5) <i>wxyz</i>	6.00 (0.05) <i>zABCDEFG</i>	10.2 (0.7) <i>pqrstu</i>	5.12 (0.10) <i>wx</i>	4.7 (0.3) <i>l</i>
Kumus (<i>Shorea laevis</i>)	7.1 (0.4) <i>DEF</i>	5.13 (0.21) <i>lmnopqr</i>	16.2 (0.4) <i>zA</i>	4.80 (0.04) <i>s</i>	8.0 (0.3) <i>rs</i>
Leban (<i>Vitex pubescens</i>)	4.4 (0.1) <i>nopqr</i>	6.49 (0.10) <i>HIJKL</i>	7.3 (0.3) <i>jk</i>	5.31 (0.03) <i>zA</i>	7.5 (0.2) <i>qr</i>
Legai (<i>Adinandra borneensis</i>)	2.9 (0.6) <i>fghij</i>	6.18 (0.06) <i>DEFGHIJ</i>	4.5 (0.2) <i>cd</i>	4.79 (0.06) <i>s</i>	7.0 (0.7) <i>pq</i>
Lun siput daun besar (<i>Shorea iliasii</i>)	5.7 (0.7) <i>wxyzA</i>	5.39 (0.04) <i>opqrstuvw</i>	8.7 (0.4) <i>mn</i>	5.01 (0.02) <i>vw</i>	11.8 (0.4) <i>w</i>
Mata ulat (<i>Kokoona</i> spp.)	1.1 (0) <i>a</i>	6.41 (0.04) <i>GHIJKL</i>	5.0 (0.1) <i>de</i>	5.60 (0.02) <i>C</i>	6.5 (0.4) <i>nop</i>
Medang luis kasar (<i>Alseodaphne insignis</i>)	2.2 (0) <i>bcdef</i>	4.70 (0.47) <i>efghijkl</i>	6.5 (0.1) <i>ghi</i>	4.01 (0.06) <i>defg</i>	6.9 (0.4) <i>pq</i>
Mempening (<i>Lithocarpus</i> spp.)	7.3 (0.4) <i>EF</i>	4.88 (0.78) <i>hijklmn</i>	10.4 (0.2) <i>qrstu</i>	4.03 (0.03) <i>efgh</i>	6.1 (0.5) <i>mno</i>

Table 4.3 continued

Wood Samples	Cold water		Hot water		Methanol
	Extractive (%)	pH	Extractive (%)	pH	Extractive (%)
Mengkulang (<i>Heritiera aurea</i>)	2.6 (0.6) cdefg	5.77 (0.04) wxyzABCD	9.5 (0.4) op	4.38 (0) no	4.3 (0.2) jkl
Meranti buaya (<i>Shorea uliginosa</i>)	2.2 (0) bcdef	4.82 (0.05) ghijklm	5.9 (0.1) fg	4.14 (0.01) ghijklm	7.7 (0.2) r
Meranti luang (<i>Shorea ovalis</i>)	4.8 (0.6) qrstuv	3.75 (0.09) a	6.3 (0.2) fgh	3.76 (0.02) ab	4.8 (0.1) l
Mergasing (<i>Mesua macrantha</i>)	4.8 (0.5) qrstuv	6.04 (0.04) ABCDEFGH	5.8 (0.3) fg	4.59 (0.04) qr	3.7 (0.4) ghij
Mersawa kunyit (<i>Anisoptera grossivenia</i>)	3.4 (0.1) ijklm	5.60 (0.14) stuvwxyzAB	8.1 (0.1) lm	4.97 (0.04) uv	5.7 (0.2) m
Nyatoh (<i>Palaquium</i> spp.)	5.4 (0.1) vwxy	5.46 (0.03) qrstuvw	9.1 (0.5) no	4.41 (0.01) op	6.6 (0.2) op
Oil palm (non-wood) (<i>Elaeis guineensis</i>)	5.3 (0.1) tuvwxyz	6.31 (0.02) EFGHIJK	9.8 (0.8) opqr	4.42 (0.04) op	4.3 (0.3) jkl
Pajang / Asam (<i>Mangifera pajang</i>)	4.7 (0.6) pqrstu	6.84 (0.22) LMN	10.2 (0.6) pqrstu	5.28 (0.16) zA	4.4 (0.2) kl
Pelong / Plajau (<i>Pentaspadon motleyi</i>)	7.7 (0.2) F	4.40 (0.10) cdefg	16.0 (0.7) z	4.03 (0.05) efgh	14.4 (0.3) C
Penyau (<i>Upuna borneensis</i>)	10.0 (0.7) G	4.36 (0.01) bcdefg	17.7 (0.4) C	4.12 (0.03) fghijkl	23.3 (0.4) E
Pulai (<i>Alstonia</i> spp.)	4.0 (0.4) mnop	5.74 (0.80) vwxyzABCD	5.6 (0.9) ef	5.13 (0.01) wxy	3.7 (0.2) ghij
Radiata pine (<i>Pinus radiata</i>)	3.9 (0.5) lmno	4.95 (0.04) ijklmno	11.6 (0.2) wx	4.21 (0.03) jklm	4.2 (0.3) ijkl

Table 4.3 continued

Wood Samples	Cold water		Hot water		Methanol
	Extractive (%)	pH	Extractive (%)	pH	Extractive (%)
Rambai / Tampoi (<i>Baccaurea polyneura</i>)	2.1 (0.1) <i>bcde</i>	5.44 (0.10) <i>pqrstuvw</i>	6.0 (0.4) <i>fg</i>	4.37 (0.02) <i>no</i>	3.3 (0.3) <i>efg</i>
Red Balau (<i>Shorea</i> spp.)	1.9 (0.4) <i>bc</i>	5.68 (0.61) <i>uvwxyzABC</i>	4.2 (0.3) <i>c</i>	4.63 (0.02) <i>r</i>	3.1 (0.6) <i>efg</i>
Red Meranti (<i>Shorea carapace</i>)	4.3 (0.3) <i>nopq</i>	4.99 (0.24) <i>ijklmnop</i>	9.5 (0.3) <i>op</i>	4.00 (0.02) <i>def</i>	4.8 (0.1) <i>l</i>
Rengas (<i>Gluta</i> spp. / <i>Melanochyla</i> spp.)	4.3 (0.1) <i>nopq</i>	3.99 (0.17) <i>abc</i>	17.4 (0.5) <i>BC</i>	4.07 (0.04) <i>efghi</i>	12.9 (0.6) <i>xy</i>
Rubberwood (<i>Hevea brasiliensis</i>)	5.1 (0.6) <i>rstuvw</i>	6.53 (0.15) <i>IJKLM</i>	15.5 (0.2) <i>z</i>	5.82 (0.02) <i>D</i>	3.6 (0.3) <i>ghi</i>
Sawih (<i>Duabanga moluccana</i>)	6.3 (0.1) <i>zABC</i>	5.64 (0.14) <i>stuvwxyzABC</i>	10.7 (0.3) <i>yuv</i>	4.16 (0.01) <i>hijklm</i>	9.8 (0.3) <i>v</i>
Segera (<i>Aglaia borneensis</i>)	2.3 (0.2) <i>cdef</i>	6.96 (0.25) <i>MN</i>	7.1 (0.2) <i>ijk</i>	5.26 (0.01) <i>yzA</i>	2.9 (0.2) <i>def</i>
Seladah (<i>Canarium apertum</i>)	6.4 (0.3) <i>ABCD</i>	6.06 (0.48) <i>BCDEFGH</i>	7.6 (0.5) <i>jkl</i>	5.12 (0.01) <i>wx</i>	4.7 (0.4) <i>l</i>
Selangan batu (<i>Shorea pluriscostata</i>)	11.0 (0.1) <i>H</i>	5.04 (0.61) <i>ijklmnopq</i>	18.5 (0.4) <i>D</i>	3.74 (0.03) <i>a</i>	14.3 (0.4) <i>BC</i>
Selangan batu (<i>Shorea</i> spp.)	-	-	-	-	-
Selangan batu kuning (<i>Shorea flava</i>)	3.2 (0.1) <i>hijkl</i>	5.91 (0.08) <i>xyzABCDE</i>	10.8 (0.6) <i>uv</i>	4.61 (0.02) <i>qr</i>	13.7 (0.3) <i>zAB</i>
Selangan merah (<i>Shorea kunstleri</i>)	2.8 (0.6) <i>efghij</i>	4.33 (0.09) <i>bcdef</i>	6.9 (0.3) <i>hij</i>	4.25 (0.31) <i>lmn</i>	4.5 (0.2) <i>kl</i>

Table 4.3 continued

Wood Samples	Cold water		Hot water		Methanol
	Extractive (%)	pH	Extractive (%)	pH	Extractive (%)
Sempilor (<i>Dacrydium elatum</i>)	5.9 (0.3) <i>xyzA</i>	5.59 (0.30) <i>rstuvwxyZA</i>	10.1 (0.3) <i>pqrstu</i>	4.81 (0.03) <i>st</i>	9.4 (0.3) <i>uv</i>
Sentang (<i>Azadirachta excelsa</i>)	5.2 (0.2) <i>stuvw</i>	4.66 (0.42) <i>efghijk</i>	10.7 (0.5) <i>tuv</i>	4.27 (0.18) <i>mn</i>	4.0 (0.2) <i>hijk</i>
Teak (Malaysia) (<i>Tectona grandis</i>)	3.1 (0.3) <i>ghijk</i>	6.60 (0.02) <i>JKLMN</i>	7.7 (0.7) <i>kl</i>	4.92 (0.16) <i>stuv</i>	4.8 (0.6) <i>l</i>
Teak (Myanmar) (<i>Tectona grandis</i>)	3.2 (0.2) <i>hijkl</i>	5.50 (0.03) <i>qrstuvwxy</i>	7.4 (0.2) <i>jkl</i>	4.92 (0.02) <i>stuv</i>	14.0 (0.3) <i>zABC</i>
Tekalong (<i>Artocarpus odoratissimus</i>)	1.5 (0.6) <i>ab</i>	6.70 (0.27) <i>KLMN</i>	6.3 (0.4) <i>fgh</i>	5.30 (0.16) <i>zA</i>	7.5 (0.1) <i>qr</i>
Tembusu (<i>Fagraea fragrans</i>)	2.4 (0.2) <i>cdefg</i>	4.24 (0.22) <i>bcde</i>	10.4 (0.5) <i>qrstu</i>	4.10 (0.24) <i>fghijk</i>	7.7 (0.3) <i>r</i>
Teruntum merah (<i>Lumnitzera littorea</i>)	6.7 (0.2) <i>BCDE</i>	5.20 (0.27) <i>mnopqrst</i>	9.6 (0.6) <i>opq</i>	4.48 (0.01) <i>opq</i>	7.4 (0.2) <i>qr</i>
Ubah urat (<i>Syzygium sarawakensis</i>)	5.7 (0.6) <i>wxyzA</i>	5.23 (0.17) <i>mnopqrstu</i>	9.9 (0.5) <i>pqrs</i>	4.21 (0.02) <i>jklm</i>	8.7 (0.3) <i>t</i>
Yellow meranti (<i>Shorea spp.</i>)	5.7 (0.5) <i>wxyzA</i>	5.43 (0.07) <i>pqrstuvw</i>	11.9 (0.3) <i>wx</i>	4.82 (0.19) <i>st</i>	12.6 (0.9) <i>x</i>

“–” denotes sample not tested due to unavailable resource. (...) = standard deviation, n= 3

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD cold water extractives = 0.7%; LSD pH (cold) = 0.46

LSD hot water extractives = 0.7%; LSD pH (hot) = 0.13

LSD methanol extractives = 0.6%

4.2.3 Natural termite resistance

One-way ANOVA (refer Appendix B Table 10 to 12) shows that percentage mass loss, absolute and termite rating differed significantly among tested wood species. Based on Table 4.4, nine wood species out of 69 tested species completely destroyed (100% mass loss). These species were *M. pearsonii*, *D. polyphylla*, *N. cadamba*, *Adinandra borneensis*, *Shorea uliginosa*, *M. pajang*, *E. guineensis* and two exotic species (*P. menziesii* and *Pinus radiata*). *E. zwageri* was found to be the most durable wood among all the tested wood species. It only sustained 0.7% mass loss. The lowest mean absolute mass loss was recorded in *P. micropedunculatus* (40 mg) while the highest mean absolute mass loss was *E. guineensis* (5570 mg) which was completely consumed by termites at the end of the experiment as shown in Table 4.4. A total of 11 out of 69 tested species were regarded as highly susceptible and visually rated 0 which were *M. pearsonii*, *P. menziesii*, *D. polyphylla*, *N. cadamba*, *A. borneensis*, *S. uliginosa*, *E. guineensis*, *M. pajang*, *P. radiata*, *H. brasiliensis* and *Aglaia borneensis*. *Terminalia phellocarpa*, *Baccaurea polyneura*, *Agathis borneensis* and *D. moluccana* also considered susceptible to termite due to their rather low termite rating (2 – 4.5). There were 25 out of 69 tested species were found to be moderately resistant to termite and these species were rated 6.5 to 8.9. They were *Kokoona reflexa*, *C. corniculata*, *Neesia borneensis*, *Calophyllum incrassatum*, *O. sumatrana*, *Casuarina equisetifolia*, *S. macrophylla*, *T. glabra*, *K. malaccensis*, *Myristica maxima*, *Kokoona* spp., *Alseodaphne insignis*, *Lithocarpus* spp., *Heritiera aurea*, *S. ovalis*, *Pentaspadon motleyi*, *Alstonia* spp., *Shorea carapace*, rengas, *C. apertum*, *D. elatum*, *Azadirachta excelsa*, *Artocarpus odoratissimus*, *F. fragrans* and *Shorea* spp.. There were 17 wood species considered resistant to termites (rating: 9 – 9.4) which were *Acacia mangium*, *Neobalanocarpus heimii*, *Dryobalanops* spp., *Dryobalanops oblongifolia*,

Syzygium spp., *Dipterocarpus* spp., *V. pubescens*, *Shorea iliasii*, *Mesua macrantha*, *A. grossivenia*, *Palaquium* spp., *Shorea* spp., *S. flava*, *S. kunstleri*, *T. grandis* (Malaysian grown), *Lumnitzera littorea* and *S. sarawakensis*. The remaining tested species (12 out of 69) species like *E. zwageri*, *Artocarpus anisophyllus*, *Hopea beccariana*, *D. beccarii*, *P. micropedunculatus*, *Dialium* spp., *Scorodocarpus borneensis*, *S. laevis*, *U. borneensis*, *S. pluricostata*, *Shorea* spp. and *T. grandis* (Burma grown) were regarded as highly resistant to termite with rating (≥ 9.5). All of the natural termite resistance results were listed in Table 4.4.

Table 4.4: Mean percentage mass loss, absolute mass loss and termite rating of tested wood species

Wood species	Percentage mass loss (%)	Absolute mass loss (mg)	Termite visual rating
Akasia (<i>Acacia mangium</i>)	8.0 (2.1) <i>abcdefghijkl</i>	397 (104) <i>abcdefg</i>	9.0 (0.7) <i>jklmnop</i>
Bajan (<i>Kokoona reflexa</i>)	14.0 (1.9) <i>jklm</i>	845 (120) <i>ij</i>	7.5 (0.6) <i>defgh</i>
Bedaru (<i>Cantleya corniculata</i>)	10.7 (1.0) <i>hijkl</i>	636 (58) <i>efghij</i>	7.0 (0) <i>def</i>
Belian (<i>Eusideroxylon zwageri</i>)	0.7 (0.1) <i>a</i>	52 (7) <i>ab</i>	10 (0) <i>p</i>
Bengang (<i>Neesia borneensis</i>)	8.6 (2.0) <i>bcdefghijkl</i>	298 (74) <i>abcdef</i>	7.8 (0.5) <i>efghi</i>
Benuah (<i>Macaranga pearsonii</i>)	100 (0) <i>s</i>	2075 (7) <i>o</i>	0 (0) <i>a</i>
Bindang (<i>Agathis borneensis</i>)	41.6 (22.5) <i>p</i>	1562 (886) <i>mn</i>	4.3 (3.1) <i>c</i>
Bintangor (<i>Calophyllum incrassatum</i>)	23.8 (1.2) <i>n</i>	759 (38) <i>ghij</i>	7.0 (0) <i>def</i>
Bintawak (<i>Artocarpus anisophyllus</i>)	2.4 (0.2) <i>abcdef</i>	107 (11) <i>abc</i>	9.5 (0) <i>mnop</i>
Binuang (<i>Octomeles sumatrana</i>)	15.2 (1.8) <i>lm</i>	745 (83) <i>ghij</i>	8.5 (0.6) <i>hijklm</i>
Casuarina (<i>Casuarina equisetifolia</i>)	6.1 (1.4) <i>abcdefghi</i>	460 (90) <i>cdefghi</i>	8.0 (0) <i>fghij</i>
Chengal (<i>Neobalanocarpus heimii</i>)	2.7 (0.4) <i>abcdef</i>	149 (22) <i>abc</i>	9.3 (0.3) <i>klmnop</i>
Chengal pasir (<i>Hopea beccariana</i>)	5.5 (0.7) <i>abcdefgh</i>	222 (29) <i>abcd</i>	9.5 (0) <i>mnop</i>

Table 4.4 continued

Wood species	Percentage mass loss (%)	Absolute mass loss (mg)	Termite visual rating
Douglas fir	100 (0)	4542 (158)	0 (0)
(<i>Pseudotsuga menziesii</i>)	s	s	a
Engkabang jantung	5.2 (2.1)	169 (67)	8.3 (0.5)
(<i>Shorea macrophylla</i>)	abcdefgh	abc	ghijk
Entuyut	20.3 (7.0)	872 (307)	6.8 (1.0)
(<i>Tetramerista glabra</i>)	mn	jk	de
Jelawei mempelam babi	81.6 (9.2)	2774 (370)	2.0 (2.3)
(<i>Terminalia phellocarpa</i>)	r	pq	b
Jelutong paya	100 (0)	2709 (41)	0 (0)
(<i>Dyera polyphylla</i>)	s	pq	a
Kapur	8.9 (6.4)	410 (297)	9.1 (0.8)
(<i>Dryobalanops</i> spp.)	cdefghijkl	abcdefg	klmnop
Kapur bukit	5.0 (0.8)	249 (39)	9.5 (0)
(<i>Dryobalanops beccarii</i>)	abcdefgh	abcde	mnop
Kapur kelansau	6.2 (0.5)	267 (16)	9.0 (0)
(<i>Dryobalanops oblongifolia</i>)	abcdefghi	abcde	jklmnop
Kayu cina	1.3 (0.2)	40 (5)	9.5 (0)
(<i>Podocarpus micropedunculatus</i>)	abc	a	mnop
Kelat	4.9 (0.4)	296 (26)	9.1 (0.3)
(<i>Syzygium</i> spp.)	abcdefgh	abcdef	klmnop
Kelempayan	100 (0)	2951 (94)	0 (0)
(<i>Neolamarckia cadamba</i>)	s	q	a
Kempas	32.3 (11.1)	1839 (616)	6.5 (0.6)
(<i>Koompassia malaccensis</i>)	o	no	d
KerANJI	1.0 (0.5)	85 (42)	9.9 (0.3)
(<i>Dialium</i> spp.)	ab	abc	op
Keruing	5.2 (0.5)	290 (30)	9.3 (0.3)
(<i>Dipterocarpus</i> spp.)	abcdefgh	abcdef	klmnop
Kulim	2.5 (0.2)	139 (13)	9.5 (0)
(<i>Scorodocarpus borneensis</i>)	abcdef	abc	mnop
Kumpang	23.0 (4.4)	817 (157)	7.5 (0.6)
(<i>Myristica maxima</i>)	n	hij	defgh
Kumus	3.6 (0.2)	216 (14)	9.5 (0)
(<i>Shorea laevis</i>)	abcdefgh	abc	mnop
Leban	4.7 (0.5)	225 (29)	9.3 (0.3)
(<i>Vitex pubescens</i>)	abcdefgh	abcd	klmnop
Legai	100 (0)	3957 (8)	0 (0)
(<i>Adinandra borneensis</i>)	s	r	a
Lun siput daun besar	6.9 (0.6)	228 (21)	9.0 (0)
(<i>Shorea iliasii</i>)	abcdefghij	abcd	jklmnop
Mata ulat	14.2 (9.9)	960 (584)	7.3 (1.0)
(<i>Kokoona</i> spp.)	jklm	jkl	defg
Medang luis kasar	7.6 (3.9)	273 (145)	7.8 (0.5)
(<i>Alseodaphne insignis</i>)	abcdefghijk	abcdef	efghi

Table 4.4 continued

Wood species	Percentage mass loss (%)	Absolute mass loss (mg)	Termite visual rating
Mempening (<i>Lithocarpus</i> spp.)	23.3 (7.2) <i>n</i>	1301 (325) <i>lm</i>	6.8 (0.3) <i>de</i>
Mengkulang (<i>Heritiera aurea</i>)	2.8 (0.4) <i>abcdef</i>	133 (18) <i>abc</i>	8.9 (0.6) <i>jklmno</i>
Meranti buaya (<i>Shorea uliginosa</i>)	100 (0) <i>s</i>	3953 (7) <i>r</i>	0 (0) <i>a</i>
Meranti luang (<i>Shorea ovalis</i>)	9.7 (3.3) <i>fghijkl</i>	251 (86) <i>abcde</i>	7.5 (0.6) <i>defgh</i>
Mergasing (<i>Mesua macrantha</i>)	9.2 (1.1) <i>defghijkl</i>	443 (54) <i>bcdefgh</i>	9.4 (0.3) <i>lmnop</i>
Mersawa kunyit (<i>Anisoptera grossivenia</i>)	5.7 (0.9) <i>abcdefgh</i>	296 (47) <i>abcdef</i>	9.1 (0.3) <i>klmnop</i>
Nyatoh (<i>Palaquium</i> spp.)	6.7 (1.6) <i>abcdefghij</i>	277 (49) <i>abcdef</i>	9.1 (0.3) <i>klmnop</i>
Oil palm stem (non-wood) (<i>Elaeis guineensis</i>)	100 (0) <i>s</i>	5570 (347) <i>t</i>	0 (0) <i>a</i>
Pajang / Asam (<i>Mangifera pajang</i>)	100 (0) <i>s</i>	4636 (133) <i>s</i>	0 (0) <i>a</i>
Pelong / Plajau (<i>Pentaspadon motleyi</i>)	13.7 (7.0) <i>ijklm</i>	611 (321) <i>defghij</i>	7.5 (0.6) <i>defgh</i>
Penyau (<i>Upuna borneensis</i>)	2.3 (0.7) <i>abcdef</i>	127 (36) <i>abc</i>	9.6 (0.3) <i>nop</i>
Pulai (<i>Alstonia</i> spp.)	9.5 (2.0) <i>efghijkl</i>	223 (62) <i>abcd</i>	8.0 (0.8) <i>fghij</i>
Radiata pine (<i>Pinus radiata</i>)	100 (0) <i>s</i>	4078 (351) <i>r</i>	0 (0) <i>a</i>
Rambai / Tampoi (<i>Baccaurea polyneura</i>)	57.8 (7.9) <i>q</i>	2903 (402) <i>pq</i>	3.0 (2.0) <i>b</i>
Red Balau (<i>Shorea</i> spp.)	1.9 (0.2) <i>abcde</i>	110 (13) <i>abc</i>	9.4 (0.3) <i>lmnop</i>
Red Meranti (<i>Shorea carapace</i>)	23.9 (25.4) <i>n</i>	1244 (1372) <i>klm</i>	6.8 (1.9) <i>de</i>
Rengas (<i>Gluta</i> spp. or <i>Melanochyla</i> spp.)	5.5 (0.5) <i>abcdefgh</i>	333 (34) <i>abcdef</i>	8.8 (0.5) <i>ijklmn</i>
Rubberwood (<i>Hevea brasiliensis</i>)	95.1 (9.8) <i>s</i>	3958 (878) <i>r</i>	0 (0) <i>a</i>
Sawih (<i>Duabanga moluccana</i>)	57.2 (4.4) <i>q</i>	1324 (94) <i>lm</i>	4.5 (1.0) <i>c</i>
Segera (<i>Aglaia borneensis</i>)	85.8 (2.9) <i>r</i>	2548 (63) <i>p</i>	0 (0) <i>a</i>
Seladah (<i>Canarium apertum</i>)	18.8 (4.5) <i>mn</i>	747 (174) <i>ghij</i>	7.3 (0.5) <i>defg</i>
Selangan batu (<i>Shorea pluriscostata</i>)	1.6 (0.2) <i>abcd</i>	105 (9) <i>abc</i>	9.5 (0) <i>mnop</i>

Table 4.4 continued

Wood species	Percentage mass loss (%)	Absolute mass loss (mg)	Termite visual rating
Selangan batu (<i>Shorea</i> spp.)	1.1 (0.3) <i>ab</i>	67 (19) <i>ab</i>	9.5 (0) <i>mnop</i>
Selangan batu kuning (<i>Shorea flava</i>)	2.6 (0.2) <i>abcdef</i>	158 (10) <i>abc</i>	9.1 (0.3) <i>klmnop</i>
Selangan merah (<i>Shorea kunstleri</i>)	2.2 (0.1) <i>abcdef</i>	127 (8) <i>abc</i>	9.4 (0.3) <i>lmnop</i>
Sempilor (<i>Dacrydium elatum</i>)	2.7 (0.4) <i>abcdef</i>	85 (14) <i>abc</i>	8.9 (0.6) <i>jklmno</i>
Sentang (<i>Azadirachta excelsa</i>)	14.6 (4.5) <i>klm</i>	659 (197) <i>fghij</i>	7.3 (0.5) <i>defg</i>
Teak (Malaysia) (<i>Tectona grandis</i>)	2.7 (0.6) <i>abcdef</i>	150 (24) <i>abc</i>	9.1 (0.8) <i>klmnop</i>
Teak (Myanmar) (<i>Tectona grandis</i>)	2.9 (0.3) <i>abcdefg</i>	129 (12) <i>abc</i>	9.5 (0) <i>mnop</i>
Tekalong (<i>Artocarpus odoratissimus</i>)	14.3 (9.2) <i>jklm</i>	452 (290) <i>bcdefgh</i>	8.4 (1.1) <i>hijkl</i>
Tembusu (<i>Fagraea fragrans</i>)	6.1 (0.9) <i>abcdefghi</i>	354 (57) <i>abcdef</i>	8.9 (0.6) <i>jklmno</i>
Teruntum merah (<i>Lumnitzera littorea</i>)	7.1 (0.6) <i>abcdefghijk</i>	325 (32) <i>abcdef</i>	9.4 (0.3) <i>lmnop</i>
Ubah urat (<i>Syzygium sarawakensis</i>)	4.7 (0.6) <i>abcdefgh</i>	271 (37) <i>abcdef</i>	9.3 (0.3) <i>klmnop</i>
Yellow meranti (<i>Shorea</i> spp.)	10.5 (1.5) <i>ghijkl</i>	330 (47) <i>abcdef</i>	8.5 (0.6) <i>hijklm</i>

“-” denotes sample not tested due to unavailable resource, (...) = standard deviation, n= 4
 Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 7.6%

LSD absolute mass loss = 390 mg

LSD termite rating = 1.0

4.3 Experiment 2: Natural termite resistance of *Dipterocarpus* spp. and *Acacia mangium*

In experiment 1, natural termite resistance of *Dipterocarpus* spp. was found to be resistant to termites with mass loss of 5.2% and termite rating of 9.3 as shown in Table 4.4. *Acacia mangium*, on the other hand, was known to be attacked by termite however in experiment 1, it was found to be resistant to termite (mass loss: 8.0, rating: 9). The trade name keruing may comprise of different species since *Dipterocarpus* spp. is not a monospecies, it can be rather misleading to conclude that keruing is considerably resistance to termite. Thus another series of termite test with different species of *Dipterocarpus* including *Acacia mangium* was tested to confirm that these two species have variability in terms of resistance towards termite.

One-way ANOVA (refer Appendix B Table 13 to 15) shows that there was a significant difference ($P < 0.05$) in percentage mass loss, absolute mass loss and termite rating among keruing and *Acacia mangium*. Based on Table 4.5, it was found that *Acacia mangium* was moderate to resistant to termite with a rating of 9 and 7.8 respectively. It was found out that *D. eurynchus* and *D. rigidus* was very susceptible to termite attack which was completely eaten (mass loss: 100%). *D. kerrii*, *D. pachyphyllus* and *Dipterocarpus* spp. sustained rather severe attack (rating: 2.8 – 5.3) while both Keruing braceply and plywood sustained rather heavy attack with termite rating of 1.8 and 4.5 respectively even though it was expected that the glue would provide certain degree of termite resistance. On the other hand, among all the tested keruing, *D. confertus* was considered resistant to termites (mass loss: 6.3%, rating: 9), followed by *D. crinitus* which was moderately resistant (mass loss: 20.4%, rating: 8.2). This study confirmed that *Dipterocarpus* spp. of different species poses different degree of natural termite resistance and as for keruing with low termite

resistance there is a need of treating such keruing hardwood and plywood using wood protective chemical especially when the wood is to be used in high termite hazard location.

Table 4.5: Mean percentage mass loss, absolute mass loss and termite rating of *Dipterocarpus* spp. and *Acacia mangium*

Species	Mass loss		Termite rating
	Percentage (%)	Absolute (mg)	
Acacia (A)	6.2 (3.4)	695 (375)	9.0 (0.5)
(<i>Acacia mangium</i>)	<i>a</i>	<i>a</i>	<i>e</i>
Acacia (ASP)	17.3 (10.9)	1775 (1099)	7.8 (1.2)
(<i>Acacia mangium</i>)	<i>a</i>	<i>a</i>	<i>de</i>
Keruing Baran	100 (0)	9537 (467)	0 (0)
(<i>Dipterocarpus eurynchus</i>)	<i>d</i>	<i>de</i>	<i>a</i>
Keruing braceply	53.4 (20.5)	2252 (859)	1.8 (3.0)
(<i>Dipterocarpus</i> spp.)	<i>bc</i>	<i>a</i>	<i>ab</i>
Keruing Gondol	73.5 (36.8)	6811 (3320)	2.8 (3.3)
(<i>Dipterocarpus kerrii</i>)	<i>c</i>	<i>cd</i>	<i>bc</i>
Keruing Kobis	6.3 (3.9)	676 (472)	9.0 (0.5)
(<i>Dipterocarpus confertus</i>)	<i>a</i>	<i>a</i>	<i>e</i>
Keruing Mempelas	20.4 (30.3)	3161 (4826)	8.2 (2.1)
(<i>Dipterocarpus crinitus</i>)	<i>a</i>	<i>ab</i>	<i>e</i>
Keruing plywood	46.6 (27.6)	5544 (3284)	4.5 (2.5)
(<i>Dipterocarpus</i> spp.)	<i>b</i>	<i>bc</i>	<i>c</i>
Keruing Sol Padi	56.0 (28.4)	6683 (3543)	4.0 (3.3)
(<i>Dipterocarpus pachyphyllus</i>)	<i>bc</i>	<i>cd</i>	<i>bc</i>
Keruing Utap	100 (0)	9773 (1790)	0 (0)
(<i>Dipterocarpus rigidus</i>)	<i>d</i>	<i>e</i>	<i>a</i>
Keruing spp.	56.2 (23.7)	5701 (2423)	5.3 (2.7)
(<i>Dipterocarpus</i> spp.)	<i>bc</i>	<i>bc</i>	<i>cd</i>

(...) = standard deviation, n= 6

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 24.8%

LSD absolute mass loss = 2928 mg

LSD termite rating = 2.5

4.4 Experiment 3: Termite resistance of *Acacia mangium*, *Hevea brasiliensis* and pine ply dip-treated with diesel, dead engine oil and combination of both oils

This study aimed to evaluate the effectiveness of diesel and dead engine oil in protecting *A. mangium* and *H. brasiliensis* with inclusion of pine plywood as reference sample against termite using dipping treatment.

Two-way ANOVA (refer Appendix B Table 16 to 18) shows that there was significant difference ($P < 0.05$) in percentage mass loss, absolute mass loss and termite rating among tested species and treatments indicate that these three species had different permeability and the movement of oils may allow different level of penetration to each wood. Based on Table 4.6, untreated *Acacia mangium* was regarded moderately resistant to termite attack (mass loss: 15%, rating: 8.6) whereas pine plywood and *H. brasiliensis* controls were non-resistant (mass loss: 100%).

All wood species including pine plywood dip-treated using diesel was found to be resistant to highly resistant to termite attack with termite rating of ≥ 9.5 (sustained superficial attack). Termite rating for *A. mangium*, *H. brasiliensis* and pine-plywood was 9.6, 9.5 and 9.7 respectively. Dip-treated *A. mangium* with dead engine oil remained resistant at the end of the test (mass loss: 9.8%, rating: 9.2). However, there was a significant reduction in termite rating for both *H. brasiliensis* and pine plywood dip-treated using used dead engine oil, for instance, *H. brasiliensis* (rating: 2) and pine-plywood (rating: 7.7). Interestingly, Table 4.6 shows that the combination of diesel and dead engine oil at the ratio of 1:1 increased the protection of wood to a certain degree against termites. For instance, treated *A. mangium* was found resistant to termite (mass loss: 13%, rating: 9.4), whereas pine plywood (mass loss: 6%, rating: 8.2) and *H. brasiliensis* (mass loss: 29%, rating: 7.5) was

found to be moderately resistant dip-treated in the combinations of diesel and dead engine oil. Percentage mass loss, absolute mass loss and termite rating were listed in Table 4.6. No doubt this study proved that wood dip-treated using diesel and dead engine oil significantly increased the termite resistance of *A. mangium*, *H. brasiliensis* and pine plywood. However, there are health, enviromental and occupational safety concerns arise when the wood is protected using diesel and other types of oil.

Table 4.6: Mean percentage mass loss, absolute mass loss and termite rating of oil treated *Acacia mangium*, *Hevea brasiliensis* and pine plywood

Species	Treatments	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>A. mangium</i>	Combination	13.0 (10.3) <i>cd</i>	555 (388) <i>bc</i>	9.4 (0.2) <i>fg</i>
	Controls	15.0 (10.6) <i>cd</i>	620 (396) <i>bc</i>	8.6 (1.1) <i>def</i>
	Dead engine	9.8 (5.8) <i>bc</i>	421 (210) <i>ab</i>	9.2 (1.1) <i>efg</i>
	Diesel	12.9 (8.6) <i>cd</i>	537 (320) <i>bc</i>	9.6 (0.5) <i>fg</i>
Pine plywood	Combination	6.0 (5.7) <i>abc</i>	199 (193) <i>ab</i>	8.2 (1.0) <i>cde</i>
	Controls	100 (0) <i>g</i>	3083 (146) <i>e</i>	0 (0) <i>a</i>
	Dead engine	1.8 (1.1) <i>ab</i>	57 (38) <i>a</i>	7.7 (0.5) <i>cd</i>
	Diesel	0.6 (0.7) <i>a</i>	18 (26) <i>a</i>	9.7 (0.3) <i>g</i>
<i>H. brasiliensis</i>	Combination	29.0 (11.6) <i>e</i>	1493 (722) <i>d</i>	7.5 (0.8) <i>c</i>
	Controls	100 (0) <i>g</i>	4781 (596) <i>g</i>	0 (0) <i>a</i>
	Dead engine	85.5 (13.2) <i>f</i>	4292 (672) <i>f</i>	2.0 (2.2) <i>b</i>
	Diesel	20.3 (7.7) <i>de</i>	1004 (413) <i>c</i>	9.5 (0.3) <i>fg</i>

(...)= standard deviation, n= 6

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 9.0%

LSD absolute mass loss = 473 mg

LSD termite rating = 1.0

4.5 Experiment 4: Termite resistance of light organic solvent preservative treated *Kokoona reflexa*, *Adinandra borneensis* and *Canarium apertum* using dipping and vacuum pressure treatment

K. reflexa, *A. borneensis* and *C. apertum* woods were dip-treated and vacuum pressure-treated using diluted LOSP (1:6 LOSP to white spirit) to form a solution that is regarded as prescribed strength) and was exposed to termites for four months. All the results were shown in Table 4.7. There was significant difference ($P < 0.05$) in percentage mass loss, absolute mass loss and termite rating in comparison of wood species and treatments as shown in two-way ANOVA (refer Appendix B Table 19 to 21) indicated that wood species and treatment methods adopted for preservative application has a significant effect on the amount of LOSP absorbed by the wood samples.

Table 4.7: Mean percentage mass loss, absolute mass loss and termite rating of LOSP treated *Kokoona reflexa*, *Adinandra borneensis* and *Canarium apertum*

Species	Treatments	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>K. reflexa</i>	Controls	12.4 (5.3) <i>b</i>	3796 (1596) <i>c</i>	8.5 (0.5) <i>c</i>
	Dipping	6.0 (1.4) <i>ab</i>	1865 (360) <i>b</i>	8.9 (0.5) <i>cd</i>
	Vacuum (Klang)	4.4 (1.4) <i>a</i>	1320 (405) <i>ab</i>	9.8 (0.3) <i>de</i>
	Vacuum (Lab)	4.2 (0.6) <i>a</i>	1315 (139) <i>ab</i>	9.8 (0.4) <i>de</i>
<i>A. borneensis</i>	Controls	59.1 (17.9) <i>d</i>	12052 (3680) <i>d</i>	3.0 (2.5) <i>a</i>
	Dipping	3.9 (2.7) <i>a</i>	799 (579) <i>ab</i>	9.3 (0.6) <i>cde</i>
	Vacuum (Klang)	0.5 (0.4) <i>a</i>	100 (79) <i>a</i>	10 (0) <i>e</i>
	Vacuum (Lab)	4.3 (0.2) <i>a</i>	928 (40) <i>ab</i>	9.9 (0.2) <i>de</i>
<i>C. apertum</i>	Controls	22.7 (8.5) <i>c</i>	4150 (1578) <i>c</i>	6.7 (0.5) <i>b</i>
	Dipping	3.0 (1.3) <i>a</i>	552 (256) <i>ab</i>	9.1 (0.6) <i>cde</i>
	Vacuum (Klang)	3.0 (1.1) <i>a</i>	545 (196) <i>ab</i>	9.2 (0.6) <i>cde</i>
	Vacuum (Lab)	1.6 (1.3) <i>a</i>	313 (264) <i>ab</i>	9.8 (0.3) <i>de</i>

(...) = standard deviation, n= 6

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 7.0%

LSD absolute mass loss = 1469 mg

LSD termite rating = 1.0

The mean density obtained for *bajan* was 0.869 g/cm³ (refer Table 4.2). In natural termite resistance test, *K. reflexa* attained termite rating of 7.5 (refer Table 4.4) whereas, in this study, untreated *K. reflexa* were found to be moderately resistant (rating: 8.5) to termite confirmed that this wood species is prone to termite attack. LOSP treatment using dipping slightly increased the resistant of *K. reflexa* to termite rating 8.9. Table 4.7 shows that *K. reflexa* vacuum pressure-treated with LOSP highly improved termite resistance of the wood towards termites (rating: 9.8). The mean retentions of dip-treated *K. reflexa* for 10 minutes were 0.0019 – 0.0021% m/m which was very low compared to the vacuum pressure-treated *bajan* in Klang industrial treatment plant (0.029 – 0.031% m/m) and in the laboratory (0.024 – 0.026% m/m) as shown in Table 4.8. It was found that vacuum pressure-treated *K. reflexa* achieved the retention recommended by approved Australian Standard (2000) for permethrin used in H2 condition which is 0.02% m/m.

Table 4.8: Mean actual retention of treated wood treated using different treatment methods

Species	Treatment	Actual retention (% m/m)
<i>K. reflexa</i>	Dipping (10 mins)	0.0019 – 0.0021
	Vacuum (Lab)	0.024 – 0.026
	Vacuum (Klang)	0.029 – 0.031
<i>A. borneensis</i>	Dipping (10 mins)	0.015 – 0.016
	Vacuum (Lab)	0.126 – 0.135
	Vacuum (Klang)	0.103 – 0.111
<i>C. apertum</i>	Dipping (10 mins)	0.0025 – 0.0027
	Vacuum (Lab)	0.019 – 0.021
	Vacuum (Klang)	0.022 – 0.024

n = 6. Actual retention was calculated based on 0.186 and 0.2% m/m Permethrin

A. borneensis had a mean density of 0.555 g/cm³ (refer Table 4.2). The wood was found to be non-resistant to termite (rating: 0) in natural termite resistance test (refer Table 4.4). However, in this study *A. borneensis* was very severely attacked (rating: 3) confirmed that this species is highly susceptible to termite. Table 4.7 shows that LOSP treatment upon *A.*

borneensis wood had drastically boosted its protection against termites. Dip-treated *A. borneensis* wood was regarded as resistant (rating: 9.3) while for vacuum pressure-treated *A. borneensis* was regarded as highly resistant (rating: 9.9 – 10) against termites. Mean retention for dip-treated *A. borneensis* was lower (0.015 – 0.016% m/m) compared to vacuum pressure-treated *A. borneensis*, both Klang (0.103 – 0.111% m/m) and in the laboratory (0.126 – 0.135% m/m). The retention of vacuum pressure-treated *A. borneensis* achieved the retention recommended by approved permethrin used in H2 condition in Australia.

For *C. apertum*, the mean density of this species was 0.535 g/cm³. Untreated *C. apertum* was severely attacked by termites (rating: 6.7) whereas, in natural termite resistance test, *C. apertum* attained termite rating of 7.3 indicated that this species is indeed prone to termite attack. LOSP treatment on seladah also increased its resistant against termites. Dip-treated *C. apertum* and vacuum pressure-treated *C. apertum* using Klang treatment plant found to be resistant (rating: 9.1 – 9.2) to termites whereas *C. apertum* vacuum pressure-treated in the laboratory regarded as highly resistant (rating: 9.8) to termites. *C. apertum* is a refractory timber, it was expected that the retention would be slightly lower than the nominal retention required by Australian standard. Dip-treated *C. apertum* had mean retention of 0.0025 – 0.0027% m/m whereas mean retention of vacuum pressure-treated *C. apertum* that treated in Klang was 0.022 – 0.024% m/m and those vacuum pressure-treated in the lab was 0.019 – 0.021% m/m respectively. The vacuum pressure-treated seladah achieved the required retention of 0.02% m/m by Australian Standard.

4.6 Experiment 5: Termite resistance of *Koompassia malaccensis* and *Hevea brasiliensis* dip-treated using chlorpyrifos, cypermethrin and permethrin

4.6.1 Low humidity exposure

4.6.1.1 Chlorpyrifos

In this experiment, both *K. malaccensis* and *H. brasiliensis* were dipped for 3 seconds or 1 minute in a series of chlorpyrifos concentrations ranging from 0.04 to 12.5%. General Linear Model (refer Appendix B Table 22 to 24) indicated that dipping time and the interaction term was not significant. Two-way ANOVA (refer Appendix B Table 25 to 27) shows that percentage mass loss, absolute mass loss and termite rating only significantly different ($P < 0.05$) in terms of species and concentrations. Thus, results shown in Table 4.9 only compares among wood species and concentrations used. It can be observed that untreated controls of *H. brasiliensis* were completely consumed (mass loss: 100%, rating: 0) and untreated *K. malaccensis* were severely attacked (mass loss: 31.2%, rating: 4.3).

For treated *H. brasiliensis*, inconsistent trend of protection upon the wood can be observed in those treated with concentrations of 0.04 to 1.6% were very severely attack (mass loss: 63.2 – 89.7%, rating: 0.8 – 3.6) indicated that these concentrations were below optimal threshold that could give protection to *H. brasiliensis*. However, increased protection was seen in *H. brasiliensis* dip-treated using concentrations of 3.1 to 12.5%. Dip-treated *H. brasiliensis* with 3.1% concentration attained good protection with slight nibbling (mass loss: 2.7%, rating: 9.4) while *H. brasiliensis* dip-treated with 6.3 and 12.5% achieved excellent protection with minimal mass losses of 0.3% and rating of 10. Generally, gradual improvement in protections (reduction in mass losses and increased in termite rating) towards *K. malaccensis* heartwood can be observed as the concentrations increased. Dip-

treated *K. malaccensis* with concentrations of 0.04 to 0.8% sustained moderate severe to severe attack (rating: 4.4 – 7.7). *K. malaccensis* dip-treated using 1.6 and 3.1% concentrations provided good protection to wood which sustained superficial attack (rating: 9.6 – 9.8). Excellent protection to *K. malaccensis* heartwood had been achieved in those dip-treated using 6.3 and 12.5% (rating: 10). Hence for this experiment, concentration of 3.1% was adequate to be used to protect wood that exposed to low humidity exposure.

Table 4.9: Mean percentage mass loss, absolute mass loss and termite rating of chlorpyrifos treated wood exposed to low humidity exposure

Species	Concentrations (%)	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>H. brasiliensis</i>	Controls	100 (0) <i>i</i>	4697 (472) <i>hi</i>	0 (0) <i>a</i>
	0.04	74.4 (37.4) <i>fgh</i>	4019 (2028) <i>fghi</i>	2.6 (3.7) <i>bcdef</i>
	0.08	89.7 (25.1) <i>hi</i>	5046 (1410) <i>i</i>	0.8 (2.1) <i>ab</i>
	0.16	77.7 (24.0) <i>ghi</i>	4324 (1392) <i>ghi</i>	2.5 (2.8) <i>abcde</i>
	0.32	65.6 (18.4) <i>efgh</i>	3460 (721) <i>efgh</i>	3.6 (2.5) <i>cdef</i>
	0.4	88.3 (13.7) <i>hi</i>	4684 (450) <i>hi</i>	1.8 (2.5) <i>abc</i>
	0.8	81.2 (23.1) <i>ghi</i>	4331 (1324) <i>ghi</i>	2.1 (3.0) <i>abcd</i>
	1.6	63.2 (40.8) <i>efg</i>	3070 (1981) <i>efg</i>	3.5 (3.8) <i>cdef</i>
	3.1	2.7 (1.6) <i>ab</i>	139 (83) <i>ab</i>	9.4 (0.3) <i>i</i>
	6.3	0.3 (0.6) <i>a</i>	14 (31) <i>a</i>	10 (0) <i>i</i>
	12.5	0.3 (0.9) <i>a</i>	13 (42) <i>a</i>	10 (0) <i>i</i>
<i>K. malaccensis</i>	Controls	31.2 (28.1) <i>cd</i>	2152 (1965) <i>cde</i>	4.3 (2.9) <i>cdefg</i>
	0.04	51.3 (38.6) <i>def</i>	3256 (2433) <i>efg</i>	4.4 (3.4) <i>defg</i>
	0.08	43.0 (35.0) <i>cde</i>	2794 (2215) <i>def</i>	4.9 (3.6) <i>efg</i>
	0.16	33.4 (30.5) <i>cd</i>	2169 (1919) <i>cde</i>	5.6 (2.7) <i>fgh</i>
	0.32	26.3 (39.5) <i>bc</i>	1353 (2012) <i>abc</i>	6.6 (4.2) <i>gh</i>
	0.4	30.8 (41.1) <i>cd</i>	1554 (1948) <i>bcd</i>	6.5 (4.1) <i>gh</i>
	0.8	19.0 (34.3) <i>abc</i>	1301 (2389) <i>abc</i>	7.7 (3.2) <i>hi</i>
	1.6	1.6 (0.5) <i>ab</i>	96 (31) <i>a</i>	9.6 (0.3) <i>i</i>
	3.1	1.5 (1.0) <i>ab</i>	96 (64) <i>a</i>	9.8 (0.2) <i>i</i>
	6.3	0.3 (0.3) <i>a</i>	19 (17) <i>a</i>	10 (0) <i>i</i>
	12.5	-0.1 (0.2) <i>a</i>	-4 (12) <i>a</i>	10 (0) <i>i</i>

(...) = standard deviation, n= 8

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 24.9%

LSD absolute mass loss = 1426 mg

LSD termite rating = 2.5

4.6.1.2 Cypermethrin

General Linear Model (refer Appendix B Table 28 to 30) indicated that dipping time and the interaction term was not significant. Two-way ANOVA (refer Appendix B Table 31 to 33) shows that percentage mass loss, absolute mass loss and termite rating only significantly different ($P < 0.05$) in terms of species and concentrations. Hence results shown in Table 4.10 only compares among wood species and concentrations used. Generally, based on Table 4.10, it can be said that increased protection upon tested wood species can be achieved with increasing dipping concentrations. Concentrations of 0.0023 to 0.0092% were too low and almost failed to protect *H. brasiliensis* wood. *H. brasiliensis* dip-treated using these concentrations were almost completely consumed (mass loss: 82.5 – 96.7%, rating: 0.5 – 1.5). Dip-treated *H. brasiliensis* using 0.053 to 0.42% sustained moderate to moderate severe attack (rating: 6.6 – 8.8). Dip-treated *H. brasiliensis* using 0.84% concentration of cypermethrin achieved good protection that only sustained nibbling (rating: 9.5). *H. brasiliensis* dip-treated using 1.68 and 3.35% achieved excellent protection whereby the treated wood is completely sound (rating: 10).

As for *K. malaccensis* dip-treated using 0.0023 to 0.0092%, treated *K. malaccensis* heartwood sustained moderate severe to severe attack (rating: 6.2 – 8.3). Good protection towards *K. malaccensis* heartwood can be achieved when the wood was dip-treated using 0.053 to 0.84% whereby the treated wood sustained nibbling to superficial attack (rating: 9.3 – 9.9). Concentrations of 1.68 and 3.35% successfully provided excellent protection to treated *K. malaccensis* whereby treated *K. malaccensis* heartwood was completely sound (rating: 10).

In conclusion, from this experiment, it can be said that concentrations of 0.84% was adequate to protect *H. brasiliensis* while concentration as low as 0.105% maybe adequate to protect *K. malaccensis* from termites.

Table 4.10: Mean percentage mass loss, absolute mass loss and termite rating of cypermethrin treated wood exposed to low humidity exposure

Species	Concentrations (%)	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>H. brasiliensis</i>	Controls	100 (0) <i>e</i>	4697 (472) <i>c</i>	0 (0) <i>a</i>
	0.0023	96.7 (7.7) <i>de</i>	5026 (533) <i>c</i>	0.5 (1.4) <i>ab</i>
	0.0046	91.3 (14.9) <i>de</i>	4840 (972) <i>c</i>	1.0 (1.8) <i>ab</i>
	0.0092	82.5 (24.6) <i>d</i>	4121 (1278) <i>c</i>	1.5 (2.8) <i>b</i>
	0.053	44.9 (12.1) <i>c</i>	2544 (577) <i>b</i>	6.6 (0.5) <i>d</i>
	0.105	11.4 (10.8) <i>a</i>	663 (641) <i>a</i>	8.2 (1.2) <i>ef</i>
	0.21	10.1 (11.3) <i>a</i>	541 (616) <i>a</i>	8.4 (1.1) <i>efg</i>
	0.42	8.8 (14.3) <i>a</i>	467 (748) <i>a</i>	8.8 (1.4) <i>efgh</i>
	0.84	2.0 (1.6) <i>a</i>	107 (86) <i>a</i>	9.5 (0) <i>fgh</i>
	1.68	0.3 (0.4) <i>a</i>	15 (18) <i>a</i>	10 (0) <i>h</i>
	3.35	0.7 (0.5) <i>a</i>	31 (24) <i>a</i>	10 (0) <i>h</i>
<i>K. malaccensis</i>	Controls	31.2 (28.1) <i>bc</i>	2152 (1965) <i>b</i>	4.3 (2.9) <i>c</i>
	0.0023	35.2 (38.2) <i>bc</i>	2421 (2649) <i>b</i>	6.2 (3.2) <i>d</i>
	0.0046	29.0 (34.8) <i>b</i>	1988 (2409) <i>b</i>	8.1 (1.4) <i>e</i>
	0.0092	13.2 (11.8) <i>a</i>	892 (798) <i>a</i>	8.3 (1.1) <i>efg</i>
	0.053	2.7 (1.8) <i>a</i>	142 (105) <i>a</i>	9.3 (0.4) <i>efgh</i>
	0.105	1.3 (0.9) <i>a</i>	72 (46) <i>a</i>	9.6 (0.4) <i>gh</i>
	0.21	2.1 (2.0) <i>a</i>	128 (120) <i>a</i>	9.8 (0.3) <i>h</i>
	0.42	1.1 (0.7) <i>a</i>	72 (42) <i>a</i>	9.9 (0.2) <i>h</i>
	0.84	0.9 (0.5) <i>a</i>	58 (35) <i>a</i>	9.9 (0.2) <i>h</i>
	1.68	0.1 (0.3) <i>a</i>	-1 (19) <i>a</i>	10 (0) <i>h</i>
	3.35	0.1 (0.1) <i>a</i>	8 (7) <i>a</i>	10 (0) <i>h</i>

(...) = standard deviation, n= 8

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 14.9%

LSD absolute mass loss = 983 mg

LSD termite rating = 1.3

4.6.1.3 Permethrin

General Linear Model (refer Appendix B Table 34 to 36) indicated that dipping time and the interaction term was not significant. Two-way ANOVA (refer Appendix B Table 37 to 39) shows that percentage mass loss, absolute mass loss and termite rating only significantly different ($P < 0.05$) in terms of species and concentrations. Permethrin concentrations of 0.0011 to 0.017% in Table 4.11 were too low to give minimal protection towards *H. brasiliensis* wood. *H. brasiliensis* dip-treated using these concentrations sustained high mass loss with low rating of 0 to 1. Gradual reduction in mass loss and increased in termite ratings were observed in dip-treated *H. brasiliensis* using 0.021 to 6.75%. Although there were reductions in mass losses and increased in termite rating, *H. brasiliensis* dip-treated using 0.021 and 0.042% sustained very heavy attack from termites. *H. brasiliensis* dip-treated using 0.084 and 0.17% sustained moderate to moderate severe attack (rating: 7.1 – 8.8). Concentrations of 0.42 to 1.69% had successfully provided good protection to *H. brasiliensis* whereby the treated wood sustained nibbling (rating: 9.2 – 9.6). *H. brasiliensis* dip-treated using concentrations of 3.38 and 6.75% obtained excellent protection whereby treated wood was completely sound (rating: 10).

The inconsistent trend in mass losses and termite rating was observed in *K. malaccensis* dip-treated using 0.0011 to 0.85%. Although *K. malaccensis* dip-treated using 0.0011 to 0.008% achieved certain degree of wood protection, the treated wood was moderate severe attack (rating: 7.3 – 7.6). Good protection towards *K. malaccensis* heartwood was achieved in those treated using concentrations of 0.017 to 1.69% whereby the wood sustained superficial to slight attack (rating: 9.0 – 9.8). Dip-treated *K. malaccensis* using 3.38 and 6.75% was completely sound (rating: 10) indicated that excellent protection had been

achieved. In conclusion, the concentration of 1.69 was adequate to provide good protection to the wood.

Table 4.11: Mean percentage mass loss, absolute mass loss and termite rating of permethrin treated wood exposed to low humidity exposure

Species	Concentrations (%)	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>H. brasiliensis</i>	Controls	100 (0) <i>f</i>	4697 (472) <i>gh</i>	0 (0) <i>a</i>
	0.0011	96.7 (6.7) <i>f</i>	4775 (462) <i>gh</i>	0 (0) <i>a</i>
	0.0022	100 (0) <i>f</i>	4898 (546) <i>h</i>	0 (0) <i>a</i>
	0.0044	100 (0) <i>f</i>	4905 (204) <i>h</i>	0 (0) <i>a</i>
	0.008	96.2 (10.8) <i>f</i>	5228 (729) <i>h</i>	0 (0) <i>a</i>
	0.017	92.0 (11.5) <i>f</i>	5217 (829) <i>h</i>	1.0 (1.9) <i>a</i>
	0.021	69.0 (35.0) <i>e</i>	3999 (2104) <i>fg</i>	3.1 (3.6) <i>b</i>
	0.042	63.5 (21.6) <i>e</i>	3745 (1368) <i>f</i>	4.0 (1.9) <i>b</i>
	0.084	24.4 (15.1) <i>cd</i>	1389 (830) <i>de</i>	7.1 (0.8) <i>c</i>
	0.17	7.4 (7.4) <i>ab</i>	439 (413) <i>abc</i>	8.8 (0.7) <i>de</i>
	0.42	3.0 (2.0) <i>a</i>	156 (106) <i>ab</i>	9.2 (0.5) <i>e</i>
	0.85	1.5 (1.7) <i>a</i>	76 (86) <i>ab</i>	9.5 (0) <i>e</i>
	1.69	0.8 (0.5) <i>a</i>	42 (28) <i>a</i>	9.6 (0.2) <i>e</i>
	3.38	-0.2 (1.1) <i>a</i>	-7 (52) <i>a</i>	10 (0) <i>e</i>
	6.75	-0.3 (0.8) <i>a</i>	-15 (33) <i>a</i>	10 (0) <i>e</i>
<i>K. malaccensis</i>	Controls	31.2 (28.1) <i>d</i>	2152 (1965) <i>e</i>	4.3 (2.9) <i>b</i>
	0.0011	19.7 (22.2) <i>bcd</i>	1192 (1389) <i>cd</i>	7.3 (1.7) <i>c</i>
	0.0022	25.3 (29.8) <i>cd</i>	1573 (1948) <i>de</i>	7.4 (2.1) <i>c</i>
	0.0044	20.5 (16.5) <i>cd</i>	1421 (1155) <i>de</i>	7.4 (1.1) <i>c</i>
	0.008	17.3 (22.4) <i>bc</i>	888 (1162) <i>bcd</i>	7.6 (2.0) <i>cd</i>
	0.017	3.4 (3.0) <i>a</i>	171 (142) <i>ab</i>	9.0 (0.7) <i>e</i>
	0.021	2.3 (1.4) <i>a</i>	130 (81) <i>ab</i>	9.2 (0.5) <i>e</i>
	0.042	2.3 (1.2) <i>a</i>	133 (71) <i>ab</i>	9.4 (0.2) <i>e</i>
	0.084	1.6 (0.9) <i>a</i>	83 (42) <i>ab</i>	9.4 (0.2) <i>e</i>
	0.17	1.0 (0.6) <i>a</i>	53 (32) <i>a</i>	9.7 (0.4) <i>e</i>
	0.42	2.7 (1.3) <i>a</i>	180 (88) <i>ab</i>	9.4 (0.4) <i>e</i>
	0.85	0.7 (0.4) <i>a</i>	49 (26) <i>a</i>	9.4 (0.4) <i>e</i>
	1.69	1.0 (0.9) <i>a</i>	65 (58) <i>ab</i>	9.8 (0.3) <i>e</i>
	3.38	0.1 (0.1) <i>a</i>	4 (4) <i>a</i>	10 (0) <i>e</i>
	6.75	0 (0.1) <i>a</i>	3 (9) <i>a</i>	10 (0) <i>e</i>

(...) = standard deviation, n= 8

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 12.9%

LSD absolute mass loss = 829 mg

LSD termite rating = 1.2

According to Table 4.12, for chlorpyrifos, the lowest retention recorded was 0.0005% m/m as observed in *K. malaccensis* dip-treated using 0.04% chlorpyrifos for 3 seconds while the highest retention was 1.443% m/m which was recorded in *H. brasiliensis* dip-treated using 12.5% for 60 seconds. For cypermethrin, *K. malaccensis* dip-treated using 0.0023% cypermethrin for 3 seconds achieved the lowest retention which was 0.00008% m/m while *H. brasiliensis* dip-treated using 3.35% cypermethrin for 60 seconds achieved the highest retention which was 0.440% m/m. As for Permethrin, *K. malaccensis* dip-treated using 0.0011% permethrin for 3 seconds achieved the lowest retention which was 0.00004% m/m while *H. brasiliensis* dip-treated using 6.75% permethrin for 60 seconds achieved the highest retention which was 0.748% m/m.

Table 4.12: Mean actual retentions of active ingredients in treated wood (low humidity exposure)

Active ingredients	Concentrations (%)	Dipping Times	Actual Retentions (% m/m)	
			<i>H. brasiliensis</i>	<i>K. malaccensis</i>
Chlorpyrifos	0.04	3 sec	0.003 (0.001)	0.0005 (0.0002)
		60 sec	0.003 (0.001)	0.0007 (0.0003)
	0.08	3 sec	0.003 (0.001)	0.0011 (0.0001)
		60 sec	0.006 (0.001)	0.0015 (0.0006)
	0.16	3 sec	0.008 (0.003)	0.0026 (0.0006)
		60 sec	0.011 (0.001)	0.0030 (0.0010)
	0.32	3 sec	0.014 (0.002)	0.0061 (0.0016)
		60 sec	0.020 (0.004)	0.0049 (0.0009)
	0.40	3 sec	0.016 (0.003)	0.0074 (0.0021)
		60 sec	0.026 (0.004)	0.0088 (0.0025)
	0.80	3 sec	0.032 (0.012)	0.018 (0.007)
		60 sec	0.050 (0.005)	0.019 (0.006)
	1.60	3 sec	0.083 (0.025)	0.033 (0.009)
		60 sec	0.138 (0.021)	0.053 (0.007)
	3.10	3 sec	0.222 (0.075)	0.106 (0.044)
		60 sec	0.247 (0.063)	0.160 (0.138)
	6.30	3 sec	0.500 (0.083)	0.192 (0.055)
		60 sec	0.629 (0.101)	0.173 (0.052)
	12.50	3 sec	0.954 (0.434)	0.476 (0.521)
		60 sec	1.443 (0.395)	0.549 (0.207)

Table 4.12 continued

Active ingredients	Concentrations (%)	Dipping Times	Actual Retentions (% m/m)	
			<i>H. brasiliensis</i>	<i>K. malaccensis</i>
Cypermethrin	0.0023	3 sec	0.0003 (0.0001)	0.00008 (0)
		60 sec	0.0003 (0.0001)	0.0001 (0)
	0.0046	3 sec	0.0003 (0)	0.0001 (0)
		60 sec	0.0005 (0)	0.0002 (0)
	0.0092	3 sec	0.0006 (0.0001)	0.0003 (0)
		60 sec	0.0010 (0.0001)	0.0004 (0.0001)
	0.053	3 sec	0.0025 (0.0003)	0.0011 (0.0003)
		60 sec	0.0033 (0.0006)	0.0013 (0.0004)
	0.105	3 sec	0.006 (0.001)	0.0018 (0.0007)
		60 sec	0.006 (0.001)	0.0024 (0.0004)
	0.21	3 sec	0.008 (0.001)	0.0026 (0.0004)
		60 sec	0.014 (0.001)	0.0047 (0.0021)
	0.42	3 sec	0.023 (0.003)	0.008 (0.003)
		60 sec	0.038 (0.011)	0.009 (0.003)
	0.84	3 sec	0.047 (0.010)	0.017 (0.003)
		60 sec	0.062 (0.011)	0.043 (0.025)
	1.68	3 sec	0.123 (0.019)	0.044 (0.020)
		60 sec	0.177 (0.010)	0.047 (0.013)
Permethrin	0.0011	3 sec	0.00007 (0.00005)	0.00004 (0.00001)
		60 sec	0.00016 (0.00003)	0.00005 (0.00001)
	0.0022	3 sec	0.00018 (0.00004)	0.00007 (0.00001)
		60 sec	0.00025 (0.00006)	0.00012 (0.00003)
	0.0044	3 sec	0.0003 (0)	0.00017 (0.00001)
		60 sec	0.0006 (0.0002)	0.00018 (0.00003)
	0.008	3 sec	0.0003 (0.0001)	0.00011 (0.00002)
		60 sec	0.0004 (0.0001)	0.00015 (0.00004)
	0.017	3 sec	0.0006 (0.0002)	0.0003 (0.0001)
		60 sec	0.0010 (0.0001)	0.0004 (0.0001)
	0.021	3 sec	0.0009 (0.0003)	0.0004 (0.0001)
		60 sec	0.0013 (0.0001)	0.0004 (0.0002)
	0.042	3 sec	0.0015 (0.0004)	0.0009 (0.0004)
		60 sec	0.0024 (0.0004)	0.0007 (0.0003)
	0.084	3 sec	0.0039 (0.0004)	0.0013 (0.0003)
		60 sec	0.0053 (0.0012)	0.0018 (0.0004)
	0.17	3 sec	0.008 (0.001)	0.003 (0.001)
		60 sec	0.013 (0.007)	0.003 (0.001)
	0.42	3 sec	0.027 (0.013)	0.006 (0.002)
		60 sec	0.033 (0.006)	0.011 (0.002)
	0.85	3 sec	0.055 (0.005)	0.014 (0.007)
		60 sec	0.075 (0.013)	0.021 (0.011)

Table 4.12 continued

Active ingredients	Concentrations (%)	Dipping Times	Actual Retentions (% m/m)	
			<i>H. brasiliensis</i>	<i>K. malaccensis</i>
Permethrin	1.69	3 sec	0.115 (0.016)	0.059 (0.023)
		60 sec	0.165 (0.034)	0.071 (0.030)
	3.38	3 sec	0.312 (0.077)	0.055 (0.009)
		60 sec	0.351 (0.067)	0.071 (0.004)
	6.75	3 sec	0.627 (0.095)	0.230 (0.109)
		60 sec	0.748 (0.079)	0.218 (0.104)

(...) = standard deviation, n = 4

4.6.2 High humidity exposure

4.6.2.1 Chlorpyrifos

General Linear Model (refer Appendix B Table 40 to 42) indicated that dipping time and the interaction term was not significant. Two-way ANOVA (refer Appendix B Table 43 to 45) shows that percentage mass loss, absolute mass loss and termite rating only differed significantly ($P < 0.05$) in terms of species and concentrations.

Untreated *H. brasiliensis* was completely consumed whereas untreated *K. malaccensis* sustained 58.7% mass loss. According to Table 4.13, *H. brasiliensis* dip-treated using concentrations of 0.04 to 0.8% failed to protect *H. brasiliensis* from termite attacks. Wood treated using these concentrations of 0.04 to 0.4% was severely consumed (mass loss: 87.5 – 100%, rating: 0) while *H. brasiliensis* dip-treated with concentrations of 0.8% chlorpyrifos sustained 78.7% mass loss and rated 2.4. Drastic reduction in mass losses and increased in termite rating was observed in *H. brasiliensis* dip-treated using concentrations of 1.6 to 12.5%. *H. brasiliensis* dip-treated using 1.6% concentration sustained moderate attack (rating: 8) with 10.4% mass loss. Concentration of 3.1% provided good protection to wood whereby the wood sustained slight attack (rating: 9.3). *H. brasiliensis* dip-treated using concentrations of 6.3 and 12.5% were excellently protected whereby the treated wood was completely sound. Although the inconsistent trend was observed in mass losses

and termite rating for *K. malaccensis* dip-treated using 0.04 to 0.32% chlorpyrifos, the treated wood using these concentrations sustained heavy attack (rating: 3.1 – 5.3). *K. malaccensis* dip-treated using 0.4 and 0.8% sustained moderate severe attack (rating: 7.8). 1.6 and 3.1% concentrations provided considerably good protection to *K. malaccensis* which sustained nibbling and slight attack (rating: 9 – 9.6). No termite attack had been done to treated *K. malaccensis* dip-treated using 6.3 and 12.5%.

Table 4.13: Mean percentage mass loss, absolute mass loss and termite rating of chlorpyrifos treated wood exposed to high humidity exposure

Species	Concentrations (%)	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>H. brasiliensis</i>	Controls	100 (0) <i>d</i>	4538 (320) <i>def</i>	0 (0) <i>a</i>
	0.04	100 (0) <i>d</i>	5073 (384) <i>f</i>	0 (0) <i>a</i>
	0.08	87.5 (13.6) <i>d</i>	4742 (801) <i>ef</i>	0 (0) <i>a</i>
	0.16	100 (0) <i>d</i>	5309 (186) <i>f</i>	0 (0) <i>a</i>
	0.32	100 (0) <i>d</i>	5602 (298) <i>f</i>	0 (0) <i>a</i>
	0.4	100 (0) <i>d</i>	5609 (197) <i>f</i>	0 (0) <i>a</i>
	0.8	78.7 (24.2) <i>cd</i>	3716 (1100) <i>de</i>	2.4 (2.7) <i>b</i>
	1.6	10.4 (8.7) <i>a</i>	540 (500) <i>a</i>	8.0 (0.8) <i>e</i>
	3.1	3.2 (2.6) <i>a</i>	163 (126) <i>a</i>	9.3 (0.3) <i>ef</i>
	6.3	0.5 (0.6) <i>a</i>	22 (32) <i>a</i>	10 (0) <i>f</i>
	12.5	0.5 (0.5) <i>a</i>	20 (20) <i>a</i>	10 (0) <i>f</i>
<i>K. malaccensis</i>	Controls	58.7 (44.9) <i>bc</i>	3406 (2550) <i>cd</i>	3.5 (3.7) <i>bcd</i>
	0.04	41.2 (40.3) <i>b</i>	2315 (2100) <i>bc</i>	4.9 (3.5) <i>cd</i>
	0.08	61.0 (44.9) <i>bc</i>	3640 (2662) <i>de</i>	3.1 (3.5) <i>bc</i>
	0.16	57.1 (47.0) <i>bc</i>	3484 (2850) <i>cd</i>	3.9 (4.4) <i>bcd</i>
	0.32	39.6 (38.1) <i>b</i>	2131 (2014) <i>b</i>	5.3 (3.6) <i>d</i>
	0.4	13.9 (15.0) <i>a</i>	785 (919) <i>a</i>	7.8 (1.8) <i>e</i>
	0.8	11.1 (9.8) <i>a</i>	758 (672) <i>a</i>	7.8 (0.8) <i>e</i>
	1.6	6.4 (6.3) <i>a</i>	426 (365) <i>a</i>	9.0 (0.8) <i>ef</i>
	3.1	2.2 (1.5) <i>a</i>	152 (98) <i>a</i>	9.6 (0.3) <i>ef</i>
	6.3	0.4 (0.6) <i>a</i>	23 (36) <i>a</i>	10 (0) <i>f</i>
	12.5	0.2 (0.4) <i>a</i>	13 (25) <i>a</i>	10 (0) <i>f</i>

(...) = standard deviation, n= 8

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 21.4%

LSD absolute mass loss = 1221 mg

LSD termite rating = 1.9

4.6.2.2 Cypermethrin

General Linear Model (refer Appendix B Table 46 to 48) indicated that dipping time and the interaction term was not significant. Two-way ANOVA (refer Appendix B Table 49 to 51) shows that percentage mass loss, absolute mass loss and termite rating only differed significantly ($P < 0.05$) in terms of species and concentrations. Based on Table 4.14, *H. brasiliensis* dip-treated using concentrations of 0.0023 to 0.0092% was too low to provide minimal protection to *H. brasiliensis*. Treated wood using 0.0023 and 0.0046% was completely destroyed (mass loss: 100%, rating: 0) while *H. brasiliensis* dip-treated using 0.0092% concentrations was almost destroyed (mass loss 98:1, rating: 0.5). Reduction in mass losses and increased in termite rating was observed in *H. brasiliensis* dip-treated using 0.053% and above. Although concentrations of 0.053, 0.105 and 0.21% provided a certain degree of protection towards treated *H. brasiliensis*, the treated wood sustained severe attack (mass loss: 28.4 – 48.8, rating: 6.5 – 6.9). Good protection to *H. brasiliensis* was achieved whereby the wood sustained nibbling to slight attack (rating: 9.4 – 9.5) when the concentrations increased by one fold (0.42%) and as well as two folds (0.84%). Complete protection against termite was achieved when *H. brasiliensis* dip-treated using 1.68 and 3.35% concentrations of cypermethrin.

Although table shows inconsistent trend in mass losses and termite rating was observed in *K. malaccensis* dip-treated using 0.0023 to 0.0092%, treated wood using these concentrations sustained moderate severe to rather heavy attack (rating: 5.3 – 7.1). As the concentrations used increased, promising protection can be seen in *K. malaccensis* dip-treated using cypermethrin. For instance, dip-treated *K. malaccensis* using 0.053 to 0.84% achieved rather good protection (rating: 9.1 – 9.4) towards termite. Concentrations of 1.68

and 3.35% had provided excellent protection to *K. malaccensis* whereby the treated wood was not attacked (rating: 10).

In conclusion, concentration of 1.68% was adequate to provide excellent protection to wood that exposed to high humidity exposure.

Table 4.14: Mean percentage mass loss, absolute mass loss and termite rating of cypermethrin treated wood exposed to high humidity exposure

Species	Concentrations (%)	Percentage mass loss (%)	Absolute mass loss (mg)	rating
<i>H. brasiliensis</i>	Controls	100 (0) <i>e</i>	4538 (320) <i>ef</i>	0 (0) <i>a</i>
	0.0023	100 (0) <i>e</i>	4836 (627) <i>f</i>	0 (0) <i>a</i>
	0.0046	100 (0) <i>e</i>	5389 (205) <i>f</i>	0 (0) <i>a</i>
	0.0092	98.1 (5.5) <i>e</i>	5280 (341) <i>f</i>	0.5 (1.4) <i>a</i>
	0.053	48.8 (11.1) <i>cd</i>	2738 (557) <i>cd</i>	6.6 (0.5) <i>c</i>
	0.105	44.4 (18.7) <i>bcd</i>	2554 (1064) <i>bcd</i>	6.5 (0.8) <i>c</i>
	0.21	28.4 (31.8) <i>b</i>	1467 (1566) <i>b</i>	6.9 (3.2) <i>c</i>
	0.42	2.0 (0.6) <i>a</i>	98 (38) <i>a</i>	9.4 (0.2) <i>d</i>
	0.84	1.4 (0.5) <i>a</i>	69 (25) <i>a</i>	9.5 (0) <i>d</i>
	1.68	0.4 (0.8) <i>a</i>	18 (41) <i>a</i>	10 (0) <i>d</i>
	3.35	0.6 (0.5) <i>a</i>	30 (28) <i>a</i>	10 (0) <i>d</i>
<i>K. malaccensis</i>	Controls	58.7 (45) <i>d</i>	3406 (2550) <i>de</i>	3.5 (3.7) <i>b</i>
	0.0023	31.2 (26.7) <i>bc</i>	2040 (1735) <i>bc</i>	6.4 (2.1) <i>c</i>
	0.0046	41.8 (43.8) <i>bcd</i>	2659 (2762) <i>cd</i>	5.3 (4.4) <i>bc</i>
	0.0092	26.9 (45.2) <i>b</i>	1646 (2756) <i>bc</i>	7.1 (4.4) <i>c</i>
	0.053	1.7 (1.3) <i>a</i>	90 (69) <i>a</i>	9.1 (0.5) <i>d</i>
	0.105	1.8 (1.6) <i>a</i>	97 (86) <i>a</i>	9.3 (0.5) <i>d</i>
	0.21	4.7 (3.4) <i>a</i>	322 (230) <i>a</i>	9.3 (0.4) <i>d</i>
	0.42	2.6 (1.3) <i>a</i>	180 (95) <i>a</i>	9.4 (0.4) <i>d</i>
	0.84	3.7 (1.7) <i>a</i>	258 (136) <i>a</i>	9.4 (0.2) <i>d</i>
	1.68	0.5 (2.0) <i>a</i>	25 (113) <i>a</i>	10 (0) <i>d</i>
	3.35	-0.1 (0.8) <i>a</i>	-10 (50) <i>a</i>	10 (0) <i>d</i>

(...) = standard deviation, n= 8

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 19.0%

LSD absolute mass loss = 1133 mg

LSD termite rating = 1.8

4.6.2.3 Permethrin

General Linear Model (refer Appendix B Table 52 to 54) indicated that the interaction term was significant ($P < 0.05$) indicated that the dipping time may have combine effect with the concentrations used penetrating the wood. Based on Table 4.15, permethrin concentrations of 0.0011 to 0.021% were too low to provide minimal protection to *H. brasiliensis* whereby treated *H. brasiliensis* using these concentrations either almost destroyed or completely destroyed (mass loss: 91.6 – 100%, rating: 0 – 1). Even though, concentrations of 0.042 to 0.42% (3 seconds) provided certain degree of protection towards *H. brasiliensis*, treated *H. brasiliensis* sustained very severe to heavy attack (rating: 4 – 6.8). However, *H. brasiliensis* dip-treated using 0.42% for 1 minute sustained moderate severe attack (rating: 7.9). Regardless of treatment time, *H. brasiliensis* dip-treated using concentrations of 3.38 and 6.75% provided complete protection (rating: 10) to wood that none of the treated wood was attacked.

K. malaccensis dip-treated using 0.0011% for 3 seconds was completely destroyed while those dipped for 60 seconds sustained 41.4% mass loss. Another obvious observation was that *K. malaccensis* dip-treated using 0.0022% for 3 seconds sustained 50.3% mass loss while those dipped for 60 seconds was completely destroyed indicating that these two concentrations were too low to provide protection to *K. malaccensis*. Overall treated *K. malaccensis* dip-treated using 0.0011 to 0.0044% sustained heavy attack to failure (rating: 0 – 5.8). As for *K. malaccensis* dip-treated using 0.008 to 0.042% (3 seconds), treated wood sustained slight to moderate attack (rating: 7.9 – 9). *K. malaccensis* achieved rather good protection when treated using 0.042% (60 seconds) to 1.69% that the treated wood sustained nibbling to slight attack (rating: 9 – 9.8). Excellent protection to *K. malaccensis*

had been achieved when treated using 3.38 and 6.75% that no termite attack (rating: 10) had been observed.

Table 4.15: Mean percentage mass loss, absolute mass loss and termite rating of treated wood dip-treated using different concentrations of Permethrin comparing different dipping times exposed to high humidity exposure

Species	Concentrations (%)	Dipping times	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>H. brasiliensis</i>	Controls	/	100 (0) <i>j</i>	4538 (345) <i>ijklm</i>	0 (0) <i>a</i>
	0.0011	3 sec	91.6 (16.9) <i>ij</i>	4831 (997) <i>klm</i>	1.0 (2.0) <i>a</i>
		60 sec	100 (0) <i>j</i>	5428 (279) <i>lmn</i>	0 (0) <i>a</i>
	0.0022	3 sec	100 (0) <i>j</i>	5032 (688) <i>klmn</i>	0 (0) <i>a</i>
		60 sec	100 (0) <i>j</i>	4715 (719) <i>ijklm</i>	0 (0) <i>a</i>
	0.0044	3 sec	100 (0) <i>j</i>	5570 (130) <i>lmn</i>	0 (0) <i>a</i>
		60 sec	100 (0) <i>j</i>	5229 (288) <i>lmn</i>	0 (0) <i>a</i>
	0.008	3 sec	100 (0) <i>j</i>	5653 (187) <i>mn</i>	0 (0) <i>a</i>
		60 sec	100 (0) <i>j</i>	5662 (187) <i>mn</i>	0 (0) <i>a</i>
	0.017	3 sec	100 (0) <i>j</i>	5667 (183) <i>mn</i>	0 (0) <i>a</i>
		60 sec	100 (0) <i>j</i>	5681 (169) <i>mn</i>	0 (0) <i>a</i>
	0.021	3 sec	100 (0) <i>j</i>	5688 (165) <i>mn</i>	0 (0) <i>a</i>
		60 sec	100 (0) <i>j</i>	5690 (165) <i>mn</i>	0 (0) <i>a</i>
	0.042	3 sec	71.2 (19.5) <i>hi</i>	4157 (1031) <i>hijkl</i>	4.0 (2.8) <i>bc</i>
		60 sec	62.6 (29.6) <i>gh</i>	3763 (1744) <i>ghijk</i>	4.8 (3.2) <i>bcd</i>
	0.084	3 sec	51.4 (16.2) <i>efgh</i>	3050 (1139) <i>defgh</i>	6.5 (0.6) <i>def</i>
		60 sec	41.4 (27.0) <i>efg</i>	2360 (1525) <i>defg</i>	6.5 (2.1) <i>def</i>
	0.17	3 sec	40.2 (26.9) <i>efg</i>	2509 (1840) <i>defg</i>	6.8 (1.9) <i>defg</i>
		60 sec	34.6 (23.3) <i>cdef</i>	1980 (1326) <i>cde</i>	6.8 (1.0) <i>defg</i>
	0.42	3 sec	33.2 (44.6) <i>bcde</i>	1672 (2232) <i>bcd</i>	6.4 (4.3) <i>def</i>
		60 sec	11.4 (4.1) <i>ab</i>	575 (245) <i>abc</i>	7.9 (1.2) <i>efgh</i>
	0.85	3 sec	2.0 (0.2) <i>a</i>	103 (8) <i>a</i>	9.5 (0) <i>h</i>
		60 sec	4.4 (3.3) <i>a</i>	224 (185) <i>a</i>	9.5 (0) <i>h</i>

Table 4.15 continued

Species	Concentrations (%)	Dipping times	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>H. brasiliensis</i>	1.69	3 sec	2.2 (0.2) <i>a</i>	110 (20) <i>a</i>	9.5 (0) <i>h</i>
		60 sec	2.1 (0.5) <i>a</i>	110 (36) <i>a</i>	9.5 (0) <i>h</i>
	3.38	3 sec	0.9 (0.5) <i>a</i>	44 (23) <i>a</i>	10 (0) <i>h</i>
		60 sec	0.3 (1.5) <i>a</i>	23 (76) <i>a</i>	10 (0) <i>h</i>
	6.75	3 sec	0.2 (0.8) <i>a</i>	8 (38) <i>a</i>	10 (0) <i>h</i>
		60 sec	-0.3 (0.4) <i>a</i>	-12 (20) <i>a</i>	10 (0) <i>h</i>
<i>K. malaccensis</i>	Controls	/	58.7 (48.5) <i>fgh</i>	3406 (2755) <i>fghij</i>	3.5 (4.0) <i>b</i>
	0.0011	3 sec	100 (0) <i>j</i>	6334 (140) <i>n</i>	0 (0) <i>a</i>
		60 sec	41.4 (39.4) <i>efg</i>	2332 (2094) <i>def</i>	5.5 (3.7) <i>bcd</i>
	0.0022	3 sec	50.3 (34.3) <i>efgh</i>	3259 (2187) <i>efghi</i>	5.8 (3.9) <i>cde</i>
		60 sec	100 (0) <i>j</i>	6339 (146) <i>n</i>	0 (0) <i>a</i>
	0.0044	3 sec	43.8 (46.4) <i>efg</i>	2728 (2733) <i>defg</i>	5.0 (3.9) <i>bcd</i>
		60 sec	39.5 (27.8) <i>defg</i>	3016 (2176) <i>defgh</i>	5.5 (1.7) <i>bcd</i>
	0.008	3 sec	6.0 (5.3) <i>a</i>	328 (301) <i>ab</i>	8.3 (1.0) <i>fgh</i>
		60 sec	15.4 (29.0) <i>abcd</i>	761 (1422) <i>abc</i>	8.1 (2.8) <i>fgh</i>
	0.017	3 sec	7.1 (6.6) <i>a</i>	410 (380) <i>ab</i>	9.0 (1.4) <i>gh</i>
		60 sec	7.9 (9.2) <i>a</i>	418 (479) <i>ab</i>	7.9 (1.7) <i>efgh</i>
	0.021	3 sec	14.6 (27.7) <i>abc</i>	788 (1489) <i>abc</i>	8.0 (2.7) <i>efgh</i>
		60 sec	4.5 (6.4) <i>a</i>	241 (345) <i>a</i>	8.5 (1.2) <i>fgh</i>
	0.042	3 sec	9.7 (13.9) <i>ab</i>	507 (724) <i>ab</i>	8.6 (1.1) <i>fgh</i>
		60 sec	7.7 (8.2) <i>a</i>	408 (422) <i>ab</i>	9.0 (0.7) <i>gh</i>
	0.084	3 sec	6.1 (8.3) <i>a</i>	308 (414) <i>ab</i>	9.0 (0.7) <i>gh</i>
		60 sec	0.9 (0.5) <i>a</i>	50 (24) <i>a</i>	9.4 (0.3) <i>h</i>

Table 4.15 continued

Species	Concentrations (%)	Dipping times	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>K. malaccensis</i>	0.17	3 sec	1.2 (0.6) <i>a</i>	67 (33) <i>a</i>	9.5 (0) <i>h</i>
		60 sec	0.7 (0.4) <i>a</i>	42 (23) <i>a</i>	9.5 (0) <i>h</i>
	0.42	3 sec	2.0 (1.6) <i>a</i>	137 (105) <i>a</i>	9.4 (0.3) <i>h</i>
		60 sec	4.7 (2.7) <i>a</i>	329 (190) <i>ab</i>	9.5 (0) <i>h</i>
	0.85	3 sec	3.0 (1.8) <i>a</i>	199 (102) <i>a</i>	9.3 (0.3) <i>h</i>
		60 sec	3.2 (1.8) <i>a</i>	211 (111) <i>a</i>	9.5 (0) <i>h</i>
	1.69	3 sec	1.3 (1.1) <i>a</i>	93 (69) <i>a</i>	9.8 (0.3) <i>h</i>
		60 sec	3.7 (2.4) <i>a</i>	241 (148) <i>a</i>	9.5 (0) <i>h</i>
	3.38	3 sec	1.0 (0.4) <i>a</i>	56 (22) <i>a</i>	10 (0) <i>h</i>
		60 sec	1.8 (0.2) <i>a</i>	92 (11) <i>a</i>	10 (0) <i>h</i>
	6.75	3 sec	1.6 (0.7) <i>a</i>	91 (29) <i>a</i>	10 (0) <i>h</i>
		60 sec	0.7 (0.5) <i>a</i>	39 (27) <i>a</i>	10 (0) <i>h</i>

(...) = standard deviation, n= 4

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 24.2%

LSD absolute mass loss = 1419 mg

LSD termite rating = 2.2

Based on Table 4.16, the lowest retention recorded for chlorpyrifos was 0.0005% m/m as observed in *K. malaccensis* dip-treated using 0.04% chlorpyrifos for 3 seconds while the highest retention was 1.295% m/m which was recorded in *K. malaccensis* dip-treated using 12.5% for 60 seconds. For cypermethrin, *K. malaccensis* dip-treated using 0.0023% cypermethrin for 3 seconds achieved the lowest retention which was 0.0001% m/m while *H. brasiliensis* dip-treated using 3.35% cypermethrin for 60 seconds achieved the highest retention which was 0.294% m/m. As for Permethrin, *K. malaccensis* dip-treated using 0.0011% permethrin for 3 seconds achieved the lowest retention which was 0.00004% m/m while *H. brasiliensis* dip-treated using 6.75% permethrin for 60 seconds achieved the highest retention which was 0.645% m/m.

Table 4.16: Mean actual retentions of active ingredients in treated wood (high humidity exposure)

Active Ingredients	Concentrations (%)	Dipping Times	Actual Retentions (% m/m)	
			<i>H. brasiliensis</i>	<i>K. malaccensis</i>
Chlorpyrifos	0.04	3 sec	0.0021 (0.0004)	0.0005 (0.0001)
		60 sec	0.0030 (0.0010)	0.0006 (0.0001)
	0.08	3 sec	0.0032 (0.0004)	0.0012 (0.0003)
		60 sec	0.0038 (0.0013)	0.0018 (0.0003)
	0.16	3 sec	0.007 (0.001)	0.002 (0.001)
		60 sec	0.011 (0.006)	0.002 (0.001)
	0.32	3 sec	0.013 (0.001)	0.005 (0.001)
		60 sec	0.018 (0.002)	0.006 (0.001)
	0.40	3 sec	0.016 (0.002)	0.007 (0.002)
		60 sec	0.026 (0.003)	0.009 (0.005)
	0.80	3 sec	0.038 (0.016)	0.016 (0.006)
		60 sec	0.052 (0.008)	0.019 (0.003)
	1.60	3 sec	0.079 (0.014)	0.036 (0.012)
		60 sec	0.132 (0.029)	0.044 (0.014)
	3.10	3 sec	0.134 (0.021)	0.061 (0.020)
		60 sec	0.276 (0.061)	0.088 (0.023)
Cypermethrin	6.30	3 sec	0.442 (0.046)	0.481 (0.568)
		60 sec	0.525 (0.072)	0.210 (0.086)
	12.50	3 sec	1.135 (0.266)	0.484 (0.056)
		60 sec	1.289 (0.216)	1.295 (0.685)
	0.0023	3 sec	0.0002 (0)	0.0001 (0)
		60 sec	0.0003 (0)	0.0001 (0)
	0.0046	3 sec	0.0004 (0)	0.0003 (0)
		60 sec	0.0006 (0)	0.0003 (0)
	0.0092	3 sec	0.0009 (0.0001)	0.0005 (0.0001)
		60 sec	0.0010 (0.0001)	0.0005 (0.0001)
	0.053	3 sec	0.0022 (0.0004)	0.0008 (0.0001)
		60 sec	0.0034 (0.0002)	0.0010 (0.0002)
	0.105	3 sec	0.004 (0.001)	0.0012 (0.0002)
		60 sec	0.007 (0.001)	0.0020 (0.0001)
	0.21	3 sec	0.007 (0.001)	0.004 (0.001)
		60 sec	0.016 (0.003)	0.006 (0.002)
	0.42	3 sec	0.021 (0.005)	0.008 (0.003)
		60 sec	0.036 (0.006)	0.008(0.001)
	0.84	3 sec	0.054 (0.009)	0.019 (0.006)
		60 sec	0.077 (0.013)	0.027 (0.011)
	1.68	3 sec	0.122 (0.018)	0.030 (0.010)
		60 sec	0.149 (0.034)	0.101 (0.083)
	3.35	3 sec	0.234 (0.044)	0.069 (0.024)
		60 sec	0.294 (0.072)	0.111 (0.033)

Table 4.16 continued

Active Ingredients	Concentrations (%)	Dipping Times	Actual Retentions (% m/m)	
			<i>H. brasiliensis</i>	<i>K. malaccensis</i>
Permethrin	0.0011	3 sec	0.00006 (0.00002)	0.00004 (0)
		60 sec	0.00011 (0.00002)	0.00005 (0.00009)
	0.0022	3 sec	0.00012 (0.00001)	0.00006 (0)
		60 sec	0.00022 (0.00006)	0.00007 (0)
	0.0044	3 sec	0.00023 (0.00006)	0.00014 (0.00002)
		60 sec	0.00051 (0.00004)	0.00013 (0.00002)
	0.008	3 sec	0.00032 (0.00002)	0.00010 (0.00003)
		60 sec	0.00049 (0.00002)	0.00011 (0.00003)
	0.017	3 sec	0.0008 (0.0001)	0.0003 (0.0001)
		60 sec	0.0010 (0.0001)	0.0003 (0.0001)
	0.021	3 sec	0.0009 (0.0001)	0.0003 (0.0001)
		60 sec	0.0121 (0.0001)	0.0003 (0.0001)
	0.042	3 sec	0.0017 (0.0001)	0.0006 (0.0001)
		60 sec	0.0024 (0.0002)	0.0009 (0.0002)
	0.084	3 sec	0.0036 (0.0003)	0.0011 (0.0002)
		60 sec	0.0047 (0.0003)	0.0016 (0.0002)
	0.17	3 sec	0.0083 (0.0003)	0.0028 (0.0006)
		60 sec	0.0117 (0.0003)	0.0034 (0.0007)
	0.42	3 sec	0.024 (0.006)	0.007 (0.003)
		60 sec	0.036 (0.008)	0.012 (0.003)
	0.85	3 sec	0.054 (0.011)	0.019 (0.009)
		60 sec	0.070 (0.016)	0.030 (0.007)
	1.69	3 sec	0.112 (0.013)	0.029 (0.011)
		60 sec	0.160 (0.032)	0.063 (0.029)
	3.38	3 sec	0.236 (0.046)	0.122 (0.076)
		60 sec	0.310 (0.061)	0.128 (0.007)
	6.75	3 sec	0.513 (0.076)	0.431 (0.165)
		60 sec	0.645 (0.052)	0.253 (0.065)

(...) = standard deviation, n = 4.

4.7 Experiment 6: Termite resistance of *Neolamarckia cadamba* and *Hevea brasiliensis* dip-treated using chlorpyrifos, cypermethrin and permethrin

4.7.1 Chlorpyrifos

Two-way ANOVA (refer Appendix B Table 55 to 57) shows that percentage mass loss, absolute mass loss and termite rating differed significantly ($P < 0.05$) in terms of species and concentrations.

According to Table 4.17, both untreated *H. brasiliensis* and *N. cadamba* sustained 100% mass loss. *H. brasiliensis* dip-treated using 0.04 to 0.16% chlorpyrifos for 1 minute failed the test (mass loss: 95.8 – 100%, rating: 0) but *H. brasiliensis* dip-treated using 0.32% concentrations onward had shown significantly increased in the protection of *H. brasiliensis* against termites. *H. brasiliensis* dip-treated using 0.32 to 0.8% had percentage mass loss of 10.8 – 19.2% and rating of 7 – 8.6. Promising protection to *H. brasiliensis* had been observed in those dip-treated using 1.6 and 3.1% whereby the treated *H. brasiliensis* attained termite rating of 9.6 – 9.8. Excellent protection whereby no termite attack had been achieved when the *H. brasiliensis* was dip-treated using concentrations of 6.3 and 12.5%.

For *N. cadamba*, dip-treated *N. cadamba* using 0.04 to 0.16% had shown a significant reduction in percentage mass loss and increased in termite rating, the test blocks sustained rather severe attacks (rating: 5.8 – 7.5). Good protection to *N. cadamba* had been achieved in those dip-treated using 0.32 to 0.8% whereby slight attacked had been recorded (rating: 9). Promising protection to dip-treated *N. cadamba* using 1.6 to 3.1% had been observed whereby the wood blocks sustained nibbling (rating: 9.5). No termite attack was observed in *N. cadamba* dip-treated using 6.3 and 12.5%, hence excellent protection to *N. cadamba* is achieved. In conclusion, both wood species dip-treated using 1.6% and 3.1% achieved

promising performance while excellent protection to wood can be achieved when the wood is treated using 6.3 and 12.5% respectively. All the results were presented in Table 4.17.

Table 4.17: Mean percentage mass loss, absolute mass loss and termite rating of *H. brasiliensis* and *N. cadamba* dip-treated using different concentrations of Chlorpyrifos

Species	Concentrations (%)	Percentage mass loss (%)	Absolute mass loss (mg)	Termite rating
<i>H. brasiliensis</i>	Controls	100 (0) <i>h</i>	5652 (35) <i>h</i>	0 (0) <i>a</i>
	0.04	95.8 (8.5) <i>h</i>	4902 (473) <i>g</i>	0 (0) <i>a</i>
	0.08	100 (0) <i>h</i>	4920 (322) <i>g</i>	0 (0) <i>a</i>
	0.16	99.1 (1.9) <i>h</i>	4918 (422) <i>g</i>	0 (0) <i>a</i>
	0.32	19.2 (5.1) <i>d</i>	1101 (301) <i>de</i>	7.0 (0) <i>c</i>
	0.40	11.2 (3.8) <i>cd</i>	634 (191) <i>bc</i>	7.8 (0.5) <i>d</i>
	0.80	10.8 (10.7) <i>bc</i>	598 (625) <i>ab</i>	8.6 (1.1) <i>e</i>
	1.60	4.0 (6.8) <i>abc</i>	238 (412) <i>ab</i>	9.8 (0.5) <i>g</i>
	3.10	1.6 (2.4) <i>a</i>	86 (134) <i>a</i>	9.6 (0.5) <i>fg</i>
	6.30	-0.1 (0.6) <i>a</i>	-4 (26) <i>a</i>	10 (0) <i>g</i>
	12.50	0.1 (0.5) <i>a</i>	5 (22) <i>a</i>	10 (0) <i>g</i>
<i>N. cadamba</i>	Controls	100 (0) <i>h</i>	2960 (620) <i>f</i>	0 (0) <i>a</i>
	0.04	45.9 (17.6) <i>g</i>	1407 (559) <i>e</i>	5.8 (1.3) <i>b</i>
	0.08	36.7 (8.7) <i>f</i>	1201 (285) <i>de</i>	6.3 (0.5) <i>b</i>
	0.16	28.4 (5.1) <i>e</i>	925 (184) <i>cd</i>	7.5 (0.6) <i>cd</i>
	0.32	3.0 (1.8) <i>ab</i>	72 (32) <i>a</i>	9.0 (0) <i>ef</i>
	0.40	4.6 (3.1) <i>abc</i>	110 (57) <i>a</i>	9.0 (0) <i>ef</i>
	0.80	2.8 (2.6) <i>ab</i>	71 (67) <i>a</i>	9.0 (0) <i>ef</i>
	1.60	2.9 (0.5) <i>ab</i>	77 (13) <i>a</i>	9.5 (0) <i>fg</i>
	3.10	2.6 (1.5) <i>a</i>	57 (32) <i>a</i>	9.5 (0) <i>fg</i>
	6.30	0.2 (1.3) <i>a</i>	5 (31) <i>a</i>	10 (0) <i>g</i>
	12.50	0 (1.0) <i>a</i>	1 (23) <i>a</i>	10 (0) <i>g</i>

(...) = standard deviation, n = 4

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 8.1%

LSD absolute mass loss = 430 mg

LSD termite rating = 0.6

4.7.2 Cypermethrin

Two-way ANOVA (refer Appendix B Table 58 to 60) shows that percentage mass loss, absolute mass loss and termite rating differed significantly ($P < 0.05$) in terms of species and concentrations. According to Table 4.18, both *H. brasiliensis* and *N. cadamba* controls sustained 100% mass loss. It was also observed that *H. brasiliensis* dip-treated using 0.0023, 0.0046, 0.0092% cypermethrin failed to protect the treated *H. brasiliensis* (rating: 0 – 3.0). Improved protection to *H. brasiliensis* can be seen in those wood dip-treated using 0.053 to 0.21% although the treated wood sustained rather moderate severe (rating: 7.5 – 8.8). Cypermethrin at concentrations 0.42 to 0.84% provided promising protection (nibbling) to *H. brasiliensis* with termite rating of 9.5. Excellent protection to *H. brasiliensis* had been achieved in *H. brasiliensis* dip-treated using 1.68 and 3.35% whereby no termite attack had been observed.

As for *N. cadamba*, 0.0023 to 0.0092% did not provide full protection to *N. cadamba* whereby the treated wood sustained very severe attack (rating: 4.5 – 5). Significant reductions in mass losses had been observed in *N. cadamba* dip-treated using 0.053% onwards. Although there was a reduction in the mass loss for *N. cadamba* dip-treated using 0.053 and 0.105%, the wood sustained rather moderate to severe attack (rating: 7 – 8). Promising protection to *N. cadamba* had been observed in those treated using concentrations of 0.42 to 0.84% whereby slight attack to nibbling had been observed (rating 9.3 – 9.5). No termite attack (rating: 10) had been observed in *N. cadamba* dip-treated using 1.68 and 3.35% hence excellent protection to *N. cadamba* was achieved.

In conclusion, *H. brasiliensis* and *N. cadamba* dip-treated using 0.42% and 0.84% achieved promising performance while excellent protection to wood can be achieved when

the wood was treated using 1.68 and 3.35 % respectively. All of the results were shown in Table 4.18.

Table 4.18: Mean percentage mass loss, absolute mass loss and termite rating of *H. brasiliensis* and *N. cadamba* dip-treated using different concentrations of Cypermethrin

Species	Concentrations (%)	Percentage mass loss (%)	Absolute mass loss (mg)	Termite rating
<i>H. brasiliensis</i>	Controls	100 (0) <i>g</i>	5652 (35) <i>f</i>	0 (0) <i>a</i>
	0.0023	87.4 (10.6) <i>f</i>	5493 (647) <i>f</i>	0 (0) <i>a</i>
	0.0046	72.5 (19.7) <i>e</i>	4509 (1256) <i>e</i>	3.0 (2.0) <i>b</i>
	0.0092	79.9 (11.1) <i>ef</i>	4856 (683) <i>e</i>	3.0 (2.0) <i>b</i>
	0.053	20.1 (11.2) <i>c</i>	1136 (619) <i>b</i>	7.5 (0.6) <i>de</i>
	0.105	6.9 (1.1) <i>ab</i>	396 (75) <i>a</i>	8.8 (0.5) <i>efgh</i>
	0.21	10.2 (8.8) <i>abc</i>	523 (433) <i>a</i>	8.4 (1.1) <i>efg</i>
	0.42	4.7 (2.0) <i>ab</i>	264 (104) <i>a</i>	9.5 (0) <i>gh</i>
	0.84	2.4 (3.8) <i>a</i>	146 (231) <i>a</i>	9.5 (0.4) <i>gh</i>
	1.68	-0.2 (1.0) <i>a</i>	-12 (49) <i>a</i>	10 (0) <i>h</i>
	3.35	0.1 (0.5) <i>a</i>	5 (27) <i>a</i>	10 (0) <i>h</i>
<i>N. cadamba</i>	Controls	100 (0) <i>g</i>	2960 (620) <i>d</i>	0 (0) <i>a</i>
	0.0023	79.3 (8.4) <i>ef</i>	1985 (211) <i>c</i>	4.5 (1.0) <i>c</i>
	0.0046	60.2 (5.3) <i>d</i>	1448 (119) <i>bc</i>	4.5 (1.0) <i>c</i>
	0.0092	60.5 (4.4) <i>d</i>	1391 (114) <i>bc</i>	5.0 (1.2) <i>c</i>
	0.053	14.8 (18.1) <i>bc</i>	437 (592) <i>a</i>	7.0 (2.0) <i>d</i>
	0.105	9.8 (1.3) <i>abc</i>	261 (67) <i>a</i>	8.0 (0) <i>def</i>
	0.21	8.0 (3.0) <i>ab</i>	193 (86) <i>a</i>	7.8 (0.5) <i>de</i>
	0.42	3.0 (1.8) <i>a</i>	79 (59) <i>a</i>	9.3 (0.3) <i>fgh</i>
	0.84	1.4 (0.8) <i>a</i>	36 (15) <i>a</i>	9.5 (0) <i>gh</i>
	1.68	0.7 (0.8) <i>a</i>	18 (21) <i>a</i>	10 (0) <i>h</i>
	3.35	0.2 (0.8) <i>a</i>	6 (27) <i>a</i>	10 (0) <i>h</i>

(...) = standard deviation, n = 4

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD % mass loss = 11.3%

LSD absolute mass loss = 598 mg

LSD termite rating = 1.3

4.7.3 Permethrin

Two-way ANOVA (refer Appendix B Table 61 to 63) shows that percentage mass loss, absolute mass loss and termite rating differed significantly ($P < 0.05$) in terms of species and concentrations. Based on Table 4.19, untreated samples for both species had completely eaten by termites (mass loss: 100%). For *H. brasiliensis*, permethrin concentrations ranges from 0.0011 to 0.0044% failed to protect the wood (mass loss: $> 75\%$, rating: 0 – 2). Dip-treated *H. brasiliensis* using 0.008 and 0.021% did not provide full protection to *H. brasiliensis* whereby the treated wood blocks sustained very severe attacks (rating: 4.3 – 5.3). *H. brasiliensis* dip-treated using 0.042 and 0.084% concentrations sustained rather severe to moderate severe attack (rating: 6.5 – 8.5). Concentration 0.17 to 1.69% had shown promising performance to treated *H. brasiliensis* (rating: 9.3 – 9.9). *H. brasiliensis* dip-treated using 3.38 and 6.75% provided *H. brasiliensis* with excellent protection (rating: 10) whereby no termite attack was observed. As for *N. cadamba*, permethrin concentrations ranges from 0.0011 to 0.0022 failed to protect the wood (mass loss: $> 75\%$, rating: 0 – 2). Increased protection to *N. cadamba* observed in those treated using 0.0044% onwards. Although there was a slight reduction in mass loss for *N. cadamba* dip-treated using 0.0044%, the treated wood sustained very severe attack (rating: 4.5). As for *N. cadamba* dip-treated using 0.008 to 0.084%, treated wood sustained moderate to severe attack (rating: 7.3 – 8.4). Good protection had been observed in *N. cadamba* dip-treated using 0.17% whereby slight attack was observed (rating: 9). *N. cadamba* dip-treated using 0.42 to 1.69% achieved promising protection (rating: 9.5 – 9.8). The concentration of 3.38 and 6.75% provided excellent protection to *N. cadamba* (rating: 10). In conclusion, *H. brasiliensis* and *N. cadamba* dip-treated achieved excellent protection to wood was achieved when the wood was treated using 3.38 and 6.75 % respectively.

Table 4.19: Mean percentage mass loss, absolute mass loss and termite rating of *H. brasiliensis* and *N. cadamba* dip-treated using different concentrations of Permethrin

Species	Concentrations (%)	Percentage mass loss (%)	Absolute mass loss (mg)	Termite rating
<i>H. brasiliensis</i>	Controls	100 (0) <i>g</i>	5652 (35) <i>fg</i>	0 (0) <i>a</i>
	0.0011	100 (0) <i>g</i>	6576 (15) <i>g</i>	0 (0) <i>a</i>
	0.0022	80.9 (22.1) <i>f</i>	5222 (1410) <i>f</i>	2.0 (2.3) <i>a</i>
	0.0044	79.4 (23.8) <i>f</i>	5022 (1495) <i>f</i>	2.0 (2.3) <i>a</i>
	0.008	63.3 (29.5) <i>ef</i>	3707 (1590) <i>e</i>	4.3 (3.1) <i>b</i>
	0.017	44.8 (38.8) <i>de</i>	2703 (2382) <i>cde</i>	5.3 (3.6) <i>bcd</i>
	0.021	47.7 (37.2) <i>de</i>	2815 (2212) <i>cde</i>	5.3 (3.6) <i>bcd</i>
	0.042	32.9 (18.7) <i>cd</i>	1968 (1114) <i>cd</i>	6.5 (1.7) <i>cde</i>
	0.084	11.6 (4.9) <i>ab</i>	711 (291) <i>ab</i>	8.5 (0.6) <i>efgh</i>
	0.17	7.0 (7.5) <i>ab</i>	424 (451) <i>a</i>	9.3 (0.3) <i>fgh</i>
	0.42	1.2 (0.3) <i>a</i>	71 (16) <i>a</i>	9.5 (0) <i>gh</i>
	0.85	0.9 (0.6) <i>a</i>	50 (34) <i>a</i>	9.5 (0) <i>gh</i>
	1.69	0.9 (2.3) <i>a</i>	47 (123) <i>a</i>	9.9 (0.3) <i>h</i>
	3.38	0.2 (0.7) <i>a</i>	11 (36) <i>a</i>	10 (0) <i>h</i>
	6.75	0.1 (0.8) <i>a</i>	3 (40) <i>a</i>	10 (0) <i>h</i>
<i>N. cadamba</i>	Controls	100 (0) <i>g</i>	2960 (620) <i>de</i>	0 (0) <i>a</i>
	0.0011	76.3 (10.3) <i>f</i>	2018 (265) <i>cd</i>	2.0 (2.3) <i>a</i>
	0.0022	100 (0) <i>g</i>	2603 (25) <i>cd</i>	0 (0) <i>a</i>
	0.0044	70.5 (7.4) <i>f</i>	1791 (204) <i>bc</i>	4.5 (1.0) <i>bc</i>
	0.008	24.1 (11.5) <i>bc</i>	613 (343) <i>a</i>	7.3 (0.5) <i>def</i>
	0.017	10.6 (4.9) <i>ab</i>	279 (106) <i>a</i>	7.8 (0.5) <i>efg</i>
	0.021	10.2 (6.5) <i>ab</i>	271 (201) <i>a</i>	7.8 (0.5) <i>efg</i>
	0.042	8.9 (1.3) <i>ab</i>	225 (35) <i>a</i>	8.0 (0) <i>efgh</i>
	0.084	8.6 (8.8) <i>ab</i>	236 (247) <i>a</i>	8.4 (1.1) <i>efgh</i>
	0.17	5.7 (4.8) <i>ab</i>	140 (102) <i>a</i>	9.0 (0.7) <i>fgh</i>
	0.42	3.4 (1.4) <i>a</i>	83 (39) <i>a</i>	9.5 (0) <i>gh</i>
	0.85	2.1 (3.1) <i>a</i>	53 (74) <i>a</i>	9.5 (0.4) <i>gh</i>
	1.69	0.7 (4.2) <i>a</i>	21 (104) <i>a</i>	9.8 (0.3) <i>gh</i>
	3.38	0.5 (2.1) <i>a</i>	15 (53) <i>a</i>	10.0 (0) <i>h</i>
	6.75	0.3 (1.1) <i>a</i>	8 (30) <i>a</i>	10.0 (0) <i>h</i>

(...) = standard deviation, n = 4

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD % mass loss = 19.6%

LSD absolute mass loss = 1144 mg

LSD termite rating = 2.0

Table 4.20 shows the mean actual retentions of particular active ingredients (chlorpyrifos, cypermethrin and permethrin) in *H. brasiliensis* and *N. cadamba* dip-treated using different concentrations. As for chlorpyrifos, the lowest retention recorded was 0.003% m/m was observed in *H. brasiliensis* dip-treated using 0.04% chlorpyrifos and the highest retention recorded was 5.503% m/m observed in *N. cadamba* treated using the 12.5% chlorpyrifos. For cypermethrin, *H. brasiliensis* dip-treated using 0.0023% cypermethrin recorded the lowest retention which was 0.0002% m/m while *N. cadamba* dip-treated using 3.35% cypermethrin recorded the highest retention which was 1.218% m/m. As for permethrin, the lowest retention was observed in *H. brasiliensis* dip-treated using 0.0011% permethrin which was 0.0001% m/m while the highest retention was recorded in *N. cadamba* dip-treated using 6.75% permethrin which was 2.196% m/m.

Table 4.20: Mean actual retentions of particular chemicals' active ingredients in woods

Active Ingredients	Concentrations (%)	Actual Retentions (% m/m)	
		<i>H. brasiliensis</i>	<i>N. cadamba</i>
Chlorpyrifos	0.04	0.003 (0.001)	0.004 (0)
	0.08	0.006 (0.002)	0.009 (0.001)
	0.16	0.012 (0.003)	0.019 (0.006)
	0.32	0.018 (0.001)	0.078 (0.049)
	0.40	0.022 (0.002)	0.092 (0.029)
	0.80	0.052 (0.005)	0.201 (0.051)
	1.60	0.140 (0.014)	0.627 (0.144)
	3.10	0.277 (0.050)	1.890 (0.915)
	6.30	0.485 (0.007)	4.330 (2.260)
	12.50	0.996 (0.124)	5.503 (1.966)
Cypermethrin	0.0023	0.0002 (0)	0.001 (0.001)
	0.0046	0.0004 (0)	0.001 (0)
	0.0092	0.0008 (0.0001)	0.002 (0)
	0.053	0.003 (0)	0.010 (0.004)
	0.105	0.006 (0.001)	0.016 (0.006)
	0.21	0.015 (0.001)	0.048 (0.009)
	0.42	0.036 (0.007)	0.079 (0.025)
	0.84	0.092 (0.009)	0.289 (0.098)
	1.68	0.149 (0.029)	0.927 (0.277)
	3.35	0.310 (0.041)	1.218 (0.467)
Permethrin	0.0011	0.0001 (0)	0.0002 (0)
	0.0022	0.0002 (0)	0.0004 (0)
	0.0044	0.0005 (0.0001)	0.0009 (0.0002)
	0.008	0.0005 (0)	0.0015 (0.0004)
	0.017	0.0009 (0)	0.003 (0.001)
	0.021	0.0012 (0)	0.004 (0.001)
	0.042	0.0024 (0.0001)	0.007 (0.002)
	0.084	0.0051 (0.0002)	0.013 (0.004)
	0.17	0.012 (0.002)	0.039 (0.008)
	0.42	0.033 (0.005)	0.164 (0.081)
	0.85	0.073 (0.008)	0.236 (0.053)
	1.69	0.155 (0.011)	1.399 (1.188)
	3.38	0.283 (0.051)	1.845 (1.326)
	6.75	0.657 (0.191)	2.196 (0.640)

(...) = standard deviation, n = 4.

4.8 Experiment 7: Termite resistance of *Neolamarckia cadamba* and *Hevea brasiliensis*

vacuum pressure-treated with chlorpyrifos, cypermethrin,
deltamethrin and permethrin

4.8.1 Chlorpyrifos

Two-way ANOVA (refer Appendix B Table 64 to 66) shows that the percentage mass loss, absolute mass loss and termite rating were found significantly different ($P < 0.05$) in terms of tested species only. Hence, no multiple comparisons were done to Table 4.21.

It can be said that the wood species and amount of retentions of agro-insecticide retained contributed to the improvement of wood protection. Part of it mainly due to the nature of the wood species, *H. brasiliensis* is known to be likable by termites as compared to *N. cadamba*. Another observable factor was that kelempayan tend to retain chlorpyrifos much more than rubberwood.

Table 4.21: Mean percentage mass loss, absolute mass loss and termite rating of *H. brasiliensis* and *N. cadamba* vacuum pressure-treated to different target retentions of Chlorpyrifos

Species	Target retention (% m/m)	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>H. brasiliensis</i>	Control	100 (0)	4995 (311)	0 (0)
	0.002	100 (0)	5008 (320)	0 (0)
	0.004	100 (0)	5038 (317)	0 (0)
	0.008	100 (0)	5153 (224)	0 (0)
<i>N. cadamba</i>	Control	87.5 (18.5)	2135 (664)	1.0 (2.0)
	0.002	91.2 (10.7)	2286 (518)	1.0 (2.0)
	0.004	79.0 (19.7)	1914 (561)	1.5 (3.0)
	0.008	68.0 (14.0)	1744 (576)	4.5 (1.0)

(...) = standard deviation, n= 4.

According to Table 4.21, *H. brasiliensis* vacuum pressure-treated to target retentions of Chlorpyrifos used in this experiment were too minimal and not able to provide protections

to wood. None of the wood vacuum pressure-treated to the target retentions able to provide protections to *H. brasiliensis* whereby all the treated *H. brasiliensis* were completely consumed at the end of the test. As for *N. cadamba* vacuum pressure-treated to 0.002 to 0.004% m/m target retentions failed to provide protection to the wood whereby very low rating of 1.0 was recorded. Although there was a certain degree of reduction in the mass loss of *N. cadamba* vacuum pressure-treated to 0.008% m/m target retention, they sustained considerably very severe attack with mean percentage mass loss of 68% and rating of 4.5.

Since only species were found to be significant in two-way ANOVA. One-way ANOVA (refer Appedix B Table 67 to Table 69) had been done to test the significance difference of percentage mass loss, absolute mass loss and termite rating of these species. One-way ANOVA shows that percentage mass loss, absolute mass loss and termite rating differed significantly ($P < 0.05$) among species. Table 4.22 shows that both *N. cadamba* and *H. brasiliensis* was non-resistant to termite (high termite mass loss) and observably termites tend to prefer *H. brasiliensis* (100% mass loss) compared to *N. cadamba* (81.4% mass loss). Higher absolute mass loss also recorded in *H. brasiliensis* as compared to *N. cadamba*. As for termite rating, *H. brasiliensis* was rated 0 and *N. cadamba* was rated 2. From this experiment, none of the wood treated to the target retentions of Chlorpyrifos used in this treatment provides protections to both wood species. Higher retentions are to be added to determine the optimal retention requirement as to protect non-resistant wood in the near future study.

Table 4.22: Mean percentage mass loss, absolute mass loss and termite rating of tested species

Species	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>N. cadamba</i>	81.4 (17.1) <i>a</i>	2020 (563) <i>a</i>	2 (2.4) <i>a</i>
<i>H. brasiliensis</i>	100 (0) <i>b</i>	5048 (272) <i>b</i>	0 (0) <i>b</i>

(...) = standard deviation, n= 16

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 8.7%

LSD absolute mass loss = 319 mg

LSD termite rating = 1.2

4.8.2 Cypermethrin

Two-way ANOVA (refer Appendix B Table 71) shows that absolute mass loss was significant in terms of both wood species and target retentions, and thus LSD was done to determine the differences of absolute mass loss among wood species and target retentions.

Based on Table 4.23, the absolute mass loss for untreated *H. brasiliensis* and *N. cadamba* was relatively higher than the vacuum pressure-treated counterparts. It can be observed that generally as the target retention increased, the absolute mass loss of the treated wood reduced, indicate that certain degree of wood protection was achieved. For *H. brasiliensis*, a significant reduction in mass loss was observed in *H. brasiliensis* vacuum pressure-treated to target retention of 0.025% m/m that sustained absolute mass loss of 1331 mg as compared to the *H. brasiliensis* control (4966 mg). Further reduction in mass loss also observed in *H. brasiliensis* vacuum pressure-treated to target retention 0.05 and 0.1% m/m. The same trend also observed in treated *N. cadamba*. Significant reduction in mass loss can be observed in *N. cadamba* vacuum pressure-treated to 0.025% m/m target retention that sustained 638 mg compared to the *N. cadamba* controls (2713 mg). Continual reduction in mass loss of *N. cadamba* to termites as the wood vacuum pressure-treated to higher target retentions (e.g. 0.05 and 0.1% m/m).

Table 4.23: Mean percentage mass loss, absolute mass loss and termite rating of *H. brasiliensis* and *N. cadamba* vacuum pressure-treated to different target retentions of Cypermethrin

Species	Target retention (% m/m)	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>H. brasiliensis</i>	Control	100 (0)	4966 (210) <i>f</i>	0 (0)
	0.025	25.8 (9.9)	1331 (488) <i>d</i>	8.4 (1.1)
	0.05	8.8 (1.3)	702 (523) <i>cd</i>	9.6 (0.3)
	0.1	4.9 (1.6)	248 (70) <i>abc</i>	10 (0)
<i>N. cadamba</i>	Control	100 (0)	2713 (298) <i>e</i>	0 (0)
	0.025	26.7 (12.8)	638 (312) <i>bc</i>	8.8 (1.2)
	0.05	8.7 (6.6)	211 (158) <i>ab</i>	9.4 (0.5)
	0.1	7.1 (5.6)	178 (139) <i>a</i>	9.5 (0.4)

(...) = standard deviation, n = 4

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD absolute mass loss = 459 mg

One-way ANOVA for percentage mass loss and termite ratings versus target retentions was done since two-way ANOVA (refer Appendix B Table 70 & 72) indicated that percentage mass loss and termite rating was significantly different ($P < 0.05$) in terms of target retentions only. Least Significant Difference was conducted to determine the differences among percentage mass loss and termite rating in terms of target retentions.

According to Table 4.24, percentage mass loss and termite rating was significantly different in terms of controls and treated counterparts. Untreated controls of both wood species were completely consumed (mass loss: 100%) indicated that these controls critically need to be protected using wood protecting chemicals. It was observed that drastic reduction in percentage mass loss in treated counterparts, whereby their percentage mass losses were less than 30%. Both wood species vacuum pressure-treated to target retention of 0.025% m/m cypermethrin successfully suppressed the attack to 26.2% while lower percentage mass losses were observed in wood vacuum pressure-treated to 0.05 and 0.1% m/m. As for termite rating, untreated control was rated 0 (failure) while the treated

counterparts attained termite rating of more than 8. Wood vacuum pressure-treated to target retention of 0.025% cypermethrin sustained moderate attack (rating 8.6) from termites while wood vacuum pressure-treated to target retention of 0.05 and 0.1% m/m cypermethrin provided good protection to wood whereby the treated wood sustained nibbling (rating: 9.5 – 9.8). As a conclusion, treating wood to target retention of 0.05% m/m cypermethrin and above can provide good protection to wood.

Table 4.24: Mean percentage mass loss and termite rating of treated wood vacuum pressure-treated to different target retentions of Cypermethrin

Target retentions (% m/m)	Percentage mass loss (%)	Rating
Controls	100 (0) <i>c</i>	0 (0) <i>a</i>
0.025	26.2 (10.6) <i>b</i>	8.6 (1.1) <i>b</i>
0.05	8.7 (4.4) <i>a</i>	9.5 (0.4) <i>c</i>
0.1	6.0 (4.0) <i>a</i>	9.8 (0.4) <i>c</i>

(...) = standard deviation, n= 8

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 6.2%

LSD termite rating = 0.6

4.8.3 Deltamethrin

Two-way ANOVA (refer Appendix Table 76) demonstrated that absolute mass loss was significantly different ($P < 0.05$) in terms of test wood species and target retentions used.

According to Table 4.25, absolute mass loss of *H. brasiliensis* and *N. cadamba* control was relatively higher than the vacuum pressure-treated counterparts. Significant reduction in mass loss can be seen in vacuum pressure-treated *H. brasiliensis* to target retention of 0.0013% m/m that sustained 1293 mg mass loss compared to control (4495 mg). There was no significant different in absolute mass loss of *H. brasiliensis* vacuum pressure-treated to target retentions of 0.0025 and 0.0051% m/m. As for *N. cadamba*, a significant reduction in the mass loss was observed in *N. cadamba* vacuum pressure-treated to target retention

0.0013% m/m that sustained 1060 mg mass loss compared to its control counterpart (2291 mg). Continual reduction in the absolute mass loss was observed in *N. cadamba* vacuum pressure-treated to target retentions of 0.0025 and 0.0051% m/m deltamethrin.

Table 4.25: Mean percentage mass loss, absolute mass loss and termite rating of *H. brasiliensis* and *N. cadamba* vacuum pressure-treated to different target retentions of Deltamethrin

Species	Target retention (% m/m)	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>H. brasiliensis</i>	Control	100 (0)	4495 (217) <i>e</i>	0 (0)
	0.0013	27.7 (1.3)	1293 (117) <i>c</i>	8.5 (1.0)
	0.0025	8.1 (3.6)	377 (179) <i>a</i>	9.5 (0)
	0.0051	8.4 (3.5)	400 (147) <i>a</i>	9.5 (0)
<i>N. cadamba</i>	Control	100 (0)	2291 (185) <i>d</i>	0 (0)
	0.0013	46.1 (36.6)	1060 (828) <i>bc</i>	6.4 (4.3)
	0.0025	24.5 (8.4)	630 (225) <i>ab</i>	8.3 (0.5)
	0.0051	11.3 (8.0)	263 (189) <i>a</i>	9.3 (0.3)

(...) = standard deviation, n = 4

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD absolute mass loss = 495 mg

Two-way ANOVA (refer Appendix Table 75 & 77) shows that the percentage mass loss and termite rating were found significantly different ($P < 0.05$) among target retentions only and thus one-way ANOVA for the percentage mass loss and termite rating versus target retentions was done. LSD was conducted to determine the differences among percentage mass loss and termite rating in comparing target retentions.

Based on Table 4.26, percentage mass loss and termite rating was significantly different in terms of the control and their treated counterparts. The untreated control of both wood species was 100% consumed. The percentage mass loss of treated wood drastically reduced to below 40%. Wood vacuum pressure-treated to target retention of 0.0013% m/m deltamethrin successfully suppressed the attack done to wood to 36.9% while lower

percentage mass loss was achieved in wood vacuum pressure-treated to target retentions of 0.0025 and 0.0051% m/m.

As for termite rating, the control was rated 0 (failure) while the treated counterparts were rated more than 7. Although wood vacuum pressure-treated to target retention of 0.0013% m/m improved the resistance of wood to termites, the treated wood sustained moderate severe attack (rating: 7.4). However, wood vacuum pressure-treated to target retention 0.0025 and 0.0051% m/m deltamethrin improved the protection of wood (rating: 8.9 – 9.4) against termite.

Table 4.26: Mean percentage mass loss and termite rating of treated wood vacuum pressure-treated to different target retentions of Deltamethrin

Target retention (% /m/m)	Percentage mass loss (%)	Rating
Controls	100 (0) <i>c</i>	0 (0) <i>a</i>
0.0013	36.9 (26.0) <i>b</i>	7.4 (3.1) <i>b</i>
0.0025	16.3 (10.6) <i>a</i>	8.9 (0.7) <i>bc</i>
0.0051	9.8 (5.9) <i>a</i>	9.4 (0.2) <i>c</i>

(...) = standard deviation, n = 8

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 14.6%

LSD termite rating = 1.6

4.8.4 Permethrin

Two-way ANOVA (refer Appendix B Table 80 to Table 82) show there was significant difference ($P < 0.05$) in percentage mass loss, absolute mass loss and termite rating among tested species, target retentions and the interaction. According to Table 4.27, both untreated *N. cadamba* and *H. brasiliensis* sustained 100% mass loss with termite rating 0. In terms of absolute mass loss, untreated control of both wood species had relatively higher absolute mass loss as compared to their treated counterparts.

Increased target retention enhanced the protections on *H. brasiliensis*. For instance, *H. brasiliensis* vacuum pressure-treated to 0.008% m/m target retention permethrin sustained rather severe attack (mass loss: 40.3%, rating: 6.3). However, *H. brasiliensis* vacuum pressure-treated to target retention of 0.017% m/m increased the protection of wood that it sustained moderate attack (mass loss: 28.4, rating: 8.3). *H. brasiliensis* vacuum pressure-treated to 0.034% m/m obtained good protection with slight attack (rating: 9.1).

As for *N. cadamba* vacuum pressure-treated to target retentions of 0.008 and 0.017% m/m permethrin failed to protect *N. cadamba* from termites (mass loss: > 70%, rating: 1 – 1.5). However, *N. cadamba* vacuum pressure-treated to target retention of 0.034% m/m provided good protection to *N. cadamba* with slight attack (rating: 9).

Table 4.27: Mean percentage mass loss, absolute mass loss and termite rating of *H. brasiliensis* and *N. cadamba* vacuum pressure-treated to different target retentions of Permethrin

Species	Target retention (% m/m)	Percentage mass loss (%)	Absolute mass loss (mg)	Rating
<i>H. brasiliensis</i>	Control	100 (0) <i>d</i>	4811 (542) <i>e</i>	0 (0) <i>a</i>
	0.008	40.3 (21.7) <i>b</i>	1975 (1107) <i>cd</i>	6.3 (1.7) <i>b</i>
	0.017	28.4 (3.2) <i>ab</i>	1448 (230) <i>bc</i>	8.3 (0.5) <i>bc</i>
	0.034	16.7 (7.1) <i>a</i>	930 (349) <i>ab</i>	9.1 (0.3) <i>c</i>
<i>N. cadamba</i>	Control	100 (0) <i>d</i>	2722 (46) <i>d</i>	0 (0) <i>a</i>
	0.008	86.2 (21.5) <i>cd</i>	2340 (598) <i>d</i>	1.0 (2.0) <i>a</i>
	0.017	76.7 (23.0) <i>c</i>	2084 (634) <i>cd</i>	1.5 (3.0) <i>a</i>
	0.034	16.8 (8.2) <i>a</i>	462 (211) <i>a</i>	9 (0.7) <i>c</i>

(...) = standard deviation, n = 4

Within column, mean values sharing the same italicized alphabets denote no significant difference by LSD

LSD percentage mass loss = 20.6%

LSD absolute mass loss = 816 mg

LSD termite rating = 2.1

In this treatment, it was found wood vacuum pressure-treated to target retention of 0.034% m/m permethrin could not fully protect the wood. Thus, it is vital to determine the optimal retention required to achieve excellent protection to non-resistant wood.

According to Table 4.28, it can be seen that whether treated wood has achieved the target retentions or either wise. For the case of chlorpyrifos, none of the *H. brasiliensis* achieved any of the target retentions but *N. cadamba* exceedingly achieved the target retentions.

As for cypermethrin, treated *H. brasiliensis* again did not achieve the target retentions but *N. cadamba* again exceedingly achieved the target retentions. For permethrin, *H. brasiliensis* exceedingly achieved target retentions of 0.008% and 0.017% m/m but did not achieved target retention of 0.034% m/m. *N. cadamba*, on the other hand, did not reach any of the target retentions of permethrin. As for deltamethrin, *H. brasiliensis* achieved the exact target retention of 0.0013% and exceedingly achieved target retentions of 0.0025% and 0.0051% m/m while *N. cadamba* achieved the exact target retention of 0.0025% m/m and exceedingly achieved the other target retentions of deltamethrin.

Table 4.28: Mean actual retentions of active ingredients in treated wood

Active Ingredients	Target Retentions (% m/m)	Actual Retentions (% m/m)	
		<i>H. brasiliensis</i>	<i>N. cadamba</i>
Chlorpyrifos	0.002	0.0018 (0.0004)	0.0022 (0.0004)
	0.004	0.0036 (0.0007)	0.0045 (0.0004)
	0.008	0.0072 (0.0011)	0.0086 (0.0012)
Cypermethrin	0.025	0.018 (0.003)	0.029 (0.003)
	0.050	0.043 (0.003)	0.058 (0.006)
	0.100	0.075 (0.009)	0.111 (0.012)
Permethrin	0.008	0.009 (0.002)	0.007 (0.001)
	0.017	0.018 (0.002)	0.015 (0.001)
	0.034	0.028 (0.002)	0.030 (0.001)
Deltamethrin	0.0013	0.0013 (0.0002)	0.0014 (0.0001)
	0.0025	0.0027 (0.0001)	0.0025 (0.0003)
	0.0051	0.0052 (0.0004)	0.0052 (0.0004)

(...) = standard deviation, n = 4.

CHAPTER 5

DISCUSSION

5.1 Termite collections

It was found that genus *Coptotermes* (41.5%) was a prominent genus found in this survey. Genus *Schedorhinotermes* (20.8%), *Macrotermes* (15.09%) and *Nasutitermes* (11.3%) also contributed to the numbers in the statistic. In this survey, *Coptotermes* not only found in urban structures (residential houses) but also in the forest attacking wood products in the DTI UNIMAS test site. Genus *Coptotermes* also found attacking ornamental trees (particularly *Araucaria cunninghamii* planted around UNIMAS campus, fruit trees planted in residential houses and plantation trees (e.g. *Acacia*). This survey concurred with Tho and Kirton (1998), which also reported that high incidence of *C. curvignathus* attack in conifer plantation in Bahau. The most preferred conifer species that *C. curvignathus* tend to attack was *Araucaria cunninghamii* (7.72%) and *A. hunsteinii* (6.65%). Lenz (2005), also reported that *C. curvignathus* was found to be the most dominant species in standing *Araucaria* while *Schedorhinotermes* was mainly found in fallen log and dead stumps in *Araucaria* plantation in Teluk Bahang, Penang. There was another case whereby *Coptotermes* attacked dead portion and living heartwood of *Acacia* in *Acacia mangium* plantation (Kirton, 1999). This survey shows that *Coptotermes* in residential houses mainly spotted attacking wall skirting, built-in cabinet, laminating flooring, door frames and store rooms. Lee (2000), also reported that common locations of infestation of termites within building usually can be found in door or window frame, skirting area, built-in cabinet, parquet flooring and others. This survey also found that *Schedorhinotermes* often attacking wood products (for instance L-joints) exposed in the DTI UNIMAS test site and as well

attacking both living and dead forest trees. *Nasutitermes* mainly found in forest area attacking the living and dead trees. Survey also found that *Nasutitermes* attacking wood products (roof trusses and hand rail). Thus, their infestation cannot be neglected as they too attack wooden structures found in local community parks. It was observed that *Coptotermes*, *Schedorhinotermes* and *Nasutitermes* are wood feeders and known to be termite pest. Nur Syuhaddah and Aumugam (2017), mentioned that termite pests are usually from wood feeders that infest living trees. Aiman *et al.* (2014), reported that limited food resources causing these wood feeders to feed on wood products as alternatives. Lee *et al.* (2005), reported in Malaysia and Singapore, few common species of termite that infest building and structure include *Coptotermes*, *Schedorhinotermes*, *Microcerotermes*, *Nasutitermes*, *Globitermes* and *Odontotermes*. *Coptotermes* (85%) was found economically important species infesting building structures. In Thailand, *C. gestroi* infested houses in rural area (Lee *et al.*, 2005). As in Australia, *Coptotermes* and *Schedorhinotermes* are widely found in mainland and tropical region of Australia while *Nasutitermes* are widely found in the tropical region of Australia. *Coptotermes* and *Schedorhinotermes* do not only prevail in urban buildings and structures but also infesting the plantation sector.

In this survey, there was no evidence observed that *Macrotermes* attacking wooden structures. All of the *Macrotermes* were collected from their mounds. However, Lee (2000), described that *Macrotermes* as peridomestic pest in the urban area that there were cases *M. gilvus* attacked wooden residential structures, rubberwood and oil palm plantations. *Globitermes* and *Bulbitermes* was collected from dead forest trees while *Hospitalitermes* was found attacking a tree bark indicated that these termite species are wood feeders and it concurred with survey by Jones and Prasetyo (2002), as well as

Jalaludin *et al.* (2018), that these species were observed to be wood feeders but also includes grass-feeders, litter-feeders and micro-epiphyte-feeders. Termite species of *Pericarpritermes* and *Procapritermes* was collected crawling on the soil surface. Jones and Prasetyo (2002) also observed that these species are soil feeders.

Termite species inventory is essential particularly to identify the main endemic species, their economic importance and virulence in designated area as well as the right approach to control them (Lee *et al.*, 2004; Kutnik *et al.*, 2018).

5.2 Basic physical properties, extractive contents and natural termite resistance of tested species

Among all the tested wood, the density of *Alstonia* spp. (pulai) was found to be the lowest which was 0.247 g/cm³ while the densest wood tested was selangan batu (*S. pluriscostata*) which was 0.919 g/cm³. Pulai, *S. macrophylla* (engkabang), *D. moluccana* (sawih), *M. pearsonii* (benuah), *S. ovalis* (meranti luang) and *N. cadamba* (kelempayan) were examples of Light Hardwood (<720 kg/m³) while *Lithocarpus* spp. (mempening), *F. fragrans* (tembusu), *A. grossivenia* (mersawa), *Dipterocarpus* spp. (keruing), *Syzygium* spp. (kelat) and *S. kunstleri* (selangan merah) were examples of Medium Hardwood (720 – 880 kg/m³) whereas *Kokoona* spp. (mata ulat), *E. zwageri* (belian) and *S. pluriscostata* were examples of Heavy Hardwood (>880 kg/m³). Brinell hardness does not necessarily affected only by density but by wood anatomical structures and direction of the materials. This explained the nature of the results in experiment 1. For instance, *S. pluriscostata* recorded the highest density only had BHN of 0.0122. On the contrary, chengal with density of 0.869 g/cm³ had a BHN of 0.0241. The previous study also found that wood extractives influence density appreciably and making density plays roles in wood characteristics

including durability (Wong *et al.*, 1983; Ona *et al.*, 1997; Antwi-Boasiako & Pitman, 2009). Higher density wood also has a higher resistance towards wood destroying organisms (Kadir & Hale, 2012; Amusant *et al.*, 2014). Interestingly belian used in this study was found less dense to *S. pluriscostata* that it was suspected that the belian was sampled from a younger aged tree. It was found that wood density varies in terms of their age group (Bhat *et al.*, 1990) that wood density of *E. grandis* was lower in 5 years old tree than 9 years old tree.

For water permeability, generally LHW exhibited higher capability to absorb water and hence recorded higher water permeability index as compared MHW and HHW. For instance, Kelempayan (LHW) had water permeability index of $0.087 \text{ gcm}^{-3}\text{h}^{-1}$ compared to *Syzygium sarawakensis* (ubah urat) (MHW) and belian (HHW) had water permeability index of $0.040 \text{ gcm}^{-3}\text{h}^{-1}$ and $0.023 \text{ gcm}^{-3}\text{h}^{-1}$ respectively. Water uptake behaviour mainly affected by the microstructure of wood and the presence of extractives (Michalec & Niklasová, 2006). Permeability sometime influenced and interfere by the presence of fats and wax in wood properties (Barnett & Jeronimidis, 2003). The difference in rate of water permeability among wood species mainly affected the rate of diffusion of both water vapour and bound water between macroscopic surface and the core of the specimen and the relaxation of the swelling and/or temperature (Engelund *et al.*, 2013). Another factor might result in higher uptake or absorptions and penetration of solution is by increasing the dipping times (Humar & Lesar, 2009; Ma *et al.*, 2013). Mori *et al.* (2014), found that increased density slower the decomposition rates of 32 Bornean wood species and greater water permeability will enhance the decomposition rate of wood species.

As for wood extractive contents, generally cold water extraction extracted the least extractives from the wood as compared to hot water extraction and methanol extractions.

The ranges of extractive extracted using cold water extraction were 0.8 to 14.6%. As for hot water extraction, the ranges of extractives were 2.9 to 18.5% whereas the ranges of extractives extracted using methanol extraction were 1.6 to 23.3%. It is believed that wood extractives contributed to wood durability as some of the wood extractives extracted may not have potency towards wood deteriorating agents (e.g. fungi and termites) while some of the extractives extracted from heavy hardwoods are toxic to termites. For instance, *T. grandis* (teak), belian and *N. heimii* (chengal) hardwood extractives are known to have antitermitic properties and are toxic to termites and thus make the wood more durable to termites. For instance, Hassan *et al.* (2018), reported that teak's extractive possesses minimal to strong antifeedant at various extractive concentrations whereby termites move towards untreated counterpart for feeding in repellency and antifeedant bioassay. In this study, for Malaysian-grown teak, cold water extracted 3.1%, hot water extracted 7.7% and methanol extracted 4.8%. For Burmese-grown teak, cold water extracted 3.2% hot water extracted 7.4% and methanol extracted 14%. Potent extractive in teak wood explained the reason Malaysian and Burmese-grown teak were naturally resistant to termite as shown by rather high termite rating of 9.1 and 9.5 respectively. Dungani *et al.* (2012), found that the age of teak wood influences the potency of the extractives means that the extractive of matured wood are more toxic. Matured wood would have better termite resistance compared to younger age wood due to the presence of high concentration of toxic compound in matured wood. It was also found that acetone-water (9:1) extracted more extractive as compared to petroleum ether and ethanol-water (8:2) extraction and 10% of the extractives give 100% termite mortality. Brocco *et al.* (2015), found that pinus treated with teak hardwood extractives extracted using absolute ethanol had the lowest percentage mass loss (3.35%) caused by *N. corniger* compared to controls (9.76% mass loss).

Another interesting wood species that its extractive can be used as a natural preservative is Chengal. Cold water extracted 7%, hot water extracted 16.9% and methanol extracted 13.6%. In this study, chengal was found to be naturally resistant to termite with termite rating of 9.3. Yamamoto & Hong (1988), also found that cold water extraction method extracted the least extractives from chengal (1.8 – 3.6%) but in their case, methanol extracted the most extractives from chengal (10.9 – 23.4%) and hot water extraction yielded 5.9 to 10.7. It was expected that methanol extraction using Soxhlet extraction would extract more extractive compared to methanol extraction using hot water bath. Kadir *et al.* (2014), found that the antitermitic properties of chemical compounds increased as the concentrations increased and that the chemical compounds extracted from bark and heartwood of *N. heimii* was more potent compared to those extracted from *M. utilis*. At the end of 14 days termite test, the consumptions of paper discs by *C. gestroi* were lower than the controls. For toxicity test, the chengal bark was found to be strongly toxic with LC50 of 1.5% followed by the chengal heartwood. Extractive extracted from wood may leave the extracted wood subjected to biodeteriogens (wood destroying insects and decay). For instance, Xie *et al.* (2012), found that extracted chengal were attacked by decay fungi *C. puteana* and *T. versicolor* with the mass loss of 36 and 28% respectively. In this study, *Gluta* spp. / *Melanochyla* spp. (rengas) yielded hot water extractives of 17.4% and methanol extractives of 12.9%, *D. polyphylla* (jelutong) yielded hot water extractives of 13.7% and methanol extractives of 7.9% while *H. brasiliensis* (rubberwood) yielded hot water extractives of 15.5% and methanol extractives of 3.6% which corresponded to Yamamoto and Hong (1989), which also found that chengal and rengas had higher extractives (hot and methanol) as compared to jelutong and rubberwood.

In this experiment, all the tested woods were subjected to sheltered aboveground termite test simulating H2 condition and their natural termite resistance to *C. curvignathus* were determined accordingly. 15 species were found to be non-resistant (rating: 0 – 4.5), 25 species were found to moderately resistant (6.5 – 8.9), 17 species were resistant (9 – 9.4) and 12 species were highly resistant (≥ 9.5) to termites. Examples of non-resistant wood species were *P. menziesii* (Douglas fir), *P. radiata* (radiata pine) rubberwood, jelutong, kelempayan and *Mangifera pajang* (pajang). All these mentioned species sustained 100% mass loss. Rubberwood is well known for its various uses in wood industries but this species also known to be non-resistant to termite whereby untreated rubberwood was completely destroyed. Grace *et al.* (1997), reported that in an accelerated field test, rubberwood completely failed the test. Wong (2005), also found that untreated rubberwood sustained a very heavy attack from termites and was rated 1 to 2 compared to their treated counterparts with imidacloprid which rated 9.5 in leached test and 9 in non-leached test. Untreated rubberwood controls used in preservative testing study by Tawi and Wong (2016), also completely destroyed which corresponded to the finding in this study and Ponpinij *et al.* (2016), also revealed that rubberwood (39.5% mass loss) is suitable to be used as termite food since it is non-resistant. Since rubberwood is non-resistant, it can be readily used as material for termite food for instance material to produce bait toxicants, besides that rubberwood can be used as wood controls for termite testing especially in tropical condition. Ariana *et al.* (2012), reported that rubberwood indeed can be included as control in the Indonesian standard for laboratory termite comparative study due to its high mass loss. Wood products containing rubberwood also will attract termite to consume it. For instance, untreated rubberwood chipboard had a mean rating of 4.6 (heavy attack) subjected to *C. formosanus* in no choice test of laboratory bioassays (Wong & Grace,

2004). Wong (2005) and Hadjib *et al.* (2012), also stressed the need to protect rubberwood prior to usage due to their susceptible to termites.

Other non-resistant wood species which is widely used are jelutong, Douglas fir, pine and kelempayan. Daß *et al.* (2015), reported that pine controls sustained high mass loss (3.52%) compared to jelutong (3.19%) in choice test. Grace and Tome (2005), found that Douglas fir (control) sustained severe attack from *C. formosanus* with visual rating rated less than 2 in both choice and no choice termite laboratory bioassay. Wood products made of kelempayan needed to be protected whereby products with untreated kelempayan are susceptible to termite attack. For instance, particleboard (both medium density and high density particleboard) made of kelempayan (or jabon in Indonesia) found to be favoured (5 – 6.9% mass loss) by *C. curvignathus* in no choice test compared to mangium particleboard (3.6 – 4.1% mass loss). This confirmed that kelempayan indeed preferred by termite (Hermawan *et al.*, 2012). Other non-resistant wood species would be assam (*Mangifera*) which also being reported to be non-resistant (mass loss: 70.9) in Ponpinij *et al.* (2016)'s study. *C. incrassatum* (Bintangor) and *C. apertum* (seladah) in this experiment was reported moderately resistant (rating: 7) but according to Hadi *et al.* (2012), bintangor was categorized under resistant to termite while seladah was assigned as moderate resistant to termite in laboratory bioassay in accordance with resistance class against subteranean termite (SNI01.7207-2006).

In this experiment, *A. mangium* (akasia) was found to be resistant (rating: 9) towards termites. However, Grace *et al.* (1997), revealed that acacia exposed to field test was severely attacked (rating 4.8 on a 5 rating scale) whereby 0 is sound and 5 is a failure. Hadi *et al.* (2016), also observed a significant attack on acacia exposed in-ground test (23.3%) which superseded Acacia's mass loss in this study which was only 8%. *A. excelsa* (sentang)

and *C. equisetifolia* (casuarina) was found moderately resistant to termite (rating: 7.3 and 8). In an accelerated field test, casuarina and sentang was reported as highly resistant with average termite rating 0 – 0.8 (whereby 0 is sound and is failure) (Grace *et al.*, 1997).

Examples of termite resistant wood in this experiment were *S. laevis* (kumus) (rating: 9.5), *S. borneensis* (kulim) (rating: 9.5), *Dryobalanops* spp. (kapur) (rating: 9.1), teak (rating: 9.1 – 9.5) and belian (rating: 10). Grace and Tome (2005), also found that kumus (known as bangkirai in Indonesia) as highly resistant to termite in both choice and no choice test which also conform to the result of this study. Roszaini *et al.* (2016), reported that kapur and kulim categorized as moderately durable in their study. Grace *et al.* (1997), and Daß *et al.* (2015), both reported that teak sustained the lowest mass loss and regarded as highly resistant which conformed to the result of this study. Yusuf *et al.* (2010), also reported that both teak from Malaysia and Indonesia were very durable to termite in force feeding bioassay. As for belian, it was the most durable wood observed in this study. Sulistyawati and Wardani (2015), observed that 10 and 25cm ironwood log sustained average of 0.4 and 0.33% mass loss to *C. curvignathus*, in their laboratory test. As for the graveyard test, the mass loss of 10, 25cm diameter ironwood and used flooring was 0.48, 0.43 and 0.17% respectively. The ironwood was designated as Class 1 (Highly resistant) based on the classification of wood resistance against subterranean and drywood termite by percent mass loss (Sulistyawati & Wardani., 2015). The degree of damages done to the same timber species may differ based on micro (e.g. the pressure of wood biodeteriorating organisms) and macro environmental factor (e.g. rainfall). The distinctive results from the field and lab could be due to the variety of wood available to choose from while in laboratory assay, termite has limited or no choice to choose from (Grace *et al.*, 1997). Another possible explanation is that the chemical recruitment system utilized by termites

during foraging. If the pheromone is strong, many termites prone to feed at that particular foraging area, therefore, concentrating foraging on attacked blocks. Campora and Grace (2007), observed that termites tend to foraged the treated wood when it was switched to foraging sites that previously contained untreated wood.

5.3 Natural termite resistance of *Dipterocarpus* spp. and *Acacia mangium*

Since keruing trade names comprises of multiple species and possess different degree of resistance towards termites, it is not possible to conclude that keruing is resistance to termite in general. Results showed that termite resistance of keruing heartwood were ranged from non-resistant (rating: 0) for [e.g. *D. rigidus* (keruing utap) and *D. eurynchus* (keruing baran)] to moderately resistant (rating: 8.2 – 9) [e.g. *D. crinitus* (keruing mempelas) and *D. confertus* (keruing kobis)] which concurred to Wong (2002), that keruing is non-durable to moderately durable when exposed to tropical conditions. Different durability testing results using various methods (in-ground stake test, laboratory termite choice test) also agreed that keruing varies in terms of their durability. For instance, Wong and Ling (2009), found that keruing heartwood of various species mainly destroyed (rating: 7 or less) within the first 2 years of exposure in the field except for keruing arong and keruing mempelas which failed within 2 to 5 years of exposure allowing them to assign these species as non-durable to moderately durable. Although termite test result from this experiment particularly keruing mempelas and keruing shows that some moderate resistance to termite however in-ground stake test shows that these species could only last up to 5 years exposing to high termite and decay pressure.

Laboratory bioassay results by Roszaini *et al.* (2017), also found that *Dipterocarpus* spp. was susceptible to termite, sustained 8.9% wood consumption indicate that this species

moderately preferred comparing to other tested species. However, Suzuki (2004) reported that *Dipterocarpus* spp. exposed to *C. formosanus* in their laboratory choice test was rated very resistant (< 3% mass loss). Untreated *D. alatus* were readily attacked by marine borers over time and eventually destroyed after 21 to 28 years exposure in Iranian coastal sea water (Rezanejad, 2004). The durability of keruing very much depending on the species tested, types of biodeteriogens (termites or borers), test conditions (whether laboratory or field) and hazard class (H2 or higher). Not all of the keruing is termite resistant and apparently not resistant to marine borers and eventually destroyed if without preservative treatment. Apparently, there is a misconception in timber trade to regard keruing as termite resistant and not requiring preservative treatment.

5.4 Termite resistance of *Acacia mangium*, *Hevea brasiliensis* and pine ply dip-treated with diesel, dead engine oil and combination of both oils

It was found that untreated pine plywood and *H. brasiliensis* (rubberwood) was completely eaten (100% mass loss) while *A. mangium* sustained only moderate (rating: 8.6) attack with 15% mass loss. It was found that all treated wood samples using diesel and dead engine oil (volume: volume, 1:1) increased their performance (rating: 7.5 – 9.4) against termites compared to wood dip-treated using dead engine oil only that attained termite rating of 2 to 9.2. Lower termite ratings were observed in wood dip-treated using dead engine oil that it was suspected that dead engine oil has lost its potent chemical that toxicates termites, causing the reduction in its protection as wood protectant. Higher termite rating was observed in wood treated using combination of both oils for the viscosity of dead engine oil increased allowing more toxic compound penetrated into the wood while lower termite rating was observed in those treated using dead engine oil could

be due to the very low penetration or losses of toxic compounds that deter termites. Results of the dead engine treated wood concurred to the study done by Olaniran *et al.* (2010), that different wood species dip-treated using dead engine oil reacted differently to termite could be due to the poor penetration and absorption level. Their study showed that *Gmelina arborea*, *Terminallia superba* and *Ceiba pentandra* cold soaked using used engine oil for 24 hours attained different degree of protection against termite. *C. pentandra* being perishable wood was penetrated by termites on the 2nd week followed by *G. arborea* was attacked on the 5.5th week and *T. superba* was attacked on the 7th week exposed to 12 weeks of termite graveyard test. Interestingly wood treated using standalone diesel tremendously increased the protections (rating: 9.5 – 9.7) against termites indicated that there are toxic compounds could deter termites. No doubts in some parts of the world particularly, oil products such as diesel, kerosene and dead engine oil are being used as termite controls. According to a survey done on farmer's perception on termite control in Ghana, there were 37.1% of respondents use diesel or kerosene to eliminate termites (Akutse *et al.*, 2012). Previous research also shows that used engine oil provides full protection to wood. For instance, Pereira *et al.* (2015), reported that no mass loss (as compared to their untreated counterparts) had been observed in *Trattinnickia rhoifolia*, *Erismia uncinatum* and *Copaifera langsdorfii* treated using used dead engine oil soaked for 5 minutes and 24 hours exposed to *Nasutitermes* sp.. Undeniably that preservative treatment using diesel or dead engine oil provide way to control termites but the adverse effect on health and safety of using these oils should be addressed. Wood treated using diesel or dead engine oil has a strong odour and the vapour would be hazardous to people. Another disadvantages of using wood treated using diesel or dead engine oil is that treated

wood hardly paintable and could burn easily. Thus, treated wood using diesel or dead engine oil should be used for outdoor application away from fire source.

5.5 Termite resistance of light organic solvent preservative treated *Kokoona reflexa*, *Adinandra borneensis* and *Canarium apertum* using dipping and vacuum pressure treatment

Untreated *K. reflexa* (bajan), *A. borneensis* (legai) and *C. apertum* (seladah) control sustained 12.4%, 59.1% and 22.1% respectively. Interestingly all the wood dip and vacuum pressure-treated using LOSP had increased the protection of wood against termites ranging from slight attack to completely sound (rating: 8.9 – 10). As for the retentions, actual retentions obtained by dipping was far lesser (0.0019 – 0.016% m/m) than the recommended retention approved by Australian Standard which the optimum permethrin retention should be 0.02% m/m. On the contrary, those underwent vacuum pressure-treated achieved the optimum requirement (0.02% m/m). Dip-treated wood although was considerably well protected, the visual ratings were slightly lower than those of vacuum pressure-treated could be due to the non-uniform distribution of permethrin into the wood causing termite to forage the part with less or no active ingredient. Kennedy and Cobham (2003), also noticed the same phenomenon whereby the permethrin distribution in the specimens dipped in the LOSP-type was poorly distributed whereby the active ingredient penetrating not only the target outer 0 to 5mm but break into the inner zone through the 5 to 10mm zone. Interestingly the colour of the treated wood using LOSP remains unchanged but they possess strong odour believed to deter termites. Yeoh & Lee (2006), reported that termites forage freely between the untreated and treated section using non-repelling termiticides however it was observed that termites only forage in limited to

untreated section whereas no foraging activity observed in bifenthrin (known to be repellent termiticide) treated section. In this experiment vacuum pressure-treated wood was excellently protected (rating: 9.8 – 10). However, seladah vacuum pressure-treated in Klang attained good protection (rating: 9.2). Seladah is a refractory timber and its heartwood is very difficult to treat with preservative (Forest Department Sarawak, 1999; Wong, 2002). Therefore, it was suspected that inadequate uniformity of LOSP penetration in some of seladah wood blocks. Qader *et al.* (2005), observed the same trend to refractory timber *Eucalyptus obliqua* heartwood vacuum-treated using LOSP sustained mean mass loss over 85% to *Mastotermes darwiniensis* due to inadequate uniformity of LOSP penetration. This study indicated that wood treated with LOSP can achieve excellent protection against termites. These results concurred with Peters & Creffield (2003), research that in the Northern Territory trial, untreated controls (radiata pine and slash pine) sustained moderate-severe to severe attack from *C. acinaciformis*. However, LOSP, 0.02% m/m permethrin successfully protected radiata pine and slash pine with mean rating of 1.2 and 1.0, whereby 1 is sound. In Queensland trial, untreated controls (radiata pine heartwood, slash pine sapwood and slash pine heartwood) failed the test as high mass loss was obtained (> 45.0g) while LOSP, 0.02% m/m permethrin successfully protected all the treated radiata pine and slash pine (sapwood and heartwood).

5.6 Termite resistance of *Koompassia malaccensis* and *Hevea brasiliensis* dip-treated using chlorpyrifos, cypermethrin and permethrin

General Linear Model shows that percentage mass loss, absolute mass loss and termite rating only significantly different ($P < 0.05$) in terms of species and concentrations in chlorpyrifos, cypermethrin and permethrin treated wood exposed to low humidity region,

chlorpyrifos and cypermethrin treated wood exposed to high humidity region indicated that wood species and agro-insecticides concentrations used for preservative application has a significant effect on the amount of agro-insecticides active ingredient absorbed by the wood samples.

Dipping time (3 seconds resembled spraying versus 60 seconds resembled dipping) tested in this experiment was not significant indicated that the time compared was too short to see the effect of time in preservative treatment. However, many previous studies had shown that actually treatment time does matter. For instance, Ma *et al.* (2013), found that the penetration depth of the preservatives ACQ-C, CA-C and TP increased as the steeping time prolonged. It was also found that the surface retentions increased as the steeping time increased and increased termite resistance on *P. radiata* and *P. asperata*. (Ma *et al.*, 2013). Humar and Lesar (2009), also found that the higher retention of preservative in spruce wood as the dipping time increased. For instance, 17 and 22 kg/m³ retained in the spruce wood dipped in one minute time. However, after one week of immersion, the spruce wood retained 275 kg/m³. They also noticed more concentrated solution penetrated deeper into the wood compared to those less concentrated. Higher retention can be observed in treated rubberwood as compared to treated kempas. Another factor that plays an important role in ensuring maximum penetration of treating chemicals into the wood is the treatability of the wood species itself. Huda *et al.* (2006), and Ilias *et al.* (2006), both observed that longer dipping times ensure higher retention of treating chemicals in the wood and non-refractory timbers retain much more treating chemicals than refractory timbers. Untreated *H. brasiliensis* (rubberwood) was completely destroyed while untreated *K. malaccensis* (kempas) sustained 31.2% and 58.7% exposed to low humidity and high humidity exposure. High mass loss of untreated rubberwood and kempas concurred with other

studies that these wood species are termite susceptible. Wong *et al.* (1998), reported that untreated rubberwood was completely destroyed while untreated kempas sustained moderate to heavy attack (rating: 3.8) when exposed to termites.

For low humidity exposure, rubberwood at least required 3.1% of chlorpyrifos, 0.84% of cypermethrin and 0.85% permethrin to achieve good protection to rubberwood (rating: 9.4 – 9.5, nibbling) whereas 1.6% chlorpyrifos, 0.105% cypermethrin and 0.042% permethrin was required to provide good protection to kempas wood (rating: 9.4 – 9.6, nibbling).

As for high humidity exposure, rubberwood required 3.1% of chlorpyrifos, 0.42% of cypermethrin and 0.85% permethrin in order to provide good protection to rubberwood (rating: 9.3 – 9.5, nibbling) while kempas required 3.1% chlorpyrifos, 0.105% cypermethrin and 0.084% permethrin to provide good protection to wood (rating: 9.3 – 9.6, nibbling).

From this study, it can be seen that in high humidity exposure, much more concentrations were needed to protect kempas. It is suspected the chemical leached out from the wood due to the humidity and the accumulation of droplets on the wood surface. No doubt, when these wood species being treated with organophosphate or synthetic pyrethroids can perform very well towards biodeteriogens particularly termites. For instance, Messaoudi *et al.* (2018), also found that untreated kempas was susceptible to termite attack (mass loss: 51.7%, rating: 4.2) while kempas dip-treated using microemulsion-based insecticides containing cypermethrin and permethrin for 3 minutes significantly improved the protection upon kempas from termite (mass loss: 0.4 – 1.1%, rating: 9.7 – 9.9).

5.7 Termite resistance of *Neolamarckia cadamba* and *Hevea brasiliensis* dip-treated using chlorpyrifos, cypermethrin and permethrin

Two-way ANOVA shows that percentage mass loss, absolute mass loss and termite rating significantly different ($P < 0.05$) in terms of species and concentrations. It can be said that the wood species and amount of agro-insecticides retained contributed to the improvement of wood protection. Untreated *H. brasiliensis* (rubberwood) and *N. cadamba* (kelempayan) were completely destroyed indicate that these species are highly susceptible to termites. Tawi and Wong (2016), also reported that untreated rubberwood was completely destroyed while untreated kelempayan sustained moderate severe attack (rating: 7.5) exposed to H2 termite field test.

Rubberwood at least required minimum concentration of 1.6% chlorpyrifos, 0.42% cypermethrin and 0.17% permethrin in order to provide good protection to rubberwood (rating: > 9.5) whereas kelempayan required 1.6% chlorpyrifos, 0.42% cypermethrin and 0.42% permethrin in order to provide good protection to it (rating: > 9.3). Concentrations used below than the recommended (giving good protection to wood) found in this experiment were sub-lethal to termites and hence not able to provide complete protection to the wood species used. Although organophosphate or synthetic pyrethroid based agro-insecticides are broad spectrums and meant to control wide ranges of insect pests including termite, their prescribed concentrations rate to control different insect pests may differ. Tawi and Wong (2016), reported that rubberwood and kelempayan dip-treated using prescribed spray-on concentrations of cypermethrin and permethrin meant for crop protection (targeting specific insect pests) did not provide complete protection to wood used. This experiment would create awareness among the homeowners that they are to buy agro-insecticides which meant for termite control and adhere to the prescribed

concentrations recommended if they wish to treat wood themselves. However, organophosphate and synthetic pyrethroid based wood preservative had been proven useful in protecting hardwood or softwood even as the preservative is applied using surface treatment (e.g. brushing) and dipping. For instance, Jenya and Meke (2018), reported that *Pinus patula* painted using Soglinum (contain permethrin) and Xotic wood preservative (mainly neem oil with the combination of Deltamethrin and Naphthalene) was well protected from different species of *Macrotermes* and *Microtermes* as compared to its untreated counterpart which was attacked (weight loss: 33%). Fadillah *et al.* (2014), found out that soaking and brushing of mahogany wood using chlorpyrifos and permethrin was very useful in enhancing the wood resistance toward *Coptotermes curvignathus* with 100% termite mortality. Sornnuwat *et al.* (1994), reported rubberwood brushed or dipped for 5 minutes using cypermethrin (0.125 – 0.5%) and permethrin (0.5 – 2%) and chlorpyrifos (1 – 2%) yielded good results (weight loss: 0 – 10%).

Organophosphate based insecticide also effective in protecting living trees. For instance, Chey (1996), reported that there was no termite revisit as long as 48 months after infested young *Gmelina arborea* trees treated with chlorpyrifos 21.2% w/w. Since rubberwood and kelempayan are well known of their susceptibility to termites, any wood product incorporated these species should be given treatment in order to provide termite resistance to the wood product.

Zaidon *et al.* (2008), also observed rubberwood particleboard, EFB (Empty Fruit Bunch) particleboard and Rubberwood-ECF particleboard sprayed using Timberlife® (= 0.2% permethrin), Stoprot® (= 0.2% permethrin), Cislin® (= 0.2% deltamethrin) to *Coptotermes curvignathus* has lower percentage weights loss as compared to the untreated controls. Donath *et al.* (2008), reported that 100g/m³ permethrin treated OSB sustained traces of

gnawing and medium attack respectively while OSB treated with 10g/m³ bifenthrin and 10g/m³ deltamethrin sustained medium attack compared to untreated OSB which was severely attacked by *R. satonensis* in a laboratory bioassay. Samerjai *et al.* (2016), reported that a modified ground board test treated using cypermethrin lasted for 9 years, permethrin lasted for 5 years and chlorpyrifos prevented termite attack for 7 years.

5.8 Termite resistance of *Neolamarckia cadamba* and *Hevea brasiliensis* vacuum pressure-treated with chlorpyrifos, cypermethrin, deltamethrin and permethrin

The experiment shows that rubberwood and kelepayan vacuum pressure-treated to target retentions of 0.002 to 0.008% m/m failed to provide termite protections to rubberwood (all treated rubberwood completely destroyed, rating: 0) and kelepayan (heavy attack to destroyed, rating: 1 – 4.5). The working concentrations to achieve target retentions of 0.002 to 0.008% m/m in rubberwood were 0.00205, 0.0041 and 0.0082% whereas for kelepayan were 0.0008, 0.0016 and 0.0032%. According to estimated mean actual retention, none of the rubberwood achieved any of the target retentions but kelepayan had exceedingly achieved the target retentions. One possible explanation that could explain why wood vacuum pressure-treated to these target retentions failed could be due to the very low working concentrations used. Although wood may achieve the target retentions, but the working concentrations (0.0008 to 0.0082%) were too low and not even within the ranges of concentrations used for dipping in experiment 6. It was found that at least 0.32% chlorpyrifos (refer Table 4.17) that could provide a certain degree of protection to rubberwood that sustained moderate severe (rating: 7) and 0.04% chlorpyrifos to provide minimal protection to kelepayan that sustained very severe attack (rating: 5.8).

Both rubberwood and kelempayan vacuum pressure-treated to target retentions of 0.025 to 0.1% m/m cypermethrin achieved a certain degree of protection to the wood. For rubberwood, the working concentrations to achieve target retentions of 0.025 to 0.1% m/m cypermethrin were 0.02625, 0.0525 and 0.105% while for kelempayan to achieve the target retentions were 0.0105, 0.021 and 0.042%. Interestingly all of the working concentrations were within the ranges of concentrations used for dipping in experiment 6. Both species vacuum pressure-treated to target retentions of 0.025 to 0.1% m/m sustained moderate to sound (rating: 8.4 – 10) whereas rubberwood dip-treated in experiment 6 using 0.0525 (= 0.05% m/m) and 0.105% (= 0.1% m/m) sustained moderate to moderate severe attack (rating: 7.5 – 8.8) whereas kelempayan dip-treated using 0.105% (= 0.025% m/m), 0.21% (0.05% m/m) and 0.42% (0.1% m/m) sustained moderate to slight attack (rating: 7.8 – 9.3). Higher termite rating was observed in wood vacuum pressure-treated than those dip-treated using the same working concentrations of cypermethrin.

The working concentrations to achieve target retentions of 0.0013 to 0.0051% m/m deltamethrin in rubberwood were 0.001325, 0.00265 and 0.0053% whereas for kelempayan were 0.0005, 0.001 and 0.002%. It was found that even wood treated to target retention of 0.0051% m/m did not fully protect the wood.

As for permethrin, the working concentrations to achieve target retentions of 0.008 to 0.034% m/m in rubberwood were 0.00885, 0.0177 and 0.0354% whereas for kelempayan were 0.00337, 0.00674 and 0.1348%. Interestingly all the working concentrations to achieve target retentions of 0.008 to 0.034% m/m permethrin used were within the ranges of concentrations used for dipping in experiment 6, that those concentrations (0.00885 to 0.1348%) if use for dipping were predicted to provide sub-lethal effect to termites causing moderate severe to heavy attack to treated wood. Even in experiment 7, rubberwood and

kelempayan vacuum pressure-treated to target retentions of 0.008 and 0.017% m/m did not provide good protection to wood that rubberwood sustained moderate to severe attack (rating: 6.3 – 8.3) while treated kelempayan was almost destroyed (rating: 1 – 1.5). Both woods treated to target retention of 0.034% m/m sustained slight attack (rating: 9 – 9.1). Target retentions adopted in this study were not able to provide full protection to wood exposed to tropical condition, therefore, it is indeed important to determine the best target retentions in wood by testing series of concentrations range for each agro-insecticides to provide complete excellent protection to wood in service. However, previous studies had shown that these chemicals (organophosphate and synthetic pyrethroids) were effective in wood preservation. For instance, Creffield *et al.* (2013), also reported that pressure treated *Pinus radiata* using permethrin (2.5 – 90g AI/m³) was exposed to *C. acinaciformis* and *C. formosanus*. It was found that low dosage of permethrin successfully suppressed the wood consumption by *C. acinaciformis* while the higher dosage of permethrin (10 – 90g AI/m³) was required to observe drastic decrement in wood consumption by *C. formosanus*. Morris *et al.* (2014), reported that pressure treated *P. contorta* using DOT plus permethrin attained rather excellent result (rating 9.2 in Hawaii, 9.5 in Japan) after 5 years of treatment. Scown and Creffield (2009) also observed that *D. globulus* laminated strand board pressure treated to nominal retention of 0.005%, 0.01% and 0.02% m/m permethrin exposed to *C. acinaciformis* sustained mass loss less than 6%. However, the same treated strand board suffered more than 50% mass loss to *Macrotermes darwiniensis*.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Termite survey had confirmed that tropical region is occupied with different termite genera. Genus *Coptotermes* was found to be the most prominent genus causing significant destruction to wood products either use indoor or expose to a forest area, living trees in plantations. Nevertheless, other genera like *Schedorhinotermes* and *Nasutitermes* also found to attack wood products exposed to a forest area that their destruction to wood must not be neglected. Hence it is important to treat tropical hardwood and wood products using wood protecting chemicals to enhance their service life. From this study also the basic physical properties, extractive contents and natural termite resistance of some selected timber species were documented. This could provide baseline data to the wood industry in terms of their physical and wood extractive contents in relation to termite resistance.

Wood preservation treatment in this study found that wood dip-treated using diesel provided considerably good and effectively protection to *Acacia mangium*, *H. brasiliensis* and pine plywood. Therefore, diesel can be used to protect wood exposed to outdoor away from fire source. Wood species treated with LOSP especially using pressure-treatment were well protected and therefore can be used effectively to treat wood used for internal application.

Termite resistance of *H. brasiliensis*, *K. malaccensis* and *N. cadamba* dip-treated using organophosphate (chlorpyrifos) and synthetic pyrethroids (cypermethrin and permethrin) has been determined. Concentrations of 6.3 and 12.5% chlorpyrifos, 1.68 and 3.35% cypermethrin, as well as 3.38 and 6.75% permethrin were found to completely protect these wood from termites (rating: 10).

This study also found that treating wood to target retentions recommended by other studies or standards may not be applicable to wood exposed to the tropical condition. For instance, both *H. brasiliensis* and *N. cadamba* vacuum pressure-treated to target retentions of 0.002 to 0.008% m/m chlordane were either destroyed or sustained very heavy attack from termites. However, *H. brasiliensis* and *N. cadamba* vacuum pressure-treated to target retentions of 0.1% m/m cypermethrin were considered well protected from termites (rating: 9.5 – 10). Good protection has been achieved in wood vacuum pressure-treated to target retentions of 0.0051% m/m deltamethrin that the treated wood sustained nibbling (rating: 9.3 – 9.5). *H. brasiliensis* and *N. cadamba* vacuum pressure-treated to target retentions of 0.034% m/m permethrin sustained slight attack (rating: 9 – 9.1).

For recommendations, a continuation of termite survey including those in the suburban area should also be included; collaboration studies with local pest controls should be encouraged as to provide more databases to the survey which will provide a basic idea of termite species distributions and their economic importance in Sarawak.

It is important to study in depth (including wood anatomy, mechanical and chemical testing, service life testing, treatability of wood, laboratory termite and decay test) of the wood species that can be obtained in order to catalogue a comprehensive baseline data for references. Other types of preservatives can also be included using dipping and pressure treatment to study their efficacy towards termites. As for dipping treatment, comparison of longer dipping time should be tested to compare the depth of penetration among tested wood. Continuation of wood preservation testing using higher working concentrations than in this study should be carried out to find out the best target retentions in wood that could provide complete protection to treated wood exposed to tropical conditions.

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APPENDICES

Appendix A: examples of termite collection form

Collection number: 1	FRIM number: ENTO 531	
Collected by: Carlson Tawi Anak Daud	Collection date: 28.11.2014.	
Identified by: Dr Shawn Cheng & AP Dr Andrew Wong	Date of Identification: 15.02.2016	
Species: <i>Coptotermes curvignathus</i>		
Location: In front of computer laboratory Faculty of Resource Science and Technology, UNIMAS	Latitude: 1°28.151'N	
	Longitude: 110°25.711'E	
General description: Termites were sighted at a dead palm tree in front of the faculty's computer laboratory. Attacked fish tail palm.		

Collection number: 2	FRIM number: ENTO 539	
Collected by: Carlson Tawi Anak Daud	Collection date: 16.02.2015	
Identified by: Dr Shawn Cheng & AP Dr Andrew Wong	Date of Identification: 29.01.2017	
Species: <i>Macrotermes</i> sp.		
Location: Underneath a <i>Cinnamomun iners</i> tree along the walkway to FSTS from Jalan Merbau.	Latitude: 1°28.239'N	
	Longitude: 110°25.504'E	
General description: A mound was sighted underneath a <i>Cinnamomun iners</i> tree. Minor soldier were collected.		

Appendix B: Data Analysis

Table 1: One-way ANOVA of tested wood density

Source	DF	SS	MS	F	P
Species	66	5.808434	0.088007	177.84	0.000
Error	134	0.066311	0.000495		
Total	200	5.874745			

S = 0.02225	R-Sq = 98.87%	R-Sq (adj) = 98.32%
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Table 2: One-way ANOVA of Brinell Hardness Number of tested wood

Source	DF	SS	MS	F	P
Species	65	0.0054913	0.0000845	86.32	0.000
Error	132	0.0001292	0.000001		
Total	197	0.0056205			

S = 0.0009893	R-Sq = 97.70%	R-Sq (adj) = 96.57%
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Table 3: One-way ANOVA of compressive strength of tested wood

Source	DF	SS	MS	F	P
Species	57	59727.9	1047.9	21.77	0.000
Error	116	5584.7	48.1		
Total	173	65312.6			

S = 6.939	R-Sq = 91.45%	R-Sq (adj) = 87.25%
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Table 4: One-way ANOVA of water permeability ($\text{gcm}^{-3}\text{h}^{-1}$) of tested wood

Source	DF	SS	MS	F	P
Species	66	0.1015710	0.0015390	63.44	0.000
Error	134	0.0032507	0.0000243		
Total	200	0.1048216			

S = 0.004925	R-Sq = 96.90%	R-Sq (adj) = 95.37%
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Table 5: One-way ANOVA of cold water extractives of tested wood

Source	DF	SS	MS	F	P
Species	66	1166.897	17.680	107.46	0.000
Error	134	22.047	0.165		
Total	200	1188.944			

S = 0.4056 R-Sq = 98.15% R-Sq (adj) = 97.23%

Table 6: One-way ANOVA of cold water extractive pH of tested wood

Source	DF	SS	MS	F	P
Species	66	146.1222	2.2140	26.84	0.000
Error	134	11.0527	0.0825		
Total	200	157.1749			

S = 0.2872 R-Sq = 92.97% R-Sq (adj) = 89.50%

Table 7: One-way ANOVA of hot water extractives of tested wood

Source	DF	SS	MS	F	P
Species	66	2851.649	43.207	256.03	0.000
Error	134	22.613	0.169		
Total	200	2874.262			

S = 0.4108 R-Sq = 99.21% R-Sq (adj) = 98.83%

Table 8: One-way ANOVA of hot water extractive pH of tested wood

Source	DF	SS	MS	F	P
Species	66	60.59304	0.91808	137.82	0.000
Error	134	0.89260	0.00666		
Total	200	61.48564			

S = 0.08162 R-Sq = 98.55% R-Sq (adj) = 97.83%

Table 9: One-way ANOVA of methanol extractives

Source	DF	SS	MS	F	P
Species	66	3613.171	54.745	454.89	0.000
Error	134	16.127	0.120		
Total	200	3629.298			

S = 0.3469 R-Sq = 99.56% R-Sq (adj) = 99.34%

Table 10: One-way ANOVA of mean percentage mass loss

Source	DF	SS	MS	F	P
Species	68	329426.8	4844.5	163.28	0.000
Error	207	6141.8	29.7		
Total	275	335568.5			

S = 5.447 R-Sq = 98.17% R-Sq (adj) = 97.57%

Table 11: One-way ANOVA of mean absolute mass loss of tested wood

Source	DF	SS	MS	F	P
Species	68	505130870	7428395	93.99	0.000
Error	207	16360547	79036		
Total	275	521491417			

S = 281.1 R-Sq = 96.86% R-Sq (adj) = 95.83%

Table 12: One-way ANOVA of mean termite rating of tested wood

Source	DF	SS	MS	F	P
Species	68	3128.301	46.004	90.48	0.000
Error	207	105.25	0.508		
Total	275	3233.551			

S = 0.7131 R-Sq = 96.75% R-Sq (adj) = 95.68%

Table 13: One-way ANOVA of percentage mass loss versus species (experiment 2)

Source	DF	SS	MS	F	P
Species	10	68439	6844	15.15	0.000
Error	55	24845	452		
Total	65	93284			

S = 21.25 R-Sq = 73.37% R-Sq (adj) = 68.52%

Table 14: One-way ANOVA of absolute mass loss versus species (experiment 2)

Source	DF	SS	MS	F	P
Species	10	649830168	64983017	10.32	0.000
Error	55	346263473	6295700		
Total	65	996093640			

S = 2509 R-Sq = 65.24% R-Sq (adj) = 58.92%

Table 15: One-way ANOVA of termite rating versus species (experiment 2)

Source	DF	SS	MS	F	P
Species	10	693.42	69.34	15.21	0.000
Error	55	250.67	4.56		
Total	65	944.09			

S = 2.135 R-Sq = 73.45% R-Sq (adj) = 68.62%

Table 16: Two-way ANOVA of percentage mass loss versus treatments and species (experiment 3)

Source	DF	SS	MS	F	P
Treatments	3	40668	13555.8	223.82	0.000
Species	2	26616	13308.1	219.73	0.000
Interaction	6	30780	5129.9	84.70	0.000
Error	60	3634	60.6		
Total	71	101697			

S = 7.782 R-Sq = 96.43% R-Sq (adj) = 95.77%

Table 17: Two-way ANOVA of absolute mass loss versus treatments and species (experiment 3)

Source	DF	SS	MS	F	P
Treatments	3	58883288	19627763	117.00	0.000
Species	2	79010636	39505318	235.50	0.000
Interaction	6	47916762	7986127	47.61	0.000
Error	60	10065260	167754		
Total	71	195875946			

S = 409.6	R-Sq = 94.86%	R-Sq (adj) = 93.92%
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Table 18: Two-way ANOVA of termite rating versus treatments and species (experiment 3)

Source	DF	SS	MS	F	P
Treatments	3	467.427	155.809	194.93	0.000
Species	2	241.938	120.969	151.34	0.000
Interaction	6	235.646	39.274	49.14	0.000
Error	60	47.958	0.799		
Total	71	992.969			

S = 0.8940	R-Sq = 95.17%	R-Sq (adj) = 94.28%
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Table 19: Two-way ANOVA of percentage mass loss versus treatments and species (experiment 4)

Source	DF	SS	MS	F	P
Treatments	3	10584.6	3528.19	96.73	0.000
Species	2	1536.2	768.12	21.06	0.000
Interaction	6	5799.9	966.65	26.5	0.000
Error	60	2188.5	36.47		
Total	71	20109.2			

S = 6.039	R-Sq = 89.12%	R-Sq (adj) = 87.12%
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Table 20: Two-way ANOVA of absolute mass loss versus treatments and species (experiment 4)

Source	DF	SS	MS	F	P
Treatments	3	456707710	152235903	94.11	0.000
Species	2	53924310	26962155	16.67	0.000
Interaction	6	221017308	36836218	22.77	0.000
Error	60	97055863	1617598		
Total	71	828705191			

S = 1272 R-Sq = 88.29% R-Sq (adj) = 86.14%

Table 21: Two-way ANOVA of termite rating versus treatments and species (experiment 4)

Source	DF	SS	MS	F	P
Treatments	3	169.528	56.5093	82.36	0.000
Species	2	18.146	9.0729	13.22	0.000
Interaction	6	78.660	13.1100	19.11	0.000
Error	60	41.167	0.6861		
Total	71	307.500			

S = 0.8283 R-Sq = 86.61% R-Sq (adj) = 84.16%

Table 22: GLM of mean percentage mass loss vs Species, Time and Concentrations of Chlorpyrifos (low humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	59678.6	59678.6	59678.6	96.89	0.000
Time (T)	1	1213.3	1213.3	1213.3	1.97	0.163
Concentrations (C)	10	116655.4	116655.4	11665.5	18.94	0.000
S*T	1	794.3	794.3	794.3	1.29	0.258
S*C	10	28090.2	28090.2	2809.0	4.56	0.000
T*C	10	9086.3	9086.3	908.6	1.48	0.155
S*T*C	10	6882.8	6882.8	688.3	1.12	0.354
Error	132	81307.8	81307.8	616.0		
Total	175	303708.6				

S = 24.8187 R-Sq = 73.23% R-Sq (adj) = 64.51%

S = species, T = times, C= concentrations

Table 23: GLM of mean absolute percentage mass loss vs Species, Time and Concentrations of Chlorpyrifos (low humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	131393664	131393664	131393664	61.91	0.000
Time (T)	1	2895372	2895372	2895372	1.36	0.245
Concentrations (C)	10	371086067	371086067	37108607	17.48	0.000
S*T	1	2040355	2040355	2040355	0.96	0.329
S*C	10	64738788	64738788	6473879	3.05	0.002
T*C	10	25493924	25493924	2549392	1.20	0.296
S*T*C	10	15657389	15657389	1565739	0.74	0.688
Error	132	280160645	280160645	2122429		
Total	175	893466204				

S = 1456.86

R-Sq = 68.64%

R-Sq (adj) = 68.64%

S = species, T = times, C= concentrations

Table 24: GLM of mean termite rating vs Species, Time and Concentrations of Chlorpyrifos (low humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	399.006	399.006	399.006	61.35	0.000
Time (T)	1	19.114	19.114	19.114	2.94	0.089
Concentrations (C)	10	1354.358	1354.358	135.436	20.82	0.000
S*T	1	8.642	8.642	8.642	1.33	0.251
S*C	10	196.057	196.057	19.606	3.01	0.002
T*C	10	78.949	78.949	7.895	1.21	0.288
S*T*C	10	60.170	60.170	6.017	0.93	0.512
Error	132	858.500	858.500	6.504		
Total	175	2974.795				

S = 2.55025

R-Sq = 71.14%

R-Sq (adj) = 61.74%

S = species, T = times, C= concentrations

Table 25: Two-way ANOVA of mean percentage mass loss vs Species and Concentrations of Chlorpyrifos (low humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	59679	59678.6	92.57	0.000
Concentrations	10	116655	11665.5	18.09	0.000
Interaction	10	28090	2809.0	4.36	0.000
Error	154	99284	644.7		
Total	175	303709			

S = 25.39 R-Sq = 67.31% R-Sq (adj) = 62.85%

Table 26: Two-way ANOVA of mean absolute mass loss vs Species and Concentrations of Chlorpyrifos (low humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	131393664	131393664	62.02	0.000
Concentrations	10	371086067	37108607	17.52	0.000
Interaction	10	64738788	6473879	3.06	0.001
Error	154	326247685	2118491		
Total	175	893466204			

S = 1456 R-Sq = 63.49% R-Sq (adj) = 58.51%

Table 27: Two-way ANOVA of mean termite rating vs Species and Concentrations of Chlorpyrifos (low humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	399.01	399.006	59.93	0.000
Concentrations	10	1354.36	135.436	20.34	0.000
Interaction	10	196.06	19.606	2.94	0.002
Error	154	1025.38	6.658		
Total	175	2974.80			

S = 2.580 R-Sq = 65.53% R-Sq (adj) = 60.83%

Table 28: GLM of mean percentage mass loss vs Species, Time and Concentrations of Cypermethrin (low humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	40051.3	40051.3	40051.3	162.77	0.000
Time (T)	1	362.5	362.5	362.5	1.47	0.227
Concentrations (C)	10	127363.8	127363.8	12736.4	51.76	0.000
S*T	1	134.1	134.1	134.1	0.54	0.462
S*C	10	36783.5	36783.5	3678.3	14.95	0.000
T*C	10	1390.5	1390.5	139.1	0.57	0.840
S*T*C	10	1239.2	1239.2	123.9	0.50	0.885
Error	132	32480.7	32480.7	246.1		
Total	175	239805.6				

S = 15.6865

R-Sq = 86.46%

R-Sq (adj) = 82.04%

S = species, T = times, C= concentrations

Table 29: GLM of mean absolute mass loss vs Species, Time and Concentrations of Cypermethrin (low humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	83149004	83149004	83149004	78.86	0.000
Time (T)	1	1668423	1668423	1668423	1.58	0.211
Concentrations (C)	10	381471855	381471855	38147186	36.18	0.000
S*T	1	870258	870258	870258	0.83	0.365
S*C	10	69937236	69937236	6993724	6.63	0.000
T*C	10	6838867	6838867	683887	0.65	0.770
S*T*C	10	6346018	6346018	634602	0.60	0.810
Error	132	139176583	139176583	1054368		
Total	175	689458244				

S = 1026.82

R-Sq = 79.81%

R-Sq (adj) = 73.24%

S = species, T = times, C= concentrations

Table 30: GLM of mean termite rating vs Species, Time and Concentrations of Cypermethrin (low humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	342.445	342.445	342.445	164.79	0.000
Time (T)	1	1.547	1.547	1.547	0.74	0.390
Concentrations (C)	10	1381.159	1381.159	138.116	66.46	0.000
S*T	1	0.036	0.036	0.036	0.02	0.896
S*C	10	292.852	292.852	29.285	14.09	0.000
T*C	10	6.125	6.125	0.613	0.29	0.981
S*T*C	10	0.511	0.511	0.051	0.02	1.000
Error	132	274.312	274.312	2.078		
Total	175	2298.987				

S = 1.44157

R-Sq = 88.07%

R-Sq (adj) = 84.18%

S = species, T = times, C= concentrations

Table 31: Two-way ANOVA of mean percentage mass loss vs Species and Concentrations of Cypermethrin (low humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	40051	40051.3	173.22	0.000
Concentrations	10	127364	12736.4	55.08	0.000
Interaction	10	36783	3678.3	15.91	0.000
Error	154	35607	231.2		
Total	175	239806			

S = 15.21

R-Sq = 85.15%

R-Sq (adj) = 83.13%

Table 32: Two-way ANOVA of mean absolute mass loss vs Species and Concentrations of Cypermethrin (low humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	83149004	83149004	82.67	0.000
Concentrations	10	381471855	38147186	37.93	0.000
Interaction	10	69937236	6993724	6.95	0.000
Error	154	154900149	1005845		
Total	175	689458244			

S = 1003

R-Sq = 77.53%

R-Sq (adj) = 74.47%

Table 33: Two-way ANOVA of mean termite rating vs Species and Concentrations of Cypermethrin (low humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	342.44	342.445	186.66	0.000
Concentrations	10	1381.16	138.116	75.28	0.000
Interaction	10	292.85	29.285	15.96	0.000
Error	154	282.53	1.835		
Total	175	3326.64			

S = 1.354 R-Sq = 87.71% R-Sq (adj) = 86.03%

Table 34: GLM of mean percentage mass loss vs Species, Time and Concentrations of Permethrin (low humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	104179.2	104179.2	104179.2	536.04	0.000
Time (T)	1	18.6	18.6	18.6	0.10	0.757
Concentrations (C)	14	164689.9	164689.9	11763.6	60.53	0.000
S*T	1	13.4	13.4	13.4	0.07	0.793
S*C	14	77499.4	77499.4	5535.7	28.48	0.000
T*C	14	787.4	787.4	56.2	0.29	0.995
S*T*C	14	813.8	813.8	58.1	0.30	0.994
Error	180	34983.0	34983.0	194.3		
Total	239	382984.7				

S = 13.9409 R-Sq = 90.87% R-Sq (adj) = 87.87%

S = species, T = times, C= concentrations

Table 35: GLM of mean absolute mass loss vs Species, Time and Concentrations of Permethrin (low humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	263725025	263725025	263725025	333.38	0.000
Time (T)	1	63343	63343	63343	0.08	0.778
Concentrations (C)	14	456650577	456650577	32617898	41.23	0.000
S*T	1	95401	95401	95401	0.12	0.729
S*C	14	203022953	203022953	14501640	18.33	0.000
T*C	14	4232147	4232147	302296	0.38	0.979
S*T*C	14	3668266	3668266	262019	0.33	0.989
Error	180	142391207	142391207	791062		
Total	239	1073848919				

S = 889.417

R-Sq = 86.74%

R-Sq (adj) = 82.39%

S = species, T = times, C= concentrations

Table 36: GLM of mean termite rating vs Species, Time and Concentrations of Permethrin (low humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	858.817	858.817	858.817	539.10	0.000
Time (T)	1	0.104	0.104	0.104	0.07	0.798
Concentrations (C)	14	1821.365	1821.365	130.097	81.67	0.000
S*T	1	0.038	0.038	0.038	0.02	0.878
S*C	14	630.215	630.215	45.015	28.26	0.000
T*C	14	7.615	7.615	0.544	0.34	0.987
S*T*C	14	8.681	8.681	0.620	0.39	0.977
Error	180	286.750	286.750	1.593		
Total	239	3613.583				

S = 1.26216

R-Sq = 92.06%

R-Sq (adj) = 89.46%

S = species, T = times, C= concentrations

Table 37: Two-way ANOVA of mean percentage mass loss vs Species and Concentrations of Permethrin (low humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	104179	104179	597.48	0.000
Concentrations	14	164690	11764	67.47	0.000
Interaction	14	77499	5536	31.75	0.000
Error	210	36616	174		
Total	239	382985			

S = 13.20

R-Sq = 90.44%

R-Sq (adj) = 89.12%

Table 38: Two-way ANOVA of mean absolute mass loss vs Species and Concentrations of Permethrin (low humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	263725025	263725025	368.11	0.000
Concentrations	14	456650577	32617898	45.53	0.000
Interaction	14	203022953	14501640	20.24	0.000
Error	210	150450364	716430		
Total	239	1073848919			

S = 846.4

R-Sq = 85.99%

R-Sq (adj) = 84.05%

Table 39: Two-way ANOVA of mean termite rating vs Species and Concentrations of Permethrin (low humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	858.82	858.817	594.85	0.000
Concentrations	14	1821.36	130.097	90.11	0.000
Interaction	14	630.21	45.015	31.18	0.000
Error	210	303.19	1.444		
Total	239	3613.58			

S = 1.202

R-Sq = 91.61%

R-Sq (adj) = 90.45%

Table 40: GLM of mean percentage mass loss vs Species, Time and Concentrations of Chlorpyrifos (high humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	55011.7	55011.7	55011.7	115.86	0.000
Time (T)	1	8.8	8.8	8.8	0.02	0.892
Concentrations (C)	10	186773.8	186773.8	18677.4	39.34	0.000
S*T	1	732.3	732.3	732.3	1.54	0.216
S*C	10	38416.1	38416.1	3841.6	8.09	0.000
T*C	10	5986.8	5986.8	598.7	1.26	0.259
S*T*C	10	4349.6	4349.6	435.0	0.92	0.521
Error	132	62673.4	62673.4	474.8		
Total	175	353952.5				

S = 21.7899

R-Sq = 82.29%

R-Sq (adj) = 76.53%

S = species, T = times, C= concentrations

Table 41: GLM of mean absolute mass loss vs Species, Time and Concentrations of Chlorpyrifos (high humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	120442637	120442637	120442637	76.95	0.000
Time (T)	1	24417	24417	24417	0.02	0.901
Concentrations (C)	10	546983071	546983071	54698307	34.95	0.000
S*T	1	2058700	2058700	2058700	1.32	0.253
S*C	10	109593981	109593981	10959398	7.00	0.000
T*C	10	17569444	17569444	1756944	1.12	0.350
S*T*C	10	12799315	12799315	1279932	0.82	0.612
Error	132	206594479	206594479	1565110		
Total	175	1016066043				

S = 1251.04

R-Sq = 79.67%

R-Sq (adj) = 73.04%

S = species, T = times, C= concentrations

Table 42: GLM of mean termite rating vs Species, Time and Concentrations of Chlorpyrifos (high humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	448.642	448.642	448.642	118.86	0.000
Time (T)	1	0.568	0.568	0.568	0.15	0.699
Concentrations (C)	10	2024.48	2024.48	202.448	53.63	0.000
S*T	1	4.778	4.778	4.778	1.27	0.263
S*C	10	269.514	269.514	26.951	7.14	0.000
T*C	10	41.088	41.088	4.109	1.09	0.376
S*T*C	10	39.315	39.315	3.932	1.04	0.412
Error	132	498.250	498.25	3.775		
Total	175	3326.636				

S = 1.94284

R-Sq = 85.02%

R-Sq (adj) = 80.14%

S = species, T = times, C= concentrations

Table 43: Two-way ANOVA of mean percentage mass loss vs Species and Concentrations of Chlorpyrifos (high humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	55012	55011.7	114.87	0.000
Concentrations	10	186774	18677.4	39.00	0.000
Interaction	10	38416	3841.6	8.02	0.000
Error	154	73751	478.9		
Total	175	353953			

S = 21.88

R-Sq = 79.16%

R-Sq (adj) = 76.32%

Table 44: Two-way ANOVA of mean absolute mass loss vs Species and Concentrations of Chlorpyrifos (high humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	120442637	120442637	77.59	0.000
Concentrations	10	546983071	54698307	35.24	0.000
Interaction	10	109593981	10959398	7.06	0.000
Error	154	239046355	1552249		
Total	175	1016066043			

S = 1456

R-Sq = 63.49%

R-Sq (adj) = 58.51%

Table 45: Two-way ANOVA of termite rating vs Species and Concentrations of Chlorpyrifos (high humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	448.64	448.642	118.31	0.000
Concentrations	10	2024.48	202.448	53.39	0.000
Interaction	10	269.51	26.951	7.11	0.000
Error	154	584.00	3.792		
Total	175	3326.64			

S = 1.947 R-Sq = 82.44% R-Sq (adj) = 80.05%

Table 46: GLM of mean percentage mass loss vs Species, Time and Concentrations of Cypermethrin (high humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	44723.8	44723.8	44723.8	107.28	0.000
Time (T)	1	508.0	508.0	508.0	1.22	0.272
Concentrations (C)	10	158948.0	158948.0	15894.8	38.13	0.000
S*T	1	86.0	86.0	86.0	0.21	0.651
S*C	10	33257.1	33257.1	3325.7	7.98	0.996
T*C	10	809.8	809.8	81.0	0.19	0.984
S*T*C	10	1172.8	1172.8	117.3	0.28	
Error	132	55031.0	55031.0	416.9		
Total	175	294536.4				

S = 20.4182 R-Sq = 81.32% R-Sq (adj) = 75.23%

S = species, T = times, C= concentrations

Table 47: GLM of mean absolute mass loss vs Species, Time and Concentrations of Cypermethrin (high humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	96654559	96654559	96654559	65.95	0.000
Time (T)	1	2852691	2852691	2852691	1.95	0.165
Concentrations (C)	10	448443197	448443197	44844320	30.6	0.000
S*T	1	128034	128034	128034	0.09	0.768
S*C	10	80001183	80001183	8000118	5.46	0.000
T*C	10	6815076	6815076	681508	0.47	0.910
S*T*C	10	2601061	2601061	260106	0.18	0.998
Error	132	193442492	193442492	1465473		
Total	175	830938293				

S = 1210.57

R-Sq = 76.72%

R-Sq (adj) = 69.14%

S = species, T = times, C= concentrations

Table 48: GLM of mean termite rating vs Species, Time and Concentrations of Cypermethrin (high humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	311.114	311.114	311.114	86.28	0.000
Time (T)	1	1.455	1.455	1.455	0.40	0.526
Concentrations (C)	10	1653.259	1653.259	165.326	45.85	0.000
S*T	1	0.364	0.364	0.364	0.10	0.751
S*C	10	264.105	264.105	26.411	7.32	0.000
T*C	10	10.514	10.514	1.051	0.29	0.982
S*T*C	10	10.668	10.668	1.067	0.30	0.981
Error	132	476.000	476.000	3.606		
Total	175	2727.477				

S = 1.89896

R-Sq = 82.55%

R-Sq (adj) = 76.86%

S = species, T = times, C= concentrations

Table 49: Two-way ANOVA of mean percentage mass loss vs Species and Concentrations of Cypermethrin (high humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	44724	44723.8	119.56	0.000
Concentrations	10	158948	15894.8	42.49	0.000
Interaction	10	33257	3325.7	8.89	0.000
Error	154	57607	374.1		
Total	175	294536			

S = 19.34 R-Sq = 80.44% R-Sq (adj) = 77.77%

Table 50: Two-way ANOVA of mean absolute mass loss vs Species and Concentrations of Cypermethrin (high humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	96654559	96654559	72.31	0.000
Concentrations	10	448443197	44844320	33.55	0.000
Interaction	10	80001183	8000118	5.99	0.000
Error	154	205839355	1336619		
Total	175	830938293			

S = 1156 R-Sq = 75.23% R-Sq (adj) = 71.85%

Table 51: Two-way ANOVA of mean termite rating vs Species and Concentrations of Cypermethrin (high humidity) (experiment 5)

Source	DF	SS	MS	F	P
Species	1	311.11	311.114	96.02	0.000
Concentrations	10	1653.26	165.326	51.02	0.000
Interaction	10	264.11	26.411	8.15	0.000
Error	154	499.00	3.240		
Total	175	2727.48			

S = 1.800 R-Sq = 81.70% R-Sq (adj) = 79.21%

Table 52: GLM of mean percentage mass loss vs Species, Time and Concentrations of Permethrin (high humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	88469.8	88469.8	88469.8	289.49	0.000
Time (T)	1	180.8	180.8	180.8	0.59	0.443
Concentrations (C)	14	232360.7	232360.7	16597.2	54.31	0.000
S*T	1	28.6	28.6	28.6	0.09	0.76
S*C	14	63470.2	63470.2	4533.6	14.83	0.000
T*C	14	5774.2	5774.2	412.4	1.35	0.183
S*T*C	14	7861.8	7861.8	561.6	1.84	0.036
Error	180	55008.7	55008.7	305.6		
Total	239	453154.8				

S = 17.4815

R-Sq = 87.86%

R-Sq (adj) = 83.88%

S = species, T = times, C= concentrations

Table 53: GLM of mean absolute mass loss vs Species, Time and Concentrations of Permethrin (high humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	224050186	224050186	224050186	213.6	0.000
Time (T)	1	799491	799491	799491	0.76	0.384
Concentrations (C)	14	706915094	706915094	50493935	48.14	0.000
S*T	1	232006	232006	232006	0.22	0.639
S*C	14	228557495	228557495	16325535	15.56	0.000
T*C	14	21304455	21304455	1521747	1.45	0.134
S*T*C	14	35667310	35667310	2547665	2.43	0.004
Error	180	188805661	188805661	1048920		
Total	239	1406331698				

S = 889.417

R-Sq = 86.74%

R-Sq (adj) = 82.39%

S = species, T = times, C= concentrations

Table 54: GLM of mean termite rating vs Species, Time and Concentrations of Permethrin (high humidity) (experiment 5)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Species (S)	1	691.901	691.901	691.901	267.51	0.000
Time (T)	1	0.176	0.176	0.176	0.07	0.794
Concentrations (C)	14	2395.306	2395.306	171.093	66.15	0.000
S*T	1	0.051	0.051	0.051	0.02	0.888
S*C	14	505.24	505.24	36.089	13.95	0.000
T*C	14	59.09	59.09	4.221	1.63	0.074
S*T*C	14	79.34	79.34	5.667	2.19	0.010
Error	180	465.562	465.562	2.586		
Total	239	4196.666				

S = 1.60825

R-Sq = 88.91%

R-Sq (adj) = 85.27%

S = species, T = times, C= concentrations

Table 55: Two-way ANOVA of mean percentage mass loss versus species and concentrations of Chlorpyrifos (experiment 6)

Source	DF	SS	MS	F	P
Species	1	8364	8363.6	255.05	0.000
Concentrations	10	110662	11066.2	337.47	0.000
Interaction	10	15362	1536.2	46.85	0.000
Error	66	2164	32.8		
Total	87	136552			

S = 5.726

R-Sq = 98.42%

R-Sq (adj) = 97.91%

Table 56: Two-way ANOVA of mean absolute mass loss versus species and concentrations of Chlorpyrifos (experiment 6)

Source	DF	SS	MS	F	P
Species	1	47503057	47503057	513.51	0.000
Concentrations	10	213226582	21322658	230.50	0.000
Interaction	10	54254594	5425459	58.65	0.000
Error	66	6105431	92507		
Total	87	321089665			

S = 304.1

R-Sq = 98.10%

R-Sq (adj) = 97.49%

Table 57: Two-way ANOVA of mean termite rating versus species and concentrations of Chlorpyrifos (experiment 6)

Source	DF	SS	MS	F	P
Species	1	94.10	94.102	447.62	0.000
Concentrations	10	1027.80	102.78	488.90	0.000
Interaction	10	174.21	17.421	82.87	0.000
Error	66	13.87	0.21		
Total	87	1309.99			

S = 0.4585 R-Sq = 98.94% R-Sq (adj) = 98.60%

Table 58: Two-way ANOVA of mean percentage mass loss versus species and concentrations of Cypermethrin (experiment 6)

Source	DF	SS	MS	F	P
Species	1	389	389.3	6.14	0.015
Concentrations	10	119263	11926.3	188.01	0.000
Error	76	4821	63.4		
Total	87	124473			

S = 7.965 R-Sq = 96.13% R-Sq (adj) = 95.57%

Table 59: Two-way ANOVA of mean absolute mass loss versus species and concentrations of Cypermethrin (experiment 6)

Source	DF	SS	MS	F	P
Species	1	36424676	36424676	203.68	0.000
Concentrations	10	232662020	23266202	130.10	0.000
Interaction	10	46760074	4676007	26.15	0.000
Error	66	11802873	178831		
Total	87	327649644			

S = 422.9 R-Sq = 96.40% R-Sq (adj) = 95.25%

Table 60: Two-way ANOVA of mean termite rating versus species and concentrations of Cypermethrin (experiment 6)

Source	DF	SS	MS	F	P
Species	1	6.28	6.2756	7.82	0.007
Concentrations	10	978.46	97.846	121.99	0.000
Interaction	10	49.26	4.9256	6.14	0.000
Error	66	52.94	0.8021		
Total	87	1086.93			

S = 0.8956 R-Sq = 95.13% R-Sq (adj) = 93.58%

Table 61: Two-way ANOVA of mean percentage mass loss versus species and concentrations of Permethrin (experiment 6)

Source	DF	SS	MS	F	P
Species	1	2963	2963.1	15.46	0.000
Concentrations	14	153963	10997.4	57.39	0.000
Interaction	14	8470	605.0	3.16	0.000
Error	90	17245	191.6		
Total	119	182641			

S = 13.84 R-Sq = 90.56% R-Sq (adj) = 87.52%

Table 62: Two-way ANOVA of mean absolute mass loss versus species and concentrations of Permethrin (experiment 6)

Source	DF	SS	MS	F	P
Species	1	74677274	74677274	114.16	0.000
Concentrations	14	311824327	22273166	34.05	0.000
Interaction	14	66516452	4751175	7.26	0.000
Error	90	58872683	654141		
Total	119	511890735			

S = 808.8 R-Sq = 88.50% R-Sq (adj) = 84.79%

Table 63: Two-way ANOVA of mean termite rating versus species and concentrations of Permethrin (experiment 6)

Source	DF	SS	MS	F	P
Species	1	17.63	17.633	9.02	0.003
Concentrations	14	1428.43	102.031	52.21	0.000
Interaction	14	58.55	4.182	2.14	0.016
Error	90	175.88	1.954		
Total	119	1680.49			

S = 1.398 R-Sq = 89.53% R-Sq (adj) = 86.16%

Table 64: Two-way ANOVA of mean percentage mass loss versus species and target retentions of Chlorpyrifos (experiment 7)

Source	DF	SS	MS	F	P
Species	1	2758.39	2758.39	21.44	0.000
Target retentions	3	635.32	211.77	1.65	0.205
Interaction	3	635.32	211.77	1.65	0.205
Error	24	3087.99	128.67		
Total	31	7117.02			

S = 11.34 R-Sq = 56.61% R-Sq (adj) = 43.96%

Table 65: Two-way ANOVA of mean absolute mass loss versus species and target retentions of Chlorpyrifos (experiment 7)

Source	DF	SS	MS	F	P
Species	1	73374498	73374498	344.10	0.000
Target retentions	3	194891	64964	0.30	0.822
Interaction	3	553041	184347	0.86	0.473
Error	24	5117690	213237		
Total	31	79240120			

S = 461.8 R-Sq = 93.54% R-Sq (adj) = 91.66%

Table 66: Two-way ANOVA of mean termite rating versus species and target retentions of Chlorpyrifos (experiment 7)

Source	DF	SS	MS	F	P
Species	1	32	32.0000	14.22	0.001
Target retentions	3	17	5.6667	2.52	0.082
Interaction	3	17	5.6667	2.52	0.082
Error	24	54	2.2500		
Total	31	120			

S = 1.5

R-Sq = 55.00%

R-Sq (adj) = 41.88%

Table 67: One-way ANOVA of percentage mass loss versus species (experiment 7)

Source	DF	SS	MS	F	P
Species	1	2758	2758	18.99	0.000
Error	30	4359	145		
Total	31	7117			

S = 12.05

R-Sq = 38.76%

R-Sq (adj) = 36.72%

Table 68: One-way ANOVA of absolute mass loss versus species (experiment 7)

Source	DF	SS	MS	F	P
Species	1	73374498	73374498	375.28	0.000
Error	30	5865622	195521		
Total	31	79240120			

S = 442.2

R-Sq = 92.60%

R-Sq (adj) = 92.35%

Table 69: One-way ANOVA of termite rating versus species (experiment 7)

Source	DF	SS	MS	F	P
Species	1	32	32	10.91	0.002
Error	30	88	2.93		
Total	31	120			

S = 1.713

R-Sq = 26.67%

R-Sq (adj) = 24.22%

Table 70: Two-way ANOVA of mean percentage mass loss versus species and target retentions of Cypermethrin (experiment 7)

Source	DF	SS	MS	F	P
Species	1	4.6	4.6	0.11	0.746
Target retention	3	46679.3	15559.8	366.55	0.000
Interaction	3	6.4	2.1	0.05	0.985
Error	24	1018.8	42.4		
Total	31	47709.0			

S = 6.515 R-Sq = 97.86% R-Sq (adj) = 97.24%

Table 71: Two-way ANOVA of mean absolute mass loss versus species and target retentions of Cypermethrin (experiment 7)

Source	DF	SS	MS	F	P
Species	1	6148648	6148648	62.17	0.000
Target retention	3	67348732	22449577	226.98	0.000
Interaction	3	5454201	1818067	18.38	0.000
Error	24	2373736	98906		
Total	31	81325316			

S = 314.5 R-Sq = 97.08% R-Sq (adj) = 96.23%

Table 72: Two-way ANOVA of mean termite rating versus species and target retentions of Cypermethrin (experiment 7)

Source	DF	SS	MS	F	P
Species	1	0.070	0.070	0.18	0.674
Target retention	3	521.961	173.987	448.40	0.000
Interaction	3	0.836	0.279	0.72	0.551
Error	24	9.313	0.388		
Total	31	532.180			

S = 0.6229 R-Sq = 98.25% R-Sq (adj) = 97.74%

Table 73: One-way ANOVA of percentage mass loss versus target retentions (experiment 7)

Source	DF	SS	MS	F	P
Target retention	3	46679.3	15559.8	423.08	0.000
Error	28	1029.8	36.8		
Total	31	47709.0			

S = 6.064 R-Sq = 97.84% R-Sq (adj) = 97.61%

Table 74: One-way ANOVA of termite rating versus target retentions (experiment 7)

Source	DF	SS	MS	F	P
Target retention	3	521.961	173.987	476.73	0.000
Error	28	10.219	0.365		
Total	31	532.180			

S = 0.6041 R-Sq = 98.08% R-Sq (adj) = 97.87%

Table 75: Two-way ANOVA of mean percentage mass loss versus species and target retentions of Deltamethrin (experiment 7)

Source	DF	SS	MS	F	P
Species	1	704.1	704.1	3.75	0.065
Target retention	3	40631.7	13543.9	72.22	0.000
Interaction	3	520.0	173.3	0.92	0.444
Error	24	4500.9	187.5		
Total	31	46356.6			

S = 13.69 R-Sq = 90.29% R-Sq (adj) = 87.46%

Table 76: Two-way ANOVA of mean absolute mass loss versus species and target retentions of Deltamethrin (experiment 7)

Source	DF	SS	MS	F	P
Species	1	2693521	2693521	23.41	0.000
Target retention	3	47658070	15886023	138.10	0.000
Interaction	3	7297913	2432638	21.15	0.000
Error	24	2760838	115035		
Total	31	60410341			

S = 339.2 R-Sq = 95.43% R-Sq (adj) = 94.10%

Table 77: Two-way ANOVA of mean termite rating versus species and target retentions of Deltamethrin (experiment 7)

Source	DF	SS	MS	F	P
Species	1	6.570	6.570	2.64	0.117
Target retention	3	456.086	152.029	61.13	0.000
Interaction	3	5.711	1.904	0.77	0.525
Error	24	59.688	2.487		
Total	31	528.055			

S = 1.577 R-Sq = 88.70% R-Sq (adj) = 85.40%

Table 78: One-way ANOVA of percentage mass loss versus target retentions (experiment 7)

Source	DF	SS	MS	F	P
Target retention	3	40632	13544	66.24	0.000
Error	28	5725	204		
Total	31	46357			

S = 14.30 R-Sq = 87.65% R-Sq (adj) = 86.33%

Table 79: One-way ANOVA of termite rating versus target retentions (experiment 7)

Source	DF	SS	MS	F	P
Target retention	3	456.09	152.03	59.15	0.000
Error	28	71.97	2.57		
Total	31	528.05			

S = 1.603 R-Sq = 86.37% R-Sq (adj) = 84.91%

Table 80: Two-way ANOVA of mean percentage mass loss versus species and target retentions of Permethrin (experiment 7)

Source	DF	SS	MS	F	P
Species	1	4453.3	4453.32	22.39	0.000
Target retention	3	28181.1	9393.70	47.23	0.000
Interaction	3	4431.5	1477.15	7.43	0.001
Error	23	4773.2	198.88		
Total	31	41839.1			

S = 14.10 R-Sq = 88.59% R-Sq (adj) = 85.26%

Table 81: Two-way ANOVA of mean absolute mass loss versus species and target retentions of Permethrin (experiment 7)

Source	DF	SS	MS	F	P
Species	1	1210568	1210568	3.87	0.061
Target retention	3	38908448	12969483	41.49	0.000
Interaction	3	9032633	3010878	9.63	0.000
Error	23	7502859	312619		
Total	31	56654508			

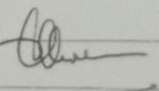
S = 559.1	R-Sq = 86.76%	R-Sq (adj) = 82.89%
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Table 82: Two-way ANOVA of mean termite rating versus species and target retentions of Permethrin (experiment 7)

Source	DF	SS	MS	F	P
Species	1	73.508	73.508	35.15	0.000
Target retention	3	335.398	111.799	53.46	0.000
Interaction	3	72.773	24.258	11.60	0.000
Error	23	50.188	2.091		
Total	31	531.867			

S = 1.446	R-Sq = 90.56%	R-Sq (adj) = 87.81%
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Appendix C: Certificate of analysis of pesticide-insectide (aqueous solution)

 UNIVERSITI SAINS MALAYSIA 11800 USM Penang, Malaysia SIJIL ANALISIS / CERTIFICATE OF ANALYSIS		No 1073 Tel.: 04-6577888 Ext. 3684, 2132 Direct Line : 04-6572407 Fax : 04-6572210															
Bil. Kami (Our Ref) UBLTS/ACU/04182/LTS/OCT/2017	Bil. Tuan (Your Ref)	Tarikh (Date) 16-NOV-2017															
Tajuk (Title) GCMS Analysis																	
Pelanggan (Client) ASSOC. PROF. DR ANDREW H.H. WONG FAKULTI SAINS DAN TEKNOLOGI SUMBER UNIVERSITI MALAYSIA SARAWAK 94300 KOTA SAMARAHAN, SARAWAK.		Pencerapan/Komen (Observation/Comment) Sample Received Date: 30-Oct-2017 Sample Description: Pesticide-Insecticide (Aqueous solution)															
Kaedah yang digunakan (Method used) Agilent 6890 Series GC with Flame Ionisation Detector (GC-FID)																	
Keputusan (Results)																	
<table border="1"> <thead> <tr> <th>PARAMETER</th> <th>ANALYSIS RESULTS</th> <th>UNIT</th> </tr> </thead> <tbody> <tr> <td>Chlorpyrifos</td> <td>33.22</td> <td>% w/w</td> </tr> <tr> <td>Cypermethrin</td> <td>9.18</td> <td>% w/w</td> </tr> <tr> <td>Deltamethrin</td> <td>3.53</td> <td>% w/w</td> </tr> <tr> <td>Permethrin</td> <td>22.21</td> <td>% w/w</td> </tr> </tbody> </table>			PARAMETER	ANALYSIS RESULTS	UNIT	Chlorpyrifos	33.22	% w/w	Cypermethrin	9.18	% w/w	Deltamethrin	3.53	% w/w	Permethrin	22.21	% w/w
PARAMETER	ANALYSIS RESULTS	UNIT															
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Permethrin	22.21	% w/w															
Nama Penganalisis (Name of Analyst) : Dr Tan Soo Choon		Tandatangan (Signature) : 															
Pengajian/Pusat (School / Centre) :		Cop (Stamp) Prof. Dr. Tan Soo Choon (PhD) Coordinator - General Manager Usains Biomics Laboratory Testing Services Sdn. Bhd. Suite 124, Eureka Complex Universiti Sains Malaysia 11800 Penang, Malaysia															
Date of Report: 16 Nov 2017																	
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