DECODING THE POTENTIALS OF VERNACULAR TIMBER PRESERVATION TECHNOLOGY FOR STRUCTURAL APPLICATIONS

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Degree of Doctor of Philosophy in Civil Engineering

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Dissertation submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Civil Engineering

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DECLARATION OF CANDIDATE AND SUPERVISOR

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ABSTRACT

Along with the celebrated history in the field of construction in the world, wood has been a building material for hundreds of years. The stability of timber structures is influenced by their reliance on external factors as it's a hygroscopic material. Where the moisture content has an impact on almost every structural parameter, including strength, stiffness, and dimensional stability. It is also extremely vulnerable to biological degradation caused by insects, fungi, and bacteria affecting the molecular structure.

These scarcities were undertaken in traditional wooden structures in a significant, yet sensitive manner in a tropical country like Sri Lanka. The durability of traditional wooden constructions exists under a highly appreciable status. In a tropical environment, the prolonged physical sustainability of wood is a challenging task. These show a greater degree of tolerance in the harsh tropical environment. Empirically expressive information sources were investigated, therefore structures for shelters were selected for further analysis.

In this case, *Tampita Vihara* (the shrines on pillars), *Devala* (shrines dedicated to deities), *Ambalam* (resting places for travelers), and *Mandapa* (the assembly spaces for administrative practices) of which physical remains are still available in a relatively preserved state of standing evidence were carefully chosen. Numerous literature findings are documented on their religious beliefs and the significance of their architecture. But the structural engineering aspects relevant to material perspectives have not been studied adequately.

A holistic investigation of timber in construction was carried out using knowledge from traditional vernacular buildings. Traditional vernacular[1] construction relied on a thorough awareness of the surrounding environment, as well as the characteristics of locally available materials and manual labor. Traditional people are essential stakeholders in forest management because they are often economically, socially, and culturally reliant on forests. This resulted in building artisans attaining a profound knowledge of the utilization and manipulation of materials.

This study examines the state of the structures, which entails a thorough understanding of past and present conditions. The goal of collecting extensive data from various typological structures is to establish a knowledge basis for the future. Field survey analysis around Sri Lanka was conducted to accumulate and consolidate the traditional vernacular timber processing and preservation technologies.

Results disclosed wood logs burying under paddy field mud as a well-established technique to treat wood. As well, three dominant plant species were identified as *Mikania micrantha, Titonia diversifolia, Gliricidia sepium* assorted with paddy field mud to enhance the properties before treatment. Further, the field survey results and the microscopic investigations proved *Mangifera indica* wood was used for roof elements utilized after the above treatment in traditional vernacular structures with in the use life range 40 to 50 years. This showed its potential to be used for structural applications after proper treatment.

Finally, an experimental trial was performed to evaluate the traditional vernacular technology with amendments, reinventing two types of wood preservatives based on the material matrix as plant extracts assorted with paddy field mud and only plant extracts obtained for water.

This combination of traditional vernacular and contemporary aspects could offer an interesting and profitable approach to the further development of the wood industry.

Keywords: Timber architectural typologies; timber preservation technology; *Mikania; Gliricidia sepium; Titonia diversifolia;* Plant extracts; wood preservatives.

[1] The term vernacular comes from linguistics, where it refers to language usage specific to a time, region, or group.

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When the broad mind has opened, I stare at the stars that shinning in the thoughtful skies and the glittering nature, as well as Earth's mysteries that I ever think of to feel by my thoughts that spread so deep on trying to work with things that sound 'creative'. Here I started my second journey, leaving 219 km away from home three years ago. This up-start was through Science, Engineering, and Design.

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TABLE OF CONTENTS

Declaration of Candidate and Supervisor iii
Abstract v
Acknowledgment vi
List of Figures xiv
List of tables xxi
Chapter 1 : INTRODUCTION 1
1.1 General 1
1.2 Research Problem 3
1.3 Research Gap 3
1.4 Aim and Objectives 4
1.5 Methodology 5
1.6 Main Findings 7
1.7 Organization of the thesis 8
Chapter 2 : LITERATURE REVIEW 9
2.1 General 9
2.2 Urbanization and the construction industry 9
2.2.1 The environmental impacts of buildings 10
2.2.2 Evaluation of construction materials 11
2.2.3 The effects of building material selection 12
2.2.4 The use of timber in construction 14
2.3 Causes of wood deterioration 15
2.3.1 Deterioration caused by insects 15
2.3.2 Deterioration caused by fungi and bacteria 18
2.3.3 Deterioration caused by fire 20
2.4 Wood Preservation Principles 22
2.4.1 Natural durability of wood 22
2.4.2 Wood 22
2.5 Wood preservation 27
2.5.1 Wood preservatives 27
2.5.2 Impacts of inorganic chemicals used for wood protection 29
2.5.3 Natural Compounds for wood protection 30
2.6 Plant extracts as wood preservatives 33
2.7 Timber modification 34

2.7.1 Thermal modification....35
2.7.2 Chemical Modification....35
2.7.3 Impregnation modification....35
2.8 Past applications of wood in construction....36
2.8.1 Local application....36
2.9 Nature and the cultural symbiosis....38
2.10 Summary....40
Chapter 3 : ANCIENT TIMBER PRACTICE IN SRI LANKA....42
3.1 General....42
3.2 Archaeological Evidence....42
3.3 *Ambalam* Structures....42
3.3.1 Identifying the potentials of traditional construction techniques....46
3.3.2 The structure of '*Ambalama*'....46
3.3.3 Materials and Methodology....49
3.3.4 Results....50
3.3.5 Discussion....52
3.4 Timber processing techniquess practice in *Ambalam*....54
3.4.1 Growth Rings and Grain Distribution....55
3.4.2 Growth Stress....55
3.4.3 Materials....56
3.4.4 Methodology....58
3.4.5 Results....61
3.4.6 Discussion....63
3.5 Strategies used to overcome the mechanical failure....66
3.5.1 Major structural components....67
3.5.2 Major structural components – Type C....67
3.6 Summary....69
Chapter 4 : DECODING THE TIMBER PRESERVATION TECHNIQUES....71
4.1 General....71
4.2 Documenting the traditional vernacular timber preservations practiced in Sri Lanka....71
4.2.1 Materials and methodology....72
4.2.2 The selected cases....72
4.2.3 Field Survey....74
4.2.4 Statistical Analysis....74

4.2.5 Sampling Technique - Snow-balling Sampling technique (SB) 74
4.3 Results and Discussion 74
4.3.1 Demographic profile 75
4.3.2 Identified characteristics of the structures (Building Description) 75
4.3.3 Awareness of the preservation technologies of the identified structures 78
4.3.4 Identification of traditional vernacular timber preservation technologies 79
4.3.5 Awareness of the Plants species used to develop the paddy field mud . 83
4.3.6 Identify the potentials to formulate a preservative solution 84
4.4 Discussion 84
4.5 Identifying and materializing the identified traditional vernacular timber preservation techniques 85
4.5.1 Mud was prepared by adding leaves 85
4.6 Identifying the wood with the potential to further investigate the preservation techniques 86
4.6.1 Materials and methodology 88
4.6.2 Results of the Experiment 2 90
4.6.3 Discussion 92
4.7 Investigating the potentials of mango timber as a sustainable construction material 93
4.7.1 Materials and Methodology 94
A. Mechanical properties were evaluated using the following standard and the equations 95
4.7.2 Results 95
4.7.3 Discussion 99
4.8 Identify the plants' species for further development 99
4.8.1 Mikania micrantha 100
4.8.2 Gliricidia sepium 101
4.8.3 *Titonia diversifolia* 101
4.9 Conduct experiments and investigate traditional vernacular technology 102
4.10 Define the experimental procedure 102
4.10.1 Conduct experiments and investigate the traditional vernacular technology 102
4.10.2 Materials and methodology 102
4.10.3 Results of the experiment 103
4.10.4 Discussions obtained from the pilot study 105

4.10.5 Conduct experiments and investigate the traditional vernacular technology with amendments. 106
4.11 Causes for the mechanical performance 107
4.11.1 Materials and methodology 109
4.11.2 Results and Discussion 114
4.12 Comparison of Mechanical properties of Mango wood treated with commercially available wood preservative. 122
4.12.1 Investigation on the Mechanical Property Variation on Timber Caused Due to the Chemical Modification 122
4.12.2 Results 123
4.13 Comparison of mechanical properties of Mango wood treated with commercially available wood preservative and the decoded treatments. 125
4.13.1 Materials and methodology 125
4.13.2 Results and discussion 127
4.14 Spectroscopic screening on the treated wood 129
4.14.1 Materials and methodology 130
4.14.2 RESULTS 133
4.14.3 Discussion 138
4.15 The Field Evaluation of Potential toxicity Against the Invasive Subterranean Termite (Isoptera: Rhinotermitidae) in tropics 139
4.15.1 Materials and methodology 140
4.15.2 Results 142
4.16 Evaluation of the antifungal activity of experimental solutions 146
4.16.1 Materials 147
4.16.2 Results and discussion 150
4.17 Summary 153
Chapter 5 : Development of the solutions 155
5.1 General 155
5.2 Identifying the optimum extraction procedure 155
5.3 Extraction Techniquess 156
5.3.1 The parameters that affect the extraction efficiency 157
A. The effect of extraction temperature 160
B. The effect of extraction time 160
C. The effect of Water to leaf powder ratio 160
D. The effect of particle size 160
E. The effect of the extraction cycle 160

F. Selection of solvent for bioactive compound extraction 161
5.3.2 Selection of the solvent for this research 161
A. Liquid water 162
5.4 Investigating the plant leaf particle size for best extraction 162
5.4.1 Effect of Particle Size on the yield extract 162
5.4.2 Defining the extraction procedure 166
5.5 Development of the extraction procedure 166
5.5.1 Identify the best fermentation time 167
5.5.2 Identify the best filtration techniques 167
5.5.3 Preparation of the paddy field mud. 169
5.5.4 Development of the procedure 171
5.6 Investigating the performance of the extracts obtained from the plant leaves
5.6.1 Solution development comprising the plant extracts. 172
5.6.2 Defining the extraction Duration 175
5.6.3 Investigating the most effective fraction of the Extraction yield 177
5.7 Evaluating the performance of the solution 178
5.7.1 Evaluating the wood treated by the above-extracted layers 178
5.7.2 Results 180
5.7.3 Discussion 180
5.8 Effect of extraction methodologies and solvent selection for Chemical analysis 181
5.8.1 Dichloromethane 181
5.8.2 Evaluation on the most effective fraction of the plant extraction 181
5.9 Evaluation of the performance against fungus (*Schizophyllum commune*) that was grown in; Agar disc diffusion method 184
5.9.1 Materials and methodology 184
5.9.2 Results and discussion 186
5.10 Performance of the Solution Toxicity against termites 189
5.10.2 Investigating the performance of the plant extracted solutions 194
5.10.3 Results of the accelerated field test. 195
5.10.4 Discussion 195
5.11 Evaluating the most toxic fraction against termites under natural feild conditions 196
5.11.2 Evaluating the toxicity against fungus 199
5.11.3 Preparation of culture plates 199
5.11.4 Results 200

5.12 Evaluation of the antifungal activity of experimental organic wood preservative 208
5.12.1 Materials and methods 208
5.12.2 Results and Discussions 210
5.12.3 Antifungal activity against white rots was presented as below, ... 216
5.12.4 Discussion 221
5.13 Leaching characteristics of the wood treated with the plant extracts 222
5.13.1 Experimental methods 223
$wieght\ loss\ \% = (Initial\ weight - present\ weight) * 100(initialweight)$ 225
5.13.2 Results 226
B. Tannin presence in the leachate 227
C. Mass loss percentage 227
5.13.3 Discussion 228
5.14 The Composition Development with optimum performance 232
5.15 Summary 234
CHAPTER 6 : A COMPARISON OF THE PERFORMANCE OF DEVELOPED SOLUTION 236
6.1 General 236
6.2 Development of the final solution 236
6.2.1 Experimental program 237
6.2.2 Experiment for the gross solution uptake 238
6.2.3 The density of the solution 240
6.2.4 Visual observation of the penetration 240
6.2.5 EDX analysis 244
6.2.6 Experiment on the toxicity performance 244
6.2.7 Accelerated Test 1 - *Filter paper test* 245
6.2.8 Antifungal properties of the two solutions 245
6.2.9 Performance of the treated wood (wood mass loss assay) 246
6.2.10 Investigating the leachate of the solution 248
6.2.11 Ferric test for tannin detection 250
6.2.12 Experiment on the performance of the treated wood after leachate against termites (Accelerated field test) 250
6.3 Study of heavy metal leaching in the treated wood 251
6.3.1 Materials and methodology 251
6.3.2 Results and Discussion 252
6.4 Mechanical performance after treatment 253

6.4.1 Material and methodology 253
6.4.2 Results 254
6.4.3 Discussion 255
6.5 Rapid Identification of Cu presence on Treated Woods Using chemical stain method 256
6.5.1 Materials and Methodology 256
6.5.2 Results and discussion 257
FSWM solution presented copper on the treated surface representing a significant color change. 257
6.6 Comparison on the mechanical performance with industrial available preservative 257
6.7 Evaluating the water absorption percentage 258
6.7.1 Materials and methodology 258
6.7.2 Results of the water absorption 259
6.7.3 Discussion 259
6.8 Effect of pressure exerted on the chemical retention during wood treatments 260
6.8.1 Materials and methodology 260
6.8.2 Results and discussion 261
6.9 GC-MS analysis of bioactive compounds of Experimental level wood preservative 261
6.9.1 Gas chromatography-mass spectrometry 262
6.9.2 Materials 262
6.9.3 Results of GC analysis 265
6.9.4 Discussion 270
6.10 Practical Application 271
6.11 Summary 274
Chapter 7 : CONCLUSION AND RECOMMENDATIONS 276
7.1 Conclusion 276
7.2 Future Works 281
References 282

LIST OF FIGURES

Figure 1-1; The above diagram presents the conceptual flow of the overall study program 6
Figure 2-1: Simple classification of the construction model 9
Figure 2-2:Then main four challenges in the concept of sustainable construction 11
Figure 2-3:Based on the design standards; for concrete [10], for steel [11], and for timber [12], the graph presents the strength normalized by the density vs modulus normalized by density. Source –[13] 13
Figure 2-4:The Life-cycle assessment from the regeneration of trees to disposal of wood materials (Source: CORRIM Presentations, www.corrim.org/ppt/2005/fps_june2005/lippke/index.sp[14]*).* 15
Figure 2-5: Flow chart on the causes of wood deterioration. 16
Figure 2-6 : a – Subterranean termites , b- dry wood termites , c-damp wood termites , d – Mud tunnels behavior of the subterranean termites , e- behavior of the dry wood termites, f- damp wood termite behavior 17
Figure 2-7: a- Carpenter Ants , b- damage to structures through their nesting behavior , c- Powder-Post Beetles, d- damage caused to the structures. e- Carpenter bee boring into wood, f- Nest of a carpenter bee 18
Figure 2-8 : Types of wood decaying fungi 19
Figure 2-9: Other molds , blue stains and the bacterial growth on wood surfaces. 20
Figure 2-10:The degradation of wood when exposed to fire on the surface A- Schematic diagram , B- Degradation zone observed in pine wood, 21
Figure 2-11; The flow chart presenting the naural polymer 22
Figure 2-12; Detail graphical ;a-The hierarchical structure of wood , b. The composition in cross section , the longitudinal direction, c- Anisotropy of wood on multiple length scales [107]. 26
Figure 2-13; The Techniques for preserving wood 27
Figure 2-14: A Flow diagram which presents the characteristics of wood preservative 28
Figure 2-15 : the main types of wood preservatives existing in the wood industry 29
Figure 2-16; The flow chart on the factors affecting the properties of wood. 29
Figure 2-17: Classification of the origins of natural compounds 30
Figure 2-18: Classification of the tannin 31
Figure 2-19; Classification of wood extractives 32
Figure 2-20; Classification of the timber modification 34
Figure 2-21; The flow chart on the classification of the wood constructions reference to time. 36
Figure 2-22; Classifications of information sources ; refereed to tangible and intangible sources 37

Figure 2-23; the photo was taken beforehand restoration –taken on late 1800's or early 1900's 39
Figure 2-24: : a- Tampita Vihara-, b-Devala , c-Ambalam d- Mandapa 40
Figure 2-25; A- Cell Structure, Cell Lumen, Wood cell wall, Micro Fibrils, Elementary Fibrils; B- Cellulose, Hemicellulose, Lignin; C- Cellulose's many hydroxyl (–OH) groups attract water molecules, making the substance hydrophilic, D - Reaction of hydrogen bonds; E -Bound and free water distribution 41
Figure 3-1;The construction details of the Ambalam ;a-, b- ,c-, d 43
Figure 3-2: A- Timber joinery in Karagahagedera Ambalama, B- Bearers on stumps, C-Panavitiya Ambalama wood carvings 44
Figure 3-3;Rukula Ambalama , Kadugannawa Ambalama 45
Figure 3-4;Mangalagama Ambalama illustration model; A - Isometric view. Mangalagama Ambalama illustration model; B – Plan 46
Figure 3-5; The six Ambalam structures are shown above ; A-Badulla Ambalama., B-Kadugannawa Ambalama, C- Karagahagedra Ambalama, D- Panavita Ambalama, E-Rukula Ambalama ,F-Managalama Ambalama. 49
Figure 3-6; Above figure explores building orientation 51
Figure 3-7;Map 1- Demonstrating on analyzing the grain distribution 58
Figure 3-8; A-Panavitiya Ambalama (Bearer), B – Badulla Ambalama ,C,D -Giruwawa Ambalama King Rafter, Rafter, Bearers) 59
Figure 3-9;Padivitiya Ambalama External bearers 60
Figure 3-10: Joint detail of the Badulla Ambalama 60
Figure 3-11;Rafters of Giruwa Ambalama 60
Figure 3-12; Mapping the curves using Auto cad Software 61
Figure 3-13;Map 28 – Shrinkage in the Tangential plain 65
Figure 3-14;The maps represent the sawn log distribution corresponding to the center, and the characteristics and distortion. 66
Figure 3-15; Direction of the force application to the structural elements 66
Figure 3-16;B-Orientation placements with regards to Applications 67
Figure 3-17; Rafter orientation ;type B 67
Figure 3-18; Type C Orientation 67
Figure 3-19; Utilization percentage of the structural elements 67
Figure 3-20; Force applications , Annual Ring orientation and wood movement in application when force applied. 68
Figure 3-21; Graphical summary of the chapter 2 69
Figure 4-1;Map 1- Locations of the identified cases; Red dots denotes the Ambalam Structures , and the green dots denotes the private residences 73

Figure 4-2;Flow chart of the detail's phases of the survey 74
Figure 4-3;Building type Vs The material composition 77
Figure 4-4; Age category of the interviewer vs building type 77
Figure 4-5;The building type Vs The timber species used. 77
Figure 4-6;The building type Vs The age of the building..... 77
Figure 4-7; The age of the building and the wood preservation technique used to treat the wood used with in the structure 79
Figure 4-8; Building Type and the preservation technic used to treat the wood with in the structure 79
Figure 4-9;– Graphical representation of knowledge transferring by generations of the Wood kept under paddy field mud 82
Figure 4-10;Plant species used to develop the paddy field mud before utilization..... 83
Figure 4-11;Wood preservation vs current usage of the decoded traditional vernacular technology..... 83
Figure 4-12; Field interviews and the case studies considered for evaluation..... 84
Figure 4-13;Further tabulated technics of timber soaking under mud. 85
Figure 4-15; Highly decoded plant species with in the survey. 86
Figure 4-16;cases selected from Uva Province ,A-Soranathota , a- roof details , B-Mahiyangana b- roof details , C- Silverland Badulla , roof details; sample preparation 88
Figure 4-18; *Flow chart represent the Dehydration of fresh material for permanent mounting using the stains safranin*..... 89
Figure 4-19 -Fig. 4. A-The weight obtained through the digital scale , B- apply pressure C-Timber samples soaked in water..... 90
Figure 4-20 -Mango (end grain 10x)..... 91
Figure 4-21- A-Transverse section , B- Tangiantial section , C- Radial Section 91
Figure 4-22; Plant selection parameters are classified as above 100
Figure 4-23; Mikania micrantha appearance of the leaves and the growth vegetation..... 100
Figure 4-24:Gliricidia Sepium 101
Figure 4-25;Titonia diversifolia..... 101
Figure 4-27; the observations when the specimens taken out from the solution 103
Figure 4-28 A clear colour variation was observed compared to the control untreated samples. (After drying)...... 103
Figure 4-29; visual observations after 15, 30 , 45, 60 treatment durations..... 103
Figure 4-30; Section the wood specimens as instructed\ed above. 104
Figure 4-31; Sliced wooden sections 105
Figure 4-32; Experimental Design..... 107
Figure 4-33; Classification of the reactions causes towards polymer degradation. 108

Figure 4-34; classification of mechanical properties 109
Figure 4-35; The compression strength (Nmm-2) the samples from the solution A- Solution G 118
Figure 4-36;-The compression strength (Nmm-2) representing the samples from the solution a- Solution g 118
Figure 4-37; The comparison among the optimized sample performance 15 days performance and 30-day performance 118
Figure 4-38; Average modulus of Elasticity(test A) 119
Figure 4-39;Average Modulus of Elasticity (test B) 119
Figure 4-40; Comparison on the optimum MOE obtained on the 15 days and 30 days respectively on test A and test B 119
Figure 4-41;Average modulus of Rupture 120
Figure 4-42; Average modulus of Rupture 120
Figure 4-43; Comparison on the optimum MOR obtained on the 15 days and 30 days respectively on test A and test B 120
Figure 4-44; Schematic diagram of the sample selecting position, gold-palladium plated ... 132
Figure 4-45; SEM analysis ,positioning the points 133
Figure 4-46- Comparison on the section to observe the penetration 135
Figure 4-47; Conclusion of the highly presented main elements 137
Figure 4-48;EDS/EDX Microstructure Interpretation: Energy -Dispersive X-rays Spectroscopy Analysis 138
Figure 4-49;Selected sites , and half dipped wood 141
Figure 4-50; Mikania micrantha(lowest mass loss percentage - A, B , C, D ; Gliricidia sepium- A, B, C, D (highest mass loss percentage)- after 12 months 142
Figure 4-51; The weight loss percentage vs treatment duration ; submerged for 15, 30 and 45 days (M. micrantha , T. diversifolia, G.sepium) 142
Figure 4-52; The weight loss percentage vs treatment duration; submerged for 15, 30, and 45 days (combinations of the three plant extracts) 143
Figure 4-53; The fungus grown on the exposed wood 145
Figure 4-54;Schizophyllum commune 146
Figure 4-55; Flow chart presenting the process of the fungus isolation for further investigations 146
Figure 4-56;Sample submitted to the national herbarium , Royal Botanic gardens , Peradeniya 147
Figure 4-57; Sampling process, PDA filled petri dish preparation and the treated wood block placement 149
Figure 4-58;lowest weight loss percentages were presented as above 150

Figure 4-59; Summary of the experiments presenting the rot resistance 151
Figure 4-60; The treated wood specimens after 16 weeks exposed to the fungus; Comparison of the weight loss percentage of the treated wood exposed to fungus 152
Figure 4-61; graphical abstract of the chapter summary 153
Figure 5-1; Flow chart representing the extraction techniques 156
Figure 5-2; Flow chart representing the solvent extraction 157
Figure 5-3; Flow chart representing the parameters of extraction 157
Figure 5-4; Flow chart representing the Solvent extraction techniques 158
Figure 5-5; The structure of the water , Encyclopædia Britannica, Inc. 162
Figure 5-6; Flow chart representing the Solutions 166
Figure 5-7; Flow chart representing of types of filtrations 168
Figure 5-8; Flow chart representing the leaf digestion speed 168
Figure 5-9;Collection of mud from the organic paddy field 169
Figure 5-10 Removing the larger unwanted particles using sieves and the washed access of water 169
Figure 5-11; Mud solubility in plant extract dissolved in water as the solvent 170
Figure 5-12;Visual observation of the surface application ;A, B, C- Darker colors observed when the impurities are applied 174
Figure 5-13;The flow chart presenting the extraction duration 175
Figure 5-14; visual appearance of the solution 175
Figure 5-22;the leaves extracted to water fermented to days 177
Figure 5-23; Solution with the layers 178
Figure 5-24; The flow chart of two major ways to evaluate the performance of the solutions 178
Figure 5-25; Treated mango wood from the above-identified fractions 179
Figure 5-26; Field exposure of the samples 180
Figure 5-27; Flow diagram representing the dichloromethane extraction procedure 182
Figure 5-28;Dicloromethane extraction procedure 182
Figure 5-29; The extracted solution fermented for 24 hours 183
Figure 5-30 The aqueous layer separated after the dichloromethane extraction 183
Figure 5-31 The fraction extracted to the dichloromethane solution 183
Figure 5-32; Flow chart representing the steps of the process 183
Figure 5-33:Schematic diagram of the practice 184
Figure 5-34;A- material matrix (Titonia Diversifolia , Gliricidia Sepium , Mikania micrantha , Mud , B- The solution developed under the protocol 1 , C- The solutions were mixed with Dichloromethane , D- The fractions were extracted using the separating funnel, E – the extracted fraction; a- original solution , b – DCM extracted fraction , c- others , F- Syringe

filters , G- punched filter papers submerged with the Solution in E And the filter air papers 185
Figure 5-35; Solutions were syringe filtered before introducing to the filter papers 186
Figure 5-36; The submerged filter apers exposed to the fungus 188
Figure 5-37 ; A- The prepared solutions ,B- 5 ml of the solution, C- the filter papers are saturated , D – the positioning of the filter papers , E- Field exposed treated filter 190
Figure 5-38;A-the control (-), B- The control (+) , C- Gs_Td_Mm_m (original solution), D-Gs_Td_Mm (Original solution) 191
Figure 5-39 ; E- C- Gs_Td_Mm_m (original solution), F- Gs_Td_Mm_m (DCM fraction),G-Gs_Td_Mm_m (D- Aqueous fraction) 192
Figure 5-40; Woos specimens submerged in the solutions 195
Figure 5-41; The fraction extracted to the DCM layer and the layer removed after the DCM fraction was removed (aqueous layer) 196
Figure 5-42 ; treated wood specimens out of the developed solutions 197
Figure 5-43; The PDA solutions and the poisoned solutions 200
Figure 5-44;Antifungal activity against Talaromyces purpureogenus(F1), Aspergillus japonicus(F2), Pleurotus ostreatus(F3), Schizophyllum commune(F4) 207
Figure 5-45; Material matrix composition 210
Figure 5-47 - timber blocks immersed in distil water ;6 hours later 225
Figure 5-49;Visual observation of the color variation presented on 6 hours later, 1 day later, 3 days later, 6 days later , 8 days later 229
Figure 5-50; Visual observation of the color variation presented on 6 hours later, 1 day later, 3 days later, 6 days later, 8 days later after the color indicator was added to the solution 230
Figure 6-1; Developed solutions from the leaf extracts 236
Figure 6-2;Figure 6 2; Cleaned Matured fresh green leaves, B- The leaves were crushed using blenders, C – the sieved paddy fields mud to remove the large particles and washed using normal tap water, and then the extra water is removed after the mud is sedimented, D-proper mix of the material matrix , E- Filtered solution 239
Figure 6-3 ; A- Treated with FSWM and B- treated with FSWOM 240
Figure 6-4; A-Physical appearance after treatment of M. indica, B- visualizing the treated surfaces compared to the non-treated Surfaces 241
Figure 6-5;Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section A-A') 242
Figure 6-6;Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section A-A') - FSWOM 242
Figure 6-7;Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section B-B')-FSWOM 242

Figure 6-8;Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section B-B')- FSWM 243
Figure 6-9; Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section A-A') - FSWM 243
Figure 6-10; classification of the grave yard test based on the exposure time 244
Figure 6-11;Leachate observed on the treated wood 249
Figure 6-12; A – control wood specimen , B- FSWOM treated specimen, C- FSWM wood specimen 254
Figure 6-13; The name of the preservative Vs Mechanical Parameters 255
Figure 6-14; The structure of the C23H13Cl2Na3O9S 256
Figure 6-15; Chrome Azurol S solution was sprayed on the wooden surfaces 256
Figure 6-16;Visual observation when the colour indicator sprayed on the surface 257
Figure 6-17; Mechanical property difference compared to the control Sample 258
Figure 6-18; Treatment process using I l volume measuring cylinders 260
Figure 6-19; the sample preparation process for GC analysis 264
Figure 6-20;Identified solution under protocol 2 271
Figure 6-21; The Initial visual observations performed to identify whether the solution is ready for the treatment 272
Figure 6-22; 50 mm x 100 mm x 2438 mm timber submerged in the solution (Similar industry available dipping technique) 272
Figure 6-23; The treated timber taken out after 4 days , b – treated wood was then washed from the normal tap water to remove the impurities 273
Figure 6-24; The appearence were further enhanced using the clear vanish application 273

LIST OF TABLES

Table 2-1 The predictable sources 37
Table 3-1:List of the case studies 50
Table 3-2:Dominantly visible timber species and their grading 50
Table 3-3:Sustainable construction strategies 52
Table 3-4:CO_2 storage and CO_2 release of for major construction materials; 53
Table 3-5:Brief information of the selected case studies 57
Table 3-6; The sectional distribution along with the tree log is presents as in Map 3 to map 14.
Table 3-7; The below table represents the mainly utilized structural components. 63
Table 3-8; the deteriorating pattern of the identified structural components. 63
Table 3-9:Four types of Structural components 67
Table 4-1- The demographic profile of the survey (n = 270) 75
Table 4-2; Building Description 75
Table 4-3; Awareness of the preservation technique 78
Table 4-4;Chi-Square test (α =0.05) 78
Table 4-5; Characteristics of the known vernacular timber preservation technologies 79
Table 4-6;Identify the opinions of the effectiveness of the known wood preservative technique
Table 4-7; Summary of the rank question- Reasons for avoiding using wood preservatives .. 81
Table 4-8;Common names, scientific names, and the Sinhalese names of the highly decoded plant species. 85
Table 4-9; Below table comprise of the utilized equations 95
Table 4-10; Scientific name and the classification of the wood Species reference to STC 95
Table 4-11; More information about the mango wood 96
Table 4-12; Types of wood species exiting and their definition 97
Table 4-13; wood type and the wood grain pattern 98
Table 4-14; mechanical properties the above woody trees 98
Table 4-15; wood type and the price 99
Table 4-16:Test Series A: Solution composition; Solution (A) to Solution (G) (only water and leaf extracts) 110
Table 4-17:test Series B: Solution composition; Solution (a) to Solution (g) (water mud mix solution leaf extracts) 110
Table 4-18:Visual Appearance of the treated wood 114
Table 4-19; Conclusion of the mechanical performance obtained as highest and lowest Solution. 117
Table 4-20; Summary on the relationship among the properties 121
Table 4-21; Timber species(mango) 125

Table 4-22; The surface applicant and the naturally synthesized applicants 125
Table 4-23; The physical appearance..... 126
Table 4-24; The preservative solution and the treatment techniques..... 126
Table 4-25; Performance of the chemical elements against wood deteriorating agents. 130
Table 4-26; Test Type A (Indicates the composition of the solution composed of. 131
Table 4-27; test Type B (Indicates the composition of the solution composed of). 131
Table 4-28 presents the data are means ± standard deviation of existing in five sample points, determination on the atomic percentage 137
Table 4-29 presents the data are means ± standard deviation of existing in five sample points, determination on the atomic percentage..... 137
Table 4-30;Description about the white rot Fungi. 147
Table 4-31; Abbreviations of the samples used 148
Table 4-32; level class resistance to test fungus 150
Table 5-1; The solvents used for extractions 161
Table 5-2; The plant matrix with different particle size 163
Table 5-3; fermented duration and the particle size..... 164
Table 5-4; Particle size and the fermentation time 164
Table 5-5; The optimum fermentation time and the particle size. 165
Table 5-6; The solution obtained from the leaf extracts with in 3 extraction durations 167
Table 5-7; The identified optimum extraction duration..... 167
Table 5-8; Ratio development Solute to solvent..... 170
Table 5-9; Solute to solvent ratio on the solution developed with only plant extracts 172
Table 5-10; Solute to solvent ratio on the solution (plant extracts) assorted with mud..... 172
Table 5-11; Visual observation of the 96 hours fermented extracted solutions..... 173
Table 5-12; Visual observation of the 96 hours fermented extracted solutions..... 174
Table 5-13; Presents the observations to further determine the extraction duration to be kept before the initial filtration. 176
Table 5-14; Density values of the solutions including the standard deviations..... 177
Table 5-15; Description of the Solutions..... 189
Table 5-16; FRIM visual rating scale to evaluate the termite attack 190
Table 5-17;material matrix used to develop the solutions 194
Table 5-18; A- The color of the treated wood specimens , the field exposure of the treated wood specimen 197
Table 5-19; Combination by weight composition of leaves: water mud 199
Table 5-20;Control Petri dishes with no exposed fungus. 200
Table 5-21; Effectiveness' of the solutions against Talaromyces purpureogenus..... 201
Table 5-22; Effectiveness' of the solutions against Aspergillus japonicus..... 202

Table 5-23; Effectiveness of the solutions against Pleurotus ostreatus 203
Table 5-24; Effectiveness of the solutions against Schizophyllum commune..... 204
Table 5-25; combination by weight composition of leaves: water mud 209
Table 5-26; Solution name and its composition..... 210
Table 5-27; Control Specimens , ... 211
Table 5-28;Description of the material matrix and the composition of the solutions 224
Table 5-29; Solution Composition..... 227
Table 5-30; The composition of the material matrix 232
Table 5-31; The material matrix assorted with mud. 232
Table 5-32 the composition was developed as follows,..... 233
Table 6-1; Source [301]; Durability classification of the timber referred to the EN BS 350 246
Table 6-2; Results conclude based on the standard , the durability classification 247
Table 6-3; The FSWM solutions treated wood specimens against the four fungus types 247
Table 6-4,; The Boron treated wood specimens against the four fungus types 247
Table 6-5; The CCB treated wood specimens against the four fungus types 247
Table 6-6; The visual observation against the fungus after 6 days 248
Table 6-7; FSWM treated mango wood, CCB treated mango wood, Boron treated mango wood..... 248
Table 6-8; the color variation after ferric chloride color indicators were used. 250
Table 6-9; the material matrix of the color indicator 256
Table 6-10-Water absorption after 10 days..... 259
Table 6-11; the material matrix used for the extraction was as follows, ... 271
Table 7-1; The summery of the experiments planed with in the study. 277

CHAPTER 1 : INTRODUCTION

1.1 General

This study seeks to investigate the traditional methods and knowledge pertaining to the preservation of vernacular use of timber for structural applications. Urbanization leads to a rapid increase in for demand goods and services [1], [2]. This erected the world of construction to build sustainable solutions in applications but relatively, to alter the way of thinking into understanding and handling that economic, environmental, and cultural values [3]. Along with that there is growing acceptance of resource management, a vital role that forest resources and timber resources should be managed to meet the social, economic, ecological, cultural needs of present and future generations and minimize the raw material depletion [4]–[8]. As a result of this people started developing techniques to improve the service life of the materials.

The pathway to sustainable development requires an eco-efficiency step. This step of reducing impacts and costs during the entire life-cycle of the built assets are parallel change options to new approaches[8]. Environmental concerns, such as water quality standards, air, the effect of treated wood on humans and other organisms, and the energy crisis, particularly when it comes to oil-based preservative systems, were the main factors driving variations in treatment technology and conservation systems around the world[9]. Environmental concerns are widespread among these[10]. Therefore, there is a significant requirement of understanding the characteristics of wood from the macro to ultra-structure towards the wood- engineering and global policies that could maximize forestry and timber construction as a benefit towards both people and the planet [11].

With this significant global attention, several elementary characteristics had been caused them kept preserved which is *terra incognita* [13]–[16]. Ancient cities of a country are unique for their geographical diversity, for their form and function[16], [17]. Where these represent a symbiosis among nature and the culture. The initial phase of the study emphasizes the requirement of revealing the existed knowledge and preserving them for future applications.

The need for cultural protection has just recently become apparent, even though the need for biodiversity protection has long been recognized [18]. Understanding their interplay and interaction is critical to guaranteeing the survival and flourishing of both

nature and culture. Nature and culture overlap in many ways. From values, beliefs, and nomenclatures to practices, ways of life, knowledge, technologies, and languages[19], [20]. Culture can be defined as the methods via which people perceive their surroundings [21]. The meanings and the interpretations have a wide range of references to the natural environment, with the most obvious communications occurring most frequently in traditional resource-dependent communities. Many modern societies regard them as distinct, if not antagonistic, entities.

Socially in-built norms and rules are also influenced by ecological knowledge[22]. These normalize human interactions and behaviors about the natural environment, and they have frequently co-evolved to ensure the survival of both people and nature [23]. These rules determine access rights acceptable behavior and the productivity and diversity of socio-ecological systems [24]. As a result of cultural extinctions induced by assimilation, language loss, and knowledge loss, these factors are also paving the way for greater cultural monocultures. Traditional livelihoods are being replaced by contemporary occupations, and rural groups are relocating to metropolitan regions at the expense of cultural variety. Orally transmitted knowledge (OTK) is being replaced by written knowledge, and traditional livelihoods are being eclipsed by modernity [25]. This comes at a cost to human society, as a decrease in knowledge reduces humanity's potential answers to future global crises.

There are significant timber constructions that still exist by overcoming wood deteriorating agents in a tropical country like Sri Lanka[26]. It was observed, these structures had used precise timber processing techniques to overcome the mechanical failures revealing proper material manipulation[27].

With regard, raising a question on how did they overcome the challenges against other main wood deteriorating agents like termite, fungi, fire, marine borers, etc. Therefore, this study attempts to accumulate and consolidate the traditional vernacular timber preservation technologies by investigating the ancient timber structures in Sri Lanka.

Although minimum scientific interest has been paid towards these architectural buildings and their technologies regard to the environmental aspect, Yet there are valuable ideas that should be scientifically well thought-out. Combining traditional and modern construction technologies could be an effective and profitable method towards the growth of sustainable building materials. Also, the study emphasizes the community

and the construction role that existed where this knowledge could play in delivering this global need.

As once mentioned above, this study attempts to trace the history and 'decode' the measures of technology that lead to the development of timber preservation technology. The study will be tabulated based on enormous leftovers of timber structures-built with respect to the traditional vernacular construction knowledge in Sri Lanka.

1.2 Research Problem

The durability of traditional wooden constructions in Sri Lanka is in a highly appreciable status. In a tropical environment, the prolonged physical sustainability of wood is a challenging task. Traditional wooden constructions show a greater degree of tolerance in the harsh tropical environment in Sri Lanka.

The prolonged sustenance of wood in utility applications directly influenced the control of overexploitation of forests for timber production and kept the balance between the interaction of nature and the culture in the past. This study intends to investigate the question on

"How did the ancient people think and act on wood preservation in their applications?".

1.3 Research Gap

The construction material selection, with the impression of "the right material in the right place" ought to be remarkable. However, urbanization, it's at risk of raw material depletion. Therefore, the application of sustainability should need many modifications to increase the service life of materials. The application of sustainability in a way should an analysis of already existing technologies.

The construction industry is enormously important to evolution for mankind within the living standards. As the construction sector develops, the demand for timber as a construction material rises, and it becomes the leading driver of tropical forest destruction. Therefore, it is necessary in determining how to increase the service life. This study identifies the practiced timber preservation technology "wood kept under paddy field mud" in traditional vernacular timber buildings and evaluates the usability of its' structural application relevant to today's context.

The use life increases of the wood treated under the traditional vernacular timber preservation technology could be due to many reasons;

1. Prolonged exposure to mud simply makes the wood fibers undesirable to fungi and especially to insects as a food source.
2. Different leaves added to the mixture get dissolved in water/ fermented and create biochemicals to penetrate to coat the cells.
3. Nano or micro-level insertion of different chemicals in mud that changes the chemical/ physical structure of the wood cells.

As there is adequate scientific proof of the performance of the traditional vernacular techniques, this research attempts to scientifically fill the above gaps on the existed timber preservation techniques. And finally, the study attempts to reinvent a commercially feasible approach-based preservative to be used in today's context.

1.4 Aim and Objectives

This research aims to conduct a comprehensive study decoding traditional vernacular timber preservation techniques practiced in Sri Lanka. Based on this, the study attempts to formulate a novel timber preservation technique that could be applied in today's context.

The objectives of this study are;

1. To investigate the timber processing and preservation techniques practiced in traditional vernacular architecture in Sri Lanka.
2. To identify wood with potential for further development using traditional vernacular preservation technology through a field survey.
3. To study the chemical elements, their compositions and to observe the penetration within the treated timber samples.
4. To investigate the application of the modified traditional vernacular technology with amendments and evaluate the performance of the treated wood.
5. To assess the susceptibility of the treated wood from the formulated solutions for possible fungal, and termite attacks.

1.5 Methodology

The following methodology was adopted to achieve the above objectives;

1. Conduct a comprehensive literature review on timber processing and preservations.
2. Conduct a field survey to document the process of traditional vernacular preservation technology and collect samples from the field survey.
3. Conduct laboratory tests to determine the chemical composition of the treated samples through spectroscopic analysis.
4. Apply the traditional vernacular preservation technology on the selected wood identified by the survey.
5. Conduct durability tests with possible approaches to develop a solution based on traditional vernacular technology with amendments.
6. Identify the most effective combination of the preservative solution

The flow diagram for the overall study program is shown below (

Figure 1-1),

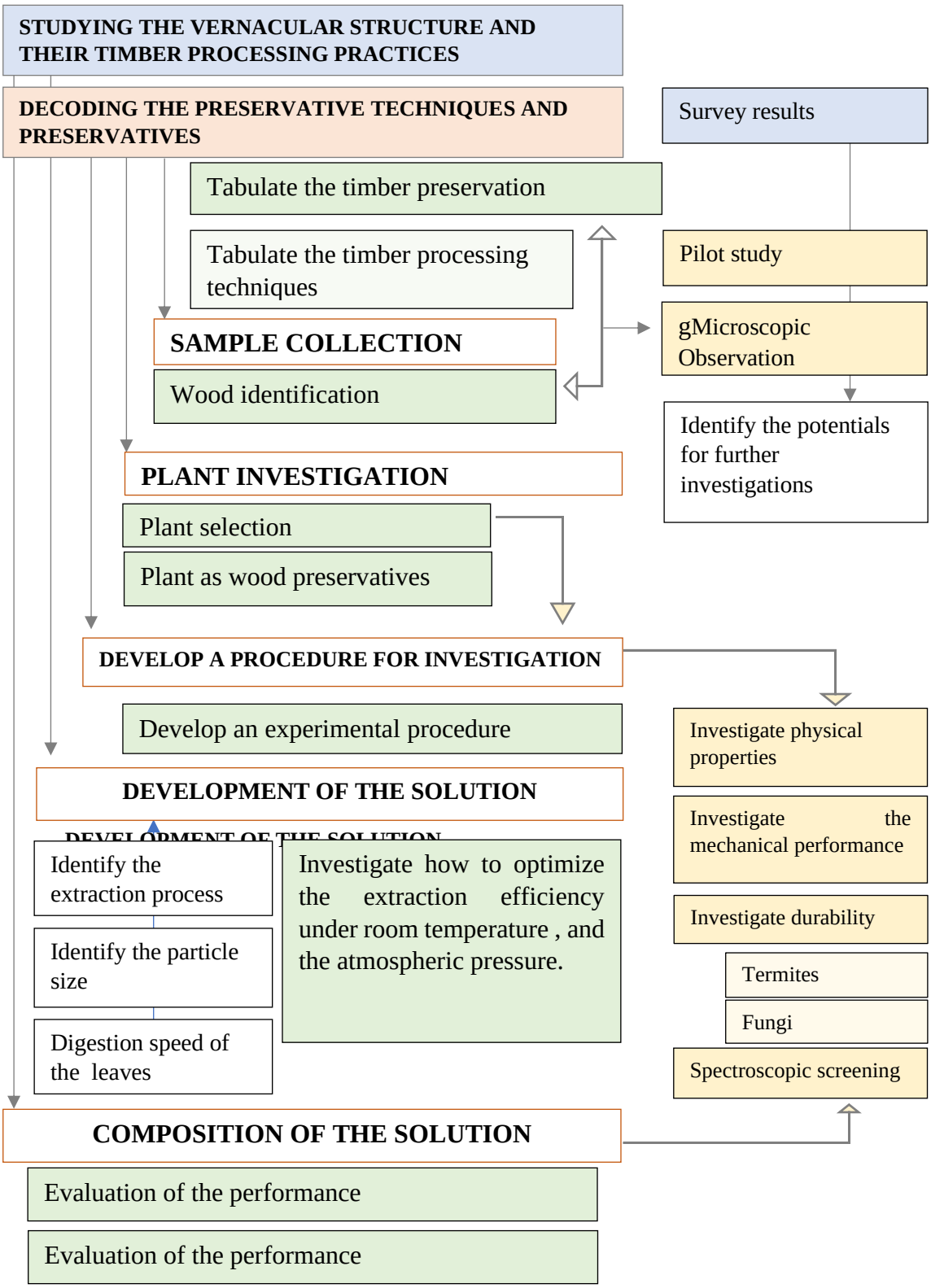


Figure 1-1; The above diagram presents the conceptual flow of the overall study program

1.6 Main Findings

a) In a method of preserving wood by soaking in an organic preservative, this step comprising the wood treated with plant leaves extract-based solution encompassing the mud, water, and plant leaves improved from the conventional extraction and filtrations.

b) A method for preparing an organic wood preservative comprises of:
Fresh plant leaves of *Gliricidia sepium*, *Tithonia diversifolia*, and *Mikania micrantha as* the main matrix, water as the solvent for the aqueous extraction assorted with paddy field mud, and was fermented for 96 hours (4 days) to develop a solution.

c) The organic wood preservative gives the optimum toxicity against white-rot fungus and the termites with minimum strength loss with minimum leachability comprising the leaf composition of 1: 1: 3 respectively using *G.sepium*, *T. diversifolia*, and *M. micrantha* the total by weight plant leaves. Then the plants' leaves were extracted to water and assorted with organic paddy field mud by weight ratio of 1:1:5 respectively.

d) The solutions comprised of the leaf extracts have presented Phenols, ketones, hydrocarbons, aldehydes, esters, and acids.

e) Wherein the solution comprises of *2,4-Di-tert-butylphenol, Phenylethyl alcohol, Benzyl alcohol, Carbamic acid , methyl -Phenyl ester, Hexadecenoic acid , 2- hydroxy-1- (hydroxymethyl) ethyl ester, [1,1' – Biphenyl]-2-3'-diol ,3,4',5,6'-tetrakis (1,1-dimethylethyl)-, Phenol,2,2'-methylenebis[6-(1,1-dimethylethyl)-4-methyl)-, Coumarin*.

f) Another solution was developed under the same procedure without using mud in the main matrix. In a method of preserving wood by long-term soaking with an organic preservative, that comprising of long-term soaking *Mangifera indica* wood with a wood-preserving solution developed using plant leaves extract-based solution, embracing plant extracts fermented in water four 72 hours improved from the conventional extraction and filtrations techniques.

g) The 96 hours fermented solution comprises the optimum pesticide, antifungal, and antimicrobial properties with minimum strength loss percentage .

1.7 Organization of the thesis

The data and the other related findings together with the conceptual formulation driven by the study are presented in the scheme below.

Chapter one: Introduction: Discussion on general information about the research background, gap, objectives, methodology, and the summary of the main findings are presented in this chapter.

Chapter two: Literature review: A comprehensive review of the literature was to find out the background of the research; where urbanization and the construction industry, timber used in construction, causes of wood deterioration, wood preservations, past applications of wood in constructions was deeply discussed.

Chapter three: Ancient timber practice in Sri Lanka: This chapter presents the archeological evidence and selection of the *Ambalam* structures for further investigations and identifying the potentials of traditional construction techniques, the usage of sustainable building materials in *Ambalam*, finally investigates the timber processing techniques and the strategies used to overcome the mechanical failure in the structures.

Chapter four: Decoding the timber preservation techniques: This chapter elaborates on decoding and documenting, identifying, and materializing the identified traditional vernacular timber preservation. The identification of wood used for the existed preservation techniques and then conduct a pilot study to reveal the said phenomenon.

Chapter five: Solution development: This chapter presents the solution development under the selected plant species, experimenting on the most effective fraction and the solution combination with the optimum toxicity and identifying the extraction efficiency, and defining the extraction duration.

Chapter six: Performance of developed solution analysis: Presents and compares the performance of the developed solutions. Investigating the performance, chemical retention, leachate generation, physical and mechanical properties of treated wood**.**

Chapter seven: conclusion and recommendations: This chapter presents a summary of each chapter and elaborates sustainable approach analysis of preservation

technology. Finally, presents the conclusion and the recommendations for future works related to this research.

CHAPTER 2 : LITERATURE REVIEW

2.1 General

By the side of an economy, innovation is well thought-out as one of the utmost important factors foremost to the development, growth, and competitiveness of a country. Environmental innovations are defined as a modified processes, practices, systems, and products that profit the environment and contribute to environmental sustainability during its entire lifecycle. Traditional vernacular timber construction practice in Sri Lanka is dealt with environmental innovations. Constructions were made upon the needs of the inhabitants with the available resources in the particular context. Societal transitions are highly complex processes that unfold over time-spans of decades as they overcome challenges in an experienced process.

2.2 Urbanization and the construction industry

With city populations rising, the demand for goods and services increases rapidly. Therefore, urbanization has started influencing the economy and the environment of a country[1], [2]. With the evolution of population, the urbanization and urban extensions with the rising economic tendencies specify a constant growth in the consumption in the building industry. Human activities started affecting the environment with positive and negative impacts.

In the future urban living is more towards organizations to transform from linear to the circular economy. With this, a significant need is built in the world of construction to build sustainable solutions in applications However relatively, to alter the way of thinking into understanding and handling that economic, environmental, and cultural values are not a trade-off with one another. By today, the construction industry has become significantly contributed to the environment all over the world by now. In the specific case of the building sector, there are two construction models as follows (Figure 2-1),

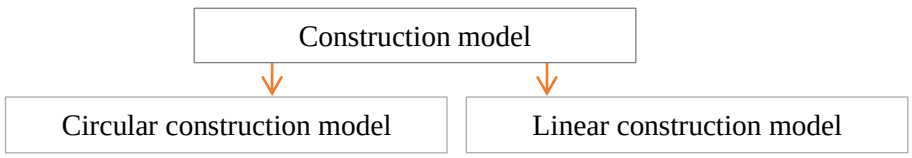


Figure 2-1: Simple classification of the construction model

With the predominant, global linear construction model, builders, contractors, and consumers pursuit for the lowest-priced building materials; cost priority. As a result of this, these raw materials are regularly gained with minor concern for the impact on local communities and with a high threat to the ecosystems.

There is wood certification in most of the countries for sustainable forestry practices. However the construction industry highlights they don't tend to pay enough attention to the sourcing of the materials[1]. Among all, copper, gold, silver, and palladium in the electronics appliances, and even the gravel and sand in concrete mixtures all have unknown origins among the construction sector.

The circular construction model seeks to maintain building materials, products, and raw materials within the economy under a maximum acceptable time during service. The circular economy attempts to fundamentally change the linear model of production, which focuses mainly on extraction, manufacture, use, and disposal. Instead, a circular economy model mainly focuses on lessening energy and material within a functioning economic model.

In addition, it also would entail a durable design of materials and attempts to design waste out of the entire system [3]. When the construction sector employs a linear economic model the concept of "take, make and dispose of," is used [28]. This concept begins with the raw material extraction from the origins, which are then processed into construction materials. These are then put together on the job site in non-destructible ways, eventually becoming useless and having to be disposed of in landfills or burnt with the rest of the waste generated [29].

Literature further states, the construction sector is in charge of over 30% of the process of obtaining raw materials worldwide than at least 25 % is a lot of waste in the world. In addition, when buildings reach the end of their lifetime, only 40% of materials are recycled or reused.

At present, unfortunately, more interest and attention are given towards increasing buildings' energy efficiency and thermal performance to reduce energy use. Where the literature emphasizes a gap and there needs to concentrate more on the embodied energy of the raw materials that go into buildings. This summarizes that around 10 % of global energy is used for mining [1]–[3], [28], [29].

2.2.1 The environmental impacts of buildings

Building activity is increasingly geared towards the creation and application of sustainable construction materials, production, and administration procedures based on biocompatibility, energy conservation, and economy. Along with that there is growing acceptance of resource management, a vital role that forest resources and timber resources ought to be managed to encounter the social, economic, ecological, cultural needs of present besides future generations and minimize the raw material depletion. The literature enhances on attention that needs to be paid towards the construction industry [30]. Under this circumstance, it is significant to find potential for environmentally friendly materials and construction processes to fulfill the sustainability dimensions of the building sector.

2.2.2 Evaluation of construction materials

The construction activities counting the manufacture of construction materials are raw materials and energy-intensive. Where the use and the operation cause environmental risks. The physical existence and conventional technologies of the built environment depend on the large consumption of nature's resources. There is a pressing need to modify the built environment's material and energy foundations. Eco-efficiency

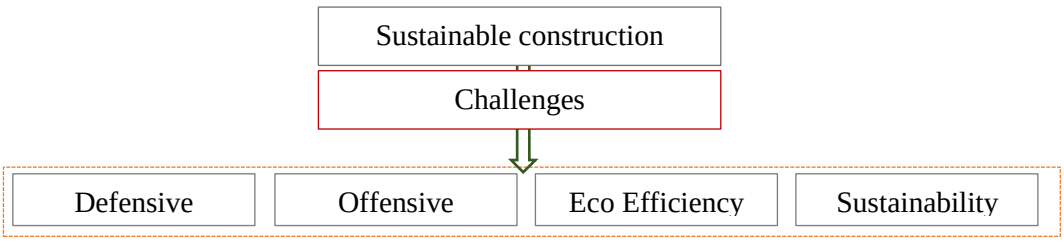


Figure 2-2:Then main four challenges in the concept of sustainable construction

is a necessary step on the road to long-term development. This step of reducing impacts and costs during the entire life-cycle of the built assets is a parallel change option to new approaches (Figure 2-2).

As per this sustainability further directs towards sustainable constructions and take actions toward sustainable development [4]. The World Business Council for Sustainable Development (WBCSD in 1992) introduced the concept of eco-efficiency; defined as "the efficiency with which ecological resources are used efficiently."

Eco-efficiency consumes highly with sustainable development, towards the environmental and economic related areas. Generally, the strong argument for

sustainability emphasizes the scarcity of resources which would require more radical changes of material and energy flows than improvement of efficiency [2],[3].

Problems related to the built environment are almost solely related to materials. Improving the eco-efficiency of materials has three facets [1],[2],[3],[5].

a. The raw material extraction should be focused on renewable materials and materials whose production is followed by low production of waste and low levels of greenhouse gas emissions.
b. The construction material producers should be more effective in terms of savings of raw material, energy, and water, and the choice of material; should be those that are more energy-efficient and create a healthier built environment.

The innovative sustainable approaches to building designs have now become current requirements for the modern construction industry. The design needs, not only to minimize the impact on the environment However also, to maximize the benefit during the lifetime. The approach for eco-effectiveness is based on innovative materials, processes, and systems wherein all waste that cannot be disposed into the biosphere is collected and redirected back to the techno-sphere.

In the short term, improving the efficiency of energy on existing buildings plays a substantial contribution in reducing the use of energy and eco-friendly implications. As a result, it is critical to include both new and existing structures while planning for environmental development [6].

Literature highlights the necessity of studying the facts affecting the environment both new and existing buildings reference to the material and technology utilized in construction. Globally about 12-16% of freshwater is consumed currently in the construction sector. Among the construction and demolition waste is approximately 30-50% of more than two billion tons of waste generated throughout the world annually (UNEP 2009).

2.2.3 The effects of building material selection

Building materials selection is one of the important parameters towards the development of sustainable construction practices all over the world. Because a building is a complex system made up of many distinct components, material selection has a direct impact on its environmental impact [8]. Material selection can also have a significant impact on the construction process. The impact of different building

materials on operating energy has also been studied [31]. Although the little study has been

undertaken on the end-of-life stage of buildings to date, the recycling component has been recognized as a significant contributor in lowering building life cycle energy use. In today's construction industry, timber is one of three structural materials used within major structures, competing with steel and reinforced concrete. The performance compared with reinforced concrete and steel is as follows,

a. The strength parallel to grain in the timber is almost similar to reinforced concrete, although it can't be matched with the compression in modern developed high-strength concrete.
b. Wood is weaker compared to concrete, and in cooperation with timber and reinforced concrete is weaker than steel.
c. When compared to reinforced concrete and steel, timber has a low density.
d. Timber is effective for tall or long-span constructions in which the structure's weight is a considerable part of the load to be handled.
e. Timber loses its strength and stiffness at lower temperatures than steel and concrete.
f. In comparison to steel structural members, At high temperatures, timber structural members may still operate adequately [32], because the char layer may help insulate the substance inside, whereas steel's high thermal conductivity causes the entire area to heat up quickly.

The graph below compares the strength-to-weight and modulus-to-weight ratios of steel, wood, and reinforced concrete, demonstrating that softwood performs similarly to steel in those areas (

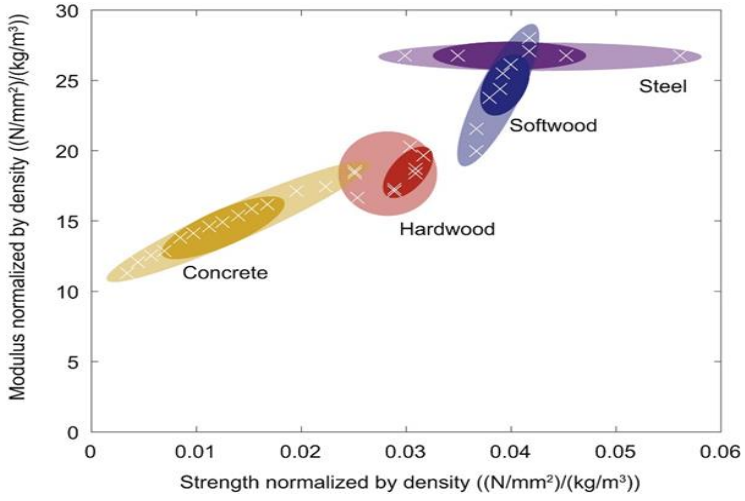


Figure 2-3).

Figure 2-3:Based on the design standards; for concrete [10], steel [11], and timber [12], the graph presents the strength normalized by the density vs modulus normalized by density. Source –[13]

The dark hues in the above figures denote the more often used grades of materials. Based on Eurocode design standards, the strength and stiffness, as well as partial variables, were reported. According to the findings, lumber is a structurally effective material in structures that are entirely or partially loaded, with the weight of the structure accounts for a significant portion of the load to be resisted. When the amount of processing required for timber is reduced, the energy efficiency of the product improves. Another advantage of utilizing heavyweight materials in buildings is that they have more thermal mass. The proper blend of heat capacity and thermal conductivity is required for this type of behavior. The ability of the wood to fulfill this duty is inadequate by its minimum thermal conductivity [12].

Other than the strength parameters, as a result of moisture content wood acts as thermal insulators utilized in doors, windows, flooring, and roofing. Further lower thermal conductivity values are present in wood-based products such as fibreboards due to the presence of high air gaps.

2.2.4 The use of timber in construction

Wood is harvested, processed, and distributed globally through a complicated network of harvesters, processors, and distributors [9]. Natural forest-derived woody tree species have become scarce in Sri Lanka. As a result, there is rising concern about employing woody tree species that do not come from natural forests. Commercial and other properties of timber are the main facts of timber popularization [33], [34].

For thousands of years of history, generally, wood can be introduced as the only construction material that is grown. Even though it is a natural product, the environmental benefits of using lumber are not apparent.

Contemporary constructions of sustainable buildings from timber, completely or partially, have a growing fascination. Simultaneously raising a question, however under what conditions is this the case? The wood harvested from the tree cannot be used in construction directly. As a result, a significant percentage of energy is expended to dry and process it.

With this, there is a big question on the construction industry which should aware of raising continues questions such as; What is the best use of this natural resource? And what are the aspects of civil and structural engineering that has the real necessity of using

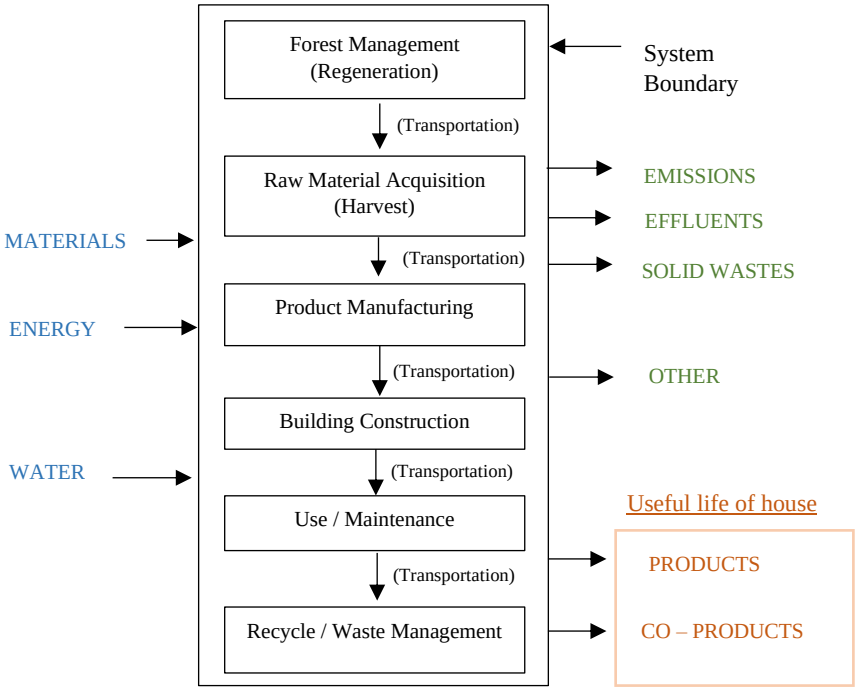


Figure 2-4:The Life-cycle assessment from the regeneration of trees to disposal of wood materials (Source: CORRIM Presentations, www.corrim.org/ppt/2005/fps_june2005/lippke/index.sp[14]*).*

this sensitive construction material. Therefore, there is a significant requirement of understanding the holistic picture ranging in wood engineering (*Figure 2-4*) [11].

2.3 Causes of wood deterioration

There is a diverse range of woody plant species all around the world. They consist of different degrees of resistance against biological attacks. Most of them are suspect of deterioration under the appropriate condition. there are main causes for wood deterioration. Food, oxygen, moisture, and warmth are the main requirements for the growth of organisms[35] (Figure 2-5).

2.3.1 Deterioration caused by insects

Insects are the main causes of wood deterioration. Among them, termites, carpenter ants, powder post beetles are the major threats to wood during service.

2.3.1.1 Termites

They are colonial social insects. Termites dwell in massive groups. There are over 2,300 termite species worldwide, with 183 species known to cause structural damage and 83 species causing considerable damage. There are three main classes as follows: [36],(Figure 2-6).

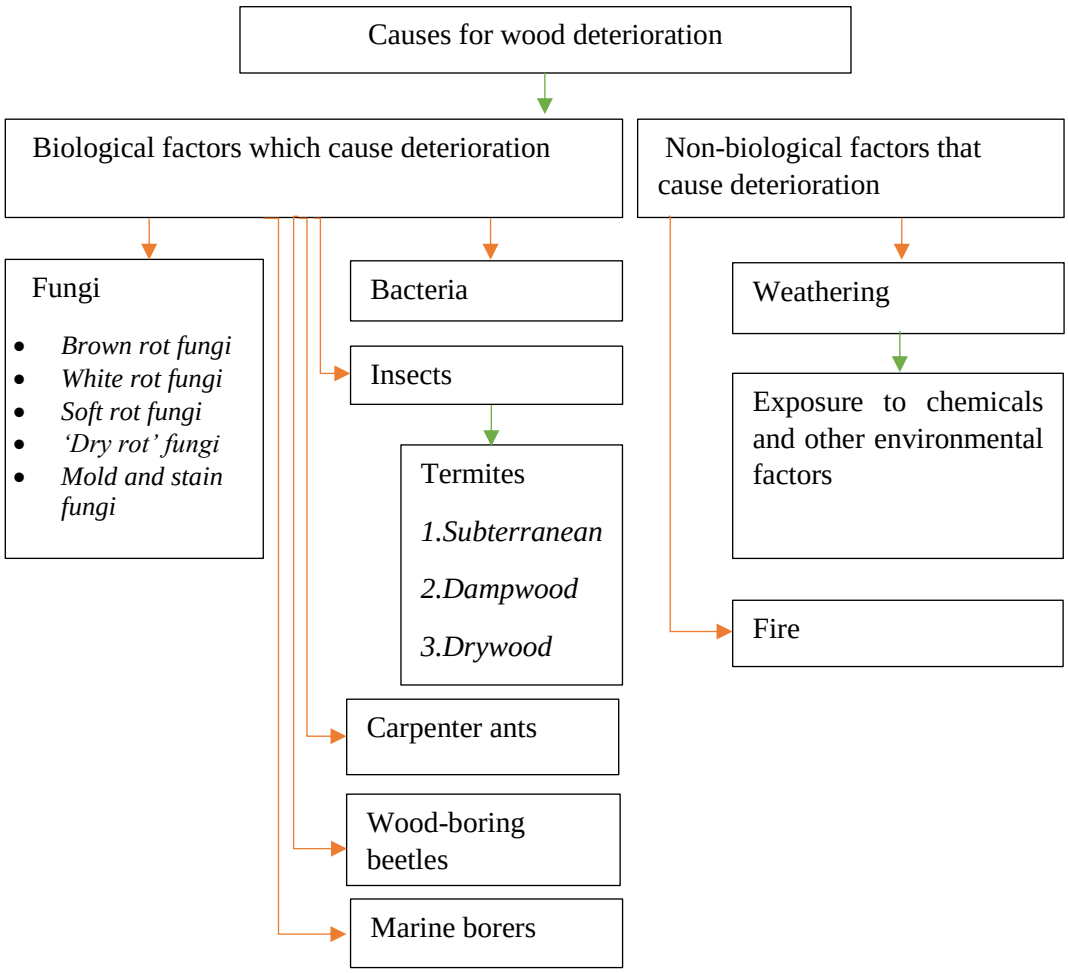


Figure 2-5: Flow chart on the causes of wood deterioration.

A. **Subterranean termites:** Among all three types serious wood damage is caused due to the subterranean termites; dwelling in wet soil in underground nests. They infest wood that comes into direct touch through the nest or they can be reached through mud tubes. The 'worker' termites degrade the wood by excavating tunnels and chambers through it. Termites' digestive systems include one-celled protozoa that break down the cellulose in the wood to create adequate 'food.'

B. ***Damp wood termites***: Generally, they build their nests in moist or decaying wood above ground. They need a lot of wetness in their nesting habitat;

However, they may also get into dry wood. They have a small economic impact when compared to subterranean termites.

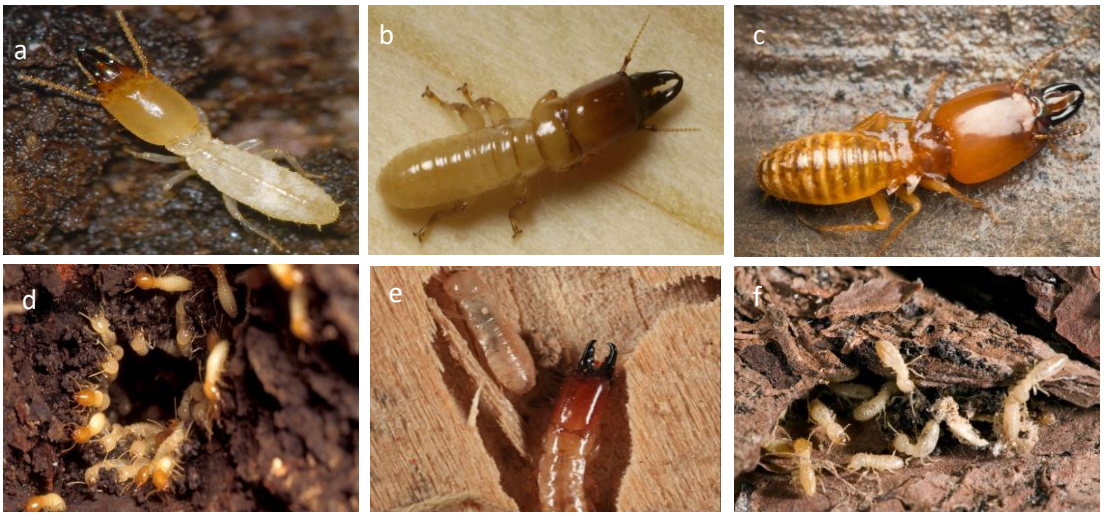


Figure 2-6 : a – Subterranean termites , b- dry wood termites , c-damp wood termites , d – Mud tunnels behavior of the subterranean termites , e- behavior of the dry wood termites, f-damp wood termite behavior

C. ***Dry wood termites***: Can survive in dry wood without needing to come into contact with soil or other sources of moisture. They reproduce at a slower rate compared to subterranean termites. They do not eat wood as speedily compared to others. However, they, too, can cause significant damage over time. [37]–[39].

2.3.1.2 The carpenter ants

Neither carpenter bees (*Hymenoptera: Anthophoridae, genus Xylocopa*) bees (*Hymenoptera: Formicidae, genus Camponotus*) feed on timber. That is, they do not digest it or use it as a source of sustenance. However, for testing purposes, both excavate and enlarge existing cavities in the wood [37]. The carpenter ants are one of the most common and destructive pests, because of their capacity to degrade hardwood. The *Camponotus* are known to be the most species-rich ant genus. They have a great ability to excavate wood. They use pre-formed cavities or unearth softer wood that has already begun to decompose. Wood is indigestible to ants, (Figure 2-7).

2.3.1.3 Powder post beetles

Powder post beetles get their name from the larval stages' ability to degrade wood to a powdery condition. "True powder post beetles" is the popular name for *Lyctids. Bostrichids*, often known as "false powder post beetles," differ from lyctids in terms of



Figure 2-7: a- Carpenter Ants , b- damage to structures through their nesting behavior , c- Powder-Post Beetles, d- damage caused to the structures. e- Carpenter bee boring into wood, f- Nest of a carpenter bee

adult appearance, exit hole size, and frass characteristics. Small holes on the wood surface and powdery falls from holes are indicators of powder post beetles. They can damage structural elements in timber constructions [38], (Figure 2-7).

The key to avoiding significant wood damage is early identification. Insecticides were put to unfinished wood surfaces, which penetrated the wood and killed or repels preventing re-infestation. Spraying all exposed wood surfaces will increase effectiveness. Boron-based treatments have a long residual lifetime when the wood is kept out of the elements, such as in crawl spaces. Copper compounds can be applied to wood, although they only go approximately 1/8 inch deep[39], [40], (Figure 2-7).

2.3.2 Deterioration caused by fungi and bacteria

Molds and blue stains are also grown on wood. However comparatively, to wood decay fungi, significant structural damage is now caused due to stains and molds. Wood is famous as a construction material due to its natural colors mainly with its aesthetic appearance. Where these stains and molds cause discoloration which adversely results in the aesthetic value of wood[23], [24].

2.3.2.1 Fungi

Concerning the trend of degradation, three groups of wood decay fungi responsible for degrading the structural polymers in wood were identified, this directly affects the deterioration of wood's strength (Figure 2-8).

A. ***Soft rot fungi***: classification - Ascomycota, fungi imperfect. They mainly degrade the hemicelluloses and cellulose, less expansively on lignin. Soft rots

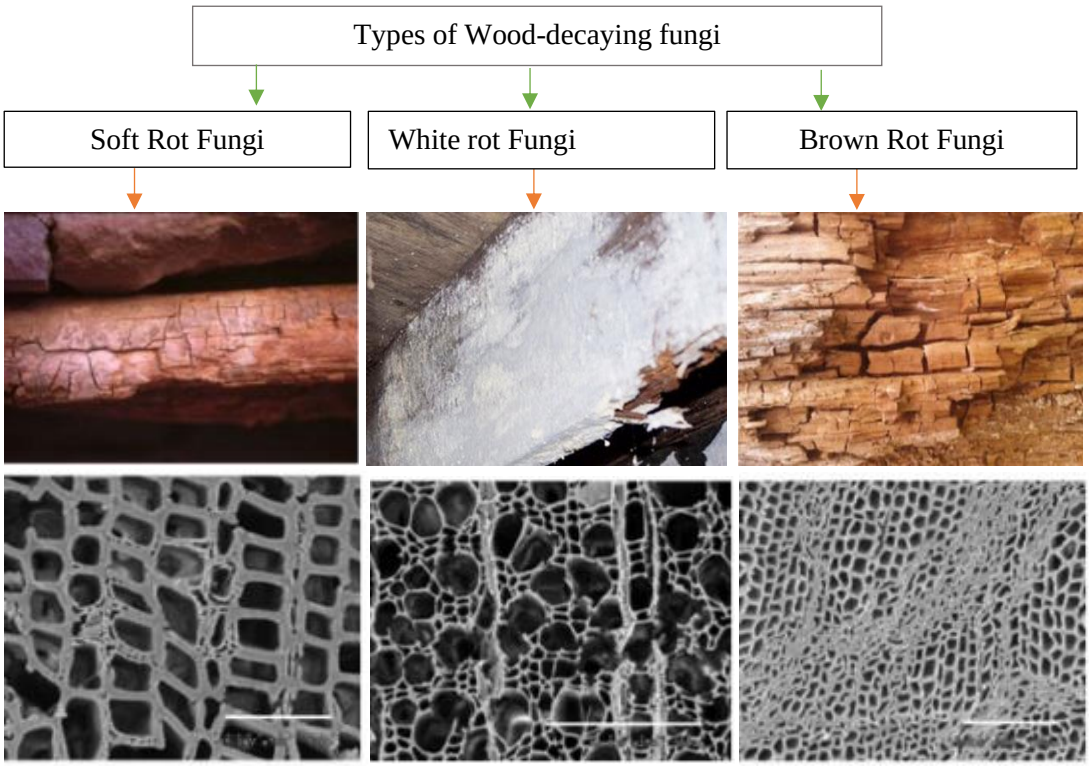


Figure 2-8 : Types of wood decaying fungi

form voids inside the cell wall. This also causes discoloration as well as the cracking pattern. This causes the wood's strength qualities to deteriorate.

B. ***Brown rot fungi:*** Classification - Basidiomycota, mainly effect on softwoods. The degradation of hemicelluloses, cellulose, and demethylation of lignin. The timber shrinks also crack into cube-shaped pieces. The brown coloration is caused due to the remained lignin. which leads to the reduction of wood mechanical properties (Figure 2-8).

C. White rot fungi: Classification of *Basidiomycota*, mainly effect on hardwoods. They also affect softwoods; induce lignin and hemicellulose breakdown, also cause cellulose degradation. Due to the presence of lighter-colored cellulose, the appearance of fiber and the white coloring of wood remain. Due to this, the wood turns out to be soft and spongy, as a part of the degradation progresses, this effect wood strength[43] (Figure 2-8).

2.3.2.2 Others

When considering furthermore other than wood deteriorating fungi, molds and stains and bacterial grown on wood also leads slowly towards wood deterioration.



Figure 2-9: Other molds , blue stains and the bacterial growth on wood surfaces.

A. ***Molds***: Classification- *Zygomycota* or *Ascomycetes*. They are simply available sugars; these are not structural polymers. This causes an apparent discoloration of wood, minor degradation of the wood surface; (Figure 2-9).

B. ***Bacteria:*** Bacterial growth is caused by high moisture content in wood, whether it is just cut, mostly found in damp soil, also found stored in water or under a water spray. While bacterial deterioration is normally a significant cause, however, it can impact significantly on a strength loss over time. Wood's permeability, or absorptivity, may be increased by some bacteria, (Figure 2-9). It is significant to consider the bacterial degradation rate and the factors influencing the rate for developing protection strategies and preservatives [43].

2.3.3 Deterioration caused by fire

A highly flammable material that has been utilized for at least 500,000 years as a source of fuel. Even though wood burns, timber constructions offer a high level of fire resistance. Temperature, moisture content, heating time, and specimen shape all influence the fire resistance of large sections. Wood ignites at a different temperature. With this lumber, constructors have severe issues regarding fire safety in a timber building. These advantages are moderated by wood combustion, and their behavior is predictable.

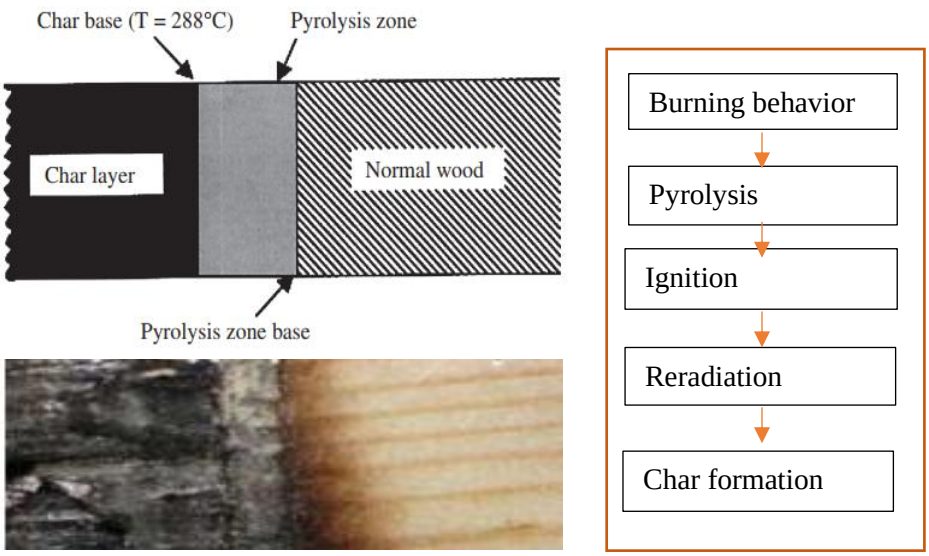


Figure 2-10:The degradation of wood when exposed to fire on the surface A- Schematic diagram , B- Degradation zone observed in pine wood,

The temperature at which wood will ignite in the presence of an open flame. This reasons on igniting the flammable gases released as the wood are heated. The commonly quoted temperature is at 200°C. However, dependent on the length of time it is exposed to that particular temperature. After approximately 30 minutes of exposure duration, most woods will ignite (at 180°C; at 300°C). Wood will ignite in about 2 minutes; and at 400°C, they will burn in 30 seconds or less. The degradation zones of a large wood part that was only exposed to fire on one face are schematically illustrated in the image below [32].

When burning begins, (*Figure 2-10*), On the surface, a char layer forms, which progressively penetrates the wood. The temperature at the base of this layer is around 288°C [9], [27]. Wood is also a great insulator; once you get past the charred base, the temperature drops quickly. At a temperature of around 66°C, the wood begins to degrade in the pyrolysis zone. Within this process water vapor, smoke, and both flammable and non-flammable gases are produced. The char zone also acts as a good insulator.

The rate at which the charred base penetrates the wood is significantly determined by the species, density, and moisture level. It takes longer for higher moisture content and density, as well as for more impermeable wood species. As the temperature rises, the rigidity and strength of wood decrease substantially [44].

2.4 Wood Preservation Principles

Using already natural durable wood is one of the main methods to overcome the deterioration of wood. This is limited to the heartwood. However, the eradication of sapwood, combined with a selection from a small number of woody tree species, is unfeasible unless extremely high construction costs can be endured and demand can be met. Before deciding on the appropriate safeguards, it is critical to assess the deteriorating hazard. For a comprehensive understanding of the decay hazard, knowledge of the basic nature of diverse wood species, and possibly even the principles for their identification, is required [45].

2.4.1 Natural durability of wood

Wood is a natural polymer in a matrix that gives structural support and some resistance to microbial attacks on living trees, (Figure 2-11).

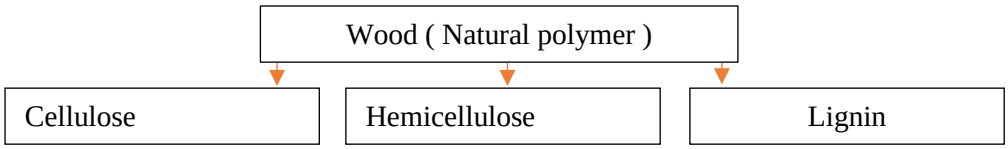


Figure 2-11; The flow chart presenting the naural polymer

Cellulose: - It is somewhat resistant to microbial action. Due to its partial crystallinity.

Lignin: - It's a heterogeneous polymer made out of phenyl propane units that's highly resistant to decay fungi. Some woody trees have grown to produce extractive complexes (the principal source of the decay resistance) that can protect the wood.

They are producing the non-living heartwood which is formed when the inner sapwood zone's live ray cells die. When sapwood dies with long-lasting heartwood, a sequence of processes in the storage or parenchyma cells of the rays convert the sugars and the starch stored in the cells into a variety of fungal toxic compounds. This formed part of the new heartwood. Almost all species' sapwood is devoid of natural oils [46]. The color, whereas in others it is very identical to sapwood in color. The resistance to wood degradation varies by tree species and even individual trees [47].

2.4.2 Wood

A complex biological framework made up of several cell varieties and chemistries that cooperate to suit the needs of living plants [48]. The usage of wood in structural engineering applications in buildings and other special engineering products is

demanding and gradually increasing. To determine whether wood elements are safe, they must have enough mechanical resistance to withstand the design loads.

2.4.2.1 The Properties of wood

The positive mechanical properties and physical properties have made timber one of the well-known materials utilized as an engineering construction material with great history around the world [49].

A. Hydroscopic property of wood

Identifying these unique characteristics of wood to build an unlimited range of timber structures [50]. Non-treated wood is one of the environmentally sustainable, economically feasible, biodegradable, and renewable construction materials that carry the lowest carbon footprint comparatively among the general construction materials. Wood's highly machine-able and scaled character allows it to be fashioned into a variety of forms and sizes to meet any construction requirement [51]. Interchangeably wood used in construction work is revered as Lumber or called timber. Regardless of length, Sections of wood that are smaller than 127 mm breath by 127 mm thick are generally referred to as lumber. Regardless of length, Sections of wood over 127 mm breath by 127 mm thick are referred to as timber[52], [53]. It also retains the ease of processing, aesthetics, and good sound-absorbing properties [54], [55]. The chemical and anatomical characteristics of the wood structure are used to determine larger-scale properties [56], [57].

The term "hygroscopicity" refers to the ability of wood to absorb moisture from the environment. After that, keep it as liquid water or vapor [58], [59]. The fundamental cause for entering moisture into the mass of wood is the attraction of water molecules. This is caused by the hydroxyls of its chemical constituents, principally due to cellulose [60]. As a result, these hydroxyls form a monomolecular layer of water that is kept together by resilient hydrogen bonds. The cellulose molecules in the amorphous regions and between the crystallites of the microfibrils push apart as a result of the formation of this layer, causing the wood to swell. More water molecules enter due to secondary attractive forces, forming a polymolecule layer [61].

A supplemental fraction may penetrate because of capillarity condensation. Finally, as the walls become saturated, liquid water seeps into the cell cavities. Water can exist in two states in wood, one of which is bound water, which is water that is contained within

cell walls. Water can also be found in liquid pockets in the cell lumen and other void areas, known as free water [62],[63].

B. Equilibrium Moisture Content (EMC).

The quantity of moisture in exposed wood varies over time. Desorption is the loss of moisture, while adsorption is the gain [64]. Equilibrium moisture content refers to wood that has been subjected to consistent circumstances of ambient relative humidity and temperature for a long enough period to desorb and adsorb moisture to achieve equilibrium with the ambient atmosphere (EMC). When wood loses and gains moisture, EMC indicates the difference. When compared to adsorption, desorption has a stronger equilibrium[65], [66]. This process is known as hysteresis. Also, it is a feature in the majority of the cellulosic materials [67].

C. Swelling and shrinkage of wood

Through the literature summarized the anisotropic property of wood affects the dimensional changes caused due to the water absorption. The effects of chemical composition, density, and microfibril angle on shrinkage differ in the longitudinal and tangential directions [68]. According to the studies presented by Suchsland (2004), longitudinal shrinkage (LS) of sound timber is normally minimal (less than 1%), However, radial and tangential shrinkage (TS) are significant, ranging from 2 to 5 percent for conifers and 6 to 8 percent for conifers, respectively [69]. The cell wall's microstructural and molecular characteristics govern wood shrinkage. Dimensional changes accompanying shrinkage and swelling may cause degradation of timber in Application[70].

D. Fiber Saturation Point (FSP)

The FSP is the moisture content on which liquid water, or sap, has been drained from the cell cavities. However, the cell walls remain saturated with absorbed water. The FSP is lower in wood with a high extractive filling content, for example. When the moisture level in wood goes below the "FSP," the wood shrinks [71], [72].

The attraction of water molecules by the hydroxyls of its chemical elements, mostly cellulose, is the primary reason for moisture entering the mass of wood [73]. As a result, the hydroxyls create a water monomolecular layer. This is held together by strong hydrogen bonds. As a result of the creation of this layer, cellulose molecules in the amorphous regions and between the crystallites of the microfibrils are pushed apart.

This causes the wood to swell. More water molecules enter due to secondary attraction forces, forming a poly molecular layer. Meanwhile, the capillarity condensation in cell-wall cavities and pit features allows an extra component to enter [74]–[77], [78], [79].

2.4.2.2 Chemical Composition of wood

The nature and structure of chemical components determine all of the qualities of wood. Wood is a natural polymer with a molecular structure based on the cellulose chain, whose cell wall is made up of cellulose fibers that are aligned laterally to its axis, comparable to natural human hair [80].

The tree's wood is the tree's intermediate and primary zone. The cellulose and hemicellulose groups are the carbohydrates that make up the majority of the cell wall, and wood is composed of four main chemical groups. Lignin functions as a "glue" that binds cells together to make a strong material [81], [82]. The extracts are compounds that are deposited in the cells and give wood certain qualities, such as natural resistance to biological decay. Biocidal extracts are found in high concentrations in woods with a high degree of natural resistance [83]. Depending on whether it has less or more moisture than the atmosphere, wood absorbs or loses moisture when exposed to the air. Because of its directed cell structure, wood has more strength in the longitudinal direction than in the transverse direction. Wood's compressive, tensile, and flexural strength all contribute to its overall strength [84],[85].

All woods are composed of a cell structure made up as follows, (Figure 2-12),

- The walls of the cells comprise bundles of a definite substance known as cellulose [86].
- The cellulose bundles are encased in lignin, which is a group of materials.
- Water, protoplasm, gums, resins, tannin, and other compounds are commonly found in cells. It is made up of cells and cell walls that are made up of micro-fibrils of cellulose (40–50%) and hemicellulose (15–25%) impregnated with lignin (15–30%) [87],[88].

Carbon and oxygen make up the vast majority of all wood. Carbon dioxide and water are combined to produce carbon, hydrogen, and oxygen [89]. Cellulose is the most frequent ingredient found in the walls of all plant cells. Plants and the fungi that cause decay, on the other hand, can both convert cellulose to starch and then convert starch to various kinds of sugar. ‘Lignin- Lignification is the process of lignin causing these

changes [88]. The chemical composition has not been determined accurately; however, it has been given variously as lignin varies from cellulose primarily in its carbon content [89], [90]. It's unclear whether all woods have the same amount of lignin.

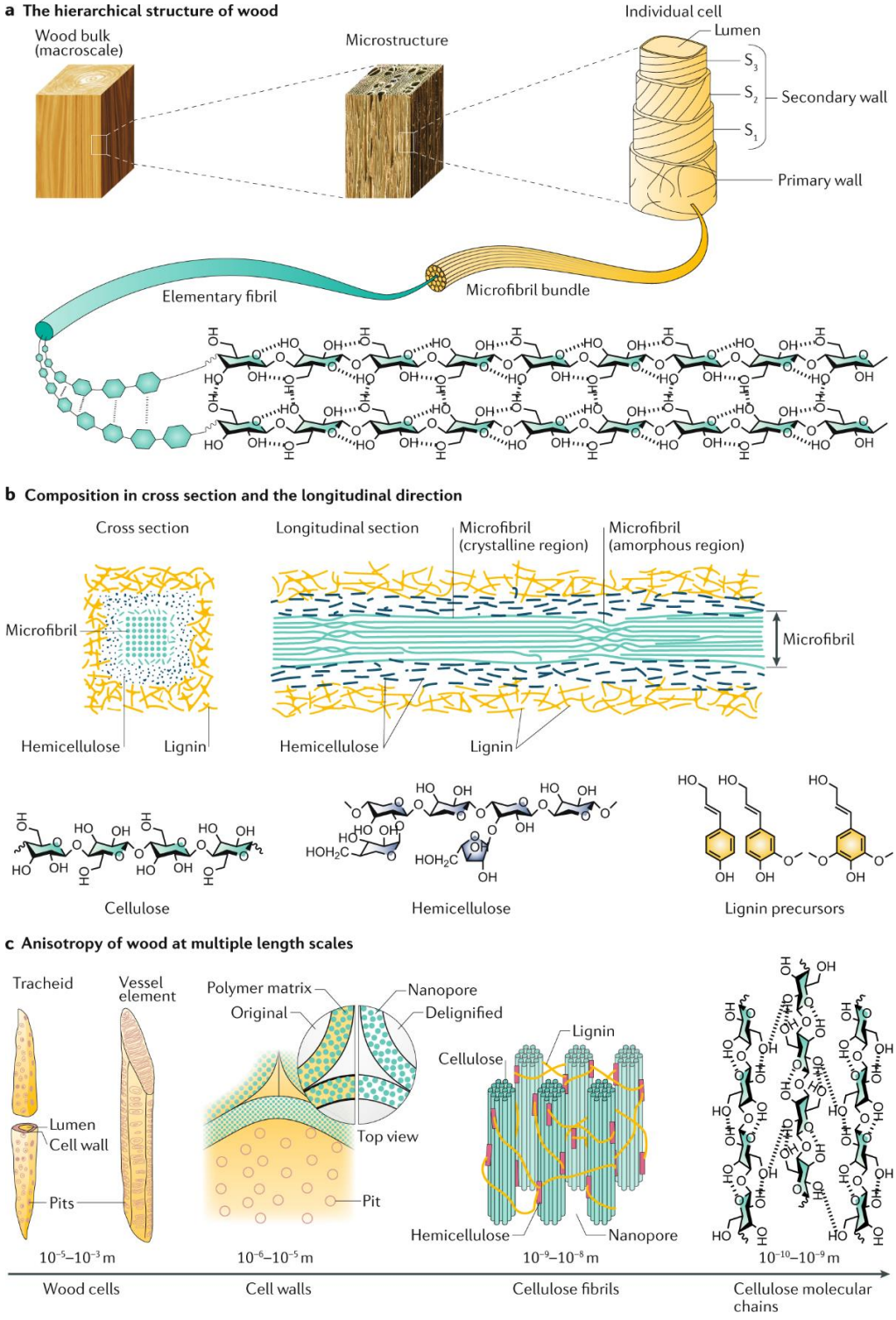


Figure 2-12; Detail graphical ;a-The hierarchical structure of wood , b. The composition in cross section , the longitudinal direction, c- Anisotropy of wood on multiple length scales [107].

2.5 Wood preservation

Wood preservation has been documented as far back as Alexander the Great's reign in ancient Greece when timber used in the bridge was steeped in olive oil. The Romans used tar to protect the wood on their ship's hulls [110],[111]. Wood preservation started evolving with the wood processing business during the industrial revolution. With preservative treatments and procedures, inventors and scientists produced historic advances in wood preservation. Before deciding on the appropriate safeguards, it is critical to assess the deteriorating hazard.

2.5.1 Wood preservatives

The type of woody species, the exposure conditions, and expenses, various approaches for wood preservation have been devised. Chemical preservatives are required in a variety of situations to protect the wood from the sorts of decay outlined previously. When comparing the relative efficiency of different types of treatments, the volume of preservative injected into the wood and the depth of infiltration should be taken into consideration. These considerations will be influenced by the preservative's application method.[90], [91](Figure 2-13).

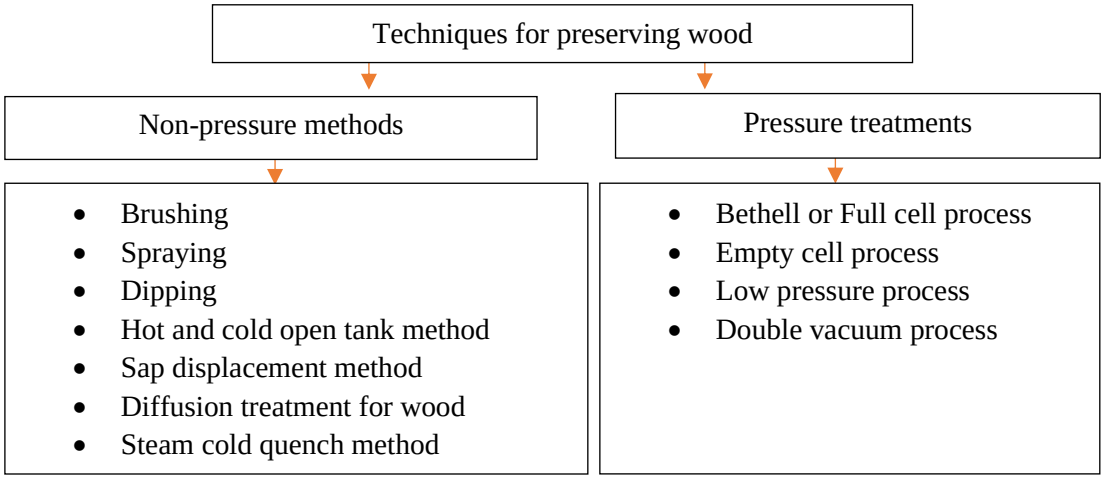


Figure 2-13; The Techniques for preserving wood

The defensive effect or the efficacy is accomplished by incorporating a preservative or repellent into the wood, the organisms will be less likely to decay. Therefore, timber preservation became progressively important.

2.5.1.1 Main characters of a wood preservative

Following characteristics are expected in developing an ideal wood preservative(Figure 2-14), Many research literature summaries are as follows [112]- [115].

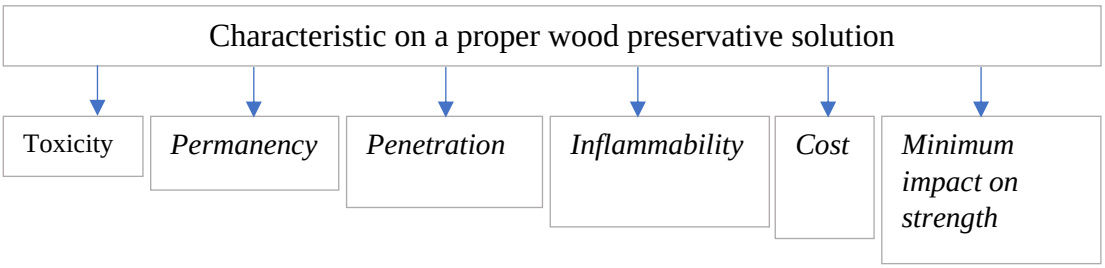


Figure 2-14: A Flow diagram which presents the characteristics of wood preservative

A. Toxicity

The preservative's fatal toxicity against fungus, insects, and marine creatures should be significant even at low concentrations, with a low degree of lethal effects for mammals. There should be no or minimal adverse effects on people during usage and handling.

B. Permanency

The wood preservative's ability to remain under varied practice, with resistance to the following,

a. Treated chemical leaching to water

b. Cause of rapid evaporation because of the heat

c. Oxidation, reduction, and polymerization are all chemical transformations.

d. The enzymatic reactions triggering towards minimizing the toxicity level

3. Preservative must be firm throughout the treatment process

4. The surface applications must not avoid the cause of the preservative.

C. Penetration

High responsiveness, allowing it to infiltrate the treated wood's whole cross-section for a longer-lasting effect.

D. Inflammability

The preservative must not increase the flammability of treated wood.

E. Cost

The preservative should be reasonably priced and easily available. And the ability to easily transport over great distances.

F. Anti – Corrosive

The preservative must not cause or motivate or trigger corrosion in the metal fasteners used during construction.

G. Minimal impact on strength

The preservatives should not have an unfavorable effect on the wood's strength or other properties. The chemical preservatives used can be dissolved in either water or oil. In any event, must not be overly combustible or non-targeted organisms. Also, must be cost-effective concerning economically beneficial to use.

Wood preservatives are further classified into two as below. This study mainly focuses on Natural wood preservatives, (Figure 2-15).



Figure 2-15 : the main types of wood preservatives existing in the wood industry

2.5.2 Impacts of inorganic chemicals used for wood protection

The factors affecting the wood after treatment is described as follows,

2.5.2.1 Factors affecting the physical and mechanical properties of the treated wood

Key factors included: chemical type, retention, species, material grade, material size, mechanical property, preliminary treatment, and post-treatment drying temperature, and incising most of the time affects the mechanical and physical properties of the treated wood, (Figure 2-16).

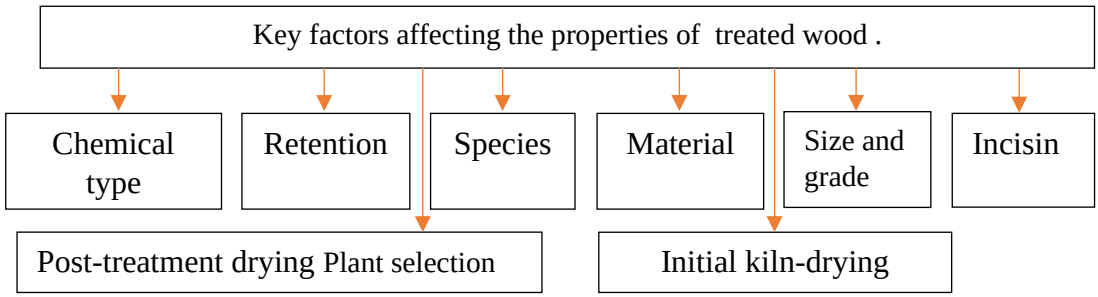


Figure 2-16; The flow chart on the factors affecting the properties of wood.

Generally, as exposure temperature, relative humidity, and duration increase, mechanical properties of treated timber are progressively reduced. At diverse temperatures, the aqueous preservative treatment affects mechanical properties differently. The majority of the mechanical properties were lowered by heat treatment. Thermally modified specimens at 220 °C for 4 hours had the most mechanical strength reductions. Borax chemically treated specimens lost less strength than non-impregnated or untreated controls, whereas boric acid-impregnated specimens lost less mechanical strength[92][92], [93].

The literature concluded the comprehensive review on waterborne preservative treatment where the modulus of rupture (MOR) is more sensitive to treatment effects

than MOE and dependent on the preservative chemistry, retention, and the redrying temperature used, the reduction can range from 0 to 20%. The thermal induced effects were deceptive at 82 °C for all samples including controls, these effects were not as severe as those resulting from H3PO4 and $NH_4H_2PO_4$. However, then again, the rate of strength degradation was alike for treated and untreated material even though large differences in strength occurred. An indication of the brittleness of materials is known as work to maximum load (WML), and treatments tend to cause embrittlement. This property is subtle to the impact of chemical type, exposure conditions, and exposure time.

2.5.3 Natural Compounds for wood protection

In terms of human health and environmental protection, today's focus is on minimizing the impact of treated wood when and after applications. With this at present, the attention to developing natural preservatives to extend the lifespan of timber in services has been a significant need. As per the literature findings, the natural compounds with a proven biocidal activity depending on the source of origin of the compounds can be classified into two, (Figure 2 -18).

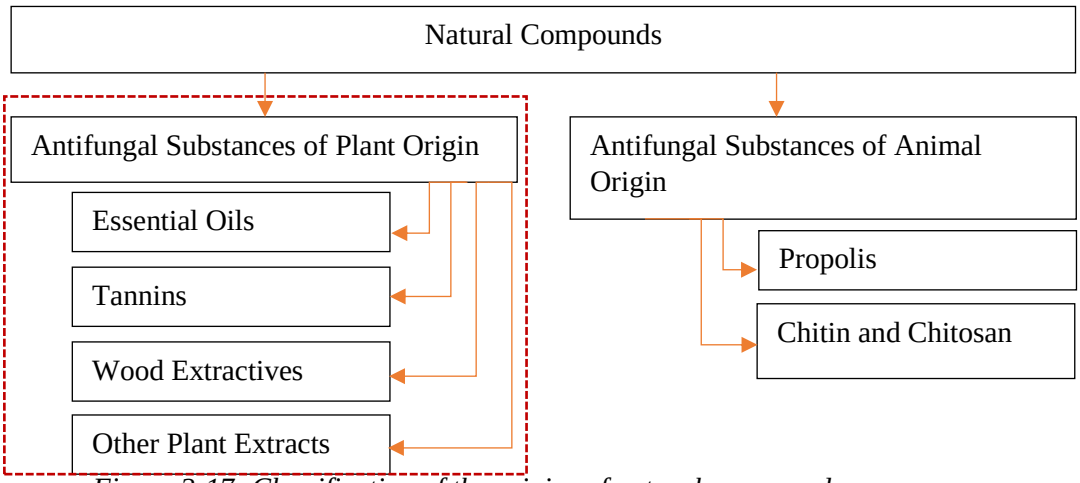


Figure 2-17: Classification of the origins of natural compounds

2.5.3.1 Impacts of organic chemicals used for wood protection against Fungi

Many indigenous plants species around the world have shown diverse varieties of essential oils to have protective properties against wood decay and molds.

- Voda et al. [94] Basil, cumin, oregano, anise, and thyme oils were found to have considerable antifungal activity contrary to brown-rot fungus. White-rot fungus with *Coniophora puteana* using the agar dilution method has been investigated. The

most efficient chemicals in preventing the development of both fungi were thymol, carvacrol, trans-anethole, methyl chavicol, and cumin aldehyde.

- Zhang et al. [95] Pure monoterpenes such as -citronellol, citral, carvacrol, eugenol, thymol, and geraniol have been shown to have antifungal effectiveness against the wood white-rot fungus Trametes hirsute, Pycnoporus sanguineus, and *Schizophyllum commune*.
- Xie et al. [96] Essential oils of Origanum vulgare, Cymbopogon citratus, Thymus vulgaris, Pelargonium graveolens, Cinnamomum zeylanicum, and Eugenia caryophyllata have been shown to have antifungal activities against wood-decaying fungi T. hirsuta and Laetiporus sulphurous, with carvacrol, citronellol, cinnamaldeh.
- Reinprecht et al. [97] displays five distinct essential oils (cinnamon, clove, oregano, basil, and thyme), with basil oil having the highest antifungal action against the brown-rot fungus Serpula lacrymans and the white-rot fungus T. versicolor, and clove oil having the lowest.
- Pánek et al. [98] Antifungal efficacy was stated. The stability of beech wood treated with 10% solutions of ten essential oils (1. tea tree birch 2. Lavender 3. Oregano 4. sweet flag 5. Clove 6. savoury 7. sage 8. Thyme 9. a mixture of eucalypt, lemon, lavender, sage, 10. thyme oils) against brown-rot fungus C. puteana and white-rot fungus T. versicolor) is also demonstrated.
- Kartal et al. [99] Sugi wood was maintained with a cassia oil-based formulation, resulting in great brown-rot resistance. White-rot C. versicolor fungus showed a mass loss of 3.6 percent and Tyromyces palustris showed a mass loss of 0.7 percent.

2.5.3.2 Tannins.

Tannins are the natural substances formed by plants to defend plants against pathogenic bacteria, fungus, and insects [100]. Differing in color, tannins (polyphenolic biomolecules) can be further elaborated as below (Figure 2-18),

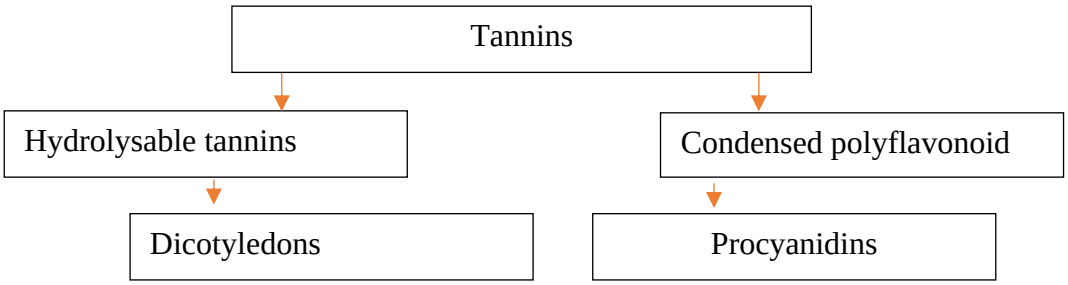


Figure 2-18: Classification of the tannin

Several studies have been carried out to test the resistance of tannin-treated wood species to molds and wood-decaying fungi [101],[102],[103].

2.5.3.3 Wood extractives

Because of the existence of a variety of extractable chemical compounds known as extractives, certain wood species comprise of inherent resistance to decay. Extractives are a group of non-structural components created by trees themselves to protect them from environmental stresses. They are mostly found in the heartwood, (Figure 2-19).

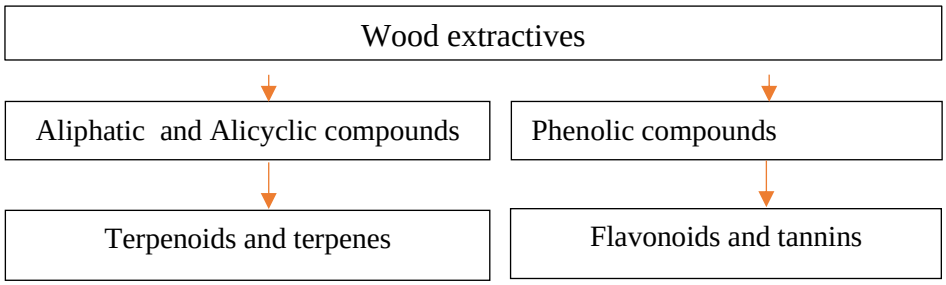


Figure 2-19; Classification of wood extractives

- Anda et al. [104] found that teak wood from Mexico had strong natural resistance against white-rot (*P. chrysosporium*) and brown-rot (*G. trabeum*) fungi, However its resistance to white-rot fungus T. The degree of versicolor was only mild.
- Brocco et al.[105] demonstrated that ethanol extracts from waste materials collected during the mechanical processing of Brazilian teak heartwood were efficient in protecting treated teak and pine sapwood from white- and brown-rot fungi. There was no antifungal action against soft-rot.
- Sablík et al. [106] described the ability of black locust (*Robinia pseudoacacia L.*) extracts of the heartwood to improve decay resistance of non-durable European beech (*Fagus sylvatica L.*) wood from class 5 (not durable) to class 3 (moderately durable) with mass loss of about 13%.

2.5.3.4 Others

Lichen (*Usnea filipendula*) and mistletoe (*Viscum album*) leaf extracts were also found to lower the susceptibility of Scots pine sapwood to the fungal assault of *C. puteana* [107]. Al-Huqail et al. discovered flowers 3 % water extracts of Acacia saligna (*Labill.)* H. L. Wendl. have moderate anti-mold activities.

2.6 Plant extracts as wood preservatives

Many research studies all over the world have presented plant species that have the potential to develop wood preservatives. A brief summary is presented as follows,

- Ajuziogu et al.2009 in Nigeria present the Leaf extracts of *Erythrophleum suaveolens* and *Pterocarpus erinaceus* where these plants presented the potential in controlling wood-degrading termites [108].
- Osman Goktas et al, 2007 in Turkey presents the Leaves and flowers extracts of *Nerium Oleander L*., toxic plant extracts from oleanders were shown to have antifungal characteristics and could be used as a wood preservative [109].
- Chittenden and T. Singh, 2012 New Zealand presents the oil extracts of *eugenol* and *cinnamaldehyde* with the antifungal action of essential oils counter to wood degrading fungi. Also, the findings revealed their applications as wood preservatives [110].
- Sen et al., 2009 Turkey presents the leaf, fruit, and bark extracts of sumac and oak valonia, the results presented their resistance to leaching. The mycological tests presented all extractives were substantially effective against decay [101].
- Da Silva et al., 2017, Brazil leaf extracts *Ocotea lancifolia* were separated and two phenolic fractions were obtained, this provided a renewable source of antioxidants and eco-friendly preservatives to treat wood [111].
- Tascioglu et al. 2013 Turkey showed the bark extracts of mimosa (*Acacia mollissima*), quebracho (*Schinopsis lorentzii*), and pine (*Pinus brutia*) with antifungal characteristics of some plant extracts used as wood preservatives.
- Sotannde et al. 2011Nigeria present the seed (*neem seed oil*), *leaf*, and bark extracts of *Azadirachta indica* (neem) with the termiticidal effect of neem extracts on the timber of Khaya senegalensis , This Leaf extract was known to be effective when compared to other plant extracts, these together create as a cheaper method while providing eco-friendly protection against termite attack [112].
- Salem et al. 2016 [113] in Egyptshowed the heartwood, leaves, and rhizomes extracts of .P. rigida *Eucalyptus camaldulensis* ,*Costus speciosus* presented antifungal properties[113].

Essential oils are natural mixtures of hydrocarbons and oxygen which are known to be aldehydes, alcohols, ketones, esters, carboxylic acids, and lactones comprising organic substances of plants with their constituents and derivatives[114]. The pesticide

activity is known to exist in the bark and the seeds and the focus has been on *asimicin, Cinnamylphenols.* The insecticidal activity of the callicarpenal, piperine amides , intermedeol, presenting repellent activities. Nepetalactone, is a catnip compound for a repellent for cockroaches, flies, termites, and mosquitoes [115], [116].

Several plants generate polyphenols known as tannins . These confer bitter taste or astringency on such plants and consequently, herbivores get rid of eating such plants[117],[118]. Among them, 20 components were recognized and the action was attributable to the occurrence of phenolic agents such as carvacol and thymol. The literature described that -cadinol gained from Taiwania heartwood possesses significant antifungal effectiveness [119],[120]. The stilbenes, flavonoids, and lignans represent phenolic extractives are present in heartwood have significant antioxidant properties[121],[122],[123].

Coumarin (2H-1-benzopyran-2-one) is an anti-inflammatory, anticoagulant, antibacterial, antifungal, antiviral, antihypertensive, antitubercular, anticonvulsant, antiadipogenic, , antioxidant, anticancer, and neuroprotective plant-derived natural substance [124].

2.7 Timber modification

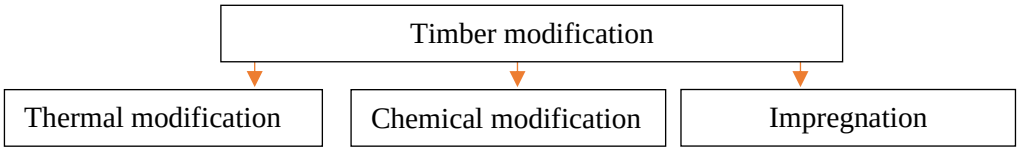


Figure 2-20; Classification of the timber modification

Nowadays timber has become a much-demanded natural construction material in the construction industry due to its performance, sustainability, aesthetics, and cost-effectiveness. Several modification methods are available under thermal, chemical, and impregnation modifications. Principles of wood modification are filled lumen, fill cell wall, reaction with wood polymers, cross-links, and cell wall degradation[125].

With the rising environmental concerns, as well as a growing need for consistent and high-quality timber or lumber. Illegal logging has also harmed the restricted availability and rising pricing of durable tropical timber (Figure 2-20).

The long-term viability of wood alteration has received more attention as environmental awareness has grown. According to the research, there should be three factors to sustainability in wood modification:

a) The environmentally friendly process

b) The renewable modifying agents
c) The biodegradable and nontoxic resultant products.

Since these procedures have the potential to improve wood qualities. The researchers are now looking into natural products and biodegradable polymers, and chemical modification with sustainable components. The use of these agents presents several issues, including penetration effectiveness, distribution uniformity, and durability. Scaling up these procedures could be difficult due to their cost, process conditions, and equipment.

2.7.1 Thermal modification

By thermal modification, the dimension stability and biological durability of timber are modified by exposing it to a greater temperature without chemicals. There are various technologies available to conduct thermal modification. Among them, performance in a nitrogen atmosphere in the kiln is mostly used. Thermal modification is significant effects on hygroscopicity, stability, mechanical properties, durability, and physical properties of the wood. This process can be done for a wide range of timber species [126], [127], [128](Figure 2-20).

2.7.2 Chemical Modification

By chemical modification, chemical agents react with polymeric components of timber and form a stable bond between the chemical agents and cell wall polymer. Chemical modification of wood forms resistance to water, decay, UV, and thermal degradation [129]. Acetylation is the term of the chemical reaction [130], [131],(Figure 2-20).

2.7.3 Impregnation modification

The cell wall of timber is impregnated with chemicals or a chemical mixture is theoretically known as impregnation modification. “For impregnation modification micropore diameter of the cell wall shall be around 2-4nm [132], [133], [134].Furthermore, in addition to evaluating environmental behaviour, several studies focus on green reagent selection and property enhancement. The ecotoxicity and degrading behavior of the treated wood should be thoroughly investigated. This leads to the development of new, long-lasting formulations [135].

2.8 Past applications of wood in construction

The importance of wooden architecture heritage blend with cultural value to contemporary wood engineering and science and politics in the world as a sign of national and regional originality and identity to be protected.

If the present circumstances prevail, wooden architecture heritage may remain only in research material and museums in the future, as presently the specialists concerned and society at large lack any agreement on which objects of wooden architecture and what kind of their features should be considered valuable and what are the most effective ways of their protection.

A possibility for the physical existence of wooden architecture heritage should be related to simplification of legal protection/ conservation requirements applied to such heritage and financial aid allocation procedures, improvement of the specialists' competence, and popularization of wooden heritage in society [136];(Figure 2-21). Among the two above, the study aims mainly on Local application in the tropics.

The literature identifies the gap inadequate knowledge on existing structures in tropical countries, where a significant case-based approach in a country like Sri Lanka could offer a pathway for a novel creation.

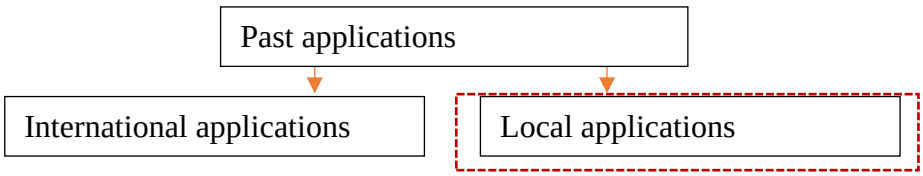


Figure 2-21; The flow chart on the classification of the wood constructions reference to time.

2.8.1 Local application

The study of the main sources of ancient timber architecture in Sri Lanka is the remains of religious edifices of Buddhist and Hindu Shrines at the current contest. There are three sources from which can date the Architectural remains of Sri Lanka (*Table 2-1*),[137], [138]. One of the most important components for meeting comfort standards is the shelter. Therefore, the study selects shelter for further investigations. Old buildings comprise a set of authentic information that the future should reveal. They have materialized centuries ago that uphold the respect and the technologies from those who lived in different social structures in a particular context in Sri Lanka. Traditional vernacular timber constructions in Sri Lanka can be expressed as an Art of creating considerate constructions[155],[156], Figure 3-22, and Table 2-3.

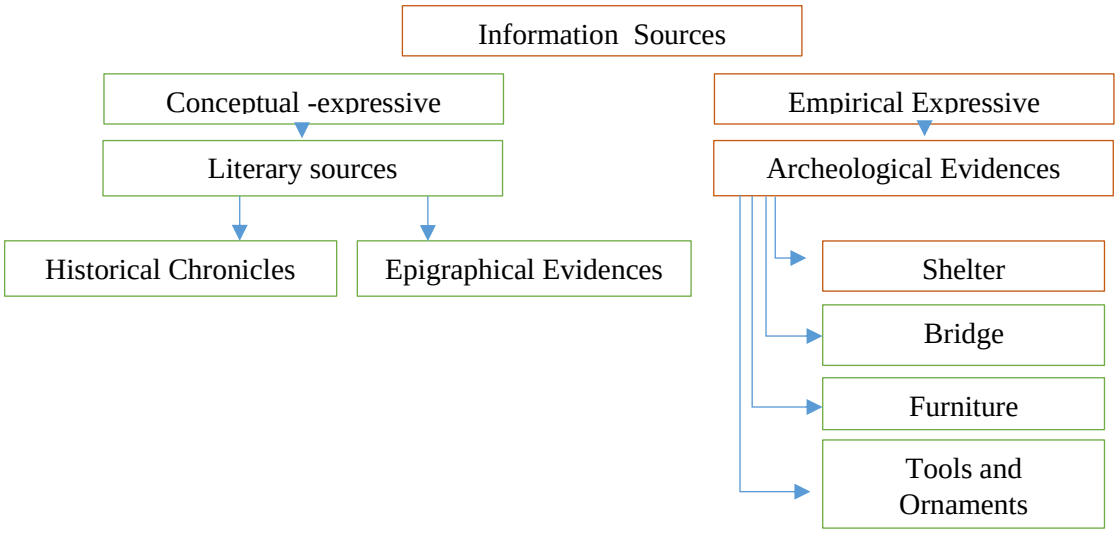


Figure 2-22; Classifications of information sources ; refereed to tangible and intangible sources

Table 2-1 The predictable sources

Source	Description	Useful
The *Mahawansa*	This massive chronicle details each King's accomplishments during his reign.	It's useful for getting a sense of the buildings themselves, as well as their construction methods and dates of construction, addition, or development.
Epigraphical evidence	Often used to mark a donation of a building or a monastery, these letters are inscribed on rock.	To record a donation of a building
Archeological Evidence	Evidence from excavation. And are physically seen.	To study the exiting remains of the materials. study of the development of architecture and architectural, engineering design over the years

The relatively is the outcome of applied research and development knowledgeable by theoretical knowledge, engineering experience, and knowledge about user needs [139]. As Literature further concludes environmental innovations possibly will be classified into three types organizational innovations, process innovation, product innovation. [151]– [153].

A. Societal transitions

Societal transitions comprise numerous actors, changes in institutions, values and technologies, and interactions across multiple sectors and scales. This research limits the values and the technologies based on timber construction practice. Defining the term societal transition is “a radical, structural change of a societal (sub)system that is the

result of a co-evolution of economic, cultural, technological, ecological, and institutional developments at different scale levels"[143], [144].

2.9 Nature and the cultural symbiosis

The need for cultural protection has just recently become apparent, even though the need for biodiversity protection has long been recognized [18]. Understanding their interplay and interaction is critical to guaranteeing the survival and flourishing of both Nature and culture. Nature and culture merge in many ways. From values, beliefs, and nomenclatures to practices, ways of life, knowledge, technologies, and languages[19], [20]. As a result, cultural systems and the environment have mutual feedback, with changes in one frequently affecting changes in the other. Culture can be defined as the methods via which people perceive their surroundings[21]. The meanings and the interpretations have a wide range of connections to the natural environment, with the most obvious connections occurring most frequently in traditional resource-dependent communities. Whereas many traditional cultures appear to make no distinction between nature and culture. Many modern societies regard them as distinct, if not antagonistic, entities. Socially in-built norms and rules are also influenced by ecological knowledge[22]. These normalise human interactions and behaviours about the natural environment, and they have frequently co-evolved to ensure the survival of both people and nature. They are frequently in the form of common property regulations that govern the usage of natural resources [23]. These rules determine access rights acceptable behaviour and the productivity and diversity of socio-ecological systems, which is ultimately in the community's best interests[24]. As a result of cultural extinctions induced by assimilation, language loss, and knowledge loss, these factors are also paving the way for greater cultural monocultures. Traditional livelihoods are being replaced by contemporary occupations, and rural groups are relocating to metropolitan regions at the expense of cultural variety.

Oral knowledge is being replaced by written knowledge, and traditional livelihoods are being replaced by modern occupations[25]. This comes at a cost to human society, as a decrease in knowledge reduces humanity's potential answers to future global crises. Culture is enclosed by nature. To use a metaphor, nature is the womb of culture, yet it is a womb that humans never really leave [11]. Nature can accomplish a great deal without the aid of culture, as seen by billions of years of evolutionary history. Culture,

which emerged late in natural history, cannot function without nature's support. In this sense, culture will always have to be built from nature and superimposed on it.

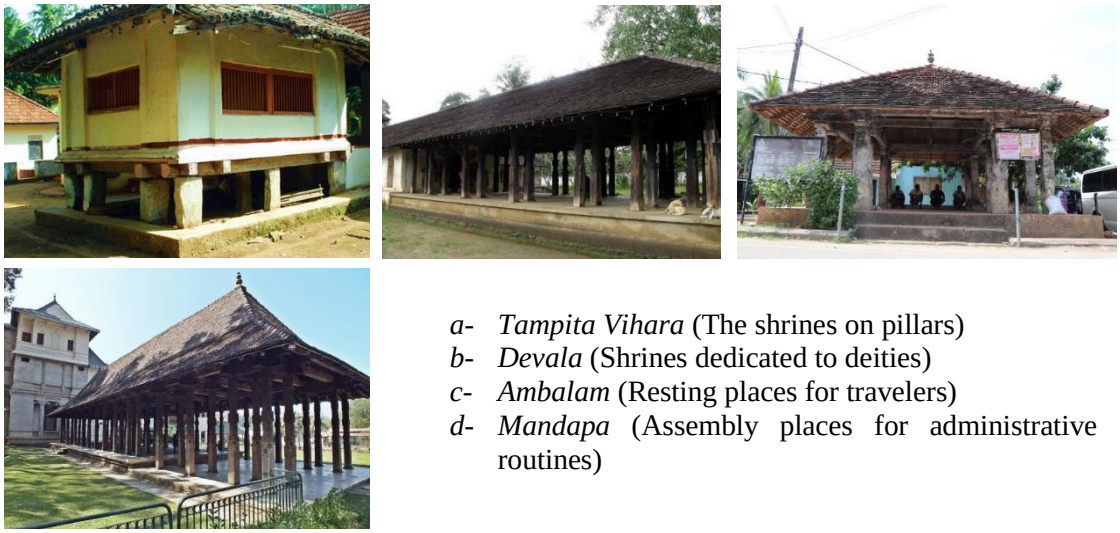
There are significant timber constructions that still exist by overcoming wood deteriorating agents in a tropical country like Sri Lanka[26]. It was observed, these structures had used precise timber processing techniques to overcome the mechanical failures revealing proper material manipulation[27]. With regard, raising a question on how did they overcome the challenges against other main wood deteriorating agents like termite, fungi, fire, marine borers, etc. Therefore, this study attempts to accumulate and consolidate the traditional vernacular timber preservation technologies by investigating the ancient timber structures in Sri Lanka. The main aim of this paper is to provide a preliminary discussion of the requirement of knowledge relevant to nature and the cultural symbiosis in the contemporary wood industry. Also, to emphasize the community and of the construction role that existed where this knowledge could play in delivering this global need.

Historical records of Sri Lanka noted the existence of buildings like *Lovamahapaya* in Anuradhapura in the 1st century B.C, one of the splendid structures made out of timber. Further, the reports state the superstructure of the *Lovamahapaya* probably would have been constructed out of wood.Figure 3-23.

Figure 2-23; the photo was taken beforehand restoration –taken on late 1800's or early 1900's



Other types of early structures that would have utilized timber include Chethiyaghara was a sort of rotunda that accommodated lesser stupas, shrines enclosing Bo-trees known to be *Bodhighara*, and a circular relic house known to be *Vatadage (*Figure 2-24*)*.



a- *Tampita Vihara* (The shrines on pillars)
b- *Devala* (Shrines dedicated to deities)
c- *Ambalam* (Resting places for travelers)
d- *Mandapa* (Assembly places for administrative routines)

Figure 2-24: : a- Tampita Vihara-, b-Devala , c-Ambalam d- Mandapa

Unfortunately, neither their physical structures nor any records informing the construction topographies are available today [145]. Among all the study selects *Ambalam* For further investigations as of its higher numbers of cases and as structures used by the public people. *Ambalama* can be introduced as a kind of architectural manifestation that remains in-tact that help understanding the knowledge of traditional timber applications in Sri Lanka

2.10 Summary

Literature summarises the significance of the need for wood as a construction material, (Figure 2-25). Which leads to more sustainable construction. Preservation is not a new term in the field of construction. When man began utilizing wood as a building material it was only a matter of time before decay became domesticated. Because of its biological nature, the wood is more vulnerable to foreign organism attack and decay. The core objective of the preservation is to introduce the preservative solution into the wood. This leads to a deep layer with the chemical penetrated so the treated wood comprises sufficient preservative to prevent decay and insect attack.

The level of protection obtained is determined by the type of preservative used. In addition, establishing optimal chemical penetration and retention is a notable feature of wood preservation. According to the literature, the failure of a structural component or application of timber used within the construction due to decay may result in an expense well higher than the cost of the wood itself. Further, preserved wood should be regarded

as a fully new construction material rather than only an improved type of wood. This treated wood can be used in a variety of conditions, including far more severe exposure situations than untreated wood.

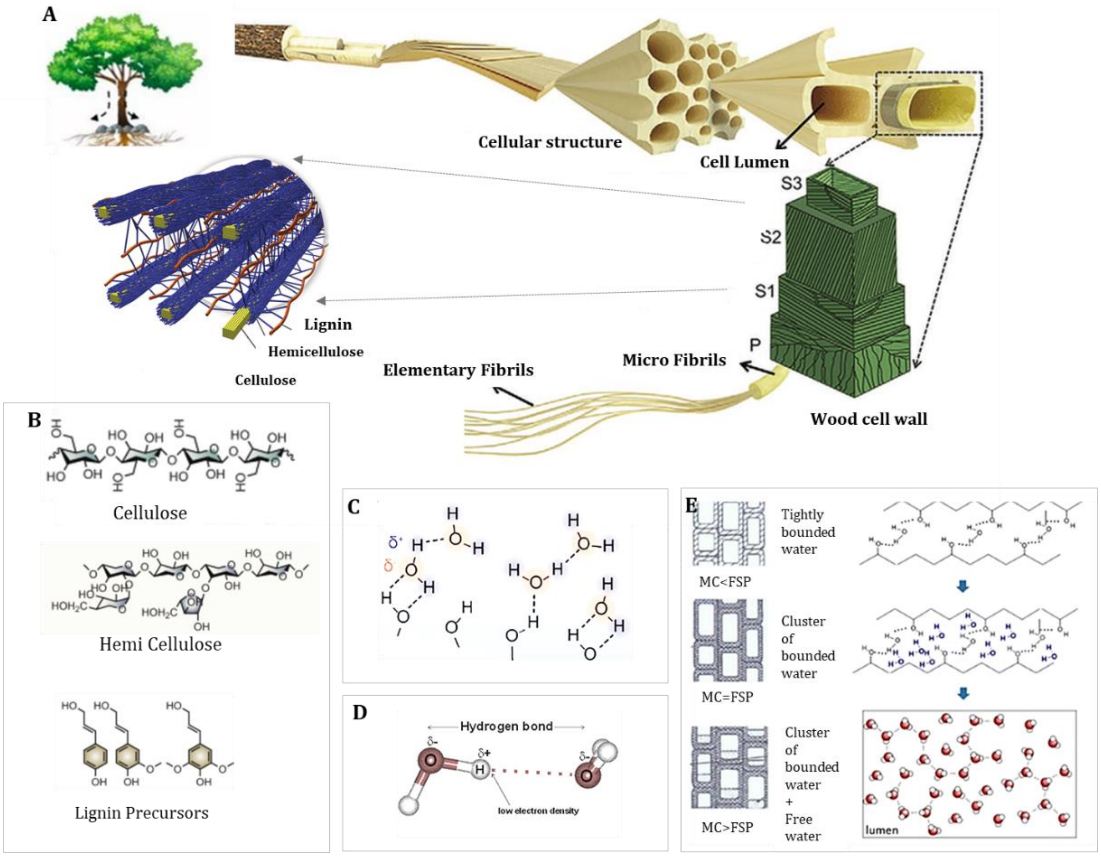


Figure 2-25; A- Cell Structure, Cell Lumen, Wood cell wall, Micro Fibrils, Elementary Fibrils; B- Cellulose, Hemicellulose, Lignin; C- Cellulose's many hydroxyl (–OH) groups attract water molecules, making the substance hydrophilic, D - Reaction of hydrogen bonds; E -Bound and free water distribution

Urbanization has begun to have an impact on a country's economy and ecology. In the future, organizations will be more focused on transitioning from a linear to a circular economy.

Heritage structures have a value that is not based on a direct and immediate economic return. Timber constructions in Sri Lanka persisted as one of the profoundly significant reflections of culture and technologies.

Literature has emphasized the importance of innovation to the future of the industry, there must be further research into where these innovations are going to come from.

CHAPTER 3 : ANCIENT TIMBER PRACTICE IN SRI LANKA

3.1 General

The sustainable strategies in traditional tropical buildings were found deliberated in response to its' users and the climate of the context. An assessment was performed on material usage in Bio Climatic Designs, focusing on *Ambalam*; well-preserved heritage structures found in the tropics, Sri Lanka. Literature evident that few pieces of research were conducted on '*Ambalam*' within the South Asian region, even within that lesser research have been focused on sustainable material usage and user comfort aspects. The study, therefore, fills the research gap intends to evaluate the design aspects and unleash on construction material utilization under traditional technology, material compositions, and their combinations along with the building orientations which affected user comforts. *Ambalam*(s) have self-survived for decades with passive means with no consumption of energy. Location, orientation, and designs are well planned to make a lesser impact on the existing environmental and social setting. Thus, it has been socially sustainable for ages by being a public community place with no conditions applied for its users, encouraging the social harmony and hospitality characteristics of Sri Lankan culture.

3.2 Archaeological Evidence

Archaeology pieces of evidence in the construction provide researchers and scientists with the opportunity to acquire knowledge about past cultures, materials, and technology through the study of artifacts, or constructions. Studying these Archaeology pieces of evidence helps to provide some perception or awareness about what life was like for people who left behind no written record which creates the significant need of studying the science behind these for present use.

The study investigates deeply the archaeological remains of *Ambalam* structures that were constructed within the local communities.

3.3 *Ambalam* Structures

An *Ambalam* is an open colonnaded, hip-roofed structure, introduced as a prestigious building type that originates under traditional vernacular architecture in Sri Lanka. It concludes the basic task of providing shelter for a comfortable stay within a considerable time. *Ambalam* was owed as charitable service commenced by the

villagers under the patronage of the chieftain. There were no architects and engineers or designers in the past. The spaces and technologies were engendered and innovated along with the needs and the experiences of inhabitants along with the prevailed social structure. Sustainable strategies were attempted in response to context and the climate comprising a proper building orientation [146]. This leads to maximizing the structures' passive heating and cooling.

Ambalam depicts the simple village lifestyle and also the religious background of the villages which simply emphasized the Buddhist philosophies and the ideology through an architectural and a structural engineering medium, over role theses created an indigenous space with aesthetically and socio-culturally pleasing setting contributed with advanced medieval technologies under prestigious traditional vernacular architecture in Sri Lanka.

This building initiates under the traditional vernacular architecture employing the heavy richly ornamental structural frame, roofs, and furniture set in a simple open colonnaded space. The elegant carving on timber, granite stone, and brick wall adds an expression that together reflects the architectural significance and the social significance of the structural monument. The *Ambalam* heritage structures have enlightened timber as an acceptable construction material with a respectable service life for tropical countries. The types of *Ambalam structures*,

- Horizontal bottom structure made of brick and mortar where wooden columns carried the load of the roof.



Figure 3-1;The construction details of the Ambalam ;a-, b- ,c-, d

- Another type with massive granite pillars holds the load of the roof.
- The timber joists, the bearers, and the posts were placed on stones that have been used as footing. The entire timber structure is directly kept on stones. There is no single visual or physical joinery along with the post and the footing. While the entire load was in the stone with structural stability where it is perfectly withstanding for wind and rain.
- Also built on raised platforms like podiums.

Ambalam(s) can be hosted as a perfect living sample that contains preserved living proof of vast construction materials utilized. Sri Lanka is a tropical country with an intermediate temperature and humidity along with a burst of sturdy sunshine throughout the year. It acts as a massive sample library to investigate the vulnerability of the Shelter as a structure that has been entirely or partially constructed in timber with other



Figure 3-2: A- Timber joinery in Karagahagedera Ambalama, B- Bearers on stumps, C- Panavitiya Ambalama wood carvings

construction materials like Granites, mortar, and brick. A thorough visual and scientific observation leads to an understanding of material decay and degradation in varying environmental and climatic conditions. It was observed that the selection of construction materials, as well as the regional material uniqueness, has been directly impacted on the microclimate of *Ambalam*(s) structures (Figure 3-2).

Since the major utilized construction material is Timber, the *Ambalam* structures visualizers the affected mechanical and physical properties due to the long-term exposure of the climatic condition under the combinations such as humidity, temperature variation, and biological attack. The integration of construction and carving skills represents the experiences and skills of the carpenter. Together with extremely rich detailing, showcasing a range of carving with material collaboration such as granites-Timber, Timber-Timber, Brick- timber. This represents a remarkable combination of creativity and engineering in manipulating the materials with or without knowledge however with an overestimated experienced understanding, (Figure 3-2).



Figure 3-3;Rukula Ambalama , Kadugannawa Ambalama

A change in temperature or humidity will result in a corresponding change in the equilibrium moisture content of the wood. During the medieval periods, skilled villagers may not learn through theories yet it was through experience.

For example; The *Mangalagama, Kengalla Ambalam* Structure is a good example to interpret the material combination in a logical perspective. The fully exposed part of the pillars of the structure was constructed out of granite to restrict the contact of water through rain or wind avoiding atmospheric moisture contamination.

Investigating on a living proof resembling's like *Ambalam*(s) scientifically know-how and the expertise that had been pragmatic and manipulating materials in constructing structures under the adequacy of Sinhalese culture in the engineering and Architectural Perspectives[147].

By safeguarding heritage, which is not always a building, it passes the best of our cultural legacy to future generations and, at the same time, provides the present generation with a connection to its past as a sense of identity, ensuring continuity of advanced traditional technologies and traditional practices.

As a way of life means of social sustainability, open up new economic opportunities such as reinventing the sustainable construction practices which have pragmatically proved the usability. spaces for education, living material libraries, and recreation.

Through time, the architecture and engineering aspects of *Ambalam* have persisted as one of the profoundly significant reflections of culture and technologies. Shelter reflects the story of the time, and how that iteration of culture and Engineering technologies wished to project itself to the future commencing as a well-preserved information library, (Figure 3-3).

3.3.1 Identifying the potentials of traditional construction techniques

A comprehensive bioclimatic design in such a given urban setting investigates and assesses the building's admission to natural sources. This captivates the negative effects that prevail around the context [148]. The constraints are important at the starting point for architectural design as they comprise the potential on leading to creative, innovative, and remarkable architectural solutions. Buildings are a type of construction that lives in a continual state of stability [149]. Space- functional point and layout of the buildings are the main constraints when designing. A thorough interpretation of a traditional building's function and building fabrics must consider the building itself as the primary tool in providing comfort to the occupant as a rich, comfortable shelter for its targeted activities, while also minimizing the impact on the natural environment for future generations. In the above sense, *Ambalam* buildings can be identified as a package of traditional knowledge on timber construction.

Here this phase of the chapter identifies the significance of '*Ambalam*'(s) buildings as a sustainable traditional tropical building type; with a view determining its comparative bioclimatic design practice along with material usage found in Sri Lankan traditional vernacular architecture. In achieving the above aim, the objectives of the study are to:

1) Examine the building orientation of '*Ambalam*' Structures in Sri Lanka
2) Investigates the qualities of timber as a building material

3.3.2 The structure of '*Ambalama*'

Traditional vernacular architecture in Sri Lanka can be expressed as an art of creating thoughtful structures and spaces including proclamations that can be consumed as a

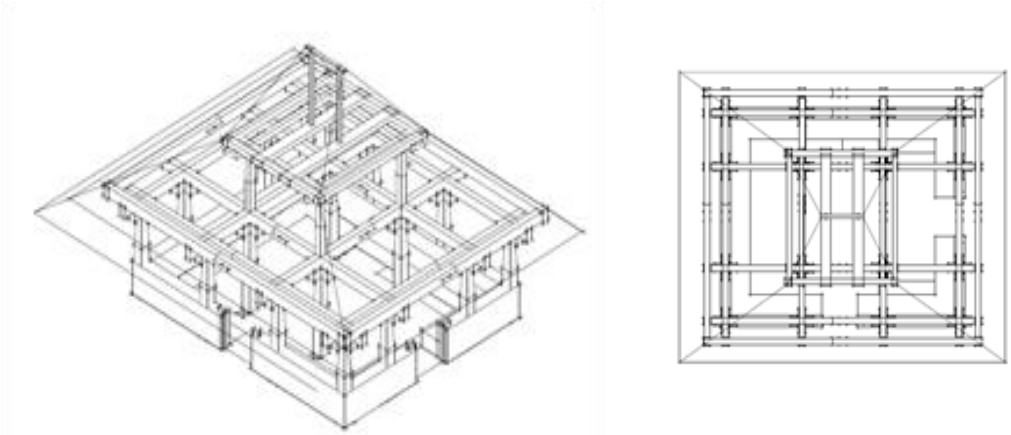


Figure 3-4;Mangalagama Ambalama illustration model; A - Isometric view. Mangalagama Ambalama illustration model; B – Plan

communicative medium of the privileged owners, which had always influenced social facts. From past years, mankind has delivered and perceived elements through various expressions "*Ambalam*" structures are fascinating living proof with non-permanent bondage of structure with the floor plan, which structurally perceives the temperateness of the construction. Structurally in some cases; The timber joists, bearers, and the posts placed on stones are used as footing. The entire timber structures are directly placed on stones. There is no single visual or physical joinery alone with post and the footing [9], [150]–[152]. While the entire load was in the stone; structurally stable where it is perfectly withstanding wind and rain, (Figure 3-4).

3.3.2.1 The Effects of Climate on Man

Changing weather conditions, expanding agriculture and population, and the development of metal tools altered early man's shelter needs. According to literature, the atmospheric conditions stimulate and invigorate human activities. Environmental constitutes such as light, sound, climate, space together act directly upon the human body. The shelter is one of the major components for fulfilling the requirements of comfort. It just changes the natural environment to get the most liveable conditions. The ideal requirement for an environmentally balanced shelter would be the fulfillment of all physiological needs. The air movement representing another climatic factor has a direct impact on bodily cooling. This does not minimize the temperature; however, it does provide a cooling sensation on the skin due to convectional heat loss and greater evaporation from the human body.

It has collaborated with improved technology in joinery such as 'Kanimadala', 'Madolkurupaawa' and 'Pekada' , emphasizing the accumulated wisdom found in traditional vernacular architecture[34], [150], [153], [154]. Timber has taken a unique and splendid role in these *Ambalam*"(s) structures when considering the utilization of construction materials. Moreover, the structural engineering aspect found in these timber structures is a significant area to study, where the major significance will be the joinery detailing with the unique inherent qualities expressed in timber species. Conferring to the medieval timber architecture, "Pekada" is a structural element in the joinery known to the beam and the pillar interference, where it handles the load transfer to the ground (Fig. 2). This significant intermediate structural bracket can be still seen

clearly in *Ambalam* structures. Architecture acts as a medium that facilitates diverse senses to people through the elements and spaces; "Pekada" is a simply interesting proof for that which has been presented with the highly detailed carving on it.

The architectural elements and the spaces within the „*Ambalam*'(s) facilitate to perceive the security and morale, relaxation, and discipline along with the users‟ comfort. "Kenimadala"; is a well-known term utilized in medieval Sinhalese timber structures to the point where the rafters get together at the top as a circular superior on the roof. "Madol Kuruppuwa"; not in as the exact elements. However, another evidence of a significant structural element under structural aspects was the intermediate connection between rafters and the ridge plate at the outer side of the pitched roofs. Its structural stability through compression, under medial architectural terms. The clearance between the joinery of Madol Kurupuwa; rafters and ridge plate interface and the end of the ridge plate that tends the Madol Kurupuwa: freedom to rotate. Another significance with *Ambalam*(s) structures is the structural strength in the timber framework; not a single steel nail or glue has been used with the joinery other than the wooden pegs. However, *Madol kuruppuwa* has gained its structural stability through compression [150]. Ex- Panavitiya, Badulla *Ambalama*. In the above sense, *Ambalam* buildings can be identified as a package of traditional knowledge on timber construction.

3.3.2.2 Bioclimatic Architecture

Bioclimatic architecture is the interaction between the climate, occupants, and the building design; This approach in architecture promotes true green principles such as "Carbon Neutrality" that involves a lesser number of environmental impacts and cost-effectively meets social needs, helping to preserve resources and biodiversity [154]. The bioclimatic design approach is also an appropriate basis that involves buildings by filtering and modifying the external/internal climate for occupants [149].

3.3.2.3 Usage of Sustainable Building Materials in *Ambalam*

The key considerations in designing a sustainable architecture are the impact on the environment, risk protection to user safety with the material usage, resource consumption, energy consumption and environmental friendliness at the end of building's life, etc[149]. Accordingly, to the ancient practice of traditional vernacular architecture, timber is identified as a material with all the above characteristics and the

lowest environmental impact on its production and its life cycle too. Therefore, the use of timber as the main building material was observed in almost every *Ambalam* building found in Sri Lanka. It is significant from the sustainability point of view.

3.3.3 Materials and Methodology

This study comprises Six *Ambalam* Structures in Sri Lanka in six different locations. The six different locations lead to conclude on a comparison among the *Ambalam* Structures and investigate the similar technology and the strategies that were followed by the constructors on constructing the *Ambalam* Structures, (*Table 3-1*), (Figure 3-5).



Figure 3-5; The six Ambalam structures are shown above ; A-Badulla Ambalama., B-Kadugannawa Ambalama, C- Karagahagedra Ambalama, D- Panavita Ambalama, E-Rukula Ambalama ,F-Managalama Ambalama.

Table 3-1:List of the case studies

Name of the case study	Location
Badulla *Ambalama*	In the *kachcheriya* premises in Badulla town.
Kadugannawa *Ambalama*	Kadugannawa
Karagahagedara *Ambalama*	Kurunegala road, Narammala
Mangalagama *Ambalama*	Rambukkana Division in the Kegale District
Naranwala *Ambalama*	12 kilometers away from Kandy towards Gampola.
Padiwita *Ambalama*	Kumbiyagoda road, Higula

3.3.4 Results

The literature has rarely investigated the facts and impacts of building orientation and climate response of the ancient *Ambalam*'(s) structures. Even though, it is important to identify the climatic response of these buildings, mainly focusing on their orientating. This study Investigates the material manipulations and the building orientation of *Ambalam* (s) located in different locations of Sri Lanka. Six case studies were selected randomly. Sri Lanka is fertile land owing to wealthy natural vegetation. Among the Sri Lankan government forests and homes, gardens consist of more than 400 woody species (Table 3-2).

Table 3-2:Dominantly visible timber species and their grading

Common name	Botanical name	Timber classification(STC)
Gammalu	*Pterocarpus marsapium*	Special Class Upper
Na	*Mesua ferrea*	Class I
Wal del	*Artocarpus nobills*	Class I
Mee	*Madhuca Longifolia*	-
Kumbuk	*Terminalia arjuna*	Special Class
Nedun	*Pericopsis mooniana*	Supper Luxury Class
Jak	*Artocarpus heterophyllus*	Luxury Class

This includes natural regenerations and artificial planted species too. For most of the close investigations of the column details; the craftsmen had intense on utilizing the timber along the grain instead of using perpendicular.

Tendrils and the tips of the carved elements that have gone across grains that have been wrecked away can still be observed. The nature of timber used to carve is considerably important, hardwoods with greater longevity and luster are difficult to shape [34]. It is

a significant need to explore how traditional vernacular architectural structures grant insights towards inheriting design strategies in construction within this framework; the paper emphasizes the building orientations of the six case studies (*Table 3-2*).



Figure 3-6; Above figure explores building orientation

3.3.5 Discussion

Remains of these medial buildings provide evidence for utilizing contribution features and technologies. Analyzing and investigating the significance tends designers, architects, and engineers to increase the timber usage blending its natural properties towards an indigenous design criterion [155]. The design strategy for these *Ambalam* constructions is precisely developed based on accumulated local knowledge, cultural value, and a thorough awareness of the natural environment. A high-pitched roof not only stimulates stack effect function but also functions as a sun-shading device, depending on the building or structural orientation. Furthermore, the *Ambalam* structure permits cross-ventilating breezes to cool the dwelling.

Also, the large roof eaves for adequate sunshine. Ventilated roof aids to reduce the internal temperature of the structure. Proper ventilation is mainly owing to the concept compartment's open interior spaces and minimum partitions (Table 3-3).

Table 3-3:Sustainable construction strategies

Sustainable construction Strategies	Description
Cross Ventilation	Open Colonnaded structure allows easy passage of air and better ventilation.
Construction material usage	Timber performs favorably in terms of energy use and ease of construction.
View and Vegetation	Vegetation helps to cool down microenvironmental Temperature. (Evaporative cooling)

Most of the *Ambalam* Structures were constructed on raised platforms like stumps and podiums at the same time mitigating the effects of the infrequent floods. This ensures the safety of the user or the travelers from the possibility of being attacked by wild animals.

Majority of *Ambalam* Structures are open colonnaded structures; ex - Badulla *Ambalam*a, Karagahagedara *Ambalam*a, Naranwala *Ambalam*a, Padivitiya Amabalam. Some are with half raised walls; Mangalagama Amablam, kadugannawa *Ambalam*a. However, they are all capable of recording high-velocity air movement while obtaining natural lighting [148],[156]. Bioclimatic architectural designs also persist through an infrastructure that bridges inhabitants' shelter and initiates the layout of cities themselves.

Analyzing the locations and placements of the existing archaeological monuments like *Ambalam*(s) includes ruins of neglected road patches of long-established ancient roadways road junctions, ferries, rural settlements, monastery sites, and geographical distribution of tanks which was highly utilized in the medieval period.

A well-organized road system in a country reflects the country's political, economic, social, and cultural growth. The above cases studies proved Timber as one of the major construction materials utilized. As indicated follow (

Table 3-4); they are suspected as highly utilized timber species under traditional vernacular timber

Table 3-4:CO_2 storage and CO_2 release of for major construction materials;

Material	**Carbon released (kg/m^3)**	**Carbon stored (kg/m^3)**
Rough sawn timber	15	250
Steel	5320	0
Concrete	120	0
Aluminium	22000	0

architectural constructions. Unlike other construction materials such as glass, steel, and aluminum, timber can repeatedly be reused. It can be remanufactured without any interruption. Trees act as storage sinks for carbon. In the phenomena of wood production through nature, a tree takes carbon dioxide (CO_2) and returns oxygen (O_2). Therefore, utilizing saw logs for long–life statures or in constructions, timber ensures that the CO_2 remains and remains fixed for a long period [157], [158]. In traditional vernacular architecture, the choice of passive design strategies for climatic control in buildings was based on experience. Ventilation requirements in traditional vernacular architecture were attained by natural means.

The six case studies have emphasized the spatial and functional arrangement, maximizing natural lighting and ventilation, building orientation, and construction materials.

These combinations play a major role based on traditional vernacular architectural concepts that lead to the development of modern, sustainable buildings.

Passive cooling techniques accompany the thermal comfort of the occupants [159]. Cooling is the transfer of energy from space to space, to achieve a lower temperature than that of the natural surroundings.

3.4 Timber processing techniques practice in *Ambalam*

The ability to become a "tree" has been acquired many times during the evolution of plants, and as such, there is great variability between tree species[160]. Trees can be classified into two, endogenous and exogenous. Exogenous trees grow outward from the center, generating approximate concentric rings across the longitudinal section of the stem in a systematic way. The pith is at the center and then the heartwood that is made up of dead cells and next to the sapwood that carries water, minerals, and glucose from roots to leaves. Then the very thin layer of living cells called the cambium is placed. These are the manufacturers of the wood. These concentric rings represent the number of years per layer. These rings are known as growth rings.

The word timber presents a fibrous rigid material of plant origin [161].

Timber has a high strength to weight ratio [162]. According to literature, there are methods of timber sawing practiced around the world which contain different physical and mechanical properties. Depending on where the saw passes through a log, the grain pattern orients differ. In this case diameter of the log directly affects to the sawing pattern [163]. These lines together contribute to communicating the material characteristics. Since wood is an anisotropic material where it contains different properties from different directions, these influence on generating the growth stress on the timber [164].

The growth stresses are very important during the sawing process to determine the appropriate application of the structural component. This research work is carried out to investigate the influence of larger timber sections and their influence on the service life of a structure.

The ability to conduct an assessment of the condition of heritage timber structures mandates a deep understanding of their past and current states, including aspects of their conservation, maintenance, and use [165]. The collection of comprehensive data from specific different typological structures is aimed at creating the knowledge base for future timber construction typologies and technologies.

Construction material assessment and the Structural assessment is also the first step towards an intervention that might itself range from mere preservation of an artistic

artifact to the full rehabilitation of a structural function and a material library to preserve it or adapt it for future use.

As such, the scope of the study is to identify and analyze the saw pattern followed in heritage structures and conclude how the saw pattern influences the service life of the structure. Thus, this paper highlights the relationship between the grain orientation and its influence on the saw pattern when utilizing timber for specific structural components.

3.4.1 Growth Rings and Grain Distribution

Tree ring analysis is a potential tool for obtaining information on a vast range of parameters. It provides information about the affiliation between growth and environmental variables such as climate and allows the detection of past environmental conditions changes. Growth rings to aid in understanding forest dynamics[166].

Orientations of the cell fibers in the wood are referred to as grains. The variation in size of the wood cells is referred to as texture. The figure refers to the pattern on a board caused by the arrangement of the different elements and the nature of the grain [167].

As an anisotropic material, the wood tissue is composed of hollow and spindle-shaped elongated cells called tracheid. Mechanical characteristics of wood are highly influenced by the grain direction such as strength, toughness, and elasticity [168]. The grain direction of wood is usually parallel to the longitudinal direction of the stem [169]. External forces and environmental factors may cause slight deviations [170], [171]. Natural deviations, such as knots or clusters of knots, are often referred to as defects of wood in the timber industry.

3.4.2 Growth Stress

Self-generated areas in the cambium during cell maturation are introduced as growth stresses. The highest growth stresses are usually found during the formation of tension wood. High growth stresses are suspected of having more tension wood, while least have wood that is different from less-stressed wood [172]. Growth Stresses are present in all plant species[173]. The growth strains are the relief of growth stresses. Strain is the dimensional change per unit of the original length (Tensile or compressive). With a given modulus of elasticity and within the proportional limit of elasticity, a greater strain results from higher stress. Growth stresses are generally

resolved in the longitudinal, tangential, and radial directions, following the natural geometry of the trees. “Lignin swelling” theory and the leading theories attempt to explain how growth stresses are generated.

The “lignin swelling” theory and the “cellulose tension” theory are two proposed theories to designate that growth stresses arise during the lignification process of maturation of newly formed cells [174].

In general polymerization of lignin reasons, contraction or swelling of wood cells in lateral directions [175], and elongation or shortening of fibers in their axial direction depending on the microfibril angles in these cells [176].

According to the “cellulose tension” theory states that growth stresses are generated as a consequence of the contraction of microfibrils in the newly formed cells. Meanwhile, their continuing crystallization is inhibited by the deposition of lignin [11], [177]. The endless formation of growth stresses during tree growth results in an uneven and continuously changing distribution of stresses across tree stems. Growth stress management and a thorough knowledge would have both a national and global economic significance.

Given the significance of timber as a construction material in tropical countries, the objectives of this study are to,

i. Analyze the prevailed log sawing techniques practiced in Sri Lanka.
ii. Investigate the influence of the sawing technique on the service life of the structure.
iii. Investigate the influence of the sawing techniques on load-bearing and structural stability.
iv. Analyze the best sawing techniques which lead to higher resistance to wood deterioration and longer service life.

3.4.3 Materials

Six *Amabalam* structures were chosen based on their main construction material as timber. These six *Ambalam* structures are situated in six different locations. The timber architectural remains include species like Jak (*Artocarpus heterophyllus*), Hora (*Dipterocarpus zeylanicus*), Gammalu (*Pterocarpus marsupium*), while some species are still unidentified. An overview of all cases used in this study is presented in (

Table 3-5) .

Table 3-5:Brief information of the selected case studies

Figure No.	Name of the Case	Location	A built year or the century	Construction materials
1.	*Giruwa Ambalama*	Aluthnuwara, Dedimunda Dewala premises	Built by Queen Sunethradevi, chief consort of King Parakramabahu II (A.D 1236-1276)	Timber & granite stone
2	*Padivitiya Ambalama*	Kumbiyagoda road, Higula	Kandyan period, before the British invasion	Timber & granite stone
3	*Karagahagedara Ambalama*	Kurunegala road, Narammala;	Believed to be built in 1837	Timber & granite stone
4	*Panavitiya Ambalama*	Dangolla in Dambadeniya	Built in the 18th century	Timber & granite stone
5	*Rukula Ambalama*	Aluth Nuwara, close to Dedimunda Dewala	According to legends, built by King Parakramabau II who ruled from Dambadeniya Kingdom in the 13th century	Timber, brick & Motor
6	*Badulla Ambalama*	inside the Kachcheriya land in the middle of the Badulla town	Built during the late 13th and 19th centuries	Timber, brick & motor

Some of these timber structures are integrated with brick and mortar and granite stones. Results indicate the utilized material percentage in *Ambalam* construction among the six case studies. According to this, timber is the major construction material utilized in the above six structures.

3.4.3.1 Selection of Structural Elements

Exposed cross-sections of the structural components representing the grain pattern were chosen. The selected materials of the study are relatively out of complete timber structures. They contain a similar frame structure constructed using two different techniques. In one technique, the structure is placed on stones maintaining significant stability and balance representing the *Tampita* concept, while in the other, the structure is placed on a simple podium.

Timber buildings under the *Tampita* concept were constructed on bearers and floor joists. On this, the edges are a well-exposed section to study the grain distribution of

the utilized timber. Therefore, structural components such as bearers, joists, wall plates, and rafters are analysed within the scope of this study.

3.4.4 Methodology

A. Documenting the Cross Sections

Close-up photographs were taken perpendicular to the surface which helps to map the grain distribution relevant to the study using a Canon 80 D, 18 - 135 mm lens and 50 mm, 500mm lens. A basic specific grid and a code were followed to plot the timber sections methodically and make the procedure a formal document. The grain distribution was then plotted using photographs on Autodesk AutoCAD software.

B. Mapping the grain distribution

Initially, the most visible arcs were drawn, and then the most justifying center of those arcs was figured out. Therefore, a line was drawn to denote the axiom length from the center to the edge of the section of the structural component. A diagonal from the center to the edge of the section justify a continual plotting area.

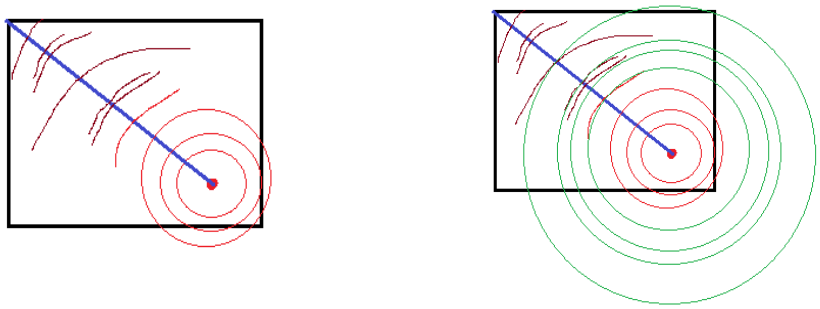


Figure 3-7;Map 1- Demonstrating on analyzing the grain distribution

C. Visual Inspection and documentation

Following this, the closest proximity was matched to tally the arc which meets the diagonal, and continued drawing circles matching with the arches. The grain distribution was thoroughly traced using the Auto cad software method, (Figure 3-7). All six selected structures are framed structures; the loads transfer through the roof to beams, beams to columns, and columns to the footings, whereas the specific “Tampita” structure, which was a prevailed building typology under traditional vernacular architecture transfers the load from the roof to the beams where the entire structure is balanced on the stones or stumps without any interference. Conferring to the medieval

timber architecture, “Pekkada” is a structural element in the joinery of the beam and the pillar interference where it handles the load transfer to the ground.

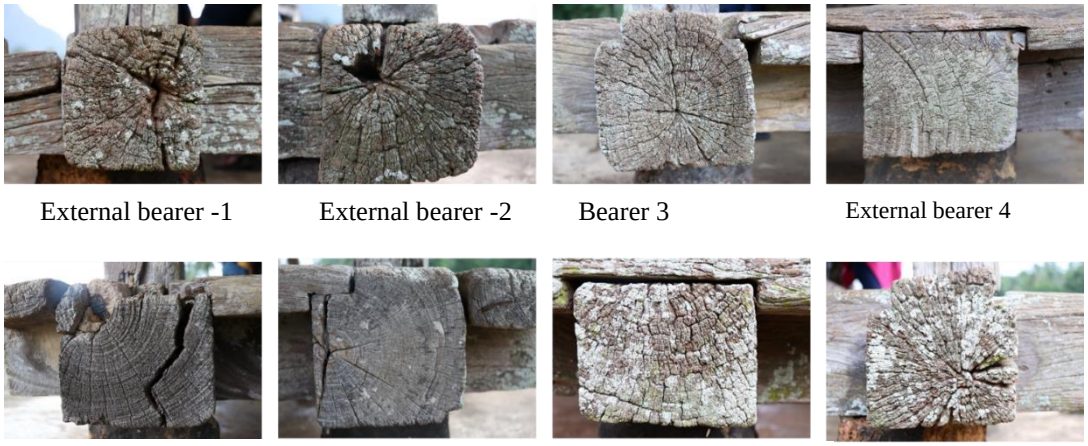


Figure 3-8; A-Panavitiya Ambalama (Bearer), B – Badulla Ambalama ,C,D -Giruwawa Ambalama King Rafter, Rafter, Bearers)

This significant intermediate structural bracket is still visually seen in *Ambalam* structures. The load is transferred from columns to bearers and finally from bearers to the footings which are stumps/stones, (Figure 3-8).

Timber bearers are one of the major structural components that directly attach to the stumps that undertake the responsibility of supporting the entire framework. *Pandivitya, Panavitiya* and *Karagahagedara Ambalama* are *Tampita* constructions. The most commonly utilized size of the bearer in *Padivitiya*, *Panavitiya*, and *Karagahagedara Ambalama* was approximately 152.4 mm by 152.4 mm, 203.2 mm by 203.2 mm, 279.4 mm by 279.4 mm (timber spices – unidentified). The visual characteristic analysis illustrates that most of them were sawn with the closest approach proximity to the center of the log or the pith. The distribution of the growth stress around the trunk is uneven in a tree. However, there is considerable growth stress distribution perpendicular to the center which means from pith to bark of a tree[178]. The experienced carpenters who created these significant structures that last for approximately 50 years or more, had predicted that the timber suits for the bearers would last long as it is sawn from close to the pith. This is evident with living samples in *Pandivitya Ambalama* that is still in good condition. Distribution of growth stress is as; pith with compression, changes to neutral in the mid area, and tension is distributed close to the bark. The timber sawn to a 200mm x 200mm was taken including the

minimum tension stress of a log along with the center where it includes a higher percentage of compression and neutral stresses. Moreover, this grain pattern grid had added a unique strength and had helped with load distribution on the bearer, (Figure 3-9), (Figure 3-10), (Figure 3-11).



External bearer -1 External bearer -2 Bearer 3 External bearer 4

External bearer -5 External bearer -6 External bearer -7 External bearer -8

Figure 3-9;Padivitiya Ambalama External bearers



Right front Detail-1 Right front Detail-2 Right front Detail-3 Right front Detail-4

Right front Detail-5 Right front Detail-6 Right front Detail-7 Right front Detail-8

Figure 3-10: Joint detail of the Badulla Ambalama



Figure 3-11;Rafters of Giruwa Ambalama

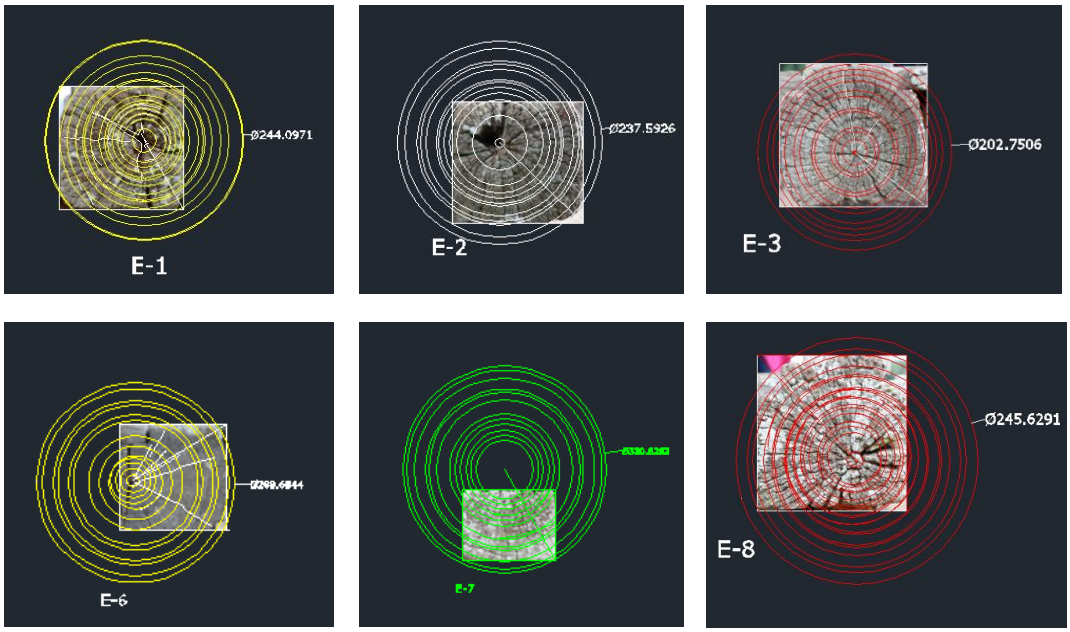


Figure 3-12; Mapping the curves using Auto cad Software

Further, it concludes that a majority has sawn as a distribution from center to the bark. It represents the approximate size of the tree and the availability of trees that suit structural usability in the particular context. The difference in texture was caused due to the distribution of pores, size, and cell arrangements or rays. Timber is an anisotropic material with vibrant properties in different directions with its makeup of oriented cell fibers. The majority of the cell fibers are oriented parallel to the longitudinal axis of the tree. Subsequently, it has proved that the strong parallels to the cell fiber direction are comparatively better when the strength is perpendicular to the cell fibers' direction. In *Ambalam* structures bearers were particularly chosen with the compression strength perpendicular to the cell fiber direction. That needs to be taken into account.

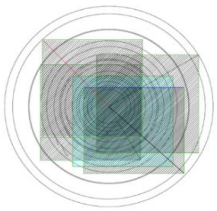
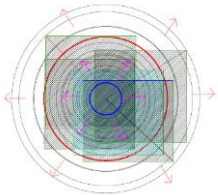
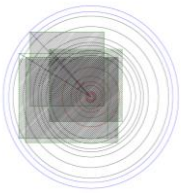
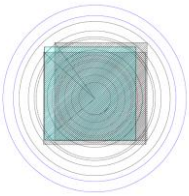
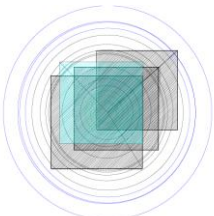
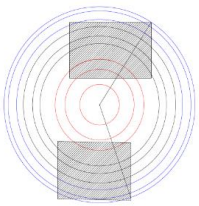
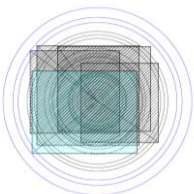
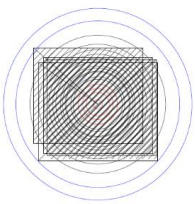
In Tampita structures, the entire structural weight lies on the tamas or the stones where the bearers and the joists are placed. The structure is balanced significantly without any connection with the bearer and the stone. The timber bearers are subjected to a compression load generated from holding the entire roof structure. The load perpendicular to the cell fibers reacts by causing considerable deformations crushing the cell fibers. The orientation of the cell fibers plays a major role to minimize the deformation caused due to the load, (Figure 3-12).

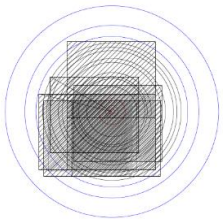
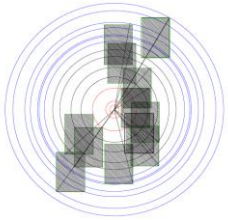
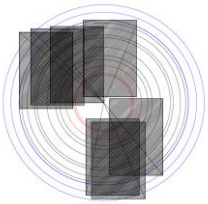
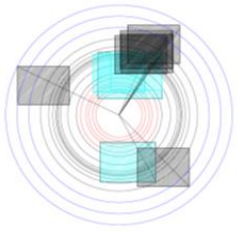
3.4.5 Results

Individually plotted grain distribution was taken to a single illustration for the analysis. Map 3 – Map 14 present the overlapped grain maps of the six case studies,

- *Map 3 -Sawing location placed on the timber log External bearers. Padivitiya Ambalama),*
- *Map 4 – Stress Zone on the cross-section perpendicular to the grains (Padivitiya Ambalama)*
- *Map 5 - Sectional placements of the internal bearers (Padivitiya Ambalama)*
- *Map 6 - Sectional placements of the internal bearers (Padivitya Ambalama),*
- *Map 7 - Sawn log distribution corresponding to the center (Panavitiya Ambalama)*
- *Map 8 - External bearers have sawn log distribution corresponding to the center (Karagahagedara Ambalama)*
- *Map 9 - External bearers have sawn log distribution corresponding to the center (Karagahagedara Ambalama)*
- *Map 10 - Sawn log distribution corresponding to the center (Giruwa Ambalama),*
- *Map 11 - Wallplate sawed log distribution corresponding to the center (Giruwa Ambalama),*
- *Map 12 – Rafters have sawn log distribution corresponding to the center (Giruwa Ambalama),*
- *Map 13 – Rafters have sawn log distribution corresponding to the center (Rukula Ambalama),*
- *Map 14 – Sawn log distribution corresponding to the center (Rukula Ambalama)*

Table 3-6; The sectional distribution along with the tree log is presented as in Map 3 to map 14.

			
Map 3	Map 4	Map 5	Map 6
			
Map 7	Map 8	Map 9	Map 10

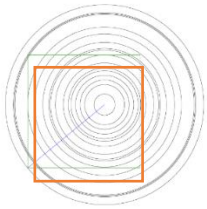
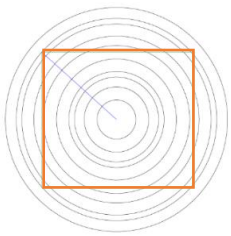
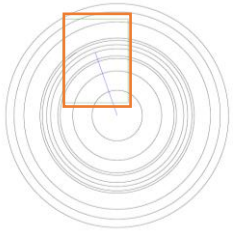
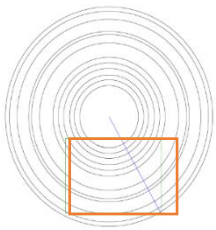
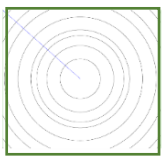
			
Map 11	Map 12	Map 13	Map 14

3.4.6 Discussion

This study identifies four different sawing patterns specific to a particular structural component such as the bearer, joist, rafter, and wall plates (Table 3-7), (

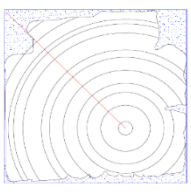
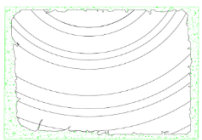
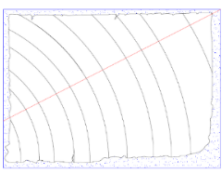
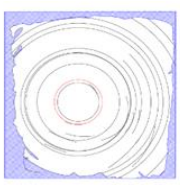
Table 3-8).

Table 3-7; The below table represents the mainly utilized structural components.

			
			
Type A	Type D	Type C	TypeB

Visual Observations of the degradation patterns of the sections was observed as follows,

Table 3-8; the deteriorating pattern of the identified structural components.

			
Type A	Type B	Type C	Type D

Among the above-mentioned stresses, the compressive strength that is perpendicular to the grain is an important parameter that determines the bearing strength as it depends on loading conditions. This study emphasizes that medieval constructors have used to grade the sawn material into strength classes by studying their applications with experience.

- Among the utilized sawn orientations, type A and type D have been utilized more in main structural components where a higher degree of load distribution has taken place.
- Type C has been used for rafters and reapers where there is lesser load distribution Type A and type D consist of a high percentage of compression and neutral stresses whereas type B and C consist of tension comparatively to the other two.

The resistance to physical and mechanical forces depends on the microstructure of wood. Strength is influenced by the dimension of the structural elements of wood. This means more elements and thicker cell walls contribute to a higher wood strength [166].

- Thorough observations concluded most of the deterioration caused among the identified types are from the outer surface to the inner surface emphasizing the service life variation from pith to the bark (Map 24, 25, 26, 27).

Comparatively deciduous wood that is from giant flowering trees with broad leaves that drop their leaves during a particular period, consists of wide rays in a radial direction and has a higher compression strength [179]. Statistically, the density variation between trees is significant. Axial and radial variation of wood density is significant characteristics when selecting the sawing pattern for the relevant structural component. This has a larger influence on the behavior of the wood that is directly proportionate to strength. Axial density variation within a tree is negligible [152]. The density variation on the radial direction within a cross-section is one of the main origins.

The density decreasing from pith to the cambium in Radial variation correspond. Density has to be defined in terms of moisture content, where the mass and the volume were dependent on the water content of a tree.

Medieval constructors had a clear understanding of this physical property where they have decided the sawing pattern for the higher loading structural components sawn close to the pith where that captures more volume with a higher magnitude knowing that magnitude of the density variation will be affecting the service life of the structural components. This is obvious with the existing timber components studied.

- This study has identified four types of sawing orientations.
- Among the four types, type D is the strongest component where it consists of the highest density of the log as it is the distribution with the core,

Type D density > Type A density >Type B density approximately equal Type C density

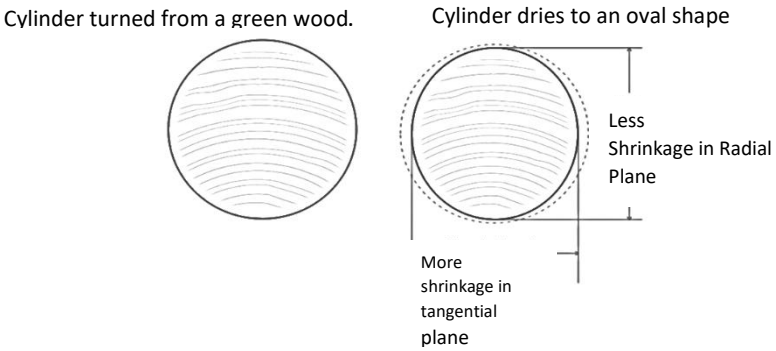
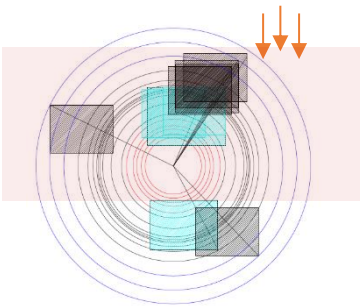


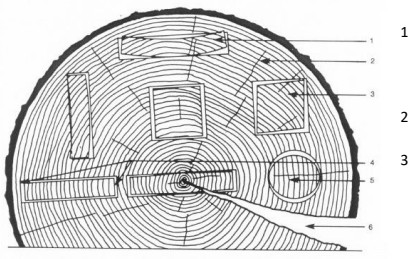
Figure 3-13;Map 28 – Shrinkage in the Tangential plain

Wood is a hygroscopic construction material [200]. This phenomenon affects the mechanical property of the particular timber within its entire service life (Map 28). The wood movement is highly influenced by grain orientation.

Subsequently, wood absorbs water when the relative humidity increases and loses water when the relative humidity decreases. With this phenomenon when wood absorbs moisture it swells and as it loses moisture it shrinks. This swelling and shrinking vary across the three main planes of the wood grain: tangential, radial, and longitudinal (Figure 3-14). The swelling or shrinking of longitudinal grain is so small, that it can be ignored and assumed that there is no wood movement along the length. These timber structural components have highlighted that the cross-grain behavior of wood can be vital to the safety and serviceability of the structure. Owing to an anisotropic structure, the mechanical properties of wood vary depending on the loading direction [180]. Generally, the deflection of any bearers or beams depends on its support configuration and its loading configuration. The placement of the structural components concerning grain orientation has influenced avoiding long-term deflection. Also, the medieval constructors have sawn the bearers with a larger depth than its width within the construction to overcome the deflection (Map 29). structural components applications were done in a way in which the force attends parallel to the grains or the annual rings, where the radial plane shrinkage is very less and the effect towards the load is very less.



Map 30 - sawn log distribution corresponding to the center (*Rukula Ambalama*)



Map 31 - Characteristic shrinkage and distortion of wood (Curatorial care of wooden objects, NPS Museum handbook Part 1, pp. N6)

1. Cupping, 2. End grain Checking, 3. Diamonding, 4. Cross grain Shrinkage, 5. Distortion of cylindrical Form, 6. Radial Cracking

Figure 3-14;The maps represent the sawn log distribution corresponding to the center, and the characteristics and distortion.

Further, medieval constructors were knowledgeable on the deformation caused by the shrinkage and swelling precisely through experience. Hence observations and analysis highlighted that the majority of the components were sawn as the curves orient concentric to the opposite of the force applied (Map 31). Grain orientation is important for three reasons (Map 30). The direction of the grain affects the amount of deflection that occurs when loads are applied. It compromises load-bearing ability.

Load-bearing timber is stronger when forces are applied parallel to the grain than when force is applied perpendicular to the grain, (Figure 3-15).

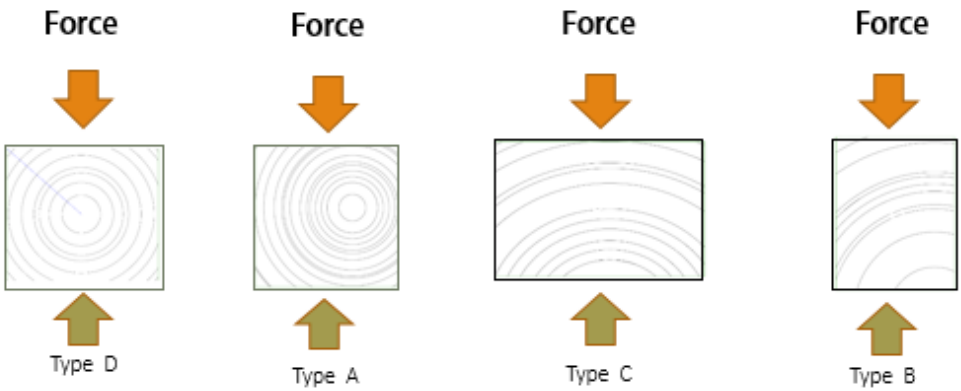


Figure 3-15; Direction of the force application to the structural elements

3.5 Strategies used to overcome the mechanical failure

Among the randomly selected six case studies the study analyses the results of 22 numbers joists, 18 numbers bearers, 36 numbers rafters, and 22 wall plates.

The Results convey that there is a high intention on utilizing the sawn type A then type D type C and type D was utilized respectively, (Table 3-9).

3.5.1 Major structural components

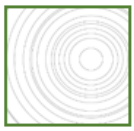
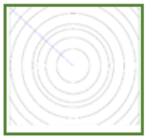
Major Structural Components			
Type A	**Type B**	**Type C**	**Type D**
			

Table 3-9:Four types of Structural components

Considered results of the study identified four main categories of Annual ring oriented timber sections utilized within *Ambalam* Structure in Sri Lanka.

3.5.2 Major structural components – Type C

A-Utilization Percentage of the component type

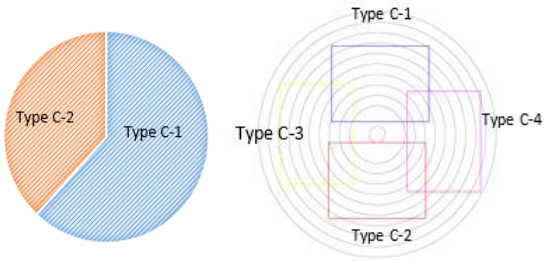


Figure 3-19; Utilization percentage of the structural elements .

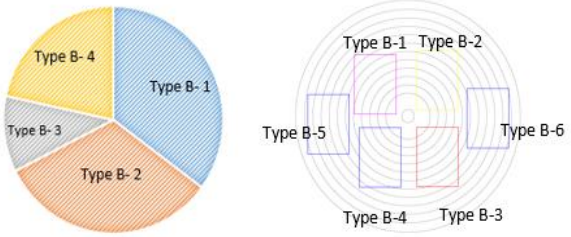


Figure 3-17; Rafter orientation ;type B

Major Structural Components – Type C			
Type C-1	**Type C-2**	**Type C-3**	**Type C- 4**
			

Figure 3-18; Type C Orientation

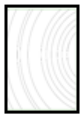
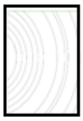
Rafters- Type B					
Type B-1	**Type B-2**	**Type B-3**	**Type B- 4**	**Type B- 5**	**Type B- 6**
					

Figure 3-16;B-Orientation placements with regards to Applications

This study has identified four types of sawing orientations. Among the four types, type D is the strongest component where it consists of the highest density of the log as it is a distribution with the core.

Further amplified investigation on Type C component which was utilized in bearers and joists was studied under the orientation placements with regards to applications such as Type (C1), Type (C2), Type (C3), Type (C4). Among the four types Type (C1), Type (C2) was the major utilized component with performing the least swelling and shrinkage where it helps the structure to be stable for a considerable period with less impact during the service life.

Further analyzing the type B component which was utilized in rafters was further studied under the Orientation placements with regards to Applications such as Type (B1), Type (B2), Type (B3), Type (B4), Type (B5), Type (B6). Among the four types Type (B1), Type (B2) was the major utilized component that performs the least swelling and shrinkage where it helps the structure to be stable for a considerable period. Then Type (B4) and the least utilized as Type (B3), Type (B5), Type (B6).

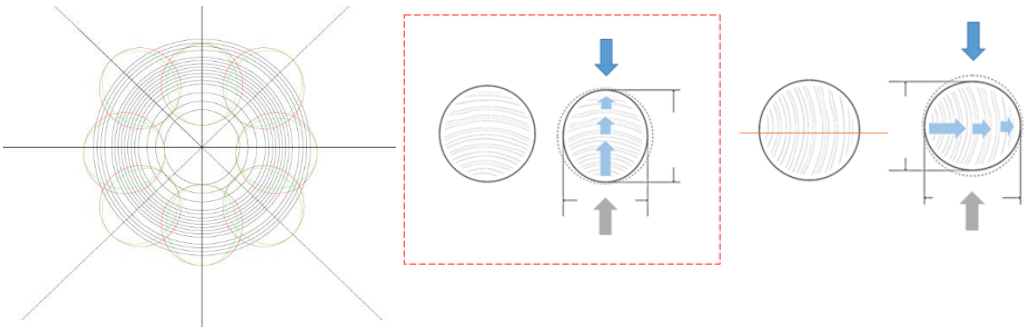


Figure 3-20; Force applications , Annual Ring orientation and wood movement in application when force applied.

The above study concludes among the utilized sawn orientations,

- The type A and type D have been utilized more in main structural components where a higher degree of load distribution has taken place.
- Type C has been used for rafters and reapers where it has been utilized in lesser load-distribution components.

The resistance to physical and mechanical forces depends on the microstructure of wood. Strength is influenced by the dimension of the structural elements of wood. This means more elements and thicker cell walls contribute to a higher wood strength.

Medieval constructors had a clear understanding of this physical property where they have decided the sawing pattern for the higher loading structural components sawn close to the pith where that captures more volume with a higher magnitude affecting the service life of the structural components.

The density decreasing from pith to the cambium in radial variation correspond [180]. Axial and radial variation of wood density is substantial characteristics when selecting the sawing pattern for the appropriate structural component. This has a grander influence on the behavior of the wood as that is directly proportionate to strength. Hence the axial density of wood is varying within a tree is negligible.

3.6 Summary

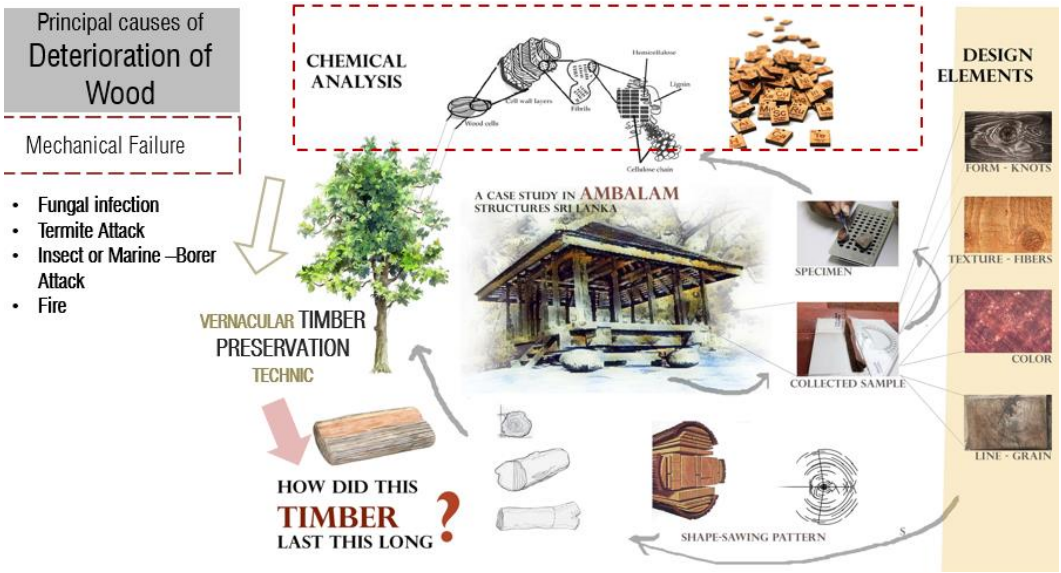


Figure 3-21; Graphical summary of the chapter 2

Wood has more strength in the longitudinal direction as correlated to the transverse direction due to its directed cell structure. Further, the chapter summarizes that medieval constructors were knowledgeable on the deformation caused by the shrinkage and swelling precisely through experience. Furthermore, the investigation emphasized that the majority of the components were sawn as the curves orient concentric to the opposite of the force applied. This concluded the wood movement is significantly influenced by grain orientation. Subsequently, wood absorbs water when the relative humidity increases and loses water when the relative humidity decreases. With this phenomenon when wood absorbs moisture it swells and as it loses moisture it shrinks. This swelling and shrinking vary across the three main planes of the wood grain:

tangential, radial, and longitudinal. The swelling or shrinking of longitudinal grain is so small, that it can be ignored and assumed that there is no wood movement along the length. These timber structural components through the case studies have highlighted that the cross-grain behavior of wood can be vital to the safety and serviceability of the structure overcoming the hygroscopic character in the wood. Construction material assessment and the structural assessment of *Ambalam* structures with a significant history is also the first step towards an intervention that itself ranges from mere preservation of an artistic artifact to the full rehabilitation of a structural function and materials unique to Sri Lanka. Therefore, this study creates access for researchers to approach construction materials in a novel way in the future (Figure 3-21).

CHAPTER 4 : DECODING THE TIMBER PRESERVATION TECHNIQUES

4.1 General

Traditional vernacular timber construction practice in Sri Lanka is dealt with environmental innovations. Constructions were made upon the needs of the inhabitants with the available resources in the particular context. Societal transitions are highly complex processes that unfold over time-spans of decades as they overcome challenges in an experienced process. This chapter aims to conduct a field survey and collect maximum timber samples; to decode and emphasize the worth of the existing information. Heritage timber structures are perfect living samples comprehending a preserved living proof of material utilization survived in a tropical climate. As a preliminary step for an investigation, a microscopic observation was conducted. To further analyze Energy Dispersive X-Ray Spectroscopy; a chemical microanalysis technique was used in conjunction with scanning electron microscopy (SEM). Survey results and analytical examinations conveyed knowledge that is not yet decoded who had experience in traditional vernacular timber construction practice. However, still, there should be useful ideas to be taken from their solutions. Therefore, results discuss the high necessity of decoding and scientifically proving the value of the traditional vernacular practice in Sri Lanka that leads to another environmental innovation in the future that navigates on societal transitions through evidenced knowledge.

4.2 Documenting the traditional vernacular timber preservations practiced in Sri Lanka

There are remarks of diverse types of timber structures in the tropics. This paper examines several case histories in Sri Lanka, focusing on the culturally varied and ecologically diverse traditional buildings with wood used for constructions. These cases eliminated traditional vernacular knowledge and practices in the quest. Information was gathered by face-to-face interviews with 270 individuals in 138 cases. The demographic profile of the informants was evaluated and cross-relationships with the recorded data were analyzed by SPSS statistical software. The Snow-balling Sampling technique was used. The main objective was to gather data and document the knowledge of wood preservation. A holistic analysis of structures was performed to understand their hidden science used to overcome the degradation mechanisms and state of conservation.

Engineering blended with aesthetics generates experiencing the “spirit” of the context, which most often is represented through traditional vernacular practice in Sri Lanka. Restoring locally important historical structures generates workplaces for both local people and international experts.

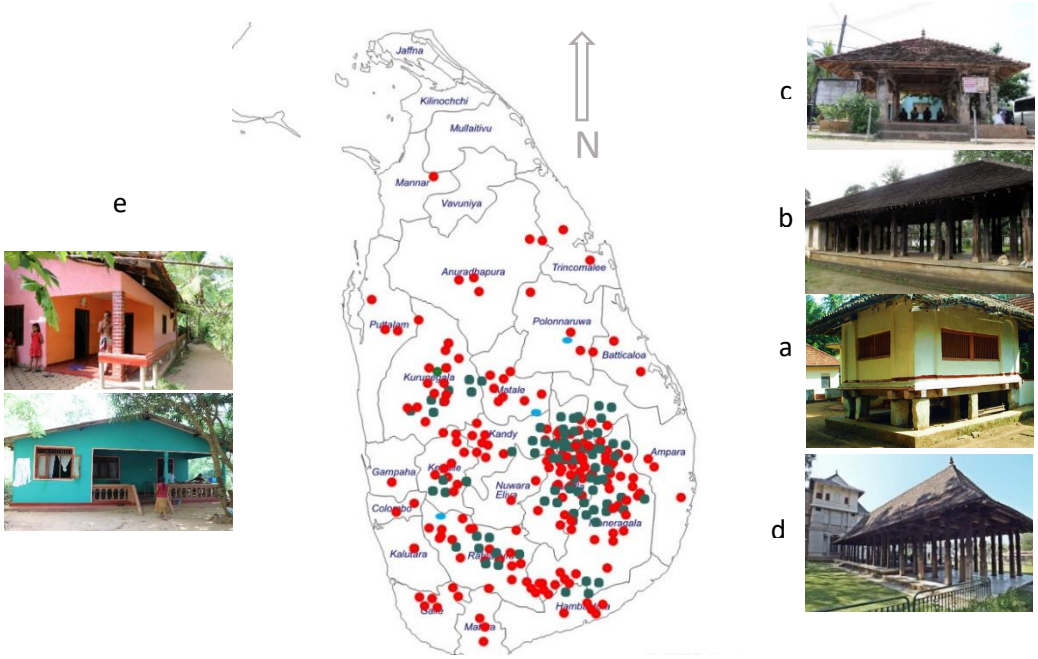
The first phase of the study assesses the condition of heritage timber structures that mandates a deep understanding of the timber structure. Concerning learning from traditional vernacular buildings, a holistic analysis of timber in construction, timber architectural typologies were carried out. A pilot study was conducted to initiate the scientific approach of the research.

4.2.1 Materials and methodology

4.2.2 The selected cases

The study of the main sources of ancient timber architecture in Sri Lanka is the remains of religious edifices of Buddhist and Hindu Shrines at the current contest [29]. There are three sources from which can date the Architectural remains of Sri Lanka. The Mahawansa; (a massive chronicle that details each King's accomplishments during his reign), Epigraphical evidence; (Often used to mark a donation of a building or a monastery, these letters are inscribed on rock), and the Archeological Evidence; (Evidence from excavation. And are physically seen). Among the three, the physical structures visualizing the construction topography were selected. The structures dedicated to gods or deities are known to be Devala. The structures are constructed as the Assembly places for administrative routines[29]. An *Ambalam*(s) is an open colonnaded, hip-roofed space, introduced as a building type that originates under traditional vernacular architecture in Sri Lanka [17]. These structures were allocated to charitable services commenced by the villages under the patronage of the village head or the chieftains. *Ambalam*(s) also conferred the travelers as a landmark to accomplish the journey and a public gathering place for the villages [28]. Identified cases of the private residents were also hip-roofed spaces as shelters originate under the traditional vernacular architecture in Sri Lanka. During the pre-Screening, it was identified that no Architects or Engineers were involved in the construction [18].

Information was collected by face-to-face interviews; 270 individuals in 138 selected cases. Information was solicited in close-ended and open-ended questions. Through this questionnaire, the demographic features of 270 individuals were determined as described in Table 1. The participants were asked about the building description and to describe the preservation technique practiced. They consciously avoided soliciting information on particular structures to prevent bias in the data collection. The interviews were generally conducted as follows: Fifteen numbers of the archeological regional offices were contacted to document the cases. A literature review was also used to identify the list of cases. Then visited the participants near the identified cases and asked them to gather neighbors who are particularly familiar with the use of preservation techniques. Some interviews were also carried out in village gathering centers, where men spend their leisure time. In each case, the men were allowed to discuss the use of any preservatives or the plant used thoroughly among each other.



e- *Tampita Vihara* (The shrines on pillars) – Indicated by blue dots
f- *Devala* (Shrines dedicated to deities) - Indicated by blue dots
g- *Ambalam* (Resting places for travelers) – Indicated by red dots
h- *Mandapa* (Assembly places for administrative routines) (Indicated by blue dots)
i- Private residences (constructed using traditional vernacular construction typographies)

Figure 4-1;Map 1- Locations of the identified cases; Red dots denotes the Ambalam Structures , and the green dots denotes the private residences

4.2.3 Field Survey

An island-wide field study was initiated as the first step in decoding and documenting the data on existing adequate knowledge practiced by Sri Lankans' on treating timber to overcome the challenges in tropical climatic contexts. The survey is based on three phases the demographic profile of the interviewer, the building description, and the documented facts on timber preservation.

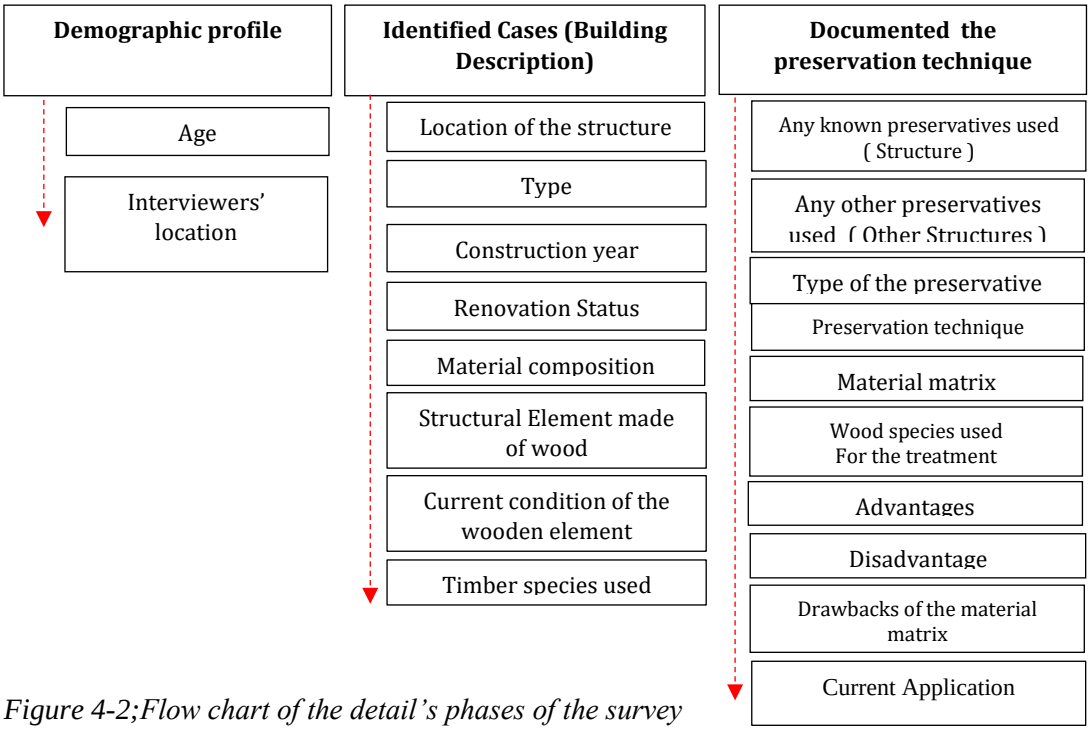


Figure 4-2;Flow chart of the detail's phases of the survey

4.2.4 Statistical Analysis

Results were evaluated statistically using SPSS 23 (Statistic Pockets for Social Science) statistical software: The chi-square test was used to compare different groups of data. Cross-relationships (i.e., How specific demographic features of the participants related to either the knowledge or the actual preservative technique and material matrix) were also analyzed.

4.2.5 Sampling Technique - Snow-balling Sampling technique (SB)

Initially, the locations were identified through sources from the Archaeological departments and a comprehensive literature review. The other locations were identified through the information gathered through the primary locations. The initial sample size was 116 and was expanded to 138 by using the SB technique (map1).

4.3 Results and Discussion

The results were analyzed as below,

4.3.1 Demographic profile

The demographic profile of the participants is summarized in Table 1. It was observed, the majority of the participants were males in gathering data representing 62 .0% of the total. The 42.0 % majority of the interviewers were in the range of 60 -79 years.

Table 4-1- The demographic profile of the survey (n = 270)

Characteristic	Test variables	Frequency	Percentage
Interviewer's age	21 - 39 years	4	1.3 %
	40 - 59 years	112	36.7 %
	60 - 79 years	128	42.0 %
	80 years above	26	8.5 %
The place where the interviewer lives	I am a villager	210	68.9 %
	I am from a nearby village	8	2.6 %
	I am new to this village	4	1.3 %
	I am an outsider	7	2.3 %
	I am a field officer from the Department of Archeology	41	13.4 %

4.3.2 Identified characteristics of the structures (Building Description)

The awareness of identified cases among the participants is summarized.

Table 4-2; Building Description

Characteristic		Frequency	Percentage
Provinces	Central Province	57	18.7%
	Eastern Province	2	.7%
	Northern Province	2	.7%
	Southern Province	28	9.2%
	Western Province	37	12.1%
	North Western Province	50	16.4%
	North Central Province	10	3.3%
	Uva Province	48	15.7%
	Sabaragamuwa Province	36	11.8%
Districts	Badulla	48	15.7 %
	Anuradhapura	10	3.3%
	Ampara District	2	.7%
	Colombo	7	2.3%
	Galle	10	3.3%
	Gampaha	30	9.8%
	Hambantota	3	1.0%
	Jaffna	4	1.3%
	Kaltura	2	.7%
	Kandy	38	12.5%

	Kegalle	33	10.8%
	Kurunegala	46	15.1%
	Matale	19	6.2%
	Matara	15	4.9%
	Rathnapura	3	1.0%
Building type	*Ambalam(s) (A wayside resting place)*	195	63.9%
	Dewala	3	1.0%
	Mandapa	2	.7%
	Tampita	7	2.3%
	Private Residents / house	63	20.7%
The material composition	Completely timber	66	21.6%
	Brick and mortar and timber	167	54.8%
	Stone and timber	32	10.5%
	Stone, brick, and timber	5	1.6%%
	Completely timber	66	21.6%
The age of the building			
	21-30 years	2	.7%
	31- 40 years	60	19.7%
	41-50 years	1	.3%
	> 50 years	207	67.9%
The timber species	Known	8	2.6%
	Not known	175	57.4%
	Not sure	25	8.2%
	to some extent	62	20.3%
	Known	8	2.6%
The current status of the building	Healthy	222	72.8%
	Visibly damaged	4	1.3%
	Started deteriorating	43	14.1 %

There were two main building categories identified in the survey, Archaeological monuments representing *Ambalam(s)* (A wayside resting place), *Dewala*, *Mandapa*,

Tampita, and the old private residences. Among them the majority represented 63.9 % of *Ambalam(s)* and then the Private Residents 20.7 %.

The results were as follows,

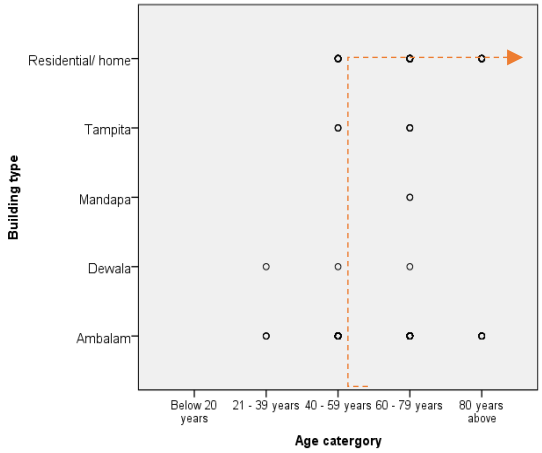


Figure 4-4; Age category of the interviewer vs building type

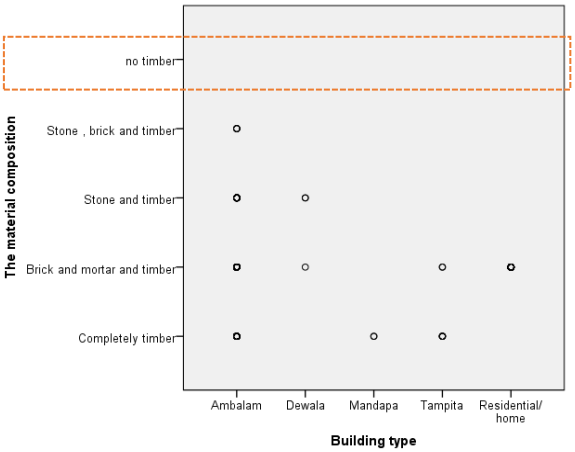


Figure 4-3;Building type Vs The material composition

Among the identified buildings 67.9% were more than 50 years old. All the identified 195 *Ambalam*(s) structures were over 50 years or more than 100 years in age, while the identified 63 private residencies were in the age range of 20-50 years old; (*figure 4-4 and figure 4-3).* The *Dewala*, *Mandapa*, *Tampita* are considered sacred places in Sri Lankan culture and, according to historical records, these structures were built for special religious reasons. Thus, the number of these structures is less as well as in the results relative to *Ambalam* and old private residences. Here the study focuses on the cases with minimum religious impacts with more ordinary people used for shelter. Therefore, *Ambalam* (63.9%) and the private residences (20.7%) are identified as the

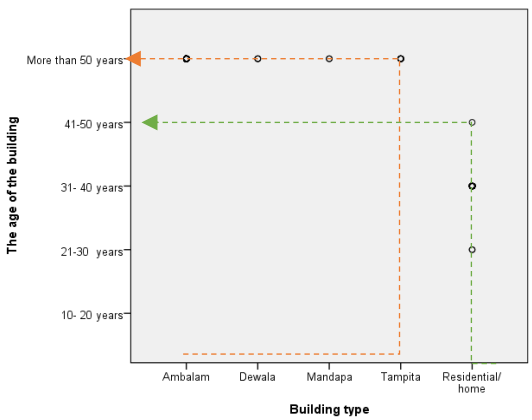


Figure 4-6;The building type Vs The age of the building

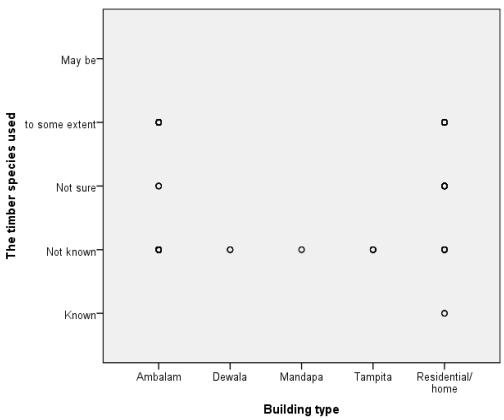


Figure 4-5;The building type Vs The timber species used.

most justifying cases. It was concluded in the majority of the *Ambalam* structures the timber species was not revealed. While the majority of the private residences' timber species were known to some extent ; (*figure 4-5 and figure 4-6)*.

4.3.3 Awareness of the preservation technologies of the identified structures

The questions were asked to identify how far the preservation technologies go back with time traditional vernacularly. The questions were asked to grasp the information about recent renovations done on the structures and to see through the possibility of revealing any preservation techniques used. Table 3 depicts the questions the frequency and the percentage of the answers.

Table 4-3; Awareness of the preservation technique

Characteristic	Test Variable	Frequency	Percentage
Any Surface applicants used for the structure recently/known period	Yes	0	0
	Known to some extent	0	0
	Neutral	26	9.63
	No	244	90.37
Awareness of the wood preservation technique used to treat the wood used in the structure	Yes	45	16.67
	Neutral	20	7.40
	Not sure/maybe yes	46	17.03
	No	159	58.89
Awareness of preservation techniques used in any other structure	Yes	78	28.89
	Known to some extent	76	28.14
	Neutral	0	0
	No	116	42.97

More than 90% of respondents' answers were presented as there were no surface applications used to any of those structures recently or in a period that they can recall. Chi-square tests were done (Table 4) to understand whether there is a significant difference between the age of the building and the awareness of the wood preservation techniques used.

Table 4-4;Chi-Square test (α =0.05)

Test Variable	Awareness of the wood preservation techniques used to treat the wood of the identified structure	Awareness of preservation techniques used in any other structure
Age of the building	p = 0.000	p=0.003

According to the results, there is a significant difference between the age of the building and the awareness of the wood preservation techniques used on the identified structures. Participants had a lack of awareness about the methods or technologies used to preserve

the wood of the cases represented over 50 years in age but, they were actively responding about the preservation techniques of the structures constructed below 50 years. The majority of the *Ambalam*(s) were constructed more than 100 years ago (Graph 3), When the age is more than 50 years the preservation technique and the

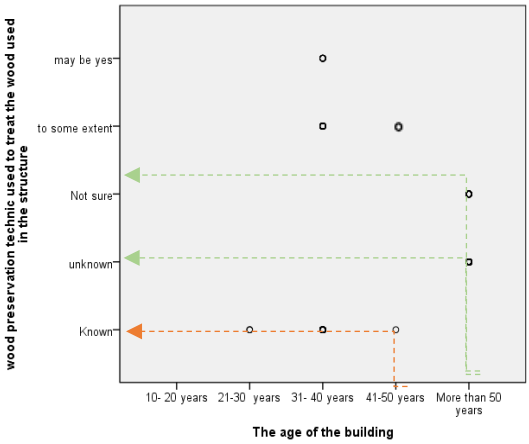


Figure 4-7; The age of the building and the wood preservation technique used to treat the wood used with in the structure

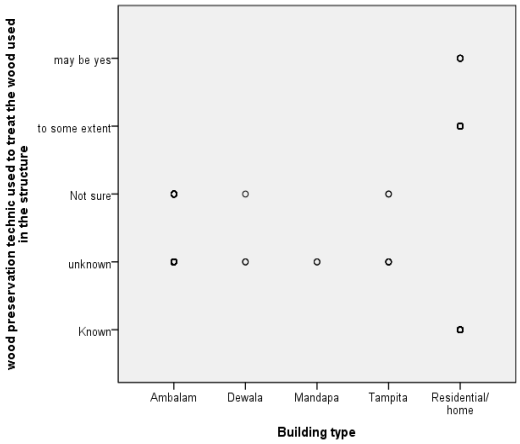


Figure 4-8; Building Type and the preservation technic used to treat the wood with in the structure

utilized wood species were not known. Therefore, the research was then narrowed down to old private residences for further analysis, which were constructed 20-50 years ago.

4.3.4 Identification of traditional vernacular timber preservation technologies

The questions were asked to identify the main characteristics of timber preservation technologies that were inherited for an averagely of 30-50 years. The open-ended questions were asked for known preservation techniques and the materials or chemicals

Table 4-5; Characteristics of the known vernacular timber preservation technologies

Characteristic	Test Variable	Frequency	Percentage
The type of known preservative	Organic	154	57.03
	Inorganic	90	33.33
	Don't know	26	9.64
Known Preservation techniques	wood kept under smoke pits	8	2.96
	wood kept under paddy field mud	134	49.62
	wood kept under the river banks	12	4.44
	Don't know	116	42.96
The Material Matrix	plant origins	132	48.88
	Animal origins	8	2.96
	mineral extracts	91	33.70
	artificial chemicals	2	0.74
	Don't know	37	13.70
The type of wood used	Know	45	16.67
	Don't know	52	19.25
	Not sure/ Maybe	132	48.8
	Known to some extent yes	41	15.18

used which weren’t documented clearly in any historical records. Table 4-5 briefs the information gathered from the participants. According to the results, there were organic and inorganic methods that they were using, and organic methods seemed to be popular among them (57.03%). There were three main preservation techniques identified from the open-ended questions which were, wood kept under smoke pits, wood kept under paddy field mud, and wood kept under the river banks. The most recorded answer was preserving wood by keeping it under paddy field mud (49.62%). The most obtained material matrix of preservation was plant origins (48.88%) and 80.65% of the respondents knew the type of wood chose to preserve to some extent, using the particular preservation techniques. Hence that the authors recommend further investigations should be conducted for timber identification to reveal the used timber species under the said preservation technique. The preservative's fatal toxicity against fungus, insects, and marine creatures should be significant even at low concentrations, with a low degree of lethal effects for mammals [18]. There should be no or minimal adverse effects on people during usage and handling. The preservative should be reasonably priced and easily available. And the ability to easily transport over great distances. The preservatives should not have an unfavorable effect on the wood's strength or other properties. The chemical preservatives used can be dissolved in either water or oil. In any event, must not be overly combustible or non-targeted organisms. Also, must be cost-effective concerning economically beneficial to use[45], [127], [181]. High responsiveness, allowing it to infiltrate the treated wood's whole cross-section for a longer-lasting effect. Among all, the toxicity of the solution against fungus, insects, was questioned. A 1-5 Likert scale question was asked to identify the experience or beliefs they had on the certain characteristics of wood preservatives accordingly. The 1 on the scale was for strongly disagree (SD), and 5 for strongly agree (SA). The 3 in the scale used for the neutral (N) opinions. The characteristics of the wood preservatives were cross-tabulated with the responses of agreeing and strongly disagreeing by the known preservative techniques. The characteristics of the wood preservatives were cross-tabulated with the responses of agreeing and strongly agreeing by the known preservative techniques. According to the responses wood kept under paddy field, mud showed more than 90% of the preservative characteristics.

Table 4-6; Identify the opinions of the effectiveness of the known wood preservative technique

	Insect repellent					Fungi repellent					Environmentally friendly					Coloring capability					Cost-Effective				
	SD	D	N	A	SA	SD	D	N	A	SA	SD	D	N	A	SA	SD	D	N	A	SA	SD	D	N	A	SA
Smoke pits	2	0	3	1	2	1	1	0	2	4	0	0	1	3	4	0	2	1	5	1	0	0	2	6	0
Paddy field mud	1	2	3	30	98	3	2	5	90	34	1	1	2	10	120	0	1	3	7	123	1	1	2	97	33
Riverbanks	0	1	1	4	6	0	1	2	6	3	0	2	1	7	2	1	2	6	2	1	1	2	6	1	2

According to the overall analysis of the identification of traditional vernacular timber preservation technologies, woods keeping under paddy field mud was the most known method of the interviewers and it seemed to successfully come through many generations. The further analysis was directly focused on the said preservation technology to identify plant species for further development. A ranking question was presented to identify the reasons for avoiding the wood preservation by keeping under paddy field mud (Table 4-2).

Table 4-7; Summary of the rank question- Reasons for avoiding using wood preservatives

Reason	Rank
The process is hard	1
Time-consuming	4
Heavy odor	3
Needs a paddy field	2

According to the ranking results, the main reason was the difficulty of the preservation process for the villagers to undertake it on some scale, and the second most identified reason was the requirement of having paddy fields. Most of the villagers did not own their paddy fields and even if they had they were reluctant to undertake these processes since they have easy modern methods. Most of the respondents' stated that the process causes heavy odor (ranks 3) and it makes them and their neighborhood uncomfortable.

3.5 Transformation of the timber preservation technologies through generations

The open-ended questions were presented to analyze the vernacular history of wood preservation technology. The questions were focused on, where did they first heard of the technology, where they learned further about the technology, have they experienced the methods, and have they or any person of his relations had done the modifications or

retentions to the technology. Figure 4-9 below represents the observed knowledge transferring map of preservation technologies in the generations. The gathered

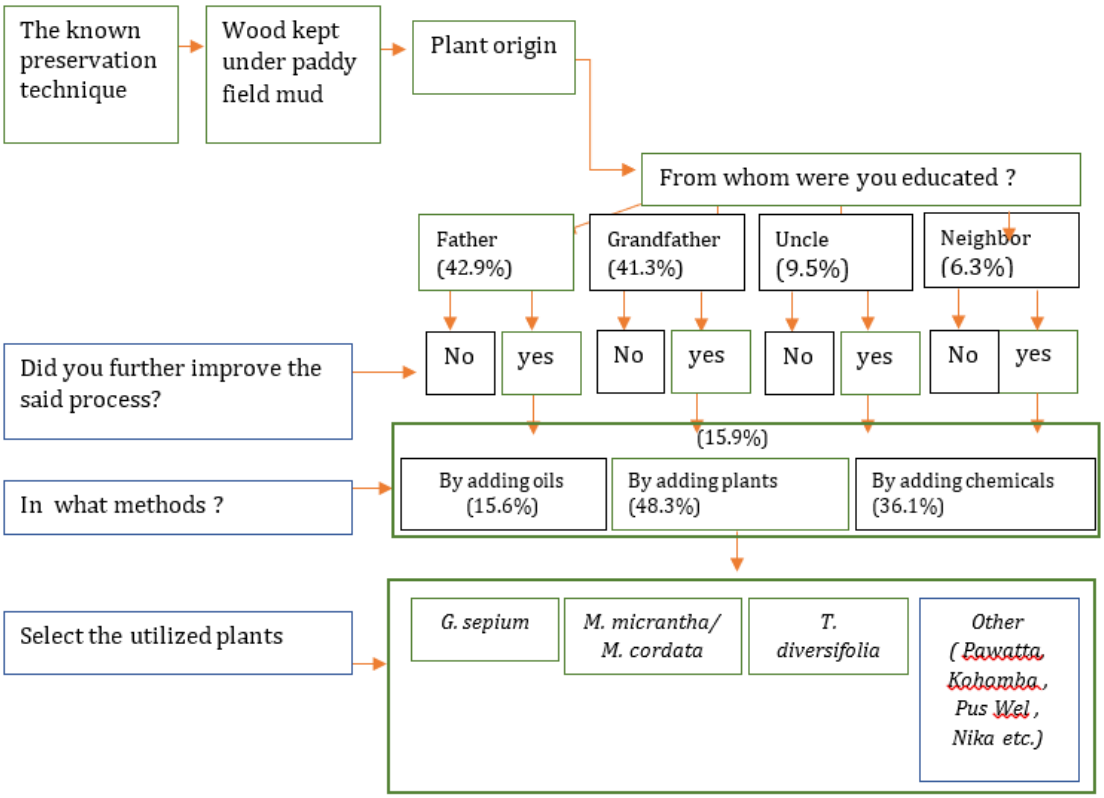


Figure 4-9;– Graphical representation of knowledge transferring by generations of the Wood kept under paddy field mud

information was further analyzed as follows. When the answer was " No" for the question " did you further improve the said process". The questions were asked to determine what technic was more effective under the interview's perception. The Wood is kept under paddy field mud or the wood is kept under the paddy field mud developed using the plant parts. The highly recoded answer was the wood kept under the mud developed using plants presenting 64.67 %. The questions were then asked to identify the awareness on any improvement done to develop the known timber process. The results disclosed 15.9 % of participants revealed on technics used to develop the wood kept under the paddy field mud. Among them, 15.6 % of participants revealed an improvement done by adding oils, and 48.3 % of participants revealed an improvement done by adding plants parts. The majority of the decoded improvement by adding plant species were further analyzed as follows,

4.3.5 Awareness of the Plants species used to develop the paddy field mud

The open-ended questions were asked for known plant species used to develop the mud before the wood was kept under the paddy field mud. According to the results, few plant species seemed to be popular among them.

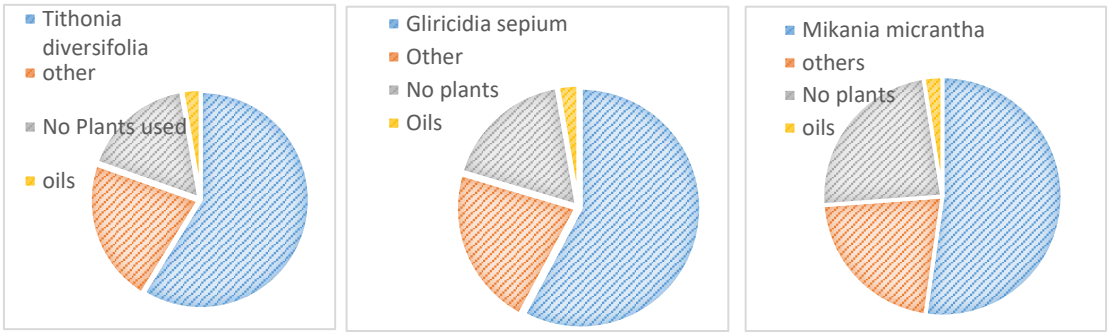


Figure 4-10;Plant species used to develop the paddy field mud before utilization

The survey revealed around 10 to 12 plant species where they have been used with the documented preserving practice. Among all, the results revealed majority used three types of plants species in common, (figure 4-10).

Further literature revealed the nutritional value, fast-growth/ growth performance, high regeneration capacity with high potential for forage productions might be the major reason for documenting the *G. sepium* [182], [183], *M.micrantha* [184], [185], *T. diversifolia* [186], [187] in developing the treatments.

The questions were then asked to finally determine the current application of the documented traditional vernacular preservation techniques. The results disclosed 87.2 % represented for not using any of the traditional vernacular preservations.

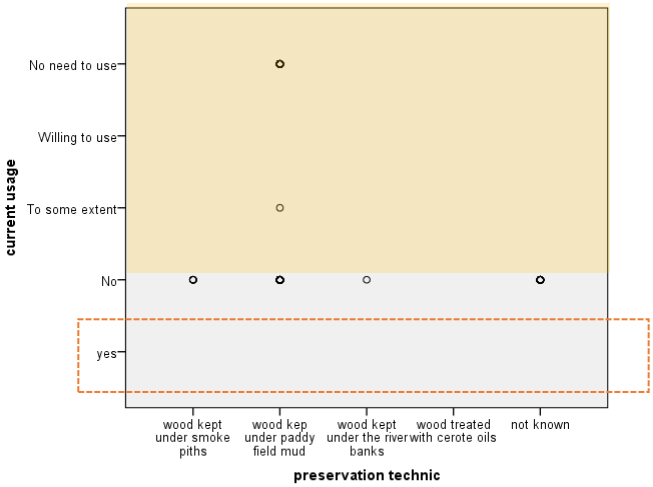


Figure 4-11;Wood preservation vs current usage of the decoded traditional vernacular technology

4.3.6 Identify the potential to formulate a preservative solution

The field survey revealed a technic used to practice by developing paddy field mud using the plant species found close by and then placing the timber under mud until it was used. This phenomenon was not yet investigated in a scientific approach with confines a research gap as follows. Prolonged exposure to mud or the mud water mix simply makes the wood fibers undesirable to fungi and especially to insects as a food source. Different extracts added to the mixture get dissolved in water/ fermented and create biopolymers that penetrate the timber and coat the cells. Nano or micro-level insertion of different chemicals in the mud-water mixture that changes the chemical and physical structure of the wood cells. The study investigates this phenomenon and tries to grab the hidden science to further develop and reinvent a preservation technic based on this decoded knowledge from history.

4.4 Discussion

This study highlights insights towards construction professionals on facts proved on environmental innovations concerning a case base study in Sri Lanka. Moreover, old buildings contain a set of authentic information that the future should disclose. They have materialized centuries ago that uphold the technologies from those who lived in different social structures in a particular context in Sri Lanka. The survey showed the structures constructed below 20 to 50 years of age revealed about few preservation techniques. According to the overall analysis of the identification of traditional vernacular timber preservation technologies, woods keeping under paddy field mud was the most known method of the interviewers and it seemed to successfully come through many generations. The technologies have transferred through oral knowledge and some were developed accordingly.

This study detects multiple plant species, including *Tithonia diversifolia, Mikania micrantha,* and *Gliricidia sepium* for further development of the mud before treating the wood. The survey's main finding decodes the wood kept under paddy fields to extend the life of the wood. The authors recommend this approach provides versatility in various fields in which a wood preservative is required utilized with less environmental impact, there for further investigating on developing wood preservative proposed to be carried out.

The major revealed preservation technic was the timber treated by wood exposing or kept under mud. Alone with the mud treatment, the survey results conclude on a few plant species that were used to develop the mud in paddy fields before the treatment was processed.

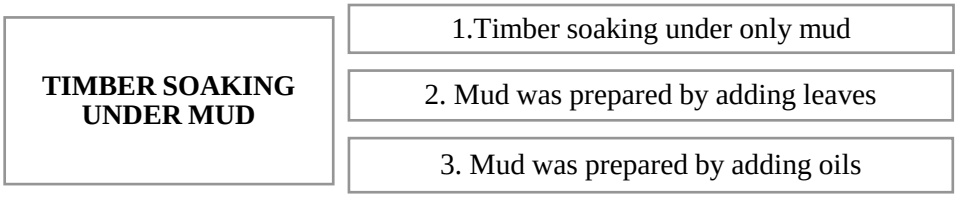


Figure 4-13;Further tabulated technics of timber soaking under mud.

4.5 Identifying and materializing the identified traditional vernacular timber preservation techniques

The decoded preservation technique was materialized as follows,

4.5.1 Mud was prepared by adding leaves

The felid interviews revealed that leaves found close by the paddy fields were mixed to develop the properties of mud (Table 4-3), (Figure 4-14).

Table 4-8; Common names, scientific names, and the Sinhalese names of the highly decoded plant species.

	Name in Sinhalese	Common Names	Scientific Name
a)	Dahaspethiya leaves	African / American / Aztec / big / Mexican marigold	*Tagetes erecta*
b)	Gampalu wel	Kiri wel	*Mikania micrantha*
c)	Kohomba	margosa, neem tree	*Azadirachta indica*
d)	Maduruthala	Maduruthala	*Ocimum sanctum*
e)	Gliricidia	Nanchi, wata mara , ladappa	*Gliricidia sepium*
f)	Nika		*Vitex negundo*
g)	Thitha kola / wal sooriyakantha	Mexican sunflower, Marigold Tree, Japanese sunflower	*Tithonia diversifolia*

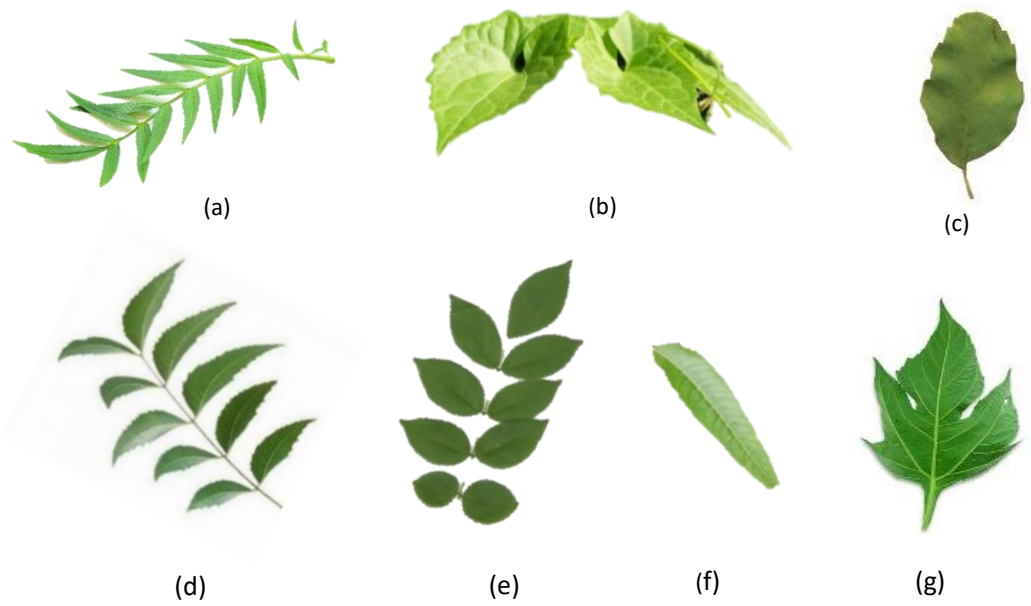


Figure 4-14; Highly decoded plant species with in the survey.

4.6 Identifying the wood with the potential to further investigate the preservation techniques

Experiment 4-1; Preliminary investigation on ancient timber structures through microscopic analysis

Visual evaluation of these structures, based on the macroscopic features of the heritage structure is not conclusive in determining the timber species utilized for construction and analyzing whether the species would have incorporated to resist timber deterioration during application. In such a case identification of wood species becomes, therefore, a compulsory step before any intervention [163]. Therefore, a microscopic approach is more reliable as the preliminary stage of the approach to an investigation of the entire timber artifact [188]. A porous, three-dimensional, hygroscopic, interconnecting matrix of cellulose, hemicelluloses, and lignin material is known as wood [189]. The vessels and their walls are composed of cellulose glued together with lignin. The strength properties, appearance, resistance to penetration by water and chemicals, resistance to decay, and many other properties are affected by the characteristics of these fibrous cells and their arrangement [190]. The specialized water-conducting cells of hardwoods are known as vessels. The rays in hardwoods are structurally more diverse compared to the fibres found in softwoods [191].

In general wood, identification is very momentous for scientists in the fields of forestry, and wood technology and wood engineering as the first step to an investigation. It reveals the cell arrangements and features. Through vast experience features like color, odor, grain patterns, density and hardness can be used to identify the wood. However, the accuracy depends on the experience of the person and the quality of the expected sample of the particular wood. It's often a challenging mission due to both the diversity of wooden species used throughout traditional vernacular timber structures and the aging and degradation phenomena affecting the wooden material appearance and sometimes even its structural integrity during its entire service life. The identification will be complicated when the wood sample is typical, decayed, insignificant, or small in size, often the identification can be incorrect. As per the literature, examining woods, especially when observing hardwoods, the magnification of 10× to 20× hand lens, greatly improves the accuracy of the identification. Even though the accuracy depends on the experience [192], [193].

Also, the literature states accurate identification requires that the wood be sectioned and examined with a light microscope for a scientific investigation where a 10X objective lens would determine many features of the particular section [194], [195]. Scientists state, simultaneously it is important for the micrographs as well as in identification a reference library of pre-identified authentic samples to which the unknown samples could be compared [196], [197].

Further scientists present if researchers lack a collection of a reference library, they can additionally refer to indexed reputed books or research journal papers including anatomical descriptions [188]. In addition to these resources, commercially available computer-assisted software or commercial libraries like delta-intkey can be used. At the same time without any physical sectioning, there are few non-destructive advanced techniques, such as X-ray phase-contrast micro-tomography, 3D-analysis throughout the volume of the wood. Along with all the most used, cost-effective, and readily available technique is the typical wood anatomy imaging techniques that include transmission light microscopy through thin microtome wood sections.

This paper presents a case study of microscopic species identification for three small samples extracted from three selected houses from Uva province constructed between 1960 and 1970 using traditional vernacular timber preservation techniques and preservatives.

4.6.1 Materials and methodology

4.6.1.1 Sample collection procedure

The three houses were constructed using a hip roof where the wood has been preserved by one of the traditional vernacular timber preservations techniques practiced in Sri Lanka; The decoded information states, village people have practiced placing the sawn timber under paddy field mud for several weeks as a long-term experienced wood preservation technique. The structural elements in a roof such as rafters, ridge beam, Hip beam, and reapers were collected in three locations in the Badulla District, Uva Province in Sri Lanka. Three samples per section (36 total samples) were transported to the pro-green laboratory of the Department of Civil Engineering, University of Moratuwa Sri Lanka for macro sample analysis and then to the laboratory in the Department of Forestry and Environmental Sciences, University of Sri Jayewardenepura Sri Lanka for micro sample analysis.



Figure 4-15;cases selected from Uva Province ,A-Soranathota , a- roof details , B-Mahiyangana b- roof details , C- Silverland Badulla , roof details; sample preparation

4.6.1.2 Macroscopic Observation

This method was based on the identification of anatomical features in end grain (cross-section) which can be observed with the unassisted eye (naked eye) or with the aid of the magnifying lens.

4.6.1.3 Wood Sectioning

20mm x 20 mm x 30 mm sized samples were extracted. Timber samples were soaked in water and left for one week. Radial, Tangential, Transverse sections of 10-15 µm thickness were cut using a sledge microtome (model Leicia SM 2000R). Following staining procedure was used to stain the timber section for permanent slide preparation; Timber sections were stained in safranin using Petri dishes. Sections were then mounted permanently using Canada balsam.

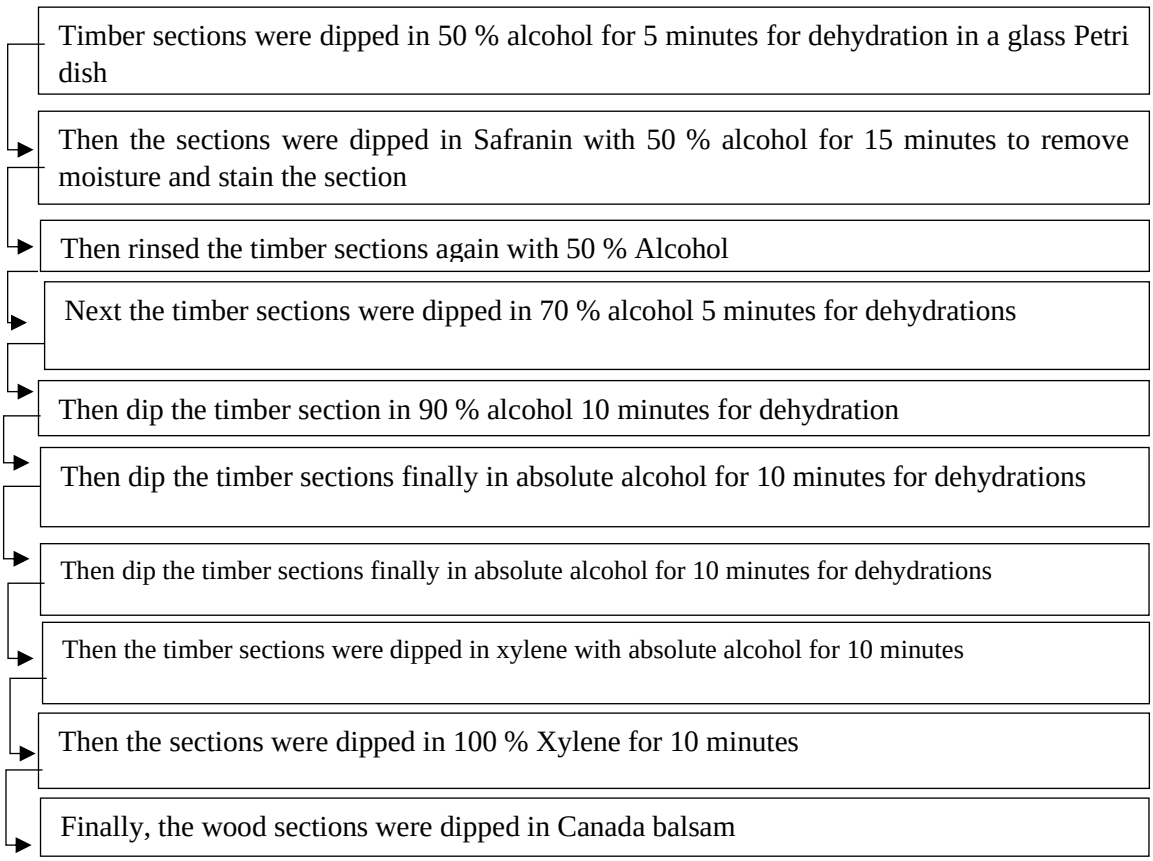


Figure 4-16; *Flow chart represent the Dehydration of fresh material for permanent mounting using the stains safranin*

4.6.1.4 Microscopic Observation

The permanent slides were prepared from all the samples. Then the slides were observed using an Axio-Cam Icc 5 – Polarize light microscope. The observed microscopic features were compared with the authentic sample library images. Timber samples were identified using anatomical features through comparing with authentic timber samples available in the Department of Forestry and Environmental Science, University of Sri Jayewardenepura, and relevant wood identification data sources; Local and International (Figure 4-15).

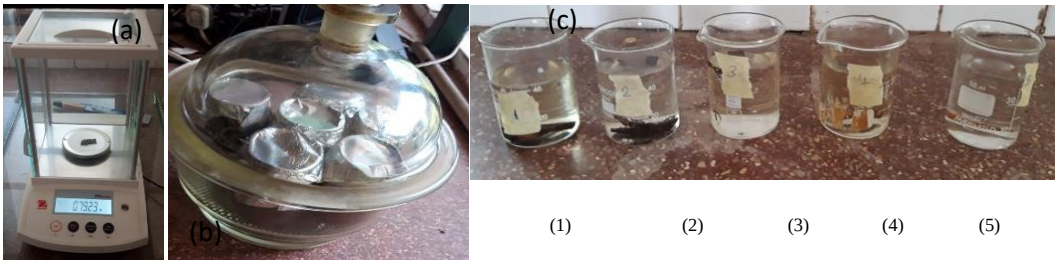


Figure 4-17 -Fig. 4.A-The weight obtained through the digital scale , B- apply pressure C-Timber samples soaked in water

4.6.1.5 Determining the Specific gravity

The relative density of the samples was also measured using the Maximum Moisture Content Method; (Figure 4-17). The specific gravity of wood is derived by the weight of the oven-dry wood divided by the weight of a volume of water equal to the volume of wood under the moisture conditions at test [33]. The specific gravity of the sample was calculated by substitution in the formula:

$$specific\ Gravity = \frac{1}{\{\frac{Mm-Mo}{Mo} + \frac{1}{1.53}\}}$$

Green weight of the samples (M_m), Oven dry weight of the samples 103±2 ^{o} C until a constant weight is obtained (M_0). 1.53 is the specific gravity of the wood cell wall substance.

4.6.2 Results of the Experiment 2

The results were interpreted as follows,

A. Macroscopic images and interpretation

Macroscopic observations showed that the growth ring boundaries are distinct or absent; (Figure 4-20).

There was no specific color difference between the sapwood color and the heartwood color. The outer surface of the elements was darker black in shade. In all the 27 samples in common rafters, ridge beam, hip beam, and reapers, the relative density values presented in the range of 0.52 – 0. 70.

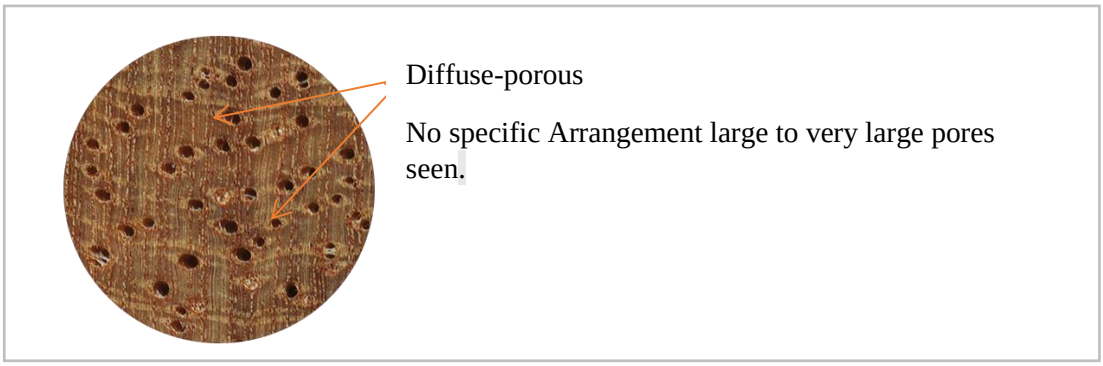


Figure 4-18 -Mango (end grain 10x)

4.6.2.1 Microscopic Interpretations

The microscopic features are presented as follows, (1). The vessel arrangement of wood is diffuse-porous. There is no specific pattern in the vessel arrangement.

The Axial Parenchyma band is more than three cells wide (Marginal or Seemingly marginal bands. The helical thickenings (spiral thickening in longitudinal tracheid's) were absent. Tyloses were commonly available. The thickness of the fiber walls gradually increases, while the very thick fiber walls are visible in the latewood region.

Axial Parenchyma in marginal bands is visible as strands (2-8 cells). The uniformed-sized rays with an absence of Aggregate rays. Perforation plates are simple. Vessel-ray pits with reduced borders or simple. Helical thickenings were absent. Tyloses were present also thin-walled. Dark reddish-brown deposits are present. Fibers of medium wall thickness were visibly seen. Fiber pits are restricted to radial walls, simple to minutely bordered. The Fibres was non-septate. The tangential section presented

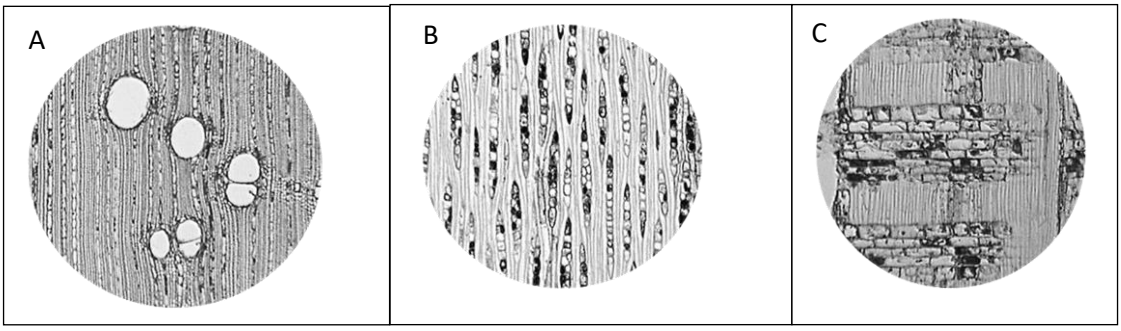


Figure 4-19- A-Transverse section , B- Tangiantial section , C- Radial Section

multiseriate rays and also uniseriate rays. Heterocellular rays are present. Intercellular canals are absent.

4.6.2.2 Timber identification

As per the above features of the macroscopic and microscopic observations, the samples were identified as *Mangifera indica* timber belonging to the family of *Anacardiaceae*. The geographic distribution of mango trees within the Sri Lankan context lies all around the country. They are mostly found in the home gardens. Macroscopic observations show that the growth ring boundaries are distinct or absent. There was no specific colour difference between the sapwood colour and the heartwood colour. The relative density values presented as 0.52 – 0.74. The preservation technique might influence the outer surface colour of the wood was in a very darker shade diverging from the light to golden brown natural wood colour.

4.6.3 Discussion

Three cases were selected from Uva province and timber samples were obtained from the roof elements. Wood anatomy imaging techniques had included microscopy through thin microtome sections. The study has identified the wood used for the roof as Mango wood that is scientifically known as *Mangifera indica* belongs to the family of *Anacardiaceae.* Reference to the timber classification published by state timber cooperation in Sri Lanka, *Mangifera indica* wood falls under the Class III category. However, as per the visual observation of the three houses and the roof elements, it still exists in an acceptable better condition including a service life of 30 to 40 years. So, the authors recommend considering this as a preliminary investigation on the preservation techniques and further investigating the preservation techniques reference to its chemical analysis. Further revealing and understanding the mechanical performance of treated mango wood after a properly defined treatment technique could be considered as a sustainable construction wood.

4.6.3.1 A wood type was identified from traditional vernacular construction practice in Sri Lanka.

Based on the results obtained from the field survey gained by investigations from the cases obtained from the majority of the provinces in Sri Lanka Mango wood *(Mangifera Indica)* was identified as an abundantly used wood source in traditional vernacular construction practice.

4.7 Investigating the potentials of mango timber as a sustainable construction material

The study also evaluates the physical and mechanical characteristics of mango wood to determine its potential. The study also attempts to respond to the suggestions raised by the state timber cooperation in Sri Lanka. Compared to other commercially available woods, this study looked into the appropriate use and identify the potential to develop mango wood in sustainable construction. Therefore, minimizing the weaknesses and maximizing the strengths leads to environmental benefits.

The uttermost assumption within the entire study is that maximizing the use of mango (*Mangifera indica*) wood may improve the environmental profile. In that case, Mango wood gives the impression to have significant potential. The study concludes to consider a specific approach on treating mango wood and utilizing it for wood in construction under a proper understanding and preservation. This could lead mango timber towards a sustainable construction material.

The natural forest cover in Sri Lanka has been depleted raising demand for timber supplies from these sources. The demand for timber has increased not only due to its properties. However also due to its aesthetic appearance. Trees acquire carbon from the atmosphere through photosynthesis during the growth process, and some of this absorbed carbon is retained in wood. According to the literature, wood provides a physical carbon storage mechanism that has climate benefits depending on temporal factors [198].

As a result, there are two significant advantages to using wood in construction:

- First, the gradual substitution of lumber for the most energy-intensive and polluting building materials minimizes climate-changing emissions connected with material production and management.
- The forest management required as a result of the use of wood in industrial sectors such as construction entails the forest's ongoing renewal, increasing its capacity to extract CO2 [199].

A. ***Suggestions raised by the State Timber Cooperation***.

STC is a state-owned enterprise in Sri Lanka responsible for the timber industry, established in the year of 1968. The records of the state timber cooperation's in 2011

have raised a few suggestions towards the development of the timber industry in Sri Lanka.

- To familiarize and endorse tree planting and address the current timber shortage in the country.
- Conduct awareness programs and user guidelines for timber consumers on selecting the right species and standing timber.
- Product diversification to use lesser-known timber species along with popular species as raw materials for sustaining the local timber industry;
- Improved service life of timber and timber products through effective seasoning and chemical treatment.
- Improve processing efficiency and production of competitive finished products through factory modernization and training.
- Familiarization of timber products of Eco timber certification from a sustainably managed forest at the expense of the consumer.

Based on the above suggestions this study focuses on addressing the product diversification and recommend a timber with potential as a raw material for sustaining the local timber industry; And also conduct awareness on the key characteristics; Surface texture, Specific gravity shrinkage, durability, workability, availability and the price and commercial properties are presented in the study.

4.7.1 Materials and Methodology

First, a survey and an assessment were conducted to identify timber with the potential to further investigate traditional vernacular construction practice. The survey was directed in Sri Lanka. Four timber species were selected for this study based on the plantations, largest timber volume movements, and having a key commercial value in the national sector. Assessment of traditional vernacular constructions is discussed to identify a wood with the potential for further utilization in the current industry. The context of sustainable construction was discussed along with the survey findings.

Quantification of the physical and mechanical properties of identified wood was compared with the wood species that are abundantly utilized in the current market in Sri Lanka.

Finally, a conversation was carried out from a comprehensive perspective to emphasize using the identified wood as a construction material as for its availability, performance, cost indicators to identify that as a potential source for the wood industry in Sri Lanka.

A. Mechanical properties were evaluated using the following standard and the equations

The following table denotes the most utilized equation (Table 4-9),

Table 4-9; Below table comprises the utilized equations

Standard	Equation	Mechanical property
BS EN 384:2016 and BS 373:1957	$= (Weight\ before\ oven\ dry) /Volume$	Density
Oven-drying method	$= \frac{(Wi - Wd)}{wd} x\ 100$	Moisture content
BS EN 384:2016 and BS 373:1957	$= \frac{F\ x\ 9.81}{bxd}$	Compression strength parallel to the grain
BS EN 384:2016 and BS 373:1957	$= (3\ x\ F\ x\ L\ )/2xWxHxH$	Modulus of rupture
BS EN 384:2016 and BS 373:1957	$= (m\ x\ lxlxl\ x\ 9.81)/48I$	Modulus of Elasticity (MOE)

Where in Wi; the weight of the original representative sample before drying, W_d; the weight of the oven-dried sample. The Load at failure F (Kg f), Average width (b), average height (d). (N/mm2). F is the force at the fracture point (N). L is the length of the support span (m). W is the width (m) and H is the thickness (m) of the wood specimen. Where MOR is bending strength (N/mm2). Where gradient (m), l (length), I (moment of inertia)

4.7.2 Results

The results were presented as follows (Table 4-10), (**Error! Reference source not found.**),

4.7.2.1 Survey results

Table 4-10; Scientific name and the classification of the wood Species reference to STC

General Name	Scientific name	Classification as per timber cooperation
Teak	*Tectona grandis*	Supper luxury class
Mahogany	*Swietenia macrophylla*	Luxury class
Rubber	*Hevea Brasiliensis*	Class III
Alastonia	*Alastonia Macrophyla*	*Class II*

Further description about Mango wood is presented as below,

Table 4-11; More information about the mango wood

Genus	Mangifera
Family	Anacardiaceae.
Adapted	The tropics and subtropics.
Distribution	Tropical regions
Size when matured **Soil**	heights around 15–30 m, cultivated 3–10 m optimal pH 5.5–7.5.
Main agroforestry uses	Home gardens
Classification (state timber cooperation Sri Lanka)	Class III

4.7.2.2 Availability of woody tree species

With the increasing demand in the population of Sri Lanka, the demand was raised towards sawn wood. There is upward acceptance for forest and timber resources which should be succeeded encounter the requirement of the social, ecological, cultural, economic, and spiritual needs of mangos that are recognized and eaten throughout Sri Lanka. In this case, the Mango tree falls under the multipurpose tree species that produce timber as a volume that considerably contributes towards the Sri Lankan

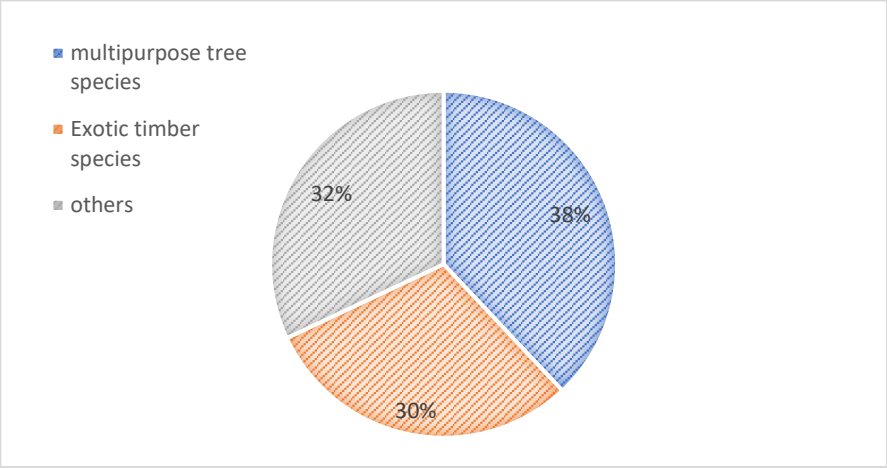


chart 4-1; the chart represents the percentage of multipurpose tree species others

timber demand. The origins and expansion of the mango tree, like the spread of human communities, are reflected in many of the names.

Ariyadasa, K.P. 2002. 'Assessment of Tree Resources in Home Gardens of Sri Lanka', FAO Publication states top ten home garden species in order of frequency of existence as Coconut, Rubber, Jak, Arecanut, Mahogany, Havari Nuga, Mango, Albizzia,

Eucalyptus, and teak respectively [200]. The above wood trees are among the top ten in terms of occurrence, according to an FAO survey of tree resources in home gardens in 22 of Sri Lanka's 25 administrative districts.

Table 4-12; Types of wood species exiting and their definition

Type of the species	Definition	Example
Multipurpose tree species	That is grown to provide more than one significant crop of function or form	Coconut, Jak, Mango
Exotic timber species	produce is of high value including a high yield rate.	Mahogany, Alstonia, Albizzia, Eucalyptus, Teak
others	Excluding the above two types	Others excluding the above

4.7.2.3 Physical properties

The comparison of the physical characteristics of Mango wood with other selected wood types is analyzed as below. The visual observations showed the mango wood grain is mostly straight or in some, they are interlocked. It contains a good natural luster with an average to coarse texture. The grain of teak wood is usually straight; further, it can be wavy or interlaced on occasion. Natural luster is moderate to low, with a coarse, uneven texture.Rubber Grain is straight, with a slight course, open texture with a low natural luster. Alstonia grain is usually straight grain or slightly interlocked. This comprises fine to medium texture and low natural luster (timber demand. The origins and expansion of the mango tree, like the spread of human communities, are reflected in many of the names.

Ariyadasa, K.P. 2002. ‘Assessment of Tree Resources in Home Gardens of Sri Lanka’, FAO Publication states top ten home garden species in order of frequency of existence as Coconut, Rubber, Jak, Arecanut, Mahogany, Havari Nuga, Mango, Albizzia, Eucalyptus, and teak respectively [200]. The above wood trees are among the top ten in terms of occurrence, according to an FAO survey of tree resources in home gardens in 22 of Sri Lanka's 25 administrative districts.

Table 4-12), (chart 4-1), (Table 4-13).

Table 4-13; wood type and the wood grain pattern

Tree species	Woodgrain pattern
Mango	
Teak	
Mahogany	
Rubber	
Alastonia	

4.7.2.4 Mechanical properties

The mechanical properties of the wood are compared with the mechanical properties of Teak, Mahogany, Alastonia, and Rubber; Table 4-9.

Table 4-14; mechanical properties of the above woody trees

	Density (kg/m^3)	(MOR, N/mm^2)	(MOE, N/mm^2)
Mango	560	67.23	8920
Teak	720	91.615	9438
Mahogany	620	51.20	9800
Alstonia	595	88	9240
Rubber	610	71	9480

A. Price

Concerning the enormous development in the construction segment in Sri Lanka, the requirement for wood as a construction material is anticipated to increase over the next half-century, (table 4-10).

Table 4-15; wood type and the price

General name	Scientific name	Size	Price
Mango	*Mangifera indica*	50mmx150mm	293.37
Teak	*Tectona grandis*	75mmx100mm	2991.42
Mahogany	*Swietenia macrophylla*	75mmx100mm	1051.27
Rubber	*Hevea Brasiliensis*	50mmx125mm	245.96
Alastonia	*Alastonia Macrophyla*	50mmx125mm	374.00

4.7.3 Discussion

Mango wood can get affected by fungus and insects. Mango wood doesn't require much maintenance However during dry weather, cracks can form over it if left dehydrated. If the wood is exposed to heat sources or sun, it has been recommended to moisturize it once every month or when the wood seems dry. It is susceptible to insect and fungal attacks. The significant fact that makes this wood sustainable is that it is the by-product of mango fruit. When the tree is completely matured, then it is ready to harvest fruits. When the tree stops bearing fruit altogether, then the tree can be harvested for timber. Hence after that, another generation of mango trees is planted. Mango wood harvesting provides farmers with more than just extra revenue.

The opportunity of applying lesser-used found on the usage of local wood helps to minimize the energy consumption. And also, it creates employment in areas far away from urban areas. Soon wood, the market is continuously expanding given the considerable possibilities due to its aesthetic appearance and the high performance concerning the technological progress of these materials, and due to its low impact on end-use.

4.8 Identify the plants' species for further development

The survey revealed the following plant species as the most documented plants species for preserving practice. *African / Mexican marigold, Gampalu wel, Kohomba , Maduruthala, Gliricidia , Nika , Mexican sunflower*, *Marigold Tree, pawatta*, *Pus wel,* etc. Among all, when considering the nutritional value, fast-growth or growth performance, high regeneration capacity with high potential for forage productions

three plant species were selected as potential plant sources for further investigations in this study (Figure 4-20).

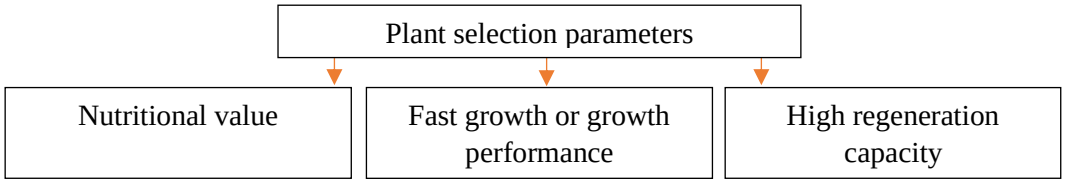


Figure 4-20; Plant selection parameters are classified as above .

a) *Gliricidia sepium* [182], [183]

b) *Mikania micrantha* [184], [185]

c) *Tithonia diversifolia* [186], [187]

Then following literature survey was conducted to identify research findings gained by using these plant species.

4.8.1 Mikania micrantha



Figure 4-21; Mikania micrantha appearance of the leaves and the growth vegetation

Ref	Source	Year	Country	Plant part	Finding
[201]	Ghosh et al.	2007	India	Leaves	Antibacterial activity of hot aqueous and methanolic extracts
[46]	Ishak et al.	2018	Malaysia	Leaves and stem	M.micrantha stems extract using ethyl acetate, extensively taken as traditional medicine; a potential source of natural antioxidant agents, their use to treat oxidative damage-related disease
[203]	Dev et al.	2015	Bangladesh	leaves	Antioxidant activity

4.8.2 Gliricidia sepium




Figure 4-22:Gliricidia Sepium

Ref	Source	Year	Country	Plant part	Findings
[204]	Akharaiyi et al.	2012	Nigeria	leaves	Anti-bacterial, Phyto-chemical, Anti-oxidant actions or activities of the Leaf , this is a plant valued for its ornamental medicinal and insect repellent purposes
[205]	Nazli et al.	2008.	Pakistan	leaves	Insecticidal, nematicidal, and present antibacterial activities
[206]	Beena jose1*and l. Joji reddy1	2010	India	leaves	leaf essential oil can be used as a potential external antiseptic. It can be combined into drug formulations.

4.8.3 *Titonia diversifolia*




Figure 4-23;Titonia diversifolia

Ref	Source	Year	Country	Plant part	Finding

[207]	Oyedokun et al.	2011	Nigeria.	Leaf	The insecticidal activity of the leaf crude extracts was evaluated.
[208]	Kerebba et al.	2019	South Africa	leaf	The pesticidal activity of *T. diversifolia*
[209]	A. O. Dada et al	2018	Brazil	Leaf	Phytotoxins from *T. diversifolia*

4.9 Conduct experiments and investigate traditional vernacular technology

As per the survey and the field interviews, the gathered data was briefed as follows;

4.10 Define the experimental procedure

With these tabulated results pilot study was conducted to understand the said phenomenon.

4.10.1 Conduct experiments and investigate the traditional vernacular technology

Experiment 4-2; Investigate the said phenomenon using Mangifera indica wood.

The initial location was selected concerning the tabulated results. A small village namely Kanupelalla, from Badulla district, Uva province was selected as the pilot study. An organic paddy field was selected to maintain minor deviations from ancient paddy field conditions. The procedure was developed as per the decoded and documented information.

4.10.2 Materials and methodology

As per the field interviews, the treatment duration or the preservation time was not noted. Hence so four treatment times were identified as 15 days, 30 days, 45 days, 60 days. The defect-free *M. indica* (Mango) samples were prepared from a maturated wood log. To claim the growing condition constant the identified plant species were taken from one context. A pith was prepared in the size of 600 x 600 x 300 mm^3. The pith was then filled with the paddy field mud and the leaves of the *G. sepium, M. micrantha, T.diversifolia* mention plants. Three replicate wood samples per treatment time were used while three replicates were maintained as control untreated samples. A continuous water supply was given until the wood was taken out.

The pith was filled with the paddy field mud and the leaves were added in the thumbs rule. Then 3 days after pith preparation the green state or high moisture (as soon as the trees were cut down into logs) defect-free wood specimens of the size of 6 inches x 1.5 inches x 4 inches were placed one foot deep in the pith. A continuous water supply was given to the pith.

4.10.3 Results of the experiment

The results were observed as follows. Observation of the moment where the samples were taken out from the pit; with water (Figure 4-24),(Figure 4-28)(*Figure 4-25*).



Figure 4-24; the observations when the specimens taken out from the solution .

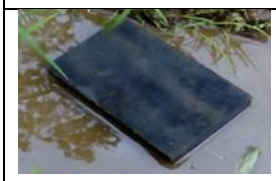
Days - 15	Days - 30	Days - 45	Days - 60
			

Figure 4-26; visual observations after 15, 30 , 45, 60 treatment durations

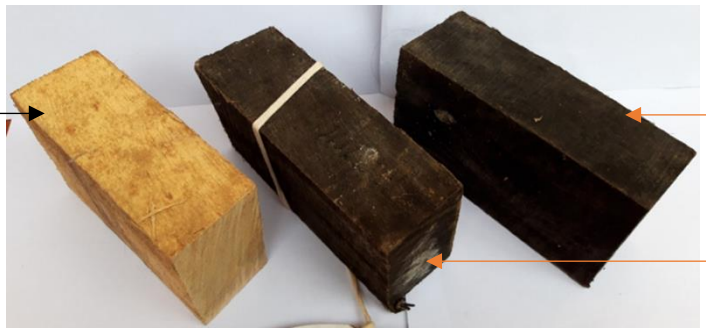
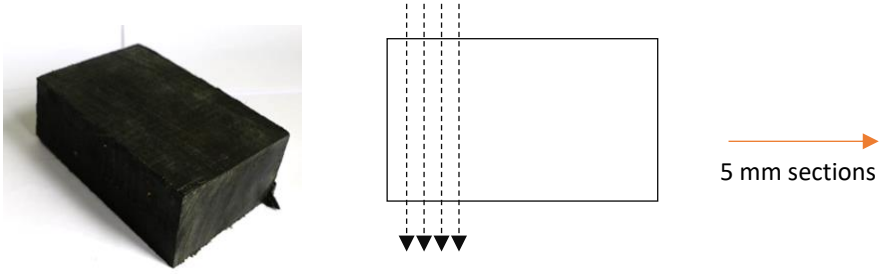


Figure 4-25 A clear colour variation was observed compared to the control untreated samples. (After drying).

A significant color variation and odor were presented compared to the control sample. For further investigation, the sample was sliced into 5 mm sections to visually observe the depth of the penetration(Figure 4-27).



The sliced wood specimens were as follows (Figure 4-28),

Figure 4-27; Section the wood specimens as instructed\ed above.

Control specimen			
5 mm	10 mm	15 mm	20 mm
			

The sample removed out from 15 days			
5 mm	10 mm	15 mm	20 mm
			

The sample removed from 30 days			
5 mm	10 mm	15 mm	20 mm



The sample removed from 45 days			
5 mm	10 mm	15 mm	20 mm



The sample removed from 60 days			
5 mm	10 mm	15 mm	20 mm



Figure 4-28; Sliced wooden sections

4.10.4 Discussions obtained from the pilot study

- It was observed significant colour variations and odour after treatment.

- The visual observations denoted that when the treatment time increases the penetration has been increased.
- The chemical has not equally penetrated within the samples.
- The study should further understand the chemical reaction caused after treatment and also to understand the impact on the mechanical performance of the wood.
- The performance against wood deteriorating agents should be evaluated.

Based on the above facts from here onwards and experimental design is undertaken for deep analysis of the decoded information.

4.10.5 Conduct experiments and investigate the traditional vernacular technology with amendments.

From the information gathered from the field interviews, many combinations of various plant species were decoded. Among them the study limits on the highly established information on the combination of G. *sepium*+ *M. micrantha* + *T. diversifolia; (*Figure 4-29*).* Here the study has focused on identifying the specific property derived from each plant species and investigating the best composition of the solution.

Therefore, investigating the performance of the developed solution and the treated wood was required. This study focuses on evaluating the specific solution and the treated wood to investigate the impact on the mechanical performance.

As for end-use where ultimate strength is an important factor for wood in construction [216], [217].

Wood is a heterogeneous conglomeration of a large number of cells that are hollow, spindle-shaped, and parallel to each other exhibiting hygroscopic and anisotropic tendencies [210].

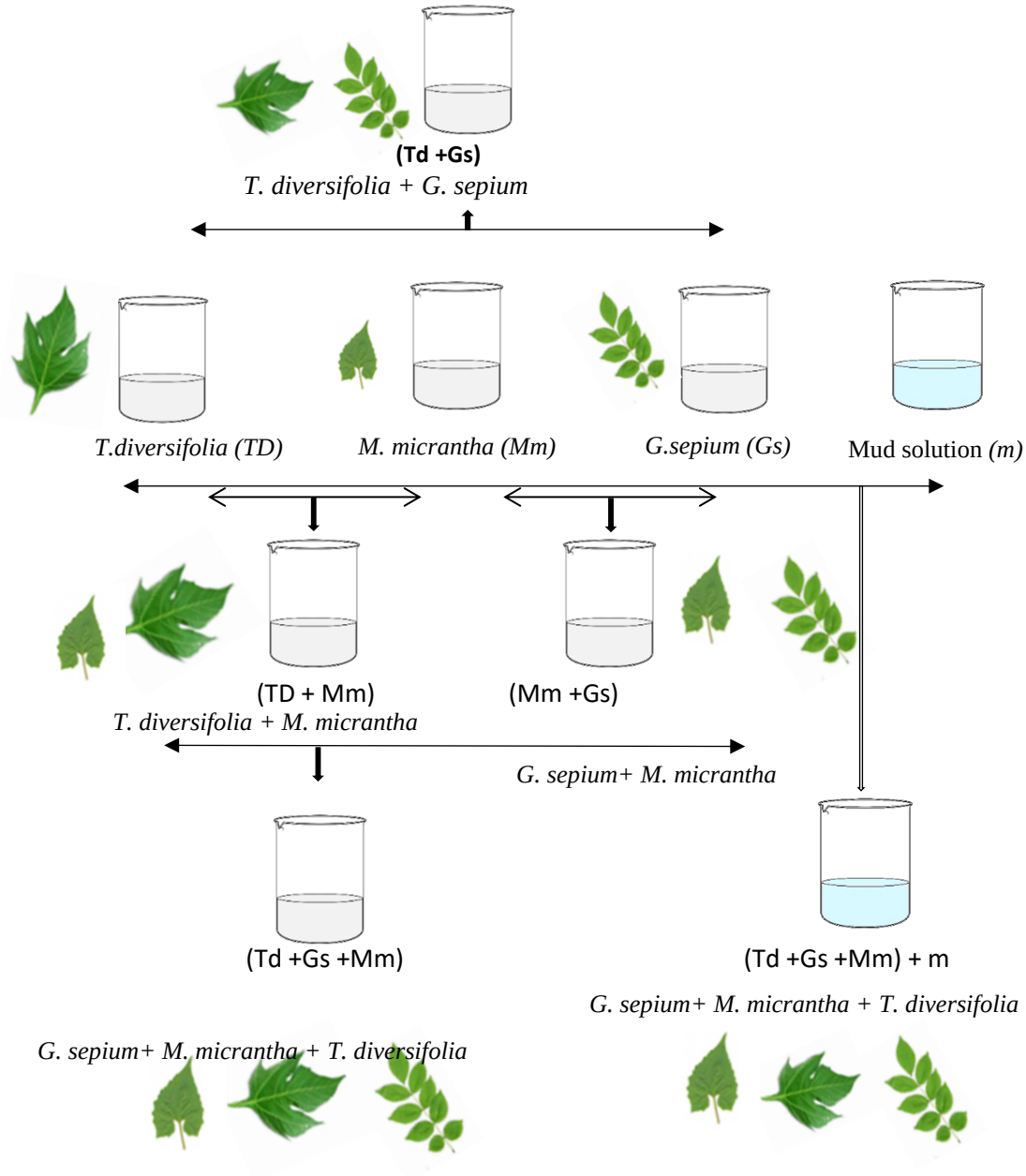


Figure 4-29; Experimental Design

4.11 Causes for the mechanical performance

Based on traditional vernacular knowledge practiced in Sri Lanka, this study investigates the influence of physical and mechanical qualities of wood treated with organically produced preservatives. As per the existing knowledge, *Mikania Micrantha*, *Gliricidia sepium*, and *Tithonia diversifolia* plants' leaves extracts were used to develop 14 preservative solutions with 14 different leaf extract combinations. 168 wood specimens were prepared by *Mangifera indica* hardwood and soaked continuously in the solutions for 15, 30, 45, and 60 days.

The properties are determined following BS EN 384:2016 and BS 373:1957. Results revealed, the samples treated with the preservative solution combined with water and leaf extracts presented the optimum mechanical properties after 30 days of soaking duration. The solution combined with leaf extracts and mud solution presented high mechanical property values after 15 days. The combination of *Mikania micrantha* and *Tithonia diversifolia* extracted to water and *Gliricidia sepium* and *Mikania micrantha* extracted for mud water solution was identified as the best combination. Comparative to the untreated specimen, the entire chemical modification series has decreased the strength values. The study identifies the preservative solution with only water leaf extracts has triggered minimal strength loss during treatment. In this critique the soaking saturates with a preservative solution by being immersed continuously effect on formulations does react with the cell wall components through undergoing hydrolytic reduction upon contact by sugars present in mango wood [211],[212], [213],[213], [214]. Therefore, this study attempts to proceed on an experimental trial under traditional vernacular knowledge-based preservative and technology with amendments [215], [216].

The growing interest in the novel, alternative wood preservatives and treatments has risen as a result of increased environmental consciousness. The use of natural products as raw materials to synthesize environmentally friendly wood preservatives has now become a major requirement in the wood preservation industry [216].

Generally, the end uses in construction the ultimate strength is important in the wood after treatment. If the preservatives do not react with wood cell wall components, they do not cause significant strength loss. If the formulations react with the cell wall components. If the solutions cause to undergo hydrolytic reduction in the presence of wood sugars, the wood cell wall components are oxidized. This results in a loss in wood strength [216], [217]. The cellulose is primarily in charge of the wood strength [218]. The wood loses its strength as this polymer degrades biologically through, [219](Figure 4-30).

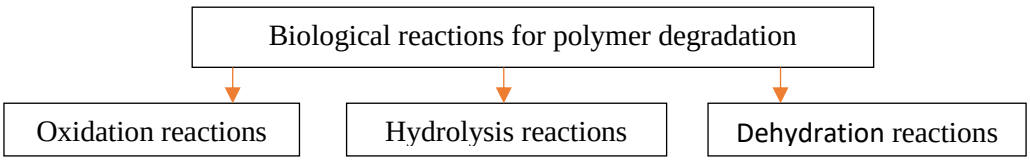


Figure 4-30; Classification of the reactions causes towards polymer degradation.

The following values have crucial importance towards the selection of timber for structural applications (Figure 4-31).

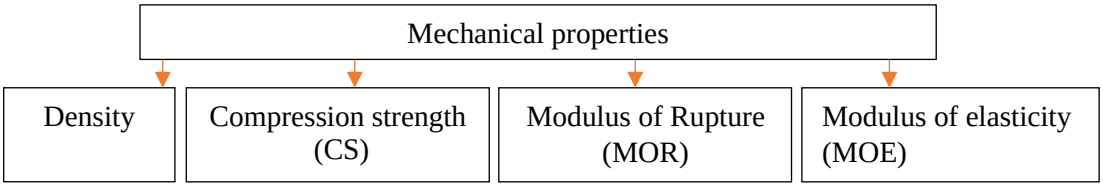


Figure 4-31; classification of mechanical properties

Therefore, it is an important parameter and needs to be studied. (The modulus of elasticity (MOE) is directly related to the stiffness of a beam; measurements of the resistance to bending and influence on the strength of a long column; and MOR governs the load a beam will carry.

Here this phase of the study focuses on 3 types of plant species based on the survey results in the previous studies; (*Title 4.2*)The study investigates solutions developed using *Gliricidia sepium, Tithonia diversifolia,* and *Mikania micrantha* plant species.

Experiment 4-3; Destructive assessment on mango wood treated with Industrially available wood preservatives and the developed solution up to now.

4.11.1 Materials and methodology

Mikania micrantha is a creeping and climbing herb that has been introduced and is exceedingly prevalent, often growing over and covering other plants and shrubs [220].

Gliricidia septum It's a perennial, medium-sized tree that's also a fast-growing, adaptable tree. During the dry season, it is generally deciduous, although, in humid locations, it is said to remain evergreen [221].

Tithonia diversifolia is a prolific shrub[222].

Mangifera Indica; wood has been identified based on traditional vernacular knowledge as the wood to experiment with the preservative and technology. As per the classification under the State Timber Cooperation, the *Mangifera indica* wood classifies under class 3 comprising the density of 598 kg/m^3 and CSPG 17.91 N/ mm^2 and 67 N/mm^2 of MOR and 8920 N/mm^2 of MOE.

This study determines the effects of naturally synthesized preservatives on the major mechanical properties of *Mangifera indica*. Therefore, this study attempts to proceed on an experimental trial under traditional vernacular knowledge-based preservative and technology with amendments. Determining these parameters is helpful to extend the wood service life overcoming the mechanical performance during service.

This attempts to infer the cause for the mechanical's properties of the wood treated with the plant-based wood preservative solutions for current applications.

A. Plant materials and preparation of the extract;

Fresh leaves of these plants were collected from the Badulla (Uva province). Leaves via weight were taken into 14 separate containers and water was added in the ratio mentioned. The solutions were kept until the solution is ready to be used as a preservative solution, kept under room temperature at 27.0 °C (81°F). Paddy field mud was collected from an organic paddy field. Fresh, matured leaves of *Gliricidia sepium*, *Tithonia diversifolia*, and *Mikania micrantha* were subjected to water extraction slowly for 4 days to obtain the first 14 solutions including 7 solutions extracted to water and 7 solutions extracted to mud mix solution.

B. Experimental Procedure;

Two experimental models as "Test series A" and "Test series B"(Table 4-11) and (table 4-12).

Table 4-16:Test Series A: Solution composition; Solution (A) to Solution (G) (only water and leaf extracts)

Solution name	**Water *(l)***	**Fresh leaves**		
		G. sepium	***T. diversifolia***	***M. micrantha***
S- (A)	10	-	500 g	-
S- (B)	10	-	-	500g
S-(C)	10	500 g	-	-
S- (D)	10	-	250 g	250 g
S-(E)	10	250 g	250 g	-
S- (F)	10	250 g	-	250 g
S-(G)	10	166.7 g	166.7 g	166.7 g

Table 4-17:test Series B: Solution composition; Solution (a) to Solution (g) (water mud mix solution leaf extracts)

Solution name	**Water *(l)***	***Mud (Kg***	**Fresh leaves**		
			G. sepium	***T.diversifolia***	***M.micrantha***
S-(a)	10	10	-	500 g	-
S- (b)	10	10	-	-	500g
S-(c)	10	10	500 g	-	-
S- (d)	10	10	-	250 g	250 g
S- (e)	10	10	250 g	250 g	-
S- (f)	10	10	250 g	-	250 g
S-(g)	10	10	166.7 g	166.7 g	166.7 g

The properties are determined under BS EN 384:2016 (Structural timber. Determination of characteristic values of mechanical properties and density) and BS 373:1957(Methods of testing small clear specimens of timber).

Three mango trees (*Mangifera indica*) with straight trunks were harvested from the Badulla district. The green logs were 3 m in length cut into 20 mm x 200 mm x 3 m size planks comprise the central pith were then cut from the logs. The wooden specimens were prepared in the size of 20 mm x 20mm x 3 m parts to achieve homogeneity. Defect-free specimens were prepared. The wooden specimens were obtained from the tree at random radial and longitudinal locations. The samples were prepared concerning the given guides under the BS codes. They were treated in green conditions with high moisture content. five specimens per solution were taken out from different soaking intervals at 15, 30, 45, and 60 days with a total number of 14 different solutions; (5x4) x (7sets) x 2 sets per test.

4.11.1.1 Physical and Mechanical Properties

The physical and mechanical properties are accessed as follows,

A. Density after treatment

The volume and mass of a wood sample depend on its water content measured before the testing [213]. Wood density is an important parameter for solid wood. This presents a strong relationship to both yield and quality [223]. For measurements of volume, the sample should be maintained at constant humidity. Density at conditioned moisture in between 12% - 18% moisture condition denotes as below; Equation 1

$$Density = weight\ before\ oven\ dry/Volume$$

B. Moisture content- Oven-drying method; Equation 2

Where M_{dr} is the mass of the wood specimen after kiln-dried (Dry weight) and Mw is the mass of the wood at moisture content w (wet weight). These are weighted before and after kiln-drying at a temperature of 103 °C ± 2 K until a constant mass is achieved. The moisture content is determined from the ratio between the mass of water in the moist specimen (Mw-Mdr). The mass of the kiln-dried specimen (Mdr). The exact moisture content m (in %) of a wood sample is defined as a percentage of the dry mass [86], [224].

$$Moistur\ content\ (\%) = (Mv - Mdr)x100/Mdr$$

The following mechanical properties of the treated *Mangifera indica* timber specimens were obtained from destructive tests. CSPG and static bending (central loading) tests were performed in reference to BS 373:1957 standard; methods of testing small clear specimens of timber. The testing was performed using a universal testing machine of 100 KN capacity in traction compression under Pro green laboratory within the university premises

C. The Compression strength parallel to the grain

The compressive strengths, in a parallel direction to the wood grains (CSPG), were obtained investigated conferring to BS 373: 1957. The specimens were prepared according to the given standard. Afterward, each specimen was placed in the compression chamber of a Universal testing machine. The load was applied at a rate of 0.01cm/s. The disappointment load (in KN) of each example was examined, perused off the dial measure, and recorded. Load at failure F (Kg f), Average width (b), average height (d).

$$CSPG(Nmm^{-2}) = \frac{F \times 9.81}{(b \times d)}$$

4.11.1.2 Determination of Stiffness Properties

The static bending test was conducted under the universal testing machine of 200 KN capacity was used for the 100 KN range. The third-point loading was applied with a total span of 300 mm. Here the central loading method was utilized. The stiffness characteristic of the treated wood specimen was determined.

A. Determination of Stiffness Properties

The principal loading point had been established. The diameter of the roller bearing was 30 mm. The test was carried out at a speed of 0.08 mm/s. Load-deflection curves were used to determine the proportional limit, ultimate load, and deflection, and the MOR (Nmm-2) was determined as follows; equation 4,

$$MOR = \frac{3 \times F \times L}{2 \times W \times H^2} \quad (At\ point\ of\ fracture)$$

The F is the load (force) at the fracture point (N), The L is the length of the support span (m), W is the width (m). The H is the thickness (m) of the wood specimen. Where MOR is bending strength (N/mm^2).

a. Modulus of Elasticity (MOE)

This measures the wood's stiffness. Also, this is a significant indicator of its strength. It's a techniques term for a measurement of the ratio of stress applied to the wood vs the strain or deformation exposed along its length [213]. The span (L) of all of the test specimens was kept at 300mm. MOE is calculated using the gradient of the graph (figure 8) using the following equations; Equation (5), (6), (7).

$$W = (48IE)/((L^3 \times 9.81)\partial$$

$$I(mm^4) = \frac{1}{12}bd^3$$

$$MOE(Nmm^{-2}) = \frac{gradient \times l^3 \times 9.81}{48I}$$

4.11.1.3 Moisture Adjustment

Wood's water content has a direct impact on its physical and mechanical properties [225]. Many researchers have contributed to quantifying the relationship between the moisture content and the mechanical properties. Samples were not tested at the reference moisture content however with mean moisture content in the range of 8% to 18% is adjusted using the procedure defined in BS EN 384:2016 based on the moisture content results[80]. Moisture correction was followed to adjust the characteristic such as Density, CSPG, MOE, MOR [227], [228] [81],[[227], [228], [230].

Adjustment of mean values of Density to the reference moisture content of 12%;

$$Density(ref) = (\partial_m)\{1 + [-0.005(m - m_{ref})]\}$$

Adjustment of mean values of Bending Strength to the reference moisture content of 12%;

$$MOR(ref) = (R_m)\{1 + 0.04(m - m_{ref})\}$$

Adjustment of mean values presented in MOE to the reference moisture content of 12%;

$$MOE(ref) = (E_m)\{1 + 0.02(m - m_{ref})\}$$

Adjustment of mean values of CSPG to the reference moisture content of 12%;

$$f_{c,o,k} = 5(f_m, k)$$

∂m = Density at m moisture content at testing, Em = Modulus of elasticity at m moisture condition, m= moisture content at testing and mref = reference moisture content at 12 %; mref=12, fm,k = value of bending strength (in N/mm2). f c,o,k = characteristic value of CSPG (in N/mm2).Rm= Modulus of rupture at m moisture condition, MOR (ref) = Modulus of elasticity at reference moisture condition. The reference moisture throughout the study is 12 %. MOE (ref) = Modulus of elasticity at reference moisture condition.

4.11.2 Results and Discussion

The above-mentioned equations were used to generate the findings.

4.11.2.1 Physical appearance

The below table indicates the visual appearance; figure 4 and figure 5, presented after the treatment under test series A and test series B; (Table 4-18).

Table 4-18:Visual Appearance of the treated wood

Test No.		Color variation
Solution (A- G)	Test series A	Shades of brown
Solution (a-g)	Test series B	Shades of dark black

A. Moisture corrections

The physical properties and the destructive assessments were conducted before the moisture conditions in between 12 % and 18 %. Then the comparison was concluded after the moisture adjustments, bringing the properties to 12 % moisture condition. Moisture adjustment was calculated.

B. Density

The following represent the density influence concerning the 7 different leaves extracted to “with” and “without mud” solutions. Chart 4-2 indicates the density influence concerning soaking duration, the test series A, the wood samples treated with “solution A” to “solution G” represents the highest density obtained within 30 days;
Meanwhile, the chart represents the specimens treated under test series B. Among them, the samples treated with “solution a” to “solution g” represents the highest density after 15 days; chart 4-3

Density values obtained from test series A are greater than the density values obtained from test series B. Where it concludes that the mass of the wood had been influenced by the treatment techniques expressly in test series B; Chart 4-4

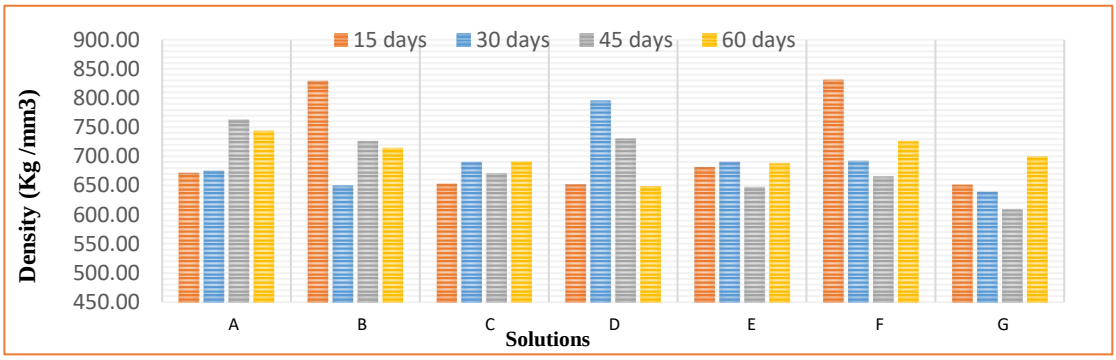


chart 4-2; Average density value relationship with solutions A- G

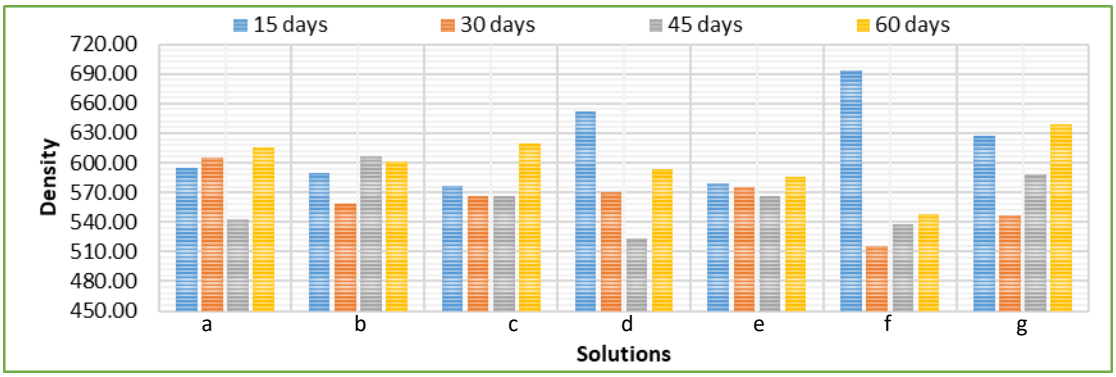


chart 4-3;Average density value relationship with solutions a-g

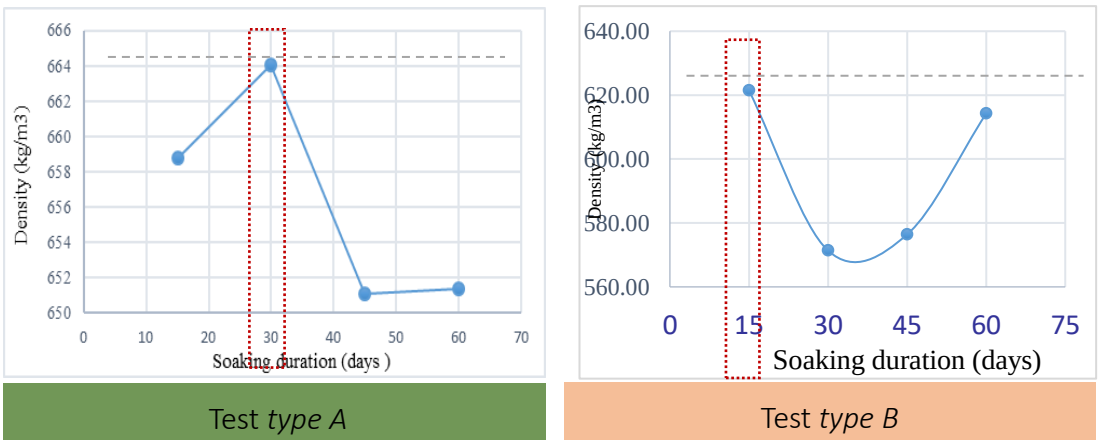


chart 4-4; Average Density values relationship with soaking duration

Among the 14 preservative solutions, the following has obtained the highest and the lowest values of density after treatment;

C. CSPG

The wood's grain orientation has a significant impact on its physical qualities during application [69]. The CSPG values from test series A; timber specimens only treated with leaf – water extracts have obtained highest values from the samples that were continuously soaked for 30 days and the lowest values of the CSPG of the test serious were obtained on the samples soaked for continuous 60 days; (chart 4-26). The distribution pattern of CSPG values obtained from test series B was much more complicated than test series A. Among the majority of CSPG values obtained from tests series B; the highest CSPG values were obtained continuously soaked within 15 days; (chart 4-27).

Results disclosed the treated wood presented less CSPG value compared to the untreated specimen. However, supposed to both the test series A and the test series B the treatment accelerated the rate of hydrolysis in the wood, resulting in a reduction in strength. As literature further states, a fixation process that oxidizes the cell wall components creates an impact within the above process and might reduce wood strength mainly on the wood treated by the test series B under Solution (a) to the solution (g); (chart 4-28).

4.11.2.2 Bending test results

The results were analysed in separate tests A and test B.

Test series A treatment under (Solution A to Solution G);

The MOR and MOE values obtained from the specimens treated under test series A; are given in (charts 4-29) and (Chart 4-32). The 30 soaking days had the higher MOR and MOE compared to other treated samples under the test series A. The lowest MOR values were obtained from the samples taken out after 60 days of soaking. Results presented this treatment reduced the MOR results of timber compared to untreated samples. However, the MOR values obtained after 30 days of soaking duration have maintained less reduction of MOR values compared to the control untreated sample.

Also, it has been illustrated the MOR values with time decrease and then again increases in the 60 days, however not reached the values obtained in the 30 days of soaking duration.

Test series B treatment under (Solution a to Solution g)

MOR and MOE values obtained by the timber specimens treated with test series B; are given in (chart 4-30) and (chart 4-33).15 days soaking duration had the higher MOR and MOE compared to other treated samples under the test series B. The lowest MOR values were obtained from the samples taken out after 45 days. The results showed that both test series reduce the MOR results of timber specimens compared to the untreated control samples. Comparatively to test series A and Test series B, the minimal effect on the preservation towards the CSPG and MOE has affected Test Series A other than Test series B. Among the 14 preservative solutions following solutions have obtained the highest and the lowest values of MOR after treatment.

This study further focuses on statistical analysis using the Minitab software. Though the moisture content is directly influenced by the mechanical properties, it can be concluded, moisture content has no significant impact on the relationship between the soaking duration and respective properties such as MOR, MOE, and Density. (Chart 4-34) and (chart 4-34) represent the comparison of the optimum properties.

(Table 4-19) represents the summary of the impact caused with soaking duration, such as 15, 30, 45, and 60-days reference to test series A (Without mud) and Test series B (With mud). And also, this summarized the relationship of the properties among the 14-preservative solution.

Table 4-19; Conclusion of the mechanical performance obtained as highest and lowest Solution.

	Mechanical Properties					
	Density		*CSPG*		*MOR*	
	Highest	*Lowest*	*Highest*	*Lowest*	*Highest*	*Lowest*
Test series A (30 days)	*M. micrantha + T.diversifolia*	*M. micrantha*	*M.micrantha and T. diversifolia*	*Mikania micrantha*	*M. micrantha and T.diversifolia*	*M. micrantha*
Test series B (15 days)	*G.sepium + M. micrantha*	*G.sepium*	*G. Sepium and M. micrantha*	*G. sepium*	*Only M. micrantha*	*T.diversifolia and G. sepium*

4.11.2.3 Compression strength parallel to grain (CSPG)

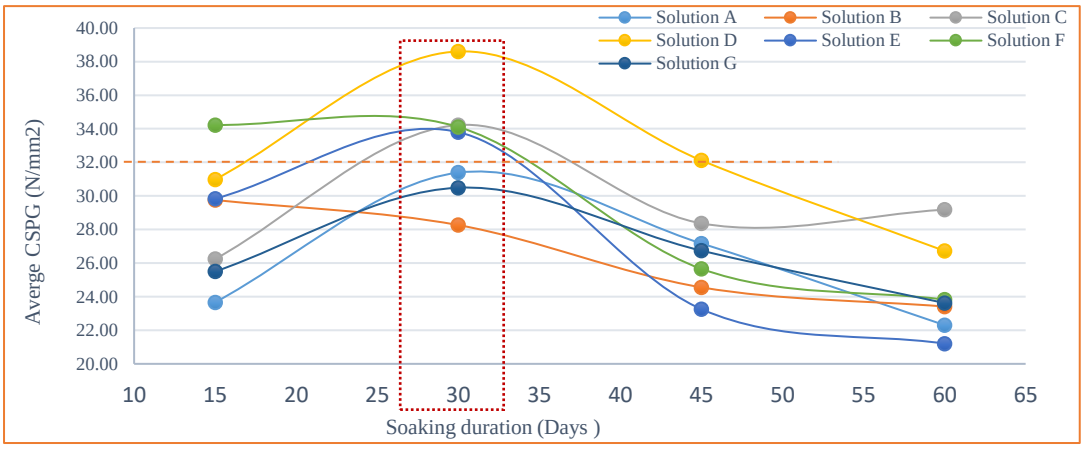


Figure 4-32; The compression strength (Nmm-2) the samples from the solution A- Solution G

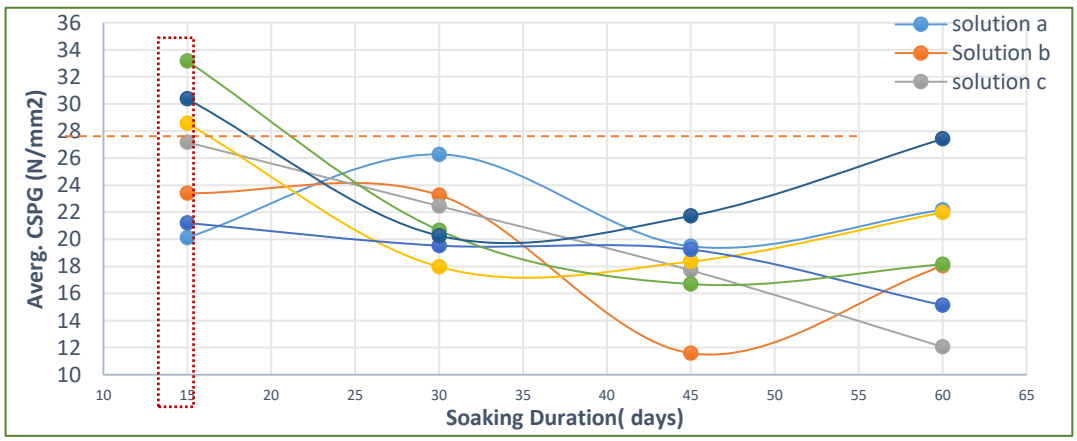


Figure 4-33;-The compression strength (Nmm-2) representing the samples from the solution a- Solution g

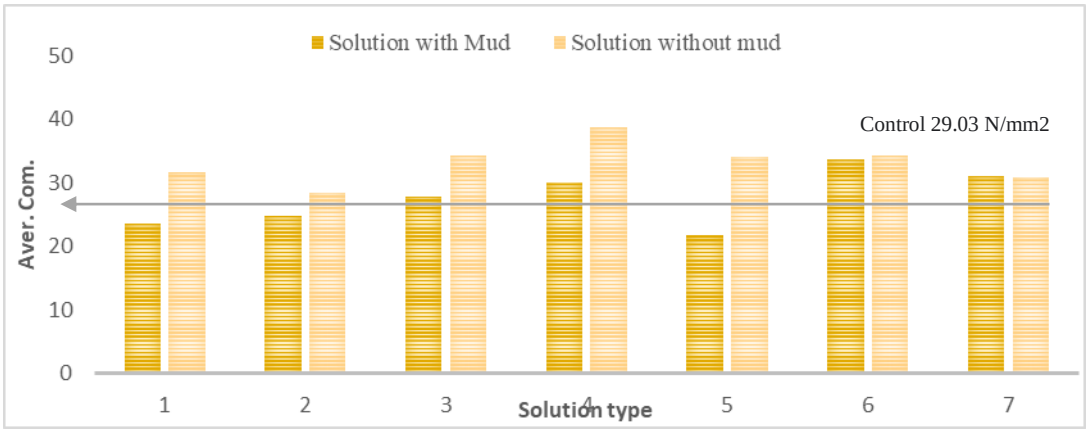


Figure 4-34; The comparison among the optimized sample performance 15 days performance and 30-day performance

4.11.2.4 Bending test results; Average modulus of Elasticity

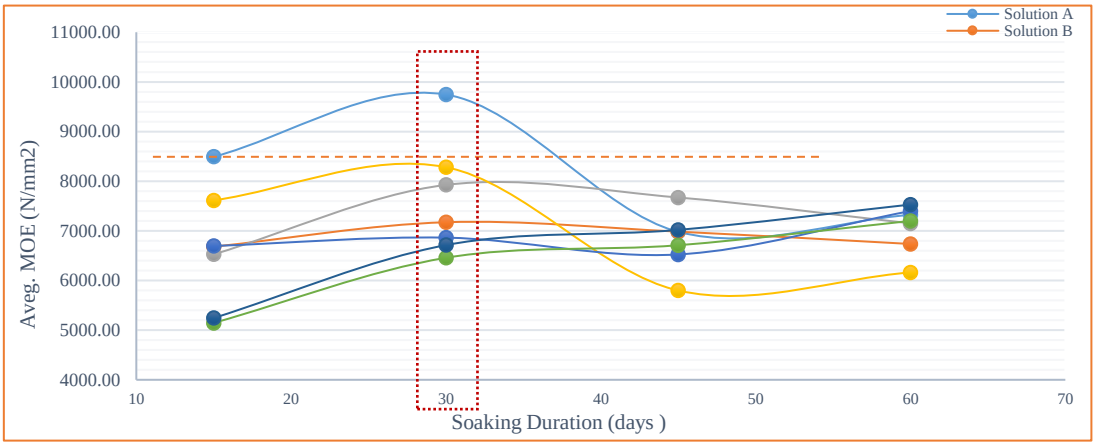


Figure 4-35; Average modulus of Elasticity(test A)

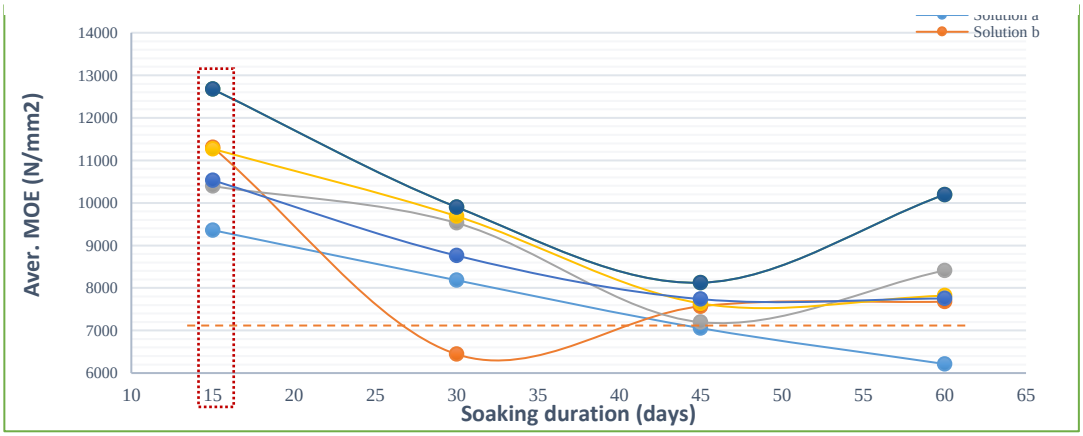


Figure 4-36;Average Modulus of Elasticity (test B)

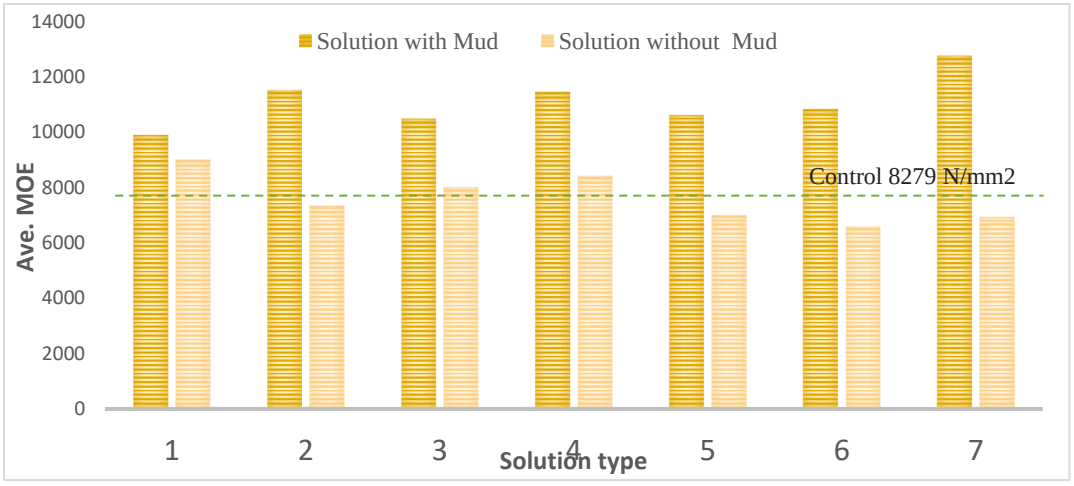


Figure 4-37; Comparison on the optimum MOE obtained on the 15 days and 30 days respectively on test A and test B

4.11.2.5 Bending test results; Average modulus of Rupture

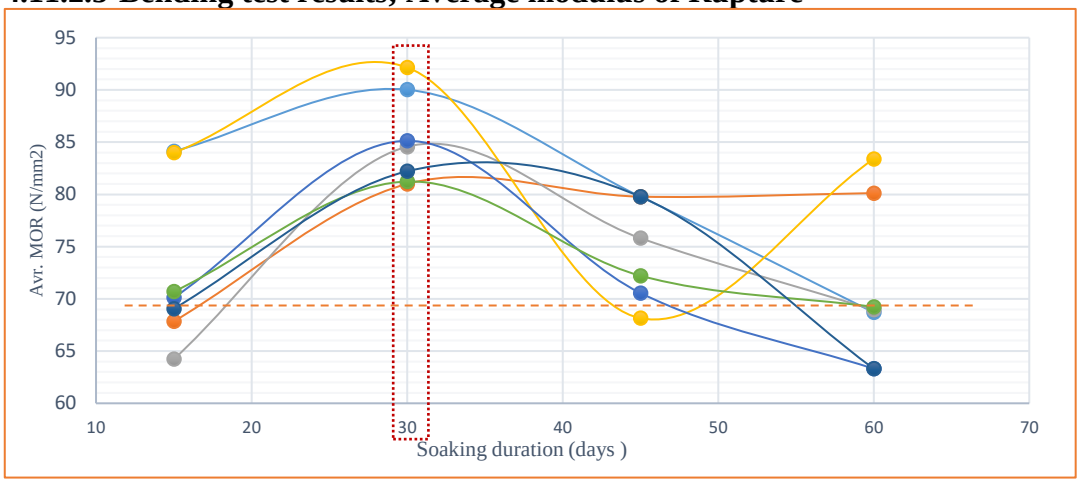


Figure 4-38;Average modulus of Rupture

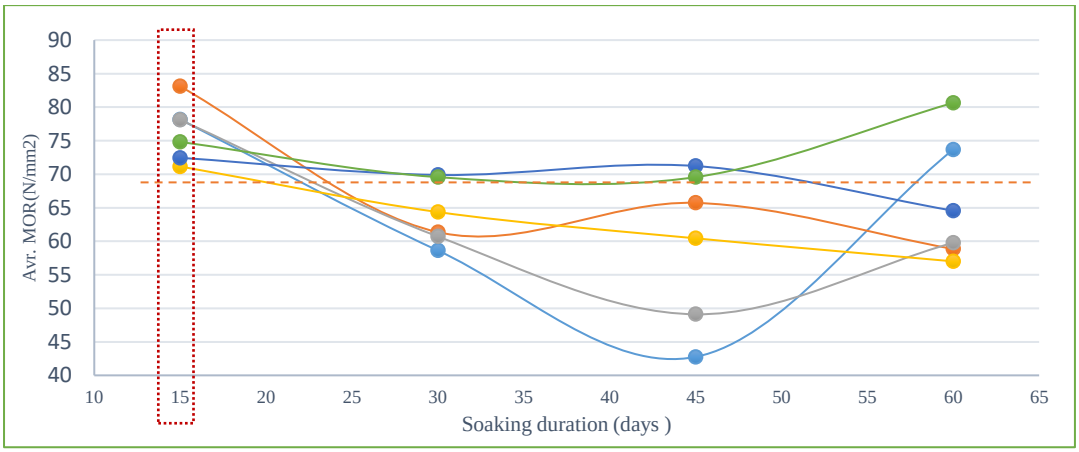


Figure 4-39; Average modulus of Rupture

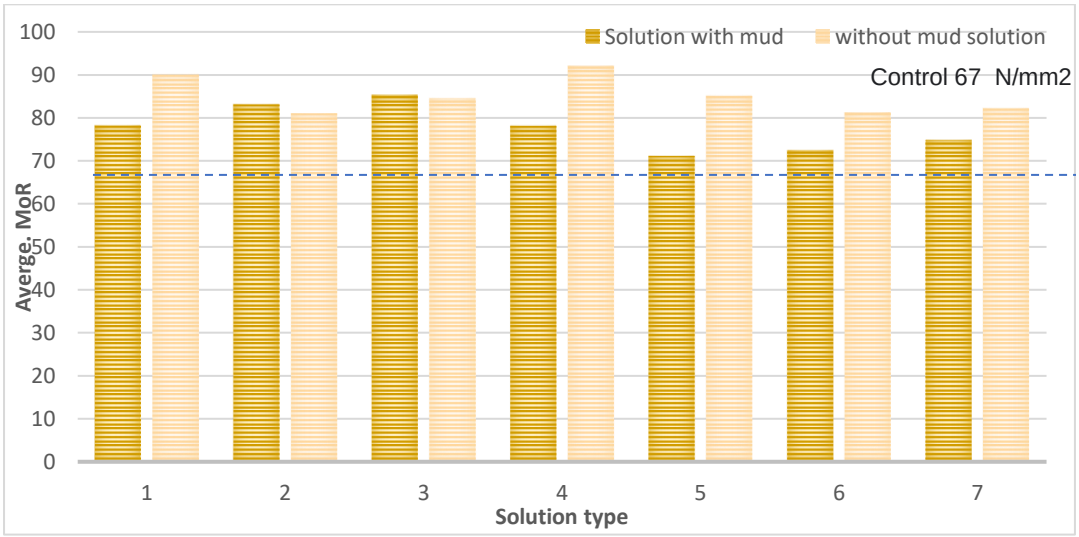


Figure 4-40; Comparison on the optimum MOR obtained on the 15 days and 30 days respectively on test A and test B

The below table represents the summary on the relationships among the mechanical properties of the solutions under test series A and test series B,(Table 4-20).

Table 4-20; Summary on the relationship among the properties

		Between soaking duration	***Between 7 preservative solutions***
CSPG	*(Test series A)*	Significant	Not significant
	(Test series B)	Significant	Not significant
Density	*(Test series A)*	Not significant	Not significant
	(Test series B)	Significant	Not significant
MOR	*(Test series A)*	Significant	Not significant
	(Test series B)	Significant	Not significant
MOE	*(Test series A)*	Not significant	Not significant
	(Test series B)	Significant	significant

The main modification technique used in this study is long-duration soaking. Also, the study identifies the best soaking duration and the best combination of the preservative solutions which have minimal effect on the mechanical properties. The key results disclosed, compression strength parallel to grain under test series A and test Series B is not significantly different among 14 different preservative solutions, however, both techniques are significantly different among Soaking duration.

The study identifies soaking duration (days) as the key feature that significantly affects mechanical physical and mechanical properties. *Mikania micrantha* with mud extraction presented the highest values of mechanical properties. The preservative solution with *Mikania micrantha*, *Tithonia diversifolia,* and *Gliricidia sepium* (1:1:1) presented mid-range values. *Mikania micrantha* and *Tithonia diversifolia* without mud extraction and the only extracted with the mud-water presented the lowest. The solution developed combining all three plant extracts contains properties as antimicrobial, antioxidant insecticidal, nematicide, and pesticide and anti-inflammatory activity.

This study concludes by evaluating the performance of traditional vernacular preservation techniques leading to protective techniques initiated by natural compounds. Based on the traditional vernacular knowledge, revealing the mechanical property impact concerning the preservation techniques in this study requires further contemplations on shreds of evidence to formulate new alternative wood preservative solution by understanding the chemistry on the treatment process on the root cause for the impact expressively on the strength variation of the wood properties due to the fixation/ precipitation reaction causes by this preservation techniques.

4.12 Comparison of Mechanical properties of Mango wood treated with commercially available wood preservative.

The physical and mechanical qualities of wood influence its quality. Timber modification techniques are employed to increase the wood's durability and dimension stability. The goal of this study is to compile a database of mechanical property variations in wood caused by chemicals used and to evaluate the effectiveness of the treatment techniques used.

To determine the most commonly used timber for structural purposes and the most commonly used preservative procedures in Sri Lanka, two separate industrial surveys were conducted: cluster-based and company-based surveys. Through the industrial survey results, three timber species were selected and specimens were prepared. The industrial survey concluded five major treatment methods; kiln dry, dipping, impregnation, brushing and spraying.

Then prepared specimens were treated by the above timber modifications techniques. Compression parallel to grain and static bending test (central loading) were conducted according to BS 373: 1957 standard. According to test results, in Alastonia timber dipping & kiln dry and impregnation & kiln dry, in Rubber timber kiln dry, dipping & kiln dry and dipping and Mango timber brushing and spraying modification techniques exemplified significant mechanical properties (compression parallel to the grain, OR (modulus of rupture) and elasticity) improvement.

Experiment 4-4; Evaluate the mechanical performance of Mango , Rubber and Alastonia treated with commercially available preservatives and preservation techniques ;

This experiment uses similar equations used in Experiment 4-3 for conclusions and then compare the performance.

4.12.1 Investigation on the Mechanical Property Variation on Timber Caused Due to the Chemical Modification

Three hardwood timber species Rubber (*Hevea brasiliensis*), Alastonia (*Alastonia macrophyla*), and Mango (*Mangifera indica*) were selected for compression parallel to grain and static bending (central loading) tests. Five specimens from each treatment method brushing, spraying, kiln dry, dipping, dipping & kiln dry, impregnation and impregnation & kiln-dry) were prepared as separately Rubber timber, Mango timber, and Alastonia timber.

4.12.1.1 Materials and Methodology

The industrial survey was conducted as two distinct surveys; clusters-based survey and companies-based survey. For the clusters-based survey, 23 sawmills and treatment plants on a small scale and not following specific standards were located in Moratuwa, Moratumulla, Koralawella, Pannipitiya, and Swarapola were selected. For companies-based survey 3 companies in the Colombo district following international standards on large scale were selected.

The questionnaire was based on the most utilized timber for beams, rafters, reapers, and door/ window frames and the most utilized treatment methods in Sri Lanka. Compression parallel to grain and static bending (central loading) tests were done for specimens treated as above mentioned techniques and three raw specimens separately for Rubber timber, Mango timber, and Alastonia timber according to BS 373:1957 standard. The chemicals used and the treatment techniques are described in the study are mentioned in (***Table 4-22***).

4.12.2 Results

The industrial survey revealed the following(chart 4-8), (Chart 4-6),(chart 4-5),(chart 4-7),Palu timber for rafters, Kempass timber for beams, Alastonia timber for reapers, and Jak timber for door/ window frames were mostly utilized in clusters. While from the companies-based survey, mostly utilized timber species were Jak timber for rafters and beams, Ginisapu timber for rafters, and variety timbers such as Ketakela, Mahogany, Jak, and Teak for door window frames. Identified preservative techniques through the industrial survey were brushing, spraying, kiln dry, dipping, and impregnation. Kiln dry was identified as the most utilized preservative technique in both cluster and company-based surveys [14].

A comparison was done on the following wood species.

1) **Alastonia (*Alastonia macrophylla*):**
2) **Rubber timber (*Hevea brasiliensis*):**
3) **Mango (Mangifera indica):**

The below charts represent density (compression parallel to grain test) compressive strength parallel to the grain, density, (static bending test), Modulus of Rupture, and elasticity variation caused due to modification techniques.

According to dipping & kiln drying and impregnation & kiln drying modification techniques show significant mechanical properties (compressive strength parallel to the grain, Modulus of Rupture, and elasticity) improvement in Alastonia timber.

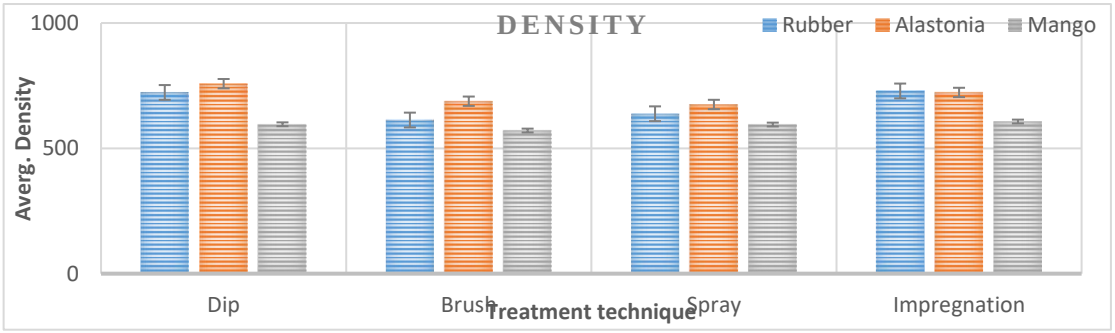


chart 4-5; The density of the wood after treatment

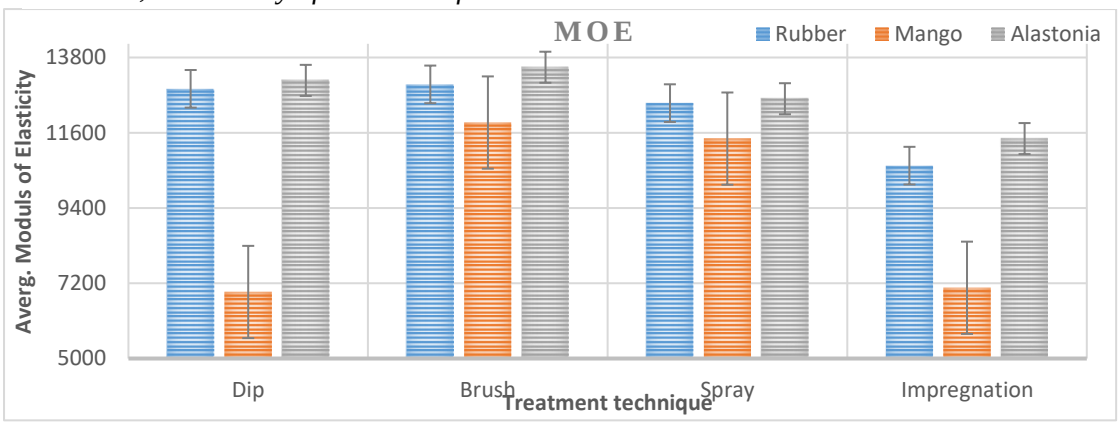


chart 4-7; The treatment techniques vs Average modulus of Elasticity

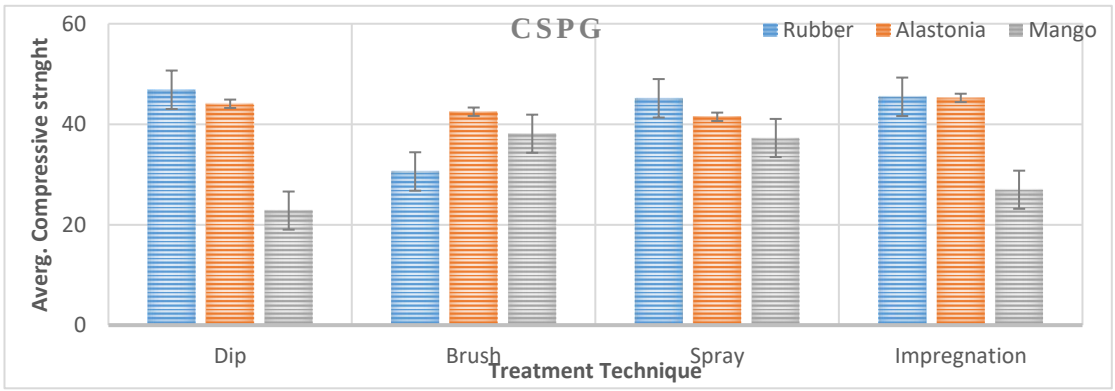


Chart 4-6; The Compression strength parallel to grain

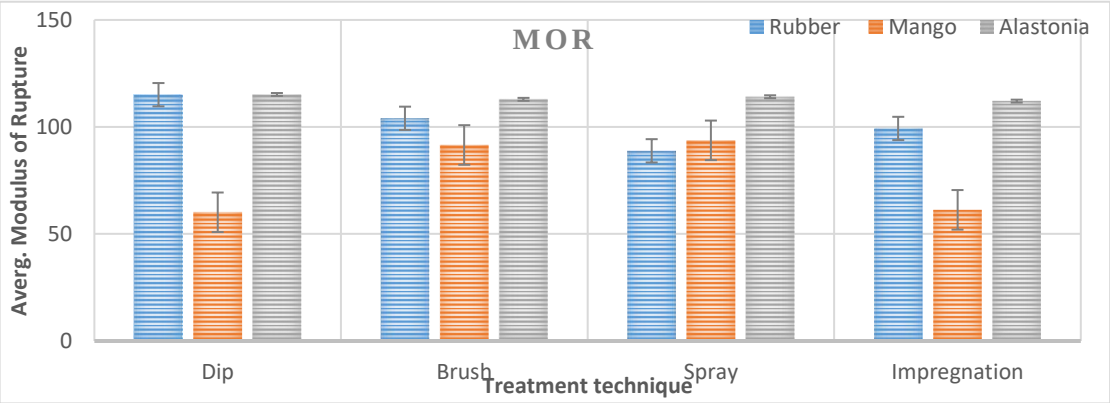


chart 4-8; The modulus of rupture vs the treatment techniques

4.13 Comparison of mechanical properties of Mango wood treated with commercially available wood preservative and the decoded treatments.

This section investigates the effect of chemical treatment on the Mechanical properties (Modulus of Rupture (MOR), Modulus of elasticity (MOE), compression strength parallel to grain) and the physical properties of *Mangifera indica* treated with the naturally synthesized solution as above and compare with industrially available boron preservative preservatives.

Experiment 4-5; Comparison on the performance of the mango wood treated with commercially available wood preservative and the developed solutions ;

4.13.1 Materials and methodology

The dimensions of wood samples were determined under British Standard (BS) 373(1957) and BS EN 384:2016. The result showed that there was a significant difference. The mechanical property values of raw (untreated wood specimens) were found as follows (Table 4-21), (*Table 4-22*).

Table 4-21; Timber species(mango)

Timber species	Mango	Reference
Classification under state timber cooperation Sri Lanka	Class 3	State timber cooperation
Density	598 Kg/m^3	(H. Amarasekera, 2012).
Compression parallel to the grain	17.91Nmm^{-2}	(B. S. Ruwanpathirana, Rathnayak, & De Silva, n.d.), (Lim, Gan, & Choo, 2003), (David-Sarogoro & Aleru, 2016) respectively
MOR	67 Nmm^{-2}	State timber cooperation
Elasticity	8920 Nmm^{-2}	State timber cooperation

Table 4-22; The surface applicant and the naturally synthesized applicants

	Boron treatment		Surface applications		Naturally Synthesized	
Preservative solution	A mixture of Boric acid and Borox	boric acid and borax	SAYERLACK Innovative wood solutions AM0549/89	two coats of SAYERLACK Innovative wood solutions AM0549/89	**(S-1)**plant-based preservatives (developed without Mud)	**(S-2)**plant-based preservatives (developed with Mud)
Treatment Method	Vacuum pressure impregnation	Dipping	Brushing	Spraying	Soaking	Soaking
Process	Initial Vacuum Period : 45min Pressure Period : 2 - 3h Pressure : 175.200 psi Final Vacuum period : 30mins	1 day	Brush application of two coats	Spraying two coats	30 days	15 days
Drying process	Air Dried	Air-dried	Air-dried	Air-dried	Air-dried	Air-dried

The above finds were compared as below, Physical observations of the colouring capabilities of the mango wood after treatment was a comparison on the mechanical properties with below industrially tread and non-industrially treated wood (Table 4-23),(Table 4-24) .

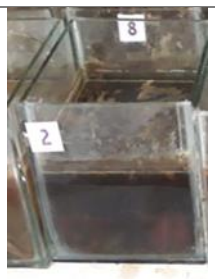
Table 4-23; The physical appearance



DIP-1	SPR-1/BRU-1	OLS-1	MLS-1

Table 4-24; The preservative solution and the treatment techniques.

Treatment techniques	Preservative solution	Abbreviation

Impregnations	The mixture of boric acid 40% and borax 60%	IMP-1	
Dipping	A mixture of boric acid 12.5 kg, Borax 25 kg, and water 200 l for 24 hours	DIP-1	
Brushing	Applied two coats of SAYERLAC K innovative wood solution AM0549/89	BRU-1	
Spraying	Applied two coats of SAYERLAC K innovative wood solution AM0549/89	SPR-1	
Dipping	The solution developed with the plant leaves of *G. Sepium* and *M.micrantha* and *T.diversifolia* extracted to the solvent used as water. (30 days)	OLS-1	
Dipping	The solution developed with the plant leaves of *G. Sepium* and *M.micrantha* and *T.diversifolia* extracted assorted with mud to the solvent used as water. (15 days)	MLS-1	

4.13.2 Results and discussion

Below charts, (chart 4-9), (chart 4-12), (chart 4-11), (chart 4-10)illustrates the mechanical performance of the artificial and the natural wood preservative. The results

denote this natural treatment significantly influences the density of the treated mango wood. This leads to an influence on the other mechanical performance of the wood. The influence against the mechanical properties are presented as follows,

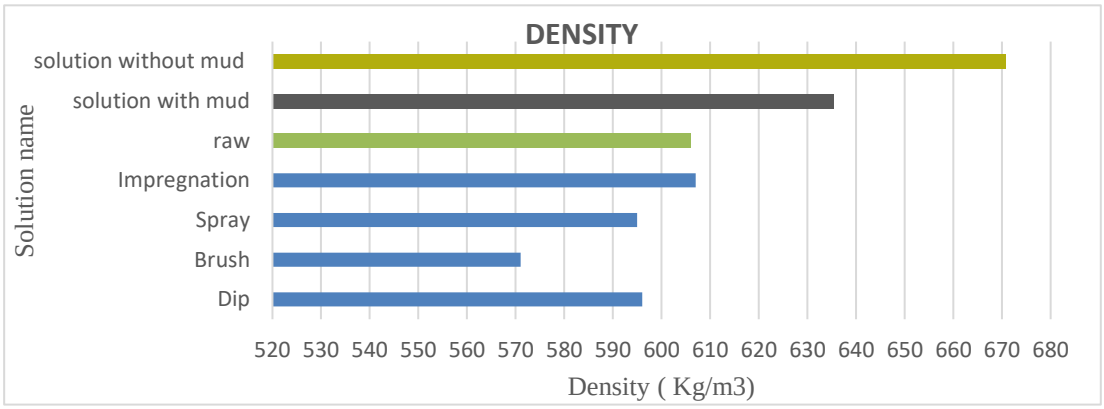


chart 4-10; A comparison on the density values obtained .

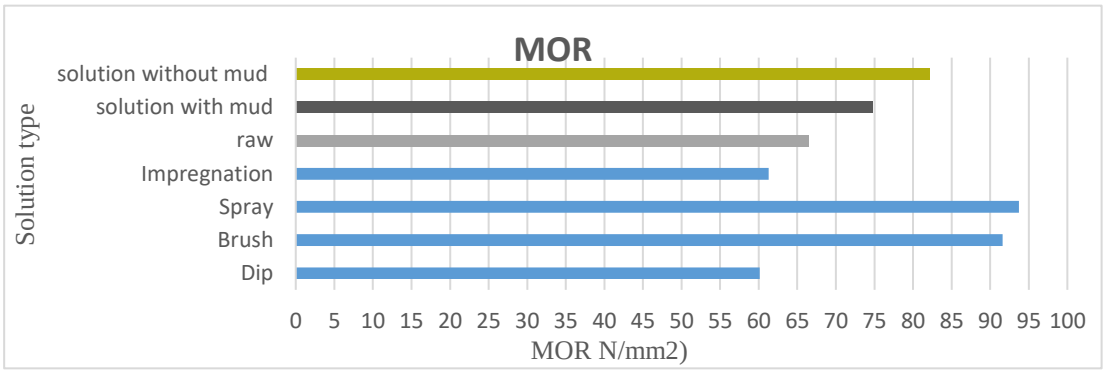


chart 4-11; A comparison on the values obtained from Modulus of rupture

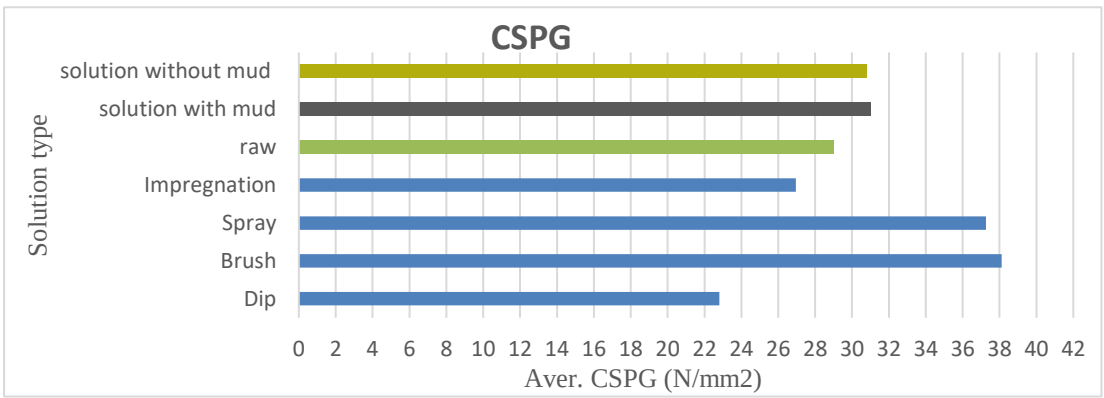


chart 4-9; A comparison on the compression strength values

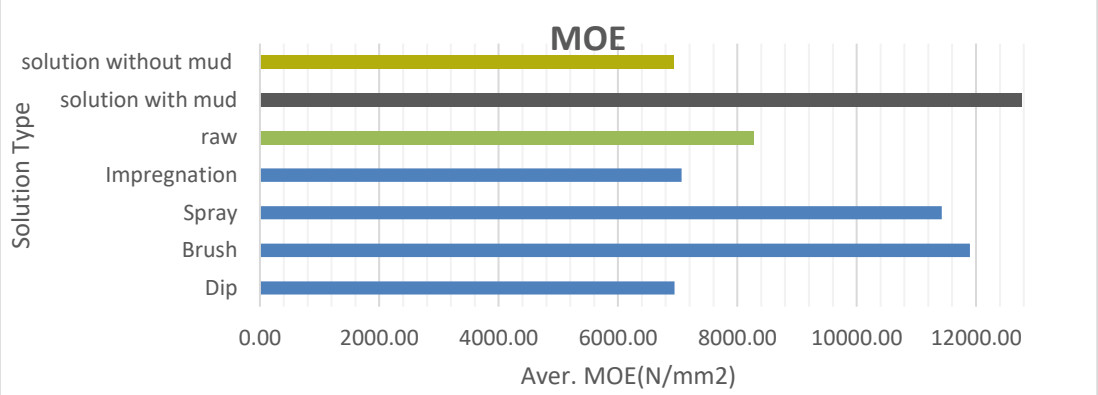


chart 4-12; A comparison on the values gained on Modulus of Elasticity

4.14 Spectroscopic screening on the treated wood

This study attempts to identify the chemical elements that penetrated to the mango wood treated by naturally synthesized wood preservative solutions through spectroscopic analysis. Fresh leaves of *Mikania micrantha*, *Gliricidia sepium*, and *Tithonia diversifolia* plant species were extracted to water. The soaking procedure was applied for 15 and 30 days at six different concentration levels developed with 14 separate solutions. Fresh leaf: water: Mud ratio was changed to identify the best concentration and the composition having the highest potential to be a natural wood preservative.

Experiment 4-6; The microstructure morphology and chemical composition of the treated specimens were examined by scanning electron microscope (SEM).

Further, elemental analysis was performed at 5 locations to obtain an average value using the energy dispersive spectroscopy coupled to SEM. SPSS statistical software was used to statistically conclude the study.

With the evaluation of the wood industry, metal-containing wood preservatives play a huge role against wood deterioration. Simultaneously it started causing a huge environmental degradation and bad impact on human health [231]. This highlights the significant potential for natural chemicals to be evaluated as wood preservatives [232], [233], [234],[235],[236].

So far, many plant species have been screened to explore potential biocidal agents by researchers. However few have investigated its trace elements which have the potential for developing into mass scale usability[96]. This study attempts to detect the chemical elements present in 14 different solutions comprised of 14 different compositions of

extracts [237]. The literature further states Copper , Zink, and Sulphur in wood preservatives may induce toxicity in addition to causing changes in multiple organs if consumed by wood deteriorating agents [238], [239]. Researches also state sulphur has been used to increase wood preservative performance. Sulphur disrupts the metabolic functioning of fungi and is one of the oldest known pesticides and its low toxicity to humans [240]. Natural antibacterial minerals such as zinc and silver are said to have powerful antibacterial capabilities [241]. Therefore, elemental sulphur is undoubtedly the oldest of all pesticides (Table 4-25).

Table 4-25; Performance of the chemical elements against wood deteriorating agents.

Chemical Element	Performance	References
Copper (Cu)	Preventing fungal growth	[242],[243]
Zink (Zn)	Preventing fungal growth antimicrobial properties	[244],[99]
Sulphur (S)	Pesticidal properties	[100], [247]

Some fungi, on the other hand, appear to be naturally resistant to copper and should be the target of future wood preservative formulations to extend the life of wooden structures in contact with soil while limiting environmental damage. Because copper is the only biocide that has substantial effects against soil-borne fungus, it is the most extensively used fungicide for treating wood in contact with soil [248].

This study seeks to characterize the plant extracts present in the leaves of *M.micrantha, G. sepium,* and *T.diversifolia* where *M. micrantha is* an invasive and the other two to be often found in Sri Lanka, and determine the atomic percentage of the chemical elements with the fungicidal, pesticidal and insecticidal potentials. The study also presents a chemical spectroscopic analysis using an analytical technique. Scanning electron microscopic analysis and EDS analysis are used in conjunction with scanning electron microscopy (SEM) known to be the energy-dispersive x-ray spectroscopy. Finally, the results discuss the necessity of screening the chemical elements for the proper development of a naturally synthesized wood preservative.

4.14.1 Materials and methodology

Mango wood (*Mangifera indica); a hardwood collected* from Uva Province Badulla district.

A. Timber Specimen preparation and Extract preparation

The specimens were prepared free of knots, infection by mold, stain, or wood-destroying fungi of the size of 25 x 25 x 25 mm^3 (r x t x l).

The fresh leaves *Mikania micrantha*, *Gliricidia sepium*, and *Tithonia diversifolia* plant species were collected from Uva Province, Badulla district and placed in polyethylene bags, and transported to the Pro-green laboratory of the Civil Engineering Department The leaves were carefully rinsed with water to remove the dust. The fresh leaves were then weighted before the extraction process

Mud was collected from a nearby organic paddy field where the fresh leaves were plucked in Uva province Badulla district and placed in polypropylene containers and transported to the Pro-green laboratory;(Table 4-26), (Table 4-27).

Table 4-26; Test Type A (Indicates the composition of the solution composed of.

Number	Leaf type (100 g of dry weight)	Water content
Sample 1	*Gliricidia sepium*	3000 ml
Sample 2	*Tithonia diversifolia*	3000 ml
Sample 3	*Mikania micrantha*	3000 ml
Sample 4	*Tithonia diversifolia and Gliricidia sepium*	3000 ml
Sample 5	*Tithonia diversifolia and Mikania micrantha*	3000 ml
Sample 6	*Gliricidia sepium and Mikania micrantha*	3000 ml
Sample 7	*Tithonia diversifolia , Gliricidia sepium and Mikania micrantha*	3000 ml

Table 4-27; test Type B (Indicates the composition of the solution composed of).

Sample No.	Leaf type (100 g of dry weight)	Water content	Mud Content
Sample 8	*Gliricidia sepium*	3000 ml	1000 g
Sample 9	*Tithonia diversifolia*	3000 ml	1000 g
Sample 10	*Mikania micrantha*	3000 ml	1000 g
Sample 11	*Tithonia diversifolia and Gliricidia sepium*	3000 ml	1000 g
Sample 12	*Tithonia diversifolia* and Mikania micrantha	3000 ml	1000 g
Sample 13	*Gliricidia sepium* and Mikania micrantha	3000 ml	1000 g
Sample 14	*Tithonia diversifolia , Gliricidia sepium* and Mikania micrantha	3000 ml	1000 g

B. The concentration of the Solutions

When the solute in a solution is a solid, a mass percent (mass/mass), which is the grams of solute per 100g of solution, is a practical method to express the concentration.

$$\text{The percent by mass}(\%) = \frac{\text{mass of Solute}}{\text{mass of solution}} \text{x}100$$

C. Treatment of process

Fourteen glass tanks were labeled before the test as per the above table 2 and table 3. The leaves were cut into small pieces, water and mud is added as per the pre-planned ratio. The solution with the plant extract was then kept to 72 hours for water extraction and stored in glass containers until it is used. Five replicate specimens were dipped in each solution. Finally, the samples were taken to out at two different intervals of 15 and 30 days as per pre-determined predictions. The samples were then air-dried and then brought to university laboratories for spectroscopic analysis. Preparation of the aqueous extracts using plant leaves is done following Flow chart 1 and Flow chart 2.

D. Sample preparation for spectroscopic analysis

Assuming the solution has penetrated within the entire sample; (25 x 25 x 25 mm^3 cube sample) a 3 mm thick layer ;(25 x 25 x 3 mm^3) sample at the center of the cube were taken out. That sample was broken into 2 parts using chromium-free blades using a rubber hammer and a 2 mm layer was taken out as the final sample for the chemical investigation. Gold palladium plated to make the wooden sample conductive. Five points of each sample; 25 x 3mm x 2mm specimen were investigated. Also, pre-determined 3mmx 3mm x 2mm sample of each side (Figure 4-41).

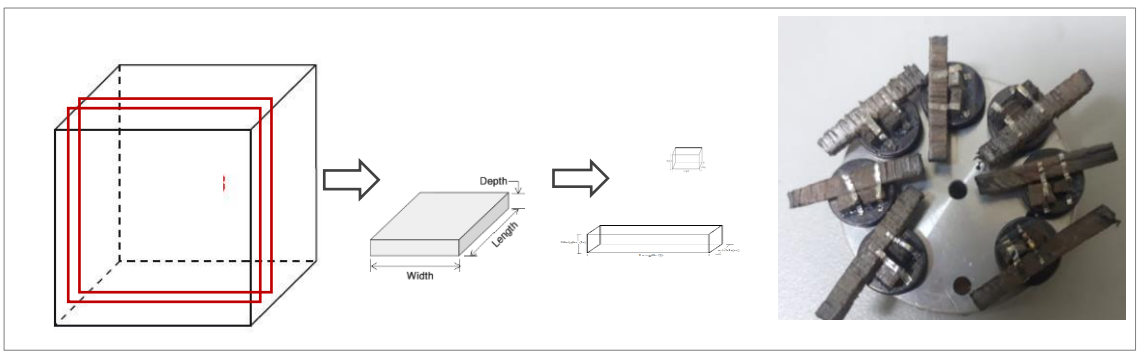


Figure 4-41; Schematic diagram of the sample selecting position, gold-palladium plated

representing the wood section plane (as transverse section, tangential Section, radial section) was placed before feeding the samples for the spectroscopic analysis.

E. SEM/ EDX *analysis*

There are three types of methods for determining the surface properties of wood: microscopic, spectroscopic, and thermodynamic. [249]. Surface morphology is determined by microscopic methods, while surface chemistry is determined by spectroscopic methods [104].

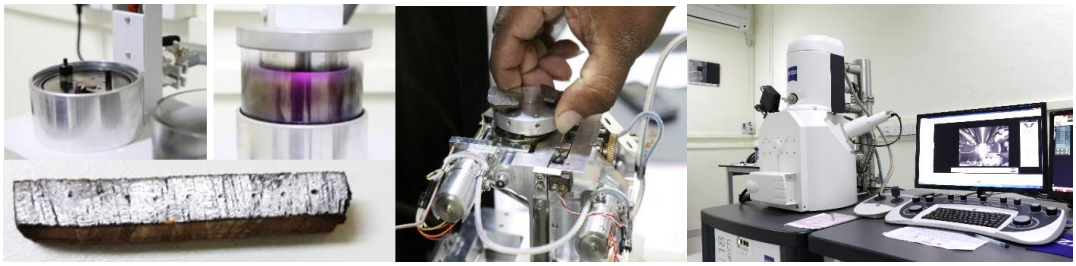


Figure 4-42; SEM analysis ,positioning the points

4.14.2 RESULTS

A. The concentration of plant extracted solutions

A significant variation of the concentration values was presented in the solutions developed using mud. Higher concertation values were presented in test type A, where the solutions were developed using mud and comparatively lower concentration values were obtained from the solutions developed without mud (test type B).

B. Using SEM in monitoring changes

This study attempted to examine the surface properties of wood using the scanning electron microscope to quantify changes in cross-sections. As radial sections presented a variety of types of cross-field pitting. Transverse sections of *Mangifera indica* wood presented types of growth rings, Semi-diffuse porous (gradual transition), and also, the vascular cambiums. Rays in longitudinal sections show very wide multiheritage rays (arrow) in mango wood (*Mangifera indica*). The scanning electron microscope (SEM) is one of the most versatile tools for examining and analyzing the morphology of microstructures. (Figure 4-43)Indicates a comparison between test type A and test type B. The high magnification images of the tangential planes specify there is a tiny particle

present at the spaces of the multi seriates. Which gives a clue on mud particles or any substance that has been penetrated among the seriates also there are visually seen tiny particles available to be seen on the rays.

Flow chart 1- Test Type A; test procedure

Add the fresh weighted leaves into the glass tank ($0.00354m^2$) and add 3000 ml tap water with 1000 mg of paddy mud .

Then place these tanks in average room temperature **27.0 °C**

After 3 days (leaf extracted solution) submerge the prepared raw (high moisture) defect free samples into the solutions.

Then let the green or raw sample to be submerge in th solution for 15 days

Take out the samples and air dry

Add fresh weighted leaves into the glass tank ($0.00354m^2$) with 3000ml Normal water .

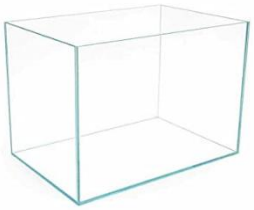
Then place these tanks in average room temperature **27.0 °C**

After 3 days (leaf extracted solution) inserst the prepared raw (high moisture) defect free samples into the solution

Then let the sample to be dipped in th solution for **30 days**

Take out the samples and air dry

1.



152.4 mm x 152.4 mm 152.4 mm Sized tank

Measuring cup with normal water

2.



3.



Weighted leaves



Weighted mud

Main materials required for the solution preparation

Flow chart 2- Test Type B; test procedure

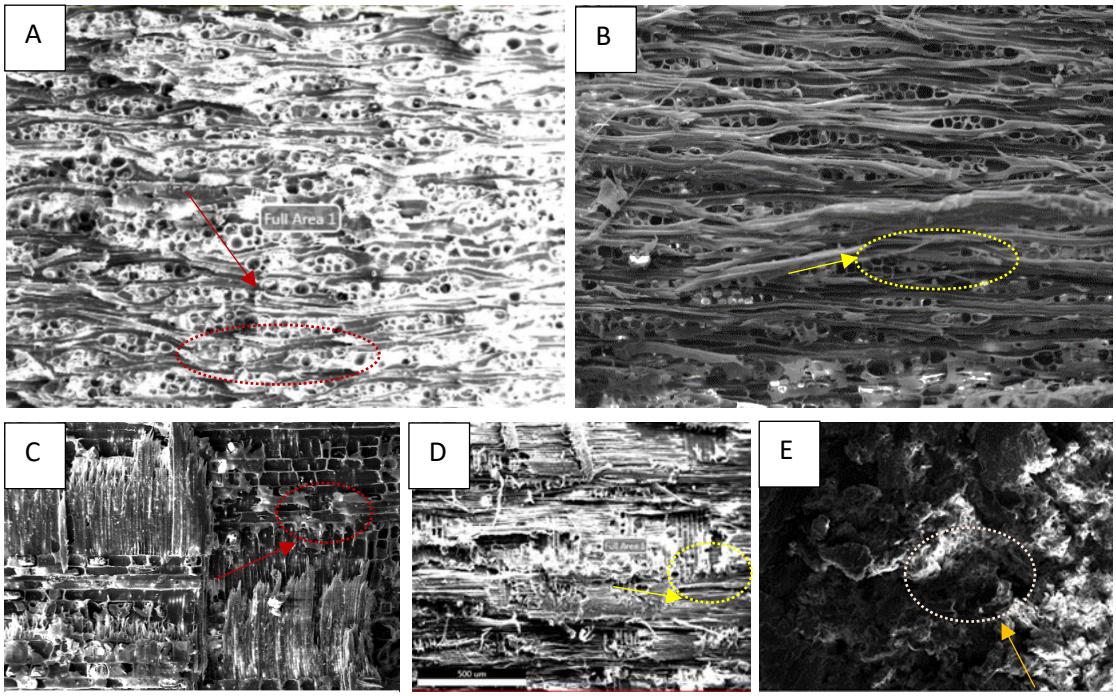


Figure 4-43- Comparison on the section to observe the penetration

4.14.2.1 EDAS RESULT

The results of the timber specimens treated under test type B presented the atomic percentages of the 13 elements (excluding carbon, nitrogen and oxygen).

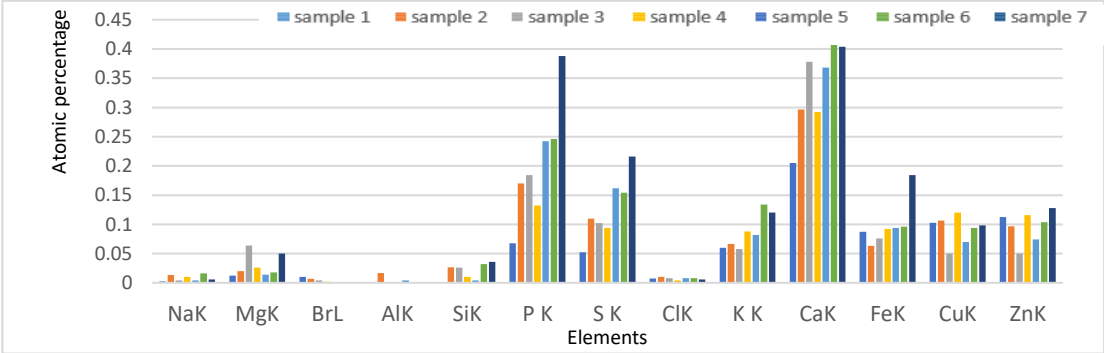


Chart 4-14- Atomic percentage analysis of sixteen elements; Sample 1 to sample 7

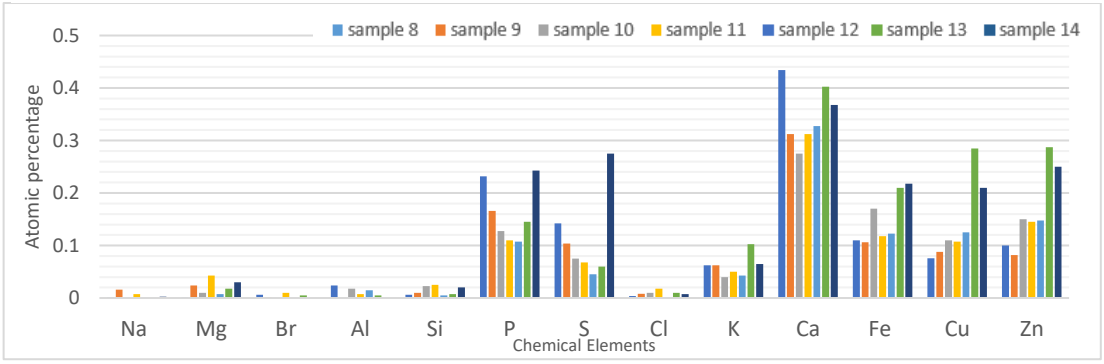


Chart 4-13-Atomic percentage analysis of sixteen elements; Sample 8 to sample 14

Sample 2, sample 3, Sample 5, Sample 6 presents a substantial atomic percentage of Sulphur. Sample 7 presents a significant level of atomic percentage of Sulphur existing on the treated wood. Comparing the timber specimens treated with solutions developed with each one leaf extract per solution as in Sample 1, sample 2 sample 3. sample 2 (*Tithonia diversifolia*) and sample 3 (*Mikania micrantha*) presented significantly higher amount or element Sulphur.

Sample 5 represents the timber specimen treated with the solution developed with the combination of *Mikania micrantha* and *Tithonia diversifolia* plant extract presented the

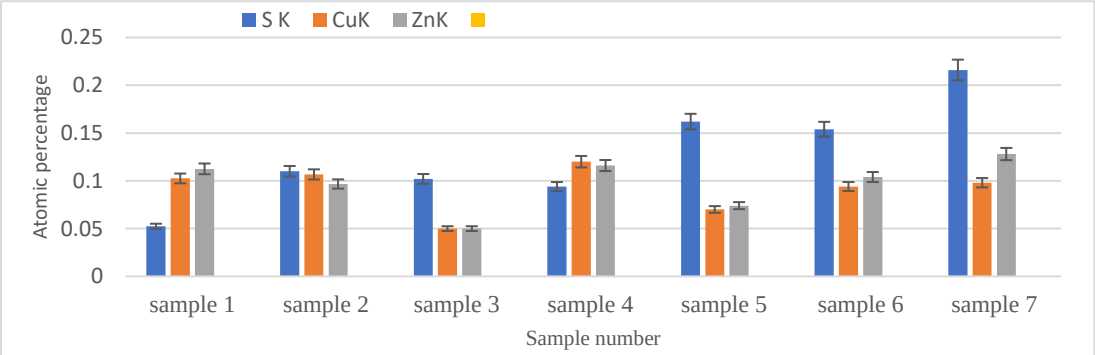


chart 4-16; Atomic percentage analysis on three selected elements; Sample 1 to sample 7

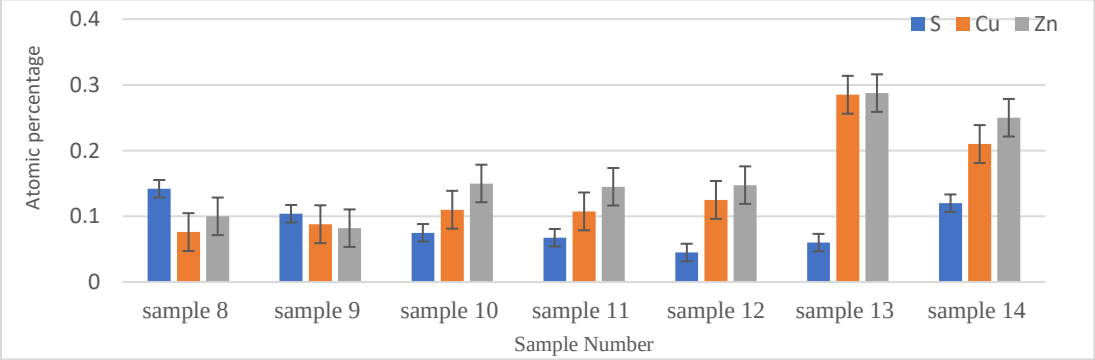


chart 4-15; Atomic percentage analysis on three selected elements; Sample 8 to sample 14

Sulphur atomic percentage higher than the values obtained in sample 2 and sample 3. It is interesting on the Sulphur availability present in Sample 2 (*Tithonia diversifolia* 100 g) and Sample 3 (*Mikania micrantha*100 g).

Hence sample 2 and sample 3 can be predicted as rich sources of Sulphur through 100 g *Tithonia diversifolia* and *Mikania micrantha*. Comparative to all seven samples, sample 7 (*Tithonia diversifolia* 100 g, *Gliricidia sepium* 100 g, and *Mikania*

*micrantha*100g) states an improvement in the average atomic percentage of all three Sulphur, copper, and Zinc.

The above charts illustrate on the Sulphur a copper atomic percentage presented in the samples treated with the solution mixed with paddy field mud. The sample has significantly presented a high atomic percentage of Copper and Zinc elements However the Sulphur atomic percentage is low. However, Sample 14 has maintained a moderate atomic percentage of Sulphur, copper, and Zinc elements.

Test type A identifies sample 7 (*T. diversifolia* 100 g, *G. sepium* 100 g, and *M.micrantha* 100g with 3000 ml of water) as the sample which contains the highest average of Sulphur and Zinc a mid-high average of copper. Sample 14 (*T.diversifolia* 100 g, *G.sepium* 100 g, and *M. micrantha* 100g with 1500 ml water with 1000 g of mud) represents a less percent of Sulphur comparative to sample 7 (*T. diversifolia* 100 g, *G. sepium* 100 g, and *M. micrantha100g* with 3000 ml of water) and a comparatively high percentage of Copper and Zinc.

Table 4-28 presents the data are means ± standard deviation of existing in five sample points, determination on the atomic percentage

	sample 1	**sample 2**	**sample 3**	**sample 4**	**sample 5**	**sample 6**	**sample 7**
Element	Atomic %	Atomic %	Atomic %	Atomic %	Atomic %	Atomic %	Atomic %
S	0.0525±0.01	0.11± 0.026	0.102± 0.05	0.094± 0.06	0.162±0.158	0.154±0.048	0.216±0.042
Cu	0.1025±0.01	0.106667±0.09	0.05±0.018	0.12±0.134	0.07±0.0324	0.094±0.043	0.098±0.0164
Zn	0.1125±0.01	0.096667±0.064	0.05±0.027	0.116±0.14	0.074±0.037	0.104±0.042	0.128±0.0319

The following tables present the data are means ± standard deviation of existing in five sample points, determination on the atomic percentage; (Table 4-28), (*Table 4-29*).

Table 4-29 presents the data are means ± standard deviation of existing in five sample points, determination on the atomic percentage

	sample 8	**sample 9**	**sample 10**	**sample 11**	**sample 12**	**sample 13**	**sample 14**
Element	Atomic %	Atomic %	Atomic %	Atomic %	Atomic %	Atomic %	Atomic %
S	0.142± 0.04	0.104± 0.02	0.075± 0.02	0.0675± 0.01	0.045± 0.02	0.06± 0.01	0.12± 0.0514
Cu	0.076± 0.04	0.088± 0.05	0.11± 0.02	0.1075± 0.06	0.125± 0.05	0.285± 0.10	0.21± 0.1529
Zn	0.1± 0.03	0.082± 0.03	0.15± 0.02	0.145± 0.05	0.1475± 0.06	0.2875± 0.09	0.25± 0.2001

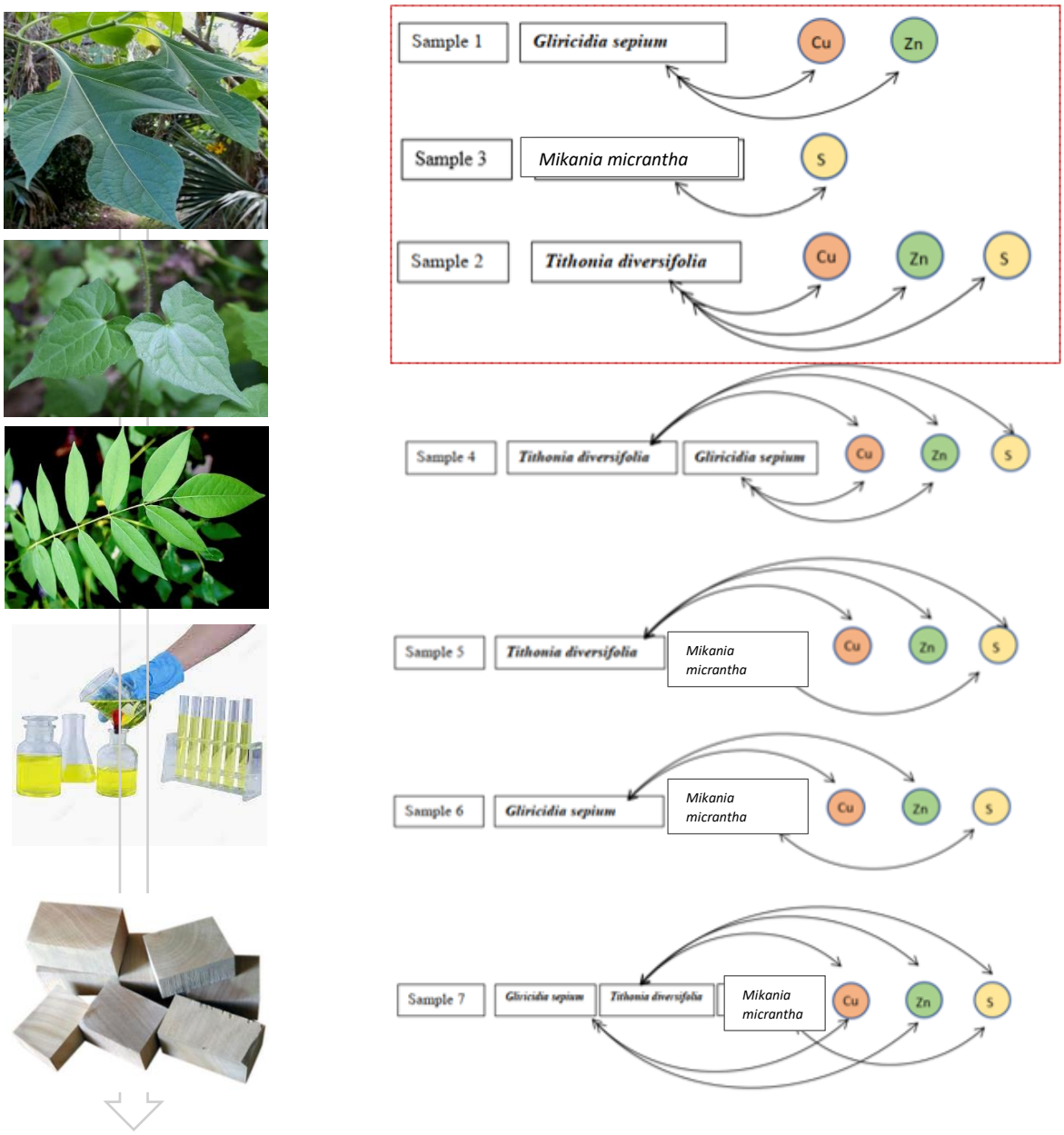


Figure 4-45;EDS/EDX Microstructure Interpretation: Energy -Dispersive X-rays Spectroscopy Analysis

4.14.3 Discussion

Although the images and data obtained from the SEM investigation show morphological changes in the treated mango wood specimens, they also show chemical composition alterations. As a result, investigations based on SEM examination seek to determine the varied conditions of the samples, clearly revealing a different SEM image obtained in test Type B on the tangential section displaying a variation on the multi seriates. However, the sample set of the same test type didn't illustrate a quantifying dissimilarity.

It was observed higher the ratio of *T. diversifolia*, and *G. sepium* leaf extracts used represented a comparatively high percentage of Copper and Zink atomic percentage penetrated within the treated mango wood (*Mangifera indica*) sample while higher the ratio of *T. diversifolia* and *M. micrantha* represented comparatively higher percentages of Sulphur in the treated mango (*Mangifera indica*) wood sample. Although copper is not as poisonous or mutagenic as arsenic or chromium, there are still certain environmental problems [105]. The resulting distribution of the chemical elements in the treated samples contains a "considerable" proportion of toxic chemical elements against wood deteriorating agents.

This study determines sample 6, sample 7, and sample 13, sample 14 as the recommended samples that comprise high atomic percentages of stated toxic chemical elements such as Copper, Zink, and Sulphur for further investigations on its performance. Copper is an important trace metal for living creatures, yet at high doses, it is hazardous.

Also, this study proposes that this data is useful for deriving an acceptable daily intake for less environmental effect with high toxicity for wood deteriorating agents to further develop these as wood preservatives, (Figure 4-45).

Based on the above results and discussion the study highlights the below points to further investigations.

- The study denotes that rather than developing solutions with each plant extract it had presented optimum toxicity when the solutions developed with the combinations of the three plant types.
- Therefore, this highlights there is a necessity to identify the best composition of the solution. The exact mixing ratio of the plant extracts.

4.15 The Field Evaluation of Potential toxicity Against the Invasive Subterranean Termite (Isoptera: Rhinotermitidae) in tropics

One of the potential characteristics of structural wood to consider for service life planning and life cycle assessment is its durability. [252]. As wood preservatives, a variety of chemicals have been proposed. Some have shown to be somewhat beneficial, while others have not. A few have shown to be effective in some situations. However, have failed miserably in others. Some preservative compounds have proven to be nearly optimal for usage in one set of circumstances with a lack of qualities that would make

them acceptable in other situations. In short, every material recommended as a wood preservative thus far has some shortcomings or lacks in terms of permanence, toxicity, leach resistance, environmental acceptability, or cost. The durability of wood in ground contact is influenced by several elements, including substrate quality, climate, and soil microflora, all of which should be taken into account when evaluating the service life of wooden components used in the ground. Here Experiment 4-8 assumes the major mass loss during the experiment is due to termites.

Experiment 4-7; Continuous field exposure under natural conditions to evaluate the performance of the treated wood.

4.15.1 Materials and methodology.

In-ground timber durability testing was carried out at a test facility at the University of Moratuwa. Durability Test for Treated Wood Exposed to termite attack was carried out to investigate the response of the treated *Mangifera indica* wood species.

A. Wood Specimen Preparation

Preparation of wood test samples, the samples of the dimension 30cm x 5cm x 5cm were made from each of 3 numbers from each treatment making a total of 48 test samples per species. The treated timber samples attain almost the same level of chemical absorption were seasoned to almost the same moisture content of about 10-12%. Visual assessment and a weight loss percentage of wood samples were obtained in the graveyard on the time duration of 3 months, 6 months, 9 months, 12 months exposure. the visual observations were rated as follows; The visual assessment of samples in respect of weight after treatment and weight loss at 3-month, 6 month, 9 months, and 24 months of exposure to biodegradation was also carried out.

B. Visual Evaluation respect to termite infections

Exposed wood samples were evaluated concerning decay every 3 months according to the rating scheme of EN 252 (1989). The rating explanation was as follows, 0 = no attack, 1 =slight attack, 2 = moderate attack, 3 = severe attack, and 4 = failure.

C. Visual Evaluation respect to fungi infections

Furthermore, the specimens were visually examined for brown rot, white rot, soft rot, and wood-destroying insects. The untreated *Mangifera indica* was used as the control

specimens, the defect-free wood specimens were treated as follows with 4 identical replicates.

4.15.1.1 Selection of the test sites

A pre-determined termite dense area was selected within the university premises,(Figure 4-46).



Figure 4-46;Selected sites , and half dipped wood

4.15.2 Results

The results presented as follows (Figure 4-47),



Figure 4-47; Mikania micrantha(lowest mass loss percentage - A, B , C, D ; Gliricidia sepium- A, B, C, D (highest mass loss percentage)- after 12 months

A. Treated time duration Vs Average weight loss percentage was graphed concerning the three plant species(Figure 4-48).

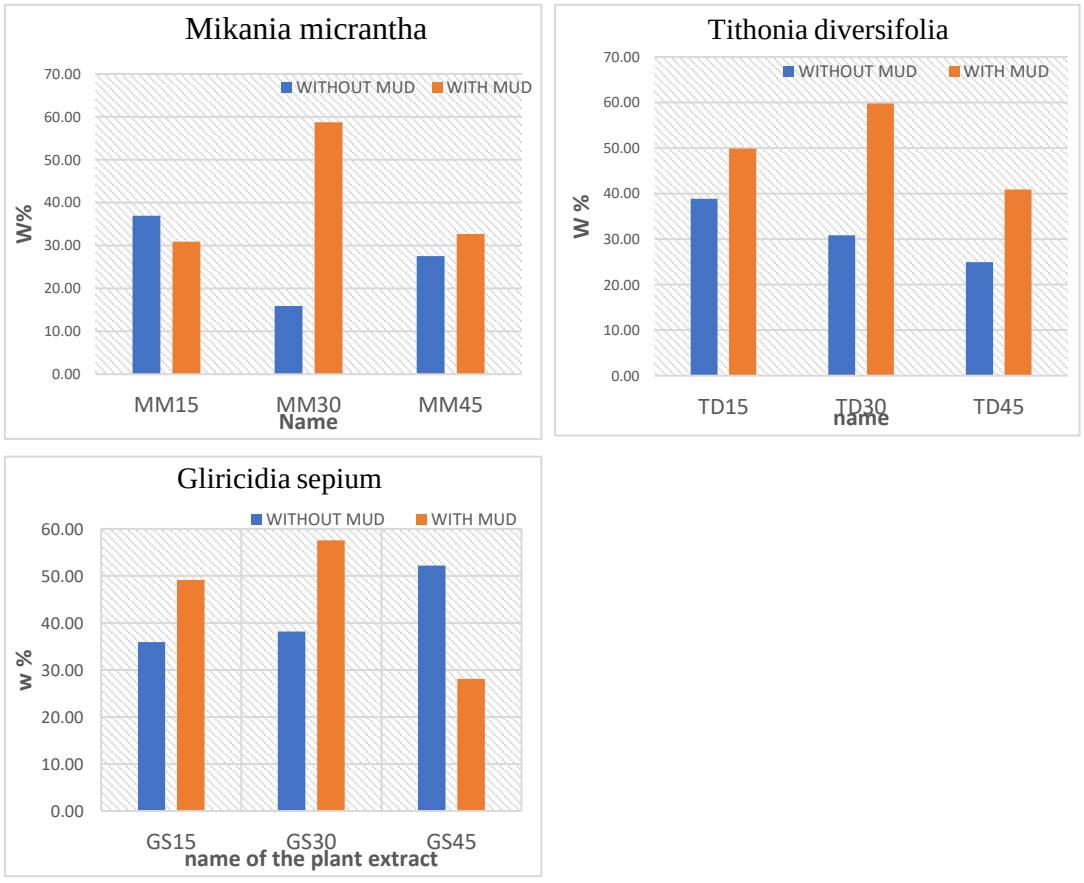


Figure 4-48; The weight loss percentage vs treatment duration ; submerged for 15, 30 and 45 days (M. micrantha , T. diversifolia, G.sepium)

A. *Treated time duration Vs Average weight loss percentage was graphed concerning the solutions developed with combined plant species*

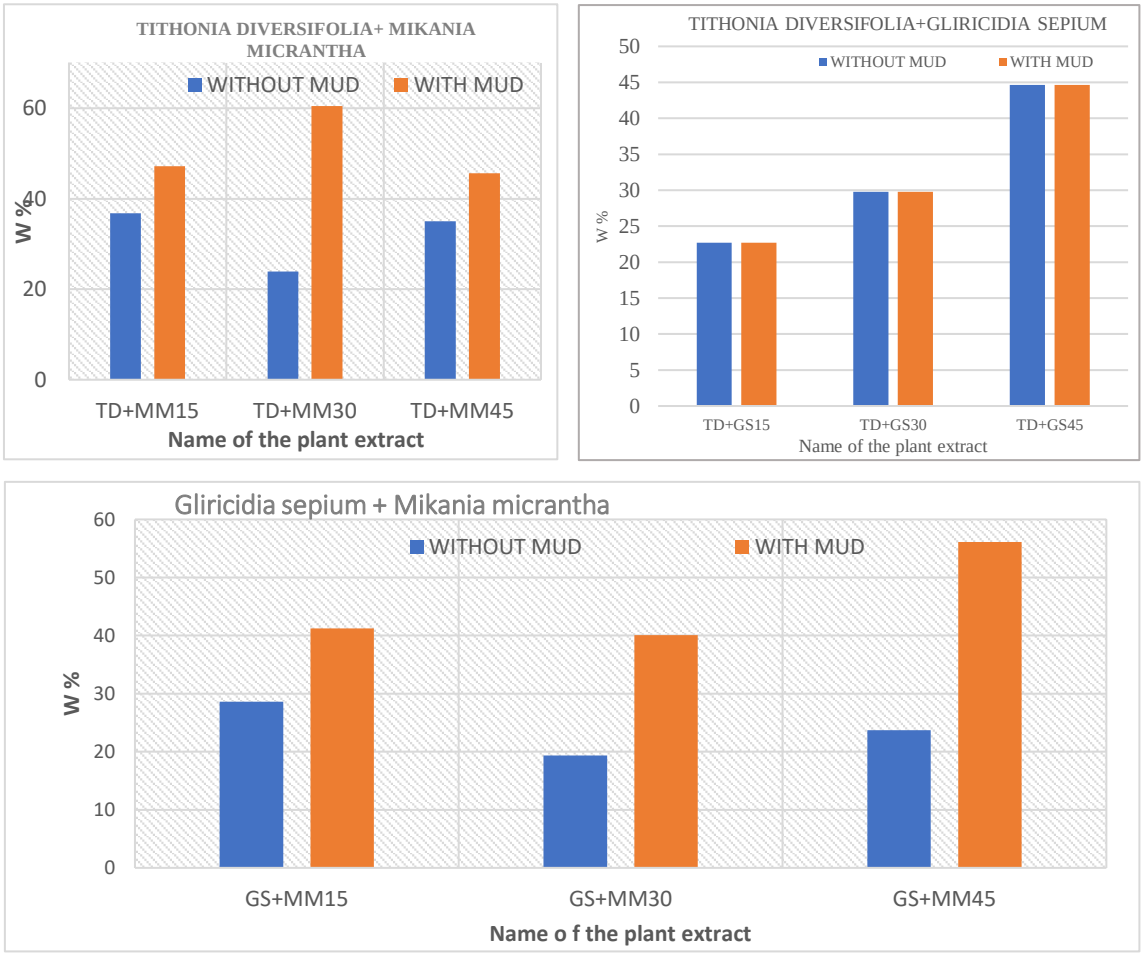


Figure 4-49; The weight loss percentage vs treatment duration; submerged for 15, 30, and 45 days (combinations of the three plant extracts)

B. Treated time duration Vs Average weight loss percentage was graphed concerning the solutions developed with combined plant species.

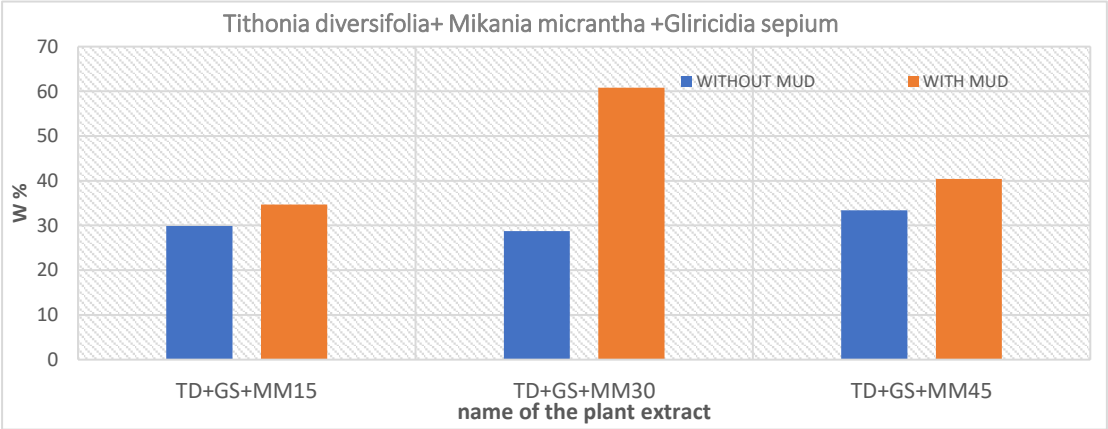


chart 4-17; Performance of the solution developed with all three plant extracts .

C. Best performance against the treated solution within 15, 30 days, and the 45 days treatment duration was presented as follows,

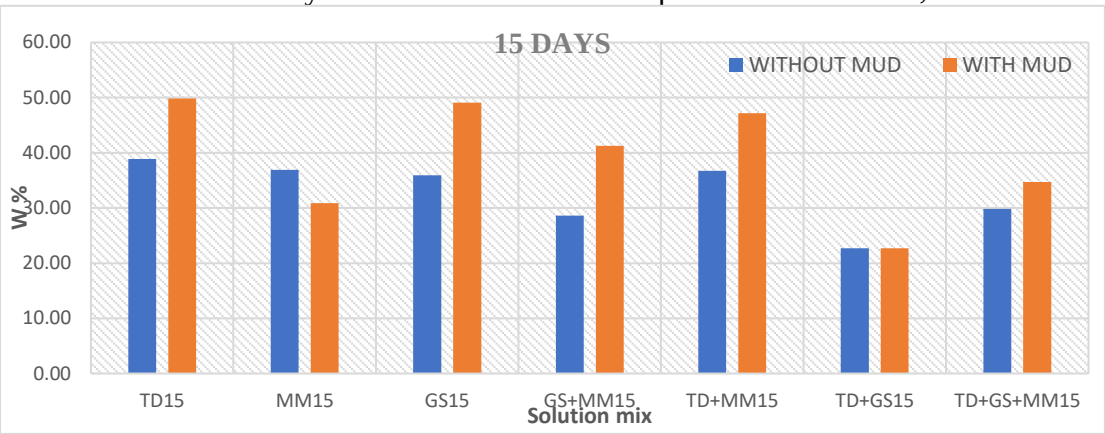


chart 4-20; treatment duration (15 durations) weight loss percentage.

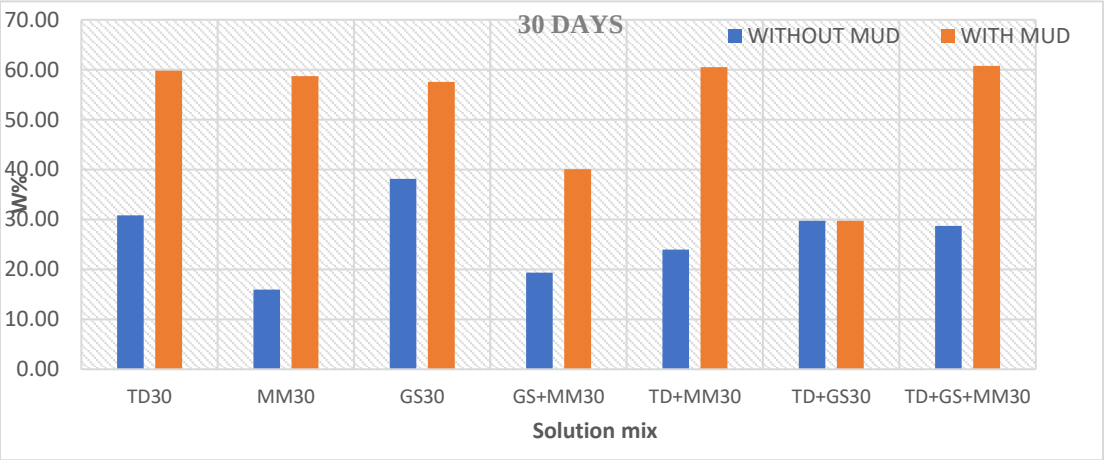


chart 4-19; treatment duration (30 durations) weight loss percentage

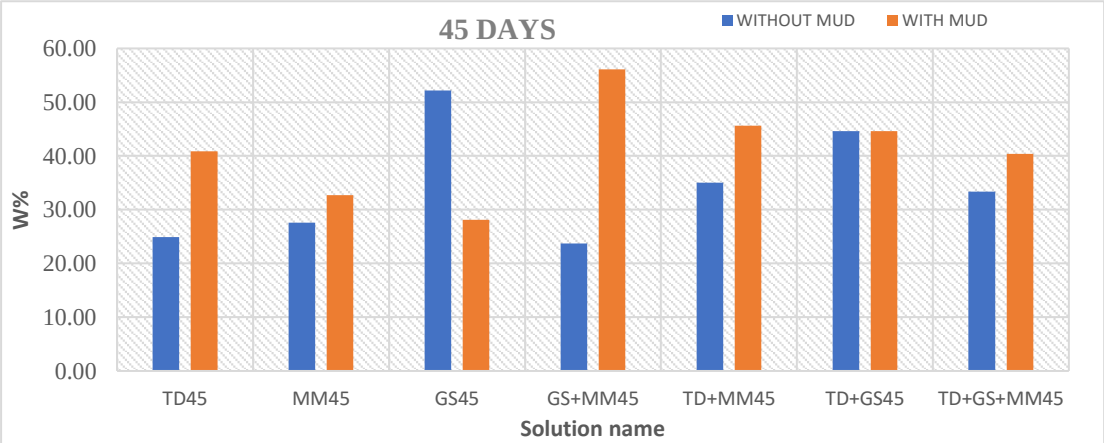


chart 4-18; treatment duration (45 durations) weight loss percentage

D. Timber treated without mud solution And the timber treated with the solution assorted with mud (chart 4-22), (Chart 4-21).

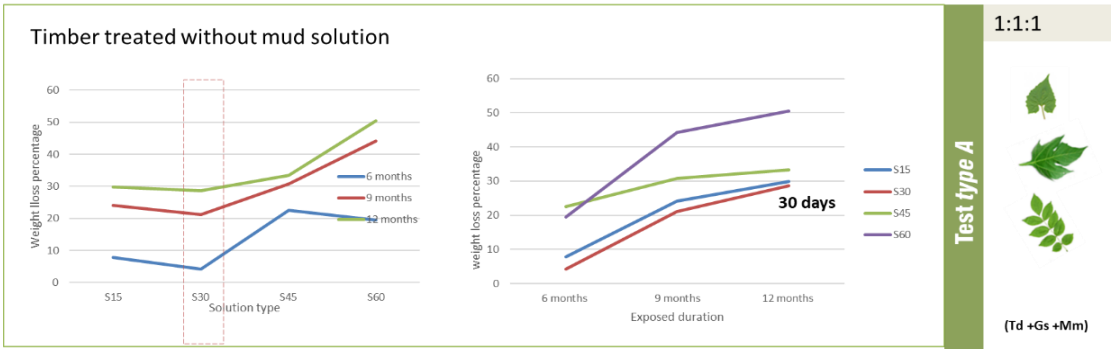


chart 4-22;weight loss performance vs solution type and the exposed duration for the field

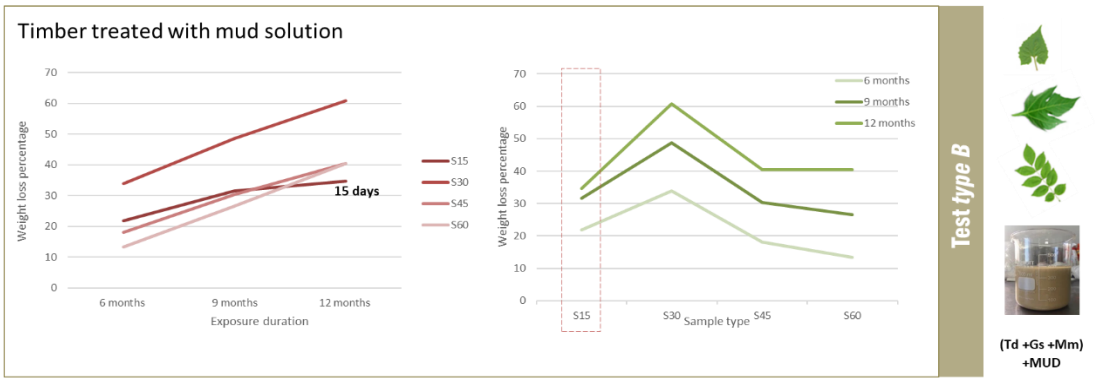


Chart 4-21;Weight loss performance vs solution type and the exposed duration for the field

The results disclosed, when the samples were long-term exposed might have decomposed as the 30 days treated wood with the mud assorted solution has the highest mass loss percentage compared to the wood treated with the only plant-based solutions for 15 days.

Therefore, this study emphasizes the necessity of identifying the optimum treatment duration for the particular treatment techniques.

E. Visual observation of the fungus growth observed on the wood surface.

The following (Figure 4-50) present the fungus growth presented on the wood specimens.



Figure 4-50; The fungus grown on the exposed wood



Figure 4-51;Schizophyllum commune

Among all, a fungus type was observed dominantly. By clear observations and the experts in the field, the dominantly present fungus was identified as was *Schizophyllum commune is* a species of fungus in the genus *Schizophyllum.*

The identified *Schizophyllum commune was* presented in the majority of the treated wood after 9 months. Considering the above, the study further investigated the performance of the toxicity of the solutions against fungus. Assess the treated wood to test and analyze the hesitant for possible mold, fungus growth.

- For further investigations, the dominantly found fungus type was taken; (Figure 4-52),

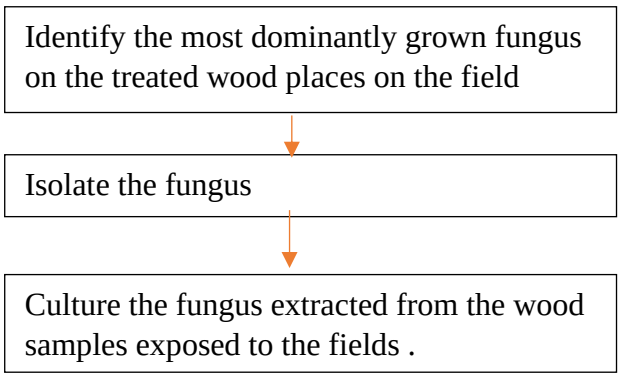


Figure 4-52; Flow chart presenting the process of the fungus isolation for further investigations

4.16 Evaluation of the antifungal activity of experimental solutions

Organic wood preservative solutions are known to prevent natural decay due to their biological activities against invading microorganisms. To resist these agents, the bioactive compounds obtained from plants are attractive approaches towards wood preservation. Development of formulations and treatment techniques derived from natural compounds could be the target of wood deteriorating organisms. The development of new organic biocides, as well as the creation and refinement of processes for using them to protect the wood, is progressing steadily [272].

Fungi inhabiting decaying wood are known as "Lignicolous" fungi [253]. They include the phyla Ascomycota and Basidiomycota, as well as a huge number of groups and

orders within each [254]. Decay fungi feed on oxygen, water, and wood as a carbon source. They comprise the biological activity holding their ability to degrade cellulose, hemicellulose, and lignin, the major components of wood. A widespread range of fungi arises on wood using various constituents for their metabolism. Among all the majority of common wood decay fungi are classified as basidiomycetes[255]. Basidiomycete decay fungi, which cause brown or white rot, are the microorganisms that cause the most structural alterations to wood and are also the most concerning for structural bio-based materials.

As a result, the study examines the structural integrity of construction materials such as wood predominantly utilizing representatives of basidiomycetes. Wood decay fungi include the two main types of basidiomycetes, known as white rots and brown rots, respectively (Table 4-30).

Table 4-30;Description about the white rot Fungi.

Types	Agent	color	Texture	chemistry
White rot	Basidiomycota	±bleached	Fibrous	Decays mostly lignin and secondary cellulose.

Experiment 4-8: Decay Resistance test (Evaluate the mass loss) Duration per completion of the test 12 weeks

4.16.1 Materials

The collection of plant materials and the fungal isolation has been conducted as follows,

A. Collection of plant material

Matured samples of *M. micrantha (Asteraceae*), *T.diversifolia* (*Asteraceae*), and *G. sepium* (*Fabaceae*) fresh plant leaves are collected from Moratuwa and transported to the pro-green laboratory. The identities of the samples were confirmed by the plant identification services, National Herbarium, Royal Botanic Gardens, Peradeniya (Figure 4-53).



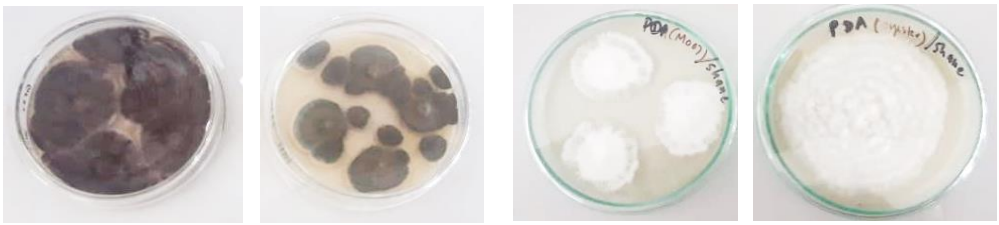
Figure 4-53;Sample submitted to the national herbarium , Royal Botanic gardens , Peradeniya

Table 4-31; Abbreviations of the samples used.

Aberration	Material matrix
A	All leaves (50 g of fresh plant leaves with 50 ml of water
R	Control – (Untreated raw wood specimens)
M	Only mud
G	Only Mikania micrantha
T	Only Titonia diversifolia
AM	All 50 g each with 100 g mud with 500 ml water
P	All leaves 500 g with 10 l water

B. Selection of test fungal isolates

Two well-identified white-rot Fungal isolates *Pleurotus ostreatus* (CODE M007), *Schizophyllum commune (*Code M008), and two common molds Aspergillus japonicas (CODE GF82), *Talaromyces purpureogenus* (CODE GF83) were used in this study. All the isolates tested in this study were generously provided by the Department of Biosystems Technology, University of Sri Jayewardenepura.



A. japonicus ***T. purpureogenus*** *S. commune* *P. ostreatus*

C. Wood material

Specimens were prepared from randomly selected defect-free mango wood (*Mangifera indica*). These were at 0.54 g cm-3 mean oven-dried densities. The study uses four replicates per treatment method.

4.16.1.1 Methodology

This type of decay is prevalent in both above- and in-ground contact situations. This preservative was evaluated after the wood is treated with this particular preservative solution to evaluate the effectiveness of the treated wood against the fungus. The BS EN 350 and EN 113 CEN, 1996 both aim to determine the natural durability of timber against wood-destroying fungi cultured on an agar medium. Agar block test used to evaluate the mass loss of the treated material exposed to the fungus with controls as the test criteria (Figure 4 47). Also, the comparison was done using three replicates using six untreated timber specimens. Parallelly three blank PDA plates were maintained for the complete evaluation process.

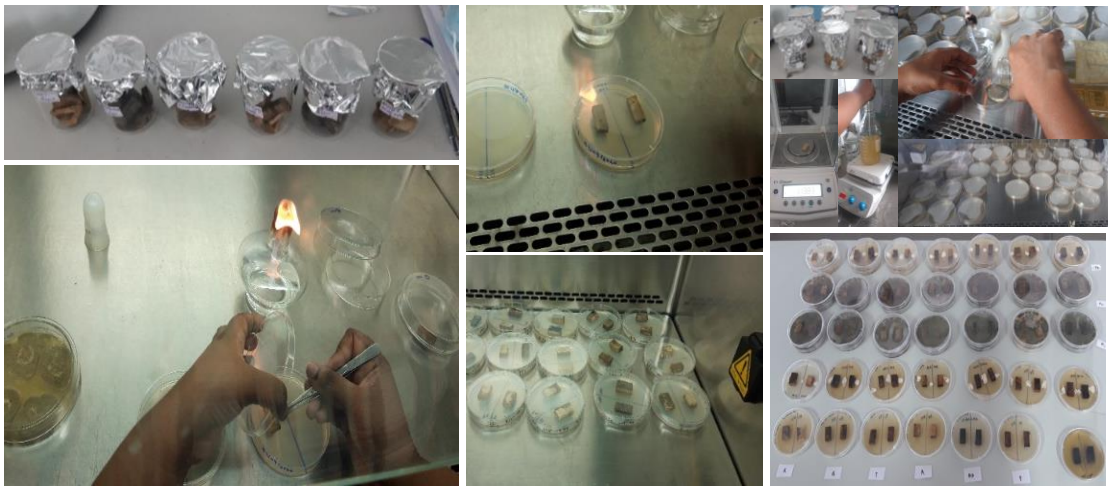


Figure 4-54; Sampling process, PDA filled petri dish preparation and the treated wood block placement

This relies on standardized conditions for moisture, temperature, light, and lack of competition for the decay organism and therefore provides optimal conditions for growth and attack by the organisms.

The test procedure is described below.

a. Preparation of woodblocks 30 x 10 x 5 mm^3.
b. Preparation of the solutions using the mud and the plant extracts.
c. All specimens were submerged in the relevant solution for 8 hours under pressure inside a vacuum desiccator. Then the samples were removed from the solution and air-dried for 3 days and oven-dried samples at 103±2 degrees Celsius for 6 hours and weighted in the accuracy of 0.001 g.
d. The wood samples were then autoclaved and then they were inoculated with a disc (85 mm diameter) of two samples per petri dish that contained 15 ml of PDA-culture (¼ of Potato dextrose dissolved with agar medium of 15 ml)
e. The treated *Mangifera indica* wood specimens were exposed to *Aspergillus japonicus, Talaramyces purpureogenus*; as the molds and the *Schizophyllum commune, Pleurotus ostreatus*; as the two white rot species.
f. A control sample without fungus was maintained and the fungus exposed samples are kept for continuous 16 weeks under the same environmental condition under room temperature.
g. Then the mass loss percentage was calculated and compared.
h. The average mass loss rate,

$$(AML\%) = \frac{W_{initial} - W_{final}}{W_{initial}} \times 100$$

(AMLR%) * of Wood Sample	Level Class Resistance to Test Fungus	Average Residual Weight (%)
0%–10%	Strong rot Resistant	90–100
11%–24%	rot resistant	76–89
25%–44%	slightly rot resistant	56–75
<45%	not resistant to rot	<55

Table 4-32; level class resistance to test fungus

4.16.2 Results and discussion

The results presented were concluded as per the ASTM D2017-05 standard.The results revealed the timber treated with the diluted solution (1:10); lowest concentration presented the Level Class Resistance to both the molds as rot-resistant against; *Aspergillus japonicus*, *Talaramyces purpureogenus* which is (AMLR%) * of 11%–24% weight loss. Also, it presented against Level Class Resistance to *Schizophyllum commune* (AMLR%) * of Wood Sample of 11%–24% weight loss presenting the rot resistance. and Level Class Resistance to *Pleurotus ostreatus* 25%–44% weight loss was indicated as slight rot resistance;

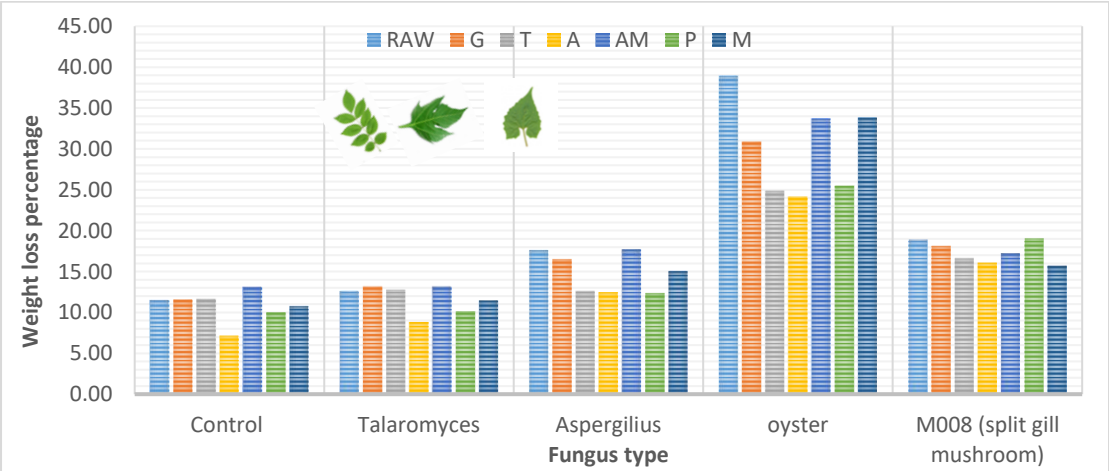


chart 4-23; weight loss percentage vs fungus types

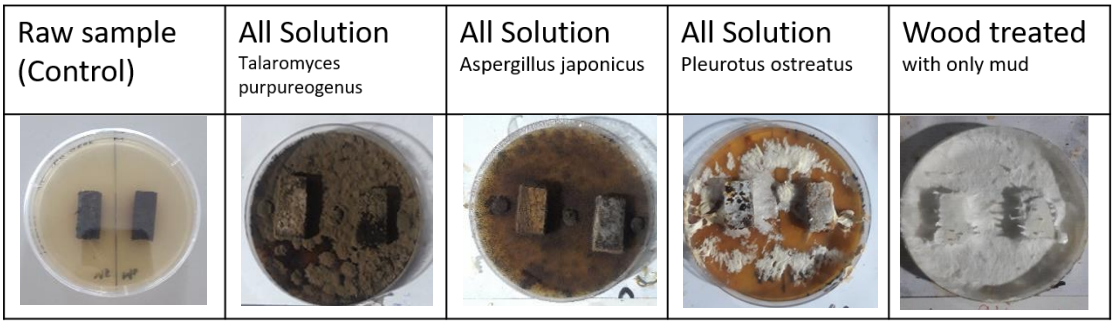


Figure 4-55;lowest weight loss percentages were presented as above

According to the literature, even with a mass loss of less than 5%, strength parameters such as work to maximum load, modulus of rupture (MOR), and modulus of elasticity (MOE) can be reduced by up to 80%, 40%, and 20%, respectively, resulting in considerable strength losses [215]. Based on the results study emphasize the extract should be further developed to a concentrated level.

- The solution should be further concentrated
- Mud treatment can be improved by plant leaves



	G	T	A	AM	P	M
Talaromyces	Rot resistance	Rot resistance	Strong rot resistant	rot resistant	; rot resistant	rot resistant
Aspergillus	Rot resistance	Rot resistance	Rot resistance	rot resistant	rot resistant	rot resistant
oyster	Slightly rot resistant	Slightly rot resistant	Slightly rot resistant	Slightly rot resistant	Slight rot resistant	slightly rot resistant
M008 (split gill mushroom)	Rot resistance	Rot resistance	Rot resistance	rot resistant	rot resistant	rot resistant

Figure 4-56; Summary of the experiments presenting the rot resistance

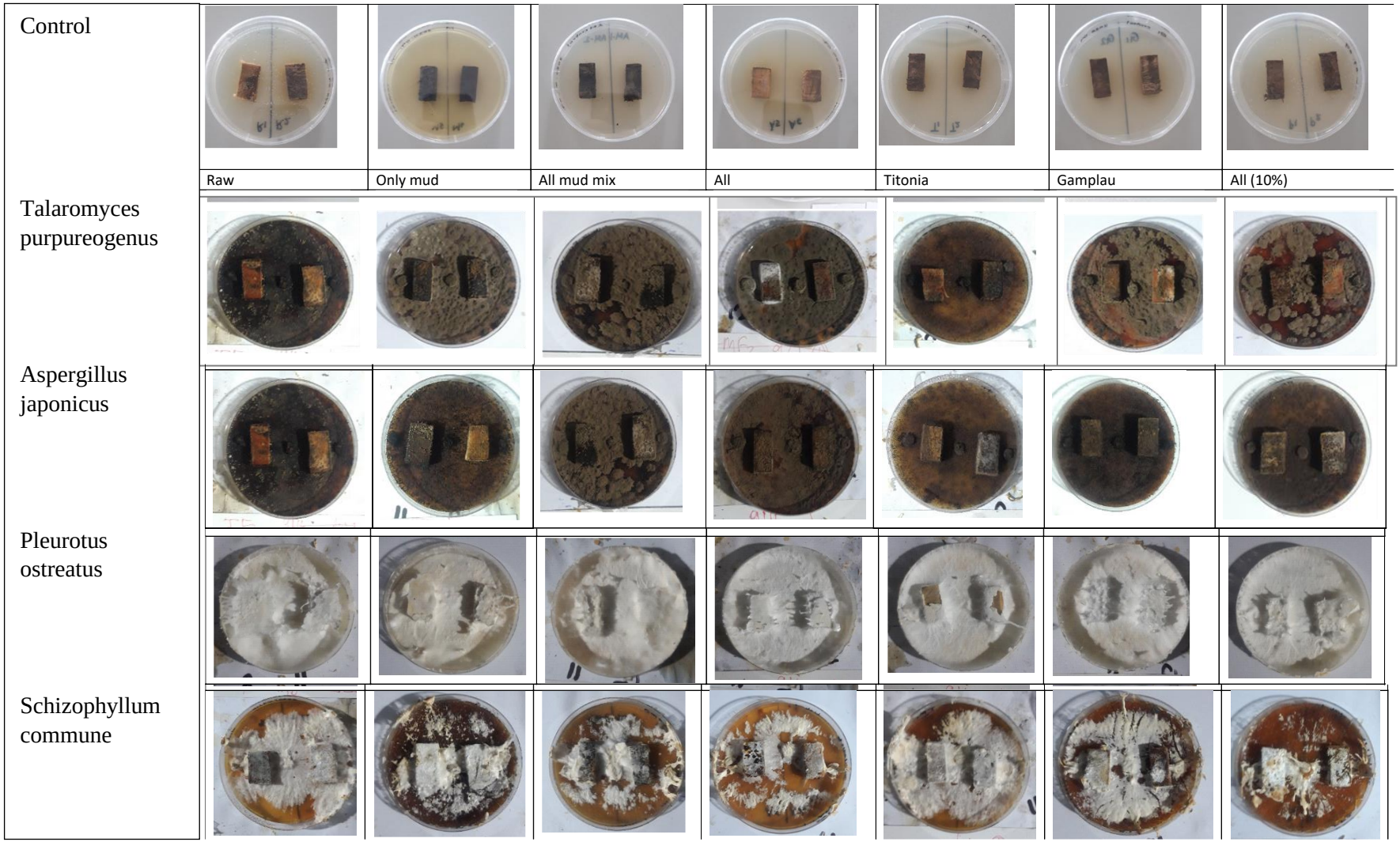


Figure 4-57; The treated wood specimens after 16 weeks exposed to the fungus; Comparison of the weight loss percentage of the treated wood exposed to fungus

4.17 Summary

In this study, the authors performed experimental work to evaluate the physical and mechanical properties of timber identified from the survey based on the traditional vernacular construction practice in Sri Lanka.



Figure 4-58; graphical abstract of the chapter summary

This study was chiefly embattled on the potentials of the utilization of *Mangifera indica* wood by comparing the availability performance and cost of the most abundantly available four types of wood species like Teak, Mahogany, Rubber, Alastonia. Mango is a hardwood with dense grains. The water absorption and thickness swelling test proves that Mango has the highest percentage of water absorption; on the other hand, it has a medium mechanical density with a medium mechanical performance meanwhile its swelling rate is low. However, mango usually stops bearing good fruit after approximately 7 to 8 years. When this happens, the tree is cut down, and the wood is used for other purposes. the mango wood with proper treatment can lead this wood to be utilized as a sustainable construction material in the wood industry for identified suitable applications.

Heritage timber structures are perfect living samples comprehending a preserved living proof of material utilization survived in a tropical climate. As a preliminary step for an investigation, a microscopic observation was conducted. To further analyze Energy Dispersive X-Ray Spectroscopy; a chemical microanalysis technique was used in conjunction with scanning electron microscopy (SEM). Survey results and analytical examinations conveyed knowledge that is not yet decoded who had experience in traditional vernacular timber construction practice. However, still, there should be useful ideas to be taken from their solutions. Therefore, results discuss the high

necessity of decoding and scientifically proving the value of the existed traditional vernacular practice in Sri Lanka that leads to another environmental innovation in the future that navigates societal transitions through evidenced knowledge.

Here the study identifies *M. micrantha*, *T. diversifolia*, and *G. sepium* as the three potential plant sources for preservative development.

Further, the study evaluated the experimental design based on the decoded information and then evaluated them as the graveyard test and the laboratory test, SEM- EDAS analysis, and the mechanical performance.

Based on the results of Experiment 4-1, Experiment 4-2, Experiment 4-3, Experiment 4-4, Experiment 4-5, Experiment 4-6, Experiment 4-7, Experiment 4-8, the study denotes that rather than developing solutions with each plant extract it has presented optimum toxicity when the solutions developed with the combinations of the three plant types.

Therefore, this highlights there is a necessity to identify the best composition of the solution. The exact mixing ratio of the plant extracts.

The study also identifies *M.micrantha* fermented extract with the highest potential for toxic extraction.

CHAPTER 5 : DEVELOPMENT OF THE SOLUTIONS

5.1 General

The primary goal of a preservative used for wood is to prolong the life of the wood. A rising amount of evidence suggests that a wood preservative chemical's potency, or combination of compounds, is influenced by the type of wood substrate in which it is employed and how it is utilized afterward. Plants, as well as their extracts, exhibit biocidal properties which contain in the form of metabolites, bioactive organic molecules are produced. The secondary metabolites were reported to have effective antifungal, insecticidal properties. Many organic preservatives have been immerged using plant extracts. However, they have a lack of awareness among the wood industry as they comprise of few shortcomings of permanency, toxicity, leach resistance, environmental acceptability, or cost are some of the factors to consider. The agents responsible for deterioration can be physical, chemical, or biological in nature and include factors such as heat, fire, pollution, humidity, climate effects, the presence of highly acidic substances, friction with other materials, and biological agents. Many organic compounds such as plant extracts have been recognized as viable chemical preservative substitutes. Many researchers reveal the toxicity against the wood deteriorating agents involved during the service. Though the attention towards leach resistance and the heavy metals leached to the environment during service and after service is inadequate. This chapter evaluates the above-said parameters defining an exact solution composition with a defined extraction protocol.

5.2 Identifying the optimum extraction procedure

Every single living body processes various chemical compounds incorporated for survival and existence. The compounds of the biological system can be classified as below (Figure 5-1),

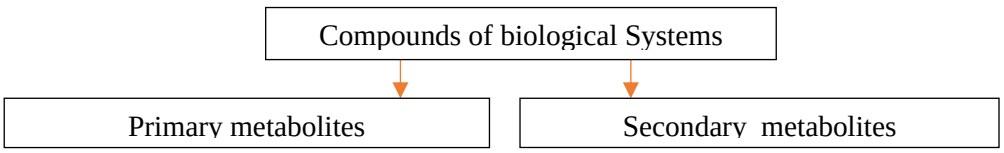


Figure 5-1; Flow chart on the classifications of the biological compounds

(a) *Primary metabolites* - The chemical substances intended for growth and development;

(b) *Secondary metabolites* - Group of compounds that allow the plant to interact with the surroundings to improve its ability to survive and overcome problems. [256],[121], [257].

A few of these metabolites are classified as bioactive compounds because they influence biological processes. Consequently, Secondary metabolites that have pharmacological or toxicological effects in humans and wildlife are referred to as bioactive chemicals in plants [257], [258]. Many literature findings present classifications for bioactive compounds. Croteau et al. (2000) state the list of plant bioactive chemicals and their classification [123], [259](Figure 5-2).

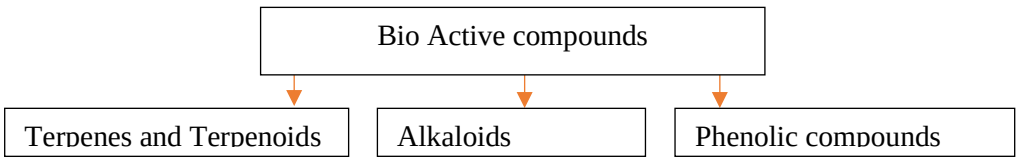


Figure 5-2; The classification of the bioactive compounds

(a) Approximately 25,000 types of terpenes and terpenoids

(b) Around 12,000 types of alkaloids

(c) Around 8000 types of phenolic compounds

Plant secondary metabolites such as glucosinolates, saponins, and broadly terpenoid phytoconstituents, such as essential oils and their components, are particularly attractive for pesticide formulations [260]. These nematicides can be used as plant extracts, phytochemical formulations, organic amendments, or model compounds for creating chemically produced derivatives [260].

5.3 Extraction Techniquess

Extraction is the term for the initial stage in separating desired natural products from raw materials [295]. The extraction principles describe the following extraction technique, (Figure 5-1).

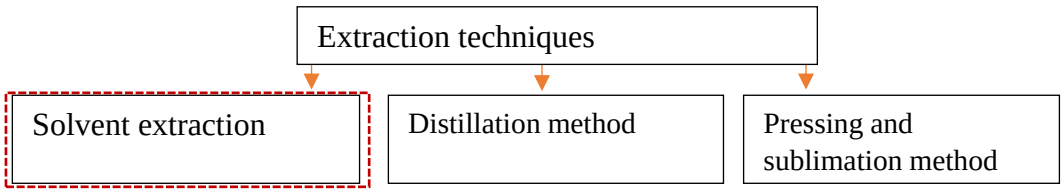


Figure 5-1; Flow chart representing the extraction techniques

Among the above, generally, solvent extraction is widely used. The following phases are elaborated in the product extraction process.

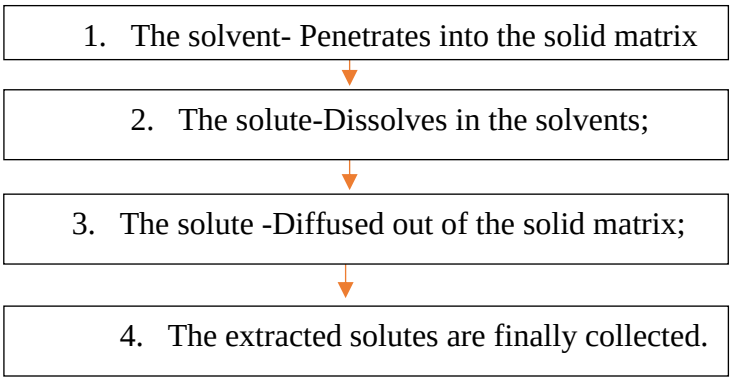


Figure 5-2; Flow chart representing the solvent extraction

5.3.1 The parameters that affect the extraction efficiency

The extraction efficiency that undertakes the diffusivity and solubility can be affected due to the solvent, solvent-to-solid ratio, the particle size of the raw materials, the extraction temperature, and the extraction duration [261]. Given the enormous number of plant species and the extensive spectrum of bioactive chemicals, a standard and integrated technique for screening out these compounds are needed. Only a suitable extraction method allows for further isolation, identification, and characterization of bioactive substances tracked (Figure 5-3).

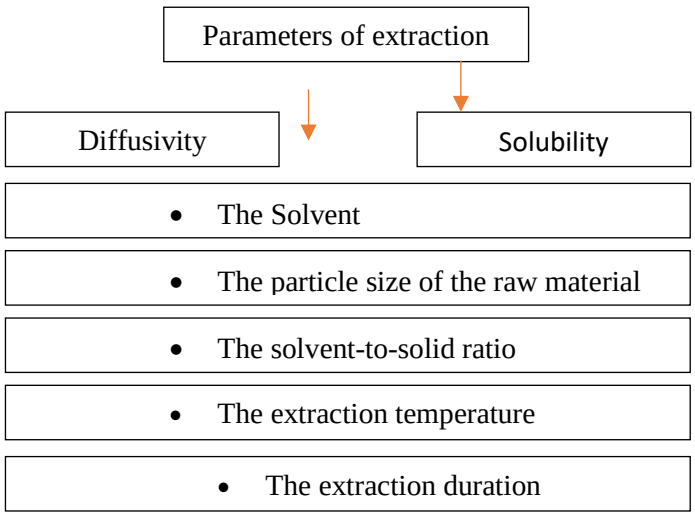


Figure 5-3; Flow chart representing the parameters of extraction

To understand the extraction procedures, selectivity from various natural sources, mostly plant origins, several extraction procedures should be applied in varied situations. The common objectives are,

(a) Targeted bioactive chemicals are extracted from complicated plant sources.

(b) To increase the selectivity of analytical methods

(c) By raising the concentration of targeted substances in the bioassay, the sensitivity of the test can be improved.

(d) To transform bioactive chemicals into a form that is easier to identify and separate

(e) To develop a robust and repeatable approach that is unaffected by changes in the sample matrix [262].

There are three primary types of traditional extraction procedures for extracting bioactive chemicals from plant materials, depending on the solvents used and the purpose [263](Figure 5-4).

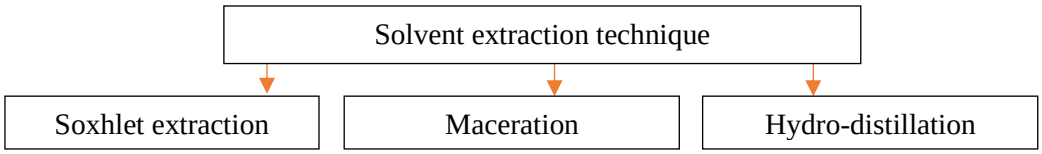


Figure 5-4; Flow chart representing the Solvent extraction techniques

A. Soxhlet extraction

It is known to be one of the most popular techniques for the extraction of analytes from solid materials. The benefit is that instead of passing multiple batches of warm solvent over the sample, only one batch is recycled [264].

B. Maceration

Maceration is known to be the general preparation of tonic for an elongated duration. It is one of the general and cost-effective methods to obtain essential oils and also bioactive compounds from plants. The steps are as follows,

(a) Initially the plant materials were ground into tiny particles to expand the area of the surface, this results in appropriate mixing with solute and solvent.

(b) Menstruum, a suitable solvent, is poured into a vessel that is closed.

(c) Liquid is then filtered to recover a significant number of occluded solutions from the solid deposit of the extraction process.

(d) Filtration is used to extract contaminants from the obtained filtrate and press-out liquid.

(e)In the maceration, infrequent shaking aids extraction in two ways;

1. Increase the diffusion
2. Remove the concentrated solution from the surface of the specimen to introduce a fresh solvent to the menstruum and increase extraction yield.

Many research works deliver as a useful guide to select the particle size and solvent to maximize extraction developed using the *G. Sepium, T. diversifolia, M. Micrantha*.

For the extraction of bioactive substances, water and various organic solvents such as ethanol, acetone, acetonitrile, hexane, and diethyl ether are commonly utilized [265].

The polarity of the solvents has an impact on the chemical constituents' solubility and extraction yield.

The extraction yield is also affected by the particle size of the plant. The smaller the material's particle size, the shorter the solvent's path must travel, reducing the time required for maximal phytochemical extraction.

Smaller particles have a bigger surface area, which allows for a faster mass transfer rate. Fonseca and colleagues (Fonseca et al.) [266], Grinding the selected part of the plant material indirectly destroys the plant cells, resulting in enhanced extraction. Baldosano et al. [132] and Roriguez-Miranda et al.[267] reported similar findings that,

- Finer particles produced a higher yield of tannin.

Gião et al (2009)[268], presents the effect of particle size based on the extent of extraction of antioxidant property of plant's Agrimonia eupatoria, Salvia sp. and Satureja montana.

- A smaller particle size led to a higher extraction extent; a typical value of 0.2 mm is accordingly recommended.

Tchabo et al (2018) [269], The study investigated the efficient use of water as a solvent. The influence of extraction temperature, particle size, extraction duration exposed to the solute and the solvent, water to leaf powder ratio, and extraction cycle on the nutraceuticals and antioxidant properties of aqueous extract mulberry leaf. As a result, the researchers looked at the effects of extraction temperature, time, water to leaf powder ratio, particle size, and extraction cycle on the nutraceuticals and antioxidant capabilities of mulberry leaf aqueous extract. Therefore the study identifies through literature that the temperature, time, particle size, and extraction cycle are the most important elements that influence extraction efficiency in terms of yield and quality [270]–[275].

Until now, nutraceutical components from the herbal plant have been extracted using solvents such as ethanol, methanol, acetone, water, and their combinations. Aqueous organic solvents are more efficient than water at extracting bioactive compounds from plant materials, according to research. Because of its low cost, non-toxicity, and environmental friendliness, water is still the commonly used solvent in the food and pharmaceutical trades.

- Therefore, the study identifies water as a potential solvent.

5.3.1.1 Concluding the facts above determines the extraction efficiency as follows,

The above literature review has been detected the following parameters as the highest influence factors to extraction efficiency.

A. The effect of extraction temperature

According to the literature, solid-liquid extraction at high extraction temperatures boosts nutraceutical yield due to its effect on diffusion coefficient (mass transfer), solubility (equilibrium), and stability of bioactive compounds [275].

B. The effect of extraction time

The extraction time on a solid-liquid extraction in arrears to its effect on solubility and mass transfer of bio compounds. These are associated with its structure and molecular weight. Yet, lengthy extraction time raises the possibility of Oxidation, Epimerization, and Degradation of bioactive compounds [276]. As a result, a long extraction period may not be suitable for all nutraceutical components [277].

C. The effect of Water to leaf powder ratio

When considering the liquid-solid extraction, The water-to-powder ratio has a significant impact on bioactive component extraction kinetics [271].

D. The effect of particle size

An increase in solubility and diffusion is caused by the reduction in particle size. The increase in surface area is available for mass transfer between the particle and the solvent. Yet this is due to this increase in the surface area accessible for mass transfer between the particle and the solvent [278]. As a result, the extraction rate has increased. [279], [280].

E. The effect of the extraction cycle

All of the above optimum extraction parameters were used to investigate the impact of numerous extraction cycles on nutraceutical components and antioxidant properties. Further to determine the effect of single, double, and triple extraction cycles on nutraceutical compounds and antioxidant properties. Defining required parameters to improve the extraction efficiency towards the development of the organic preservative.

F. Selection of solvent for bioactive compound extraction

Concluding the above literature, the extraction efficiency, and the polarity of the target compounds are mainly depending on the selection of the solvents. The main factors affecting the choice of solvent for the extraction of the bioactive compound are as follows,

The molecular affinity between solvent and solute,

a) Mass Transfer,
b) Use of co-solvent,
c) Environmental safety,
d) Human Toxicity,
e) Financial Feasibility,

As Cowan, M.M., (1999) presents in his study here are some examples of a bioactive compound extracted using different solvents; (Table 5-1).

Table 5-1; The solvents used for extractions

Water	**Ethanol**	**Methanol**	**Chloroform**	**Dichloromethanol**	**Ether**	**Acetone**
Anthocyanins	Tannins	Anthocyanin	Terpenoids	Terpenoids	Alkaloids	Flavonoids
Tannins	Polyphenols	Terpenoids	Flavonoids		Terpenoids	
Saponins	Flavonol	Saponoins				
Terpenoids	Terpenoids	Tannins				
	Alkaloids	Flavones				
		Polyphenols				

Source – [281].

5.3.2 Selection of the solvent for this research

Considering the above factors mainly because of the financial feasibility the study selects water as the solvent for further development of the organic solution.

5.3.2.1 Normal tap water

Water is made up of the chemical elements hydrogen and oxygen and can be found in three states: gaseous, liquid, and solid. An odourless and tasteless liquid at room temperature. Water's versatility potential solvent for living organisms. Although simple H_2O structure, the compound's physical and chemical characteristics are complicated.

A. Structure of water

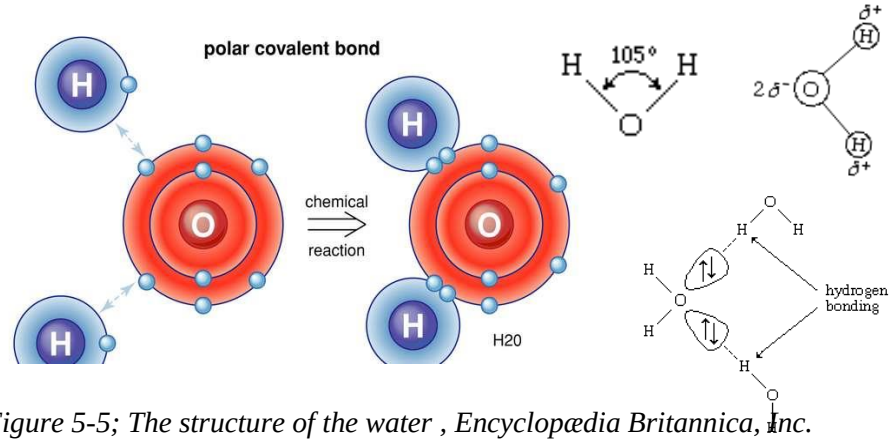


Figure 5-5; The structure of the water , Encyclopædia Britannica, Inc.

The water molecule is made up of two hydrogen atoms, these hydrogen atoms were linked by a single chemical bond to an oxygen atom. This has a total of eight electrons in it. The outer electron shell of oxygen is filled as two hydrogen atoms are bonded to it. The water molecule's uniqueness is that it is bent rather than linear. Among the three states of water, this study uses the liquid state of normal tap water(Figure 5-5).

A. Liquid water

Water has a very high viscosity, surface tension, heat of vaporization, and entropy of vaporization due to the low molar mass of its constituent molecules. The enormous range of hydrogen bonding interactions inherent in liquid water can be credited for all of this [282].

5.4 Investigating the plant leaf particle size for best extraction

Determining the importance of the particle size towards the extraction is as significant as determining the solvent. Subsequently, here the influence on the efficiency of the particle size towards the extraction yield is investigated. As per the concluded literature, the finer particles produced a higher yield of tannin. And also, the smaller particle size led to a higher extraction extent; where 0.2 mm particle size is accordingly recommended. This study wanted to identify the optimum extraction duration for appropriate particle size.

Experiment 5-1; Investigating the plant leaf particle size for best extraction to develop the solution

5.4.1 Effect of Particle Size on the yield extract

Obtaining a specific and accurate extraction protocol is so sensitive and challengeable within these researches. This yield obtained through plants can be enhanced by the use of the solvent, temperature, extraction technique, solvent: sample ratio, and particle

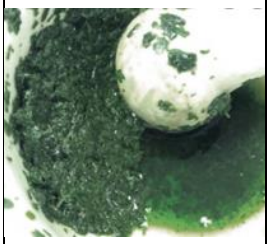
size[283]–[286]. The effect of particle size must be investigated independently for each phytochemical targeted and its extraction techniques. The stimulus of particle size of the fresh leaves used for extraction was investigated.

5.4.1.1 Materials and methods

The fresh plant leaves were used in the extraction procedure as below, three particle size ranges were selected to investigate the extraction efficiency and compare the extraction efficacy among the three plant species. The extraction efficiency (diffusivity and solubility) was evaluated by varying the plant type and the particle size by keeping the other factors constant.

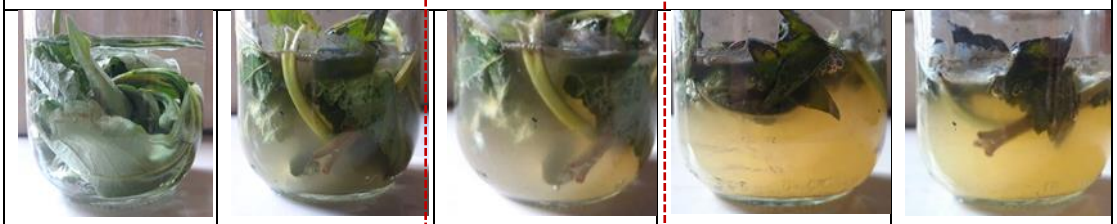
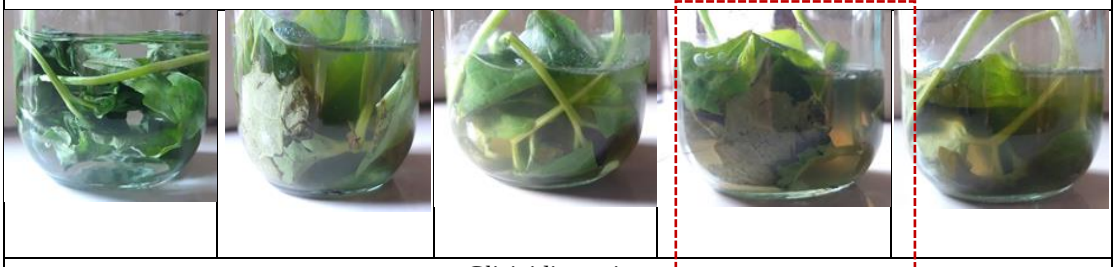
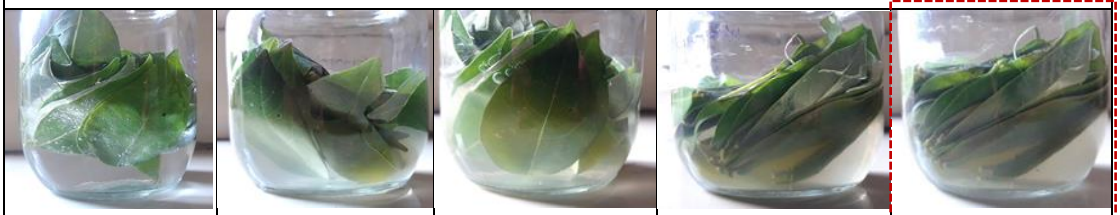
5.4.1.2 Results and discussion

Table 5-2; The plant matrix with different particle size

	Tithonia diversifolia	*Mikania micrantha*	*Gliricidia sepium*
Entire leaf			
10 mm – 20 mm			
1 mm – 2 mm			

The solvent, the solvent-to-solid ratio, the extraction temperature, pressure, and the extraction duration were kept constant. 50 g of fresh leaves were used for extraction. The solvent-to-solid ratio is 1 :1, the extraction was conducted under room temperature and the extraction duration was in 10 minutes, 24 hours, 72 hours, and 96 hours respectively.

Table 5-3; fermented duration and the particle size

10 min	24 hrs.	48 hrs.	72 hrs.	96 hrs.
Tithonia diversifolia				
				
Mikania micrantha				
				
Gliricidia sepium				
				

A. The leaves were chopped in the range of 10 mm – 20 mm.

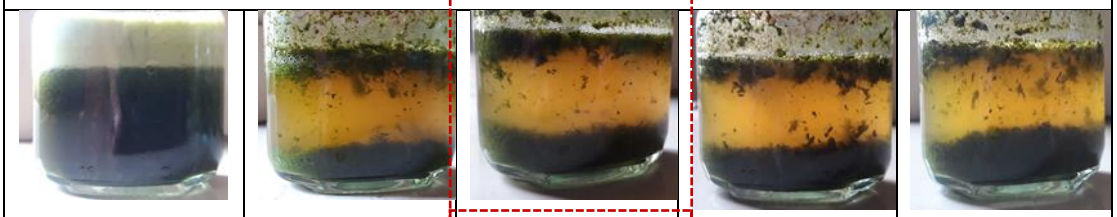
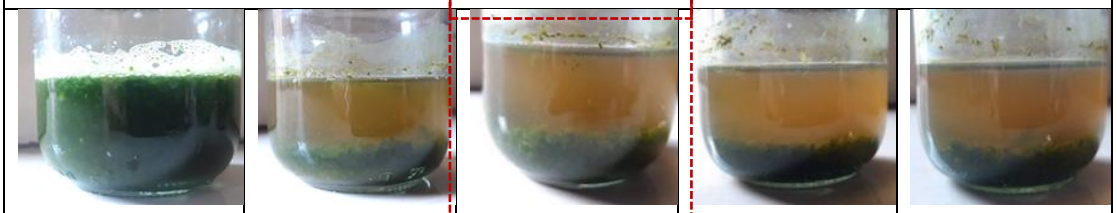
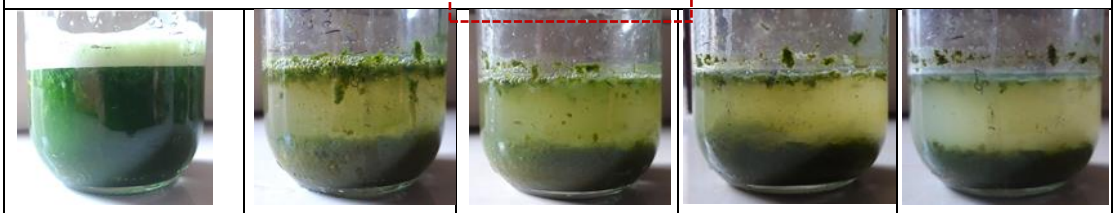
Table 5-4; Particle size and the fermentation time

10 mins.	24 hrs.	48 hrs.	72 hrs.	96 hrs.
Tithonia diversifolia				
				
Mikania micrantha				
				
Gliricidia sepium				



B. The leaves were ground in the range of 1 mm – 2 mm.

Table 5-5; The optimum fermentation time and the particle size.

10 mins.	24 hrs.	48 hrs.	72 hrs.	96 hrs.
Tithonia diversifolia				
				
Mikania micrantha				
				
Gliricidia sepium				
				

The extraction efficiency can be increased by minimizing the particle size when the other factors are constant. The visual observation and the visual rating revealed the extraction efficiency is significant among the plant species where the fastest leaf digestion was observed in *Titonia diversifolia* then in *Mikania micrantha* and the lowermost leaf digestion to water was observed in *Gliricidia sepium*.

Where when the entire leaf is introduced to the solvent the required extraction yield is obtained within 96 hours or more than especially to obtain the required extract of *Gliricidia sepium*. When considering the leaves crushed into 10 mm – 20 mm the required extraction yield is obtained within 72 hours. Then when the leaves were ground in the range of 1 mm – 2 mm and then introduced to the solvent the required extraction yield is obtained within 48 hours. The extraction duration can be reduced by

reducing the particle size. The plant leaves extraction protocol at this stage is maintained at room temperature under atmospheric pressure using water as the solvent. The smaller the particle size presented the harder it is to obtain a filtrate(Table 5-2), (Table 5-3), (Table 5-4), (Table 5-5).

5.4.2 Defining the extraction procedure

The extraction procedures were separately developed as of,

1. Experimental organic wood preservative developed with only the plant extracts
2. Experimental organic wood preservative developed with only the plant extracts assorted with mud.

Experiment 5-2; Defining an Extraction protocol to the solution assorted with mud and plant extracts and only plant extracts, Experiment 5-3

5.4.2.1 Materials Used:

Materials used in this experimental wood preservatives were fresh plant leaves of *Gliricidia sepium*, *Tithonia diversifolia,* and *Mikania micrantha* the main matrix, water as the solvent for the aqueous extraction. Paddy field mud is used to improve the properties of the solution.

Water: Normal tap water was used. **Paddy field Mud:** Paddy field mud was collected from an organic paddy field;

Mangifera indica defect-free wood is treated for investigations.

5.5 Development of the extraction procedure

The study develops two Solutions and two unique extraction procedures with similar preliminary steps (Figure 5-6),

Final Solution Without Mud (FSWOM)- The main matrix of the solution is only the three plant species; *Gliricidia sepium*, *Titonia diversifolia*, and *Mikania micrantha.*

Final Solution with Mud (FSWM) - The main matrix of the solution is the plant species (*Gliricidia sepium*, *Titonia diversifolia*, and *Mikania micrantha*) assorted with mud.

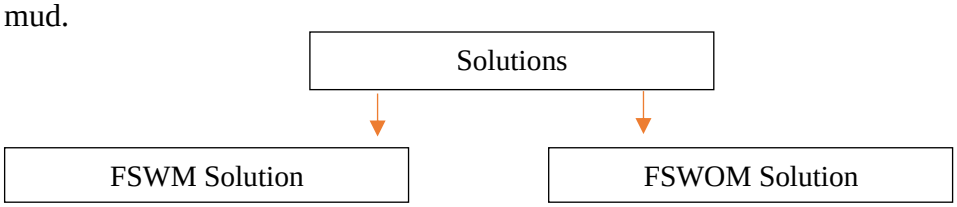


Figure 5-6; Flow chart representing the Solutions

5.5.1 Identify the best fermentation time

The best fermentation time was identified after 96 hours. The lowest leaf degradation was visualized in *Gliricidia sepium*. Significant extraction yield in *T. diversifolia* was observed in 24 hours, M. micrantha was observed in 48 hours and the G. sepium was observed in 96 hours (Table 5-6), (Table 5-7).

Table 5-6; The solution obtained from the leaf extracts within 3 extraction durations

24 hours	48 hours	96 hours
Tithonia diversifolia	*Mikania micrantha*	*Gliricidia sepium*
		

Table 5-7; The identified optimum extraction duration

48 hours	48 hours	48 hours
		

5.5.2 Identify the best filtration techniques

This is one of the main parameters of the entire research on defining the appropriate particle size under defined extraction duration to obtain an optimum extracted yield with a proper filtrate.

- **Filtration:** Filtration is a technique for removing solid contaminants from organic solutions. Further, define as isolating an organic solid.
- **Purpose of filtration:** By flowing water through a porous material layer, suspended particles are removed from the water. Straining and sedimentation are used to keep larger particulates out, while adsorption, coagulation, and sedimentation are used to keep colloidal materials out. Biological interactions

take place only when the water passes extremely slowly through the porous mass, (Figure 5-7).

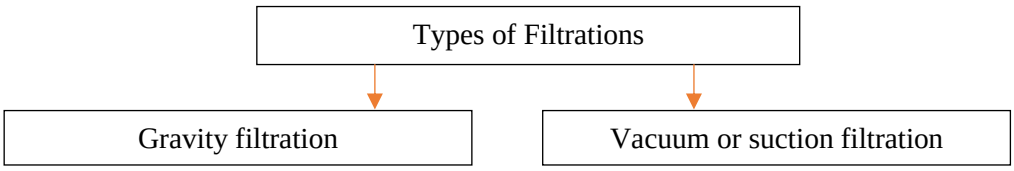


Figure 5-7; Flow chart representing of types of filtrations

5.5.2.1 The Specification of filtering Materials for Rapid-Gravity Filtration

A method for removing solid impurities from an organic liquid. A drying agent or a residual reactant could be the impurity. These techniques can be used to gather solid products. Even though vacuum filtration is utilized for this as it is speedier than gravity filtrating. The apparatus is made based on the fact that the solid impurities from the solution developed with the plant extract. This does not pass through the filter membrane.

5.5.2.2 Define the extraction duration and the filtering procedure for the study

Considering all the above facts the study concludes when smaller particle sizes are higher the extraction efficiency within a short extraction duration. However smaller the particle sizes the time allocated to the gravity filter is higher and it's challengeable. And when the sediments are not properly filtered, these may affect when the solution is used to treat the wood. The application of the solution with an improper filtration effect on an applied surface (rough textures as not a smooth application) and un-uniform colors and the main issue was highlighted due to potentials of molds growth on the applied surface if there were impurities (Figure 5-8).

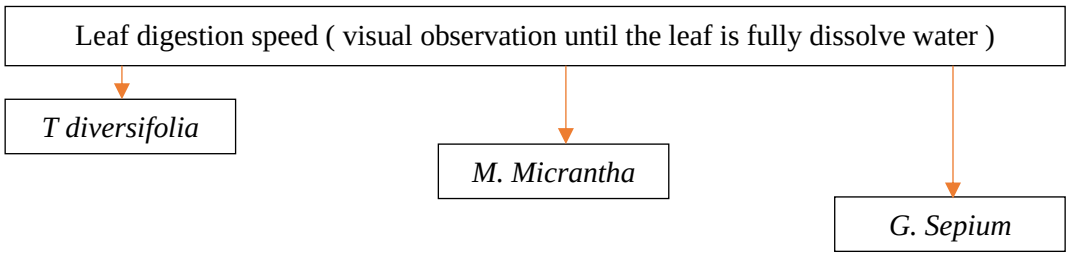


Figure 5-8; Flow chart representing the leaf digestion speed

Also, leaf digestion speed influences filtering. It's also hard to filter when the extraction duration is high. The digestion speed of *M. Micrantha* and *T. diversifolia* is high compared to *G. Sepium.* Therefore, it forms a slurry sludge (as a result of breaking the particles further into small particles) and decreases the filtration speed. So, the study

identifies after 48 hours the initial filtering should be conducted, and the filtrate is further kept to another 48 hours for further fermentation and then filter the solution and then taken for use.

5.5.3 Preparation of the paddy field mud.



Figure 5-9;Collection of mud from the organic paddy field

Generally, paddy fields are flooded fields of arable land used for growing semiaquatic crops. This soil does not refer to a specific soil type. This soil refers to soils that have been submerged for an incredibly long time. The phrase 'water regime' is used to divide soils' environments into wide-ranging ecosystems. Rice is generally grown in the lowlands, with irrigated and rainfed rice in the uplands, upland rice in aerated soil conditions in the uplands, and deep-water rice in flood-prone river deltas and coastal regions [287]. The intensification was together with the deviations in chemical, biological, and physical processes in the soil–floodwater system. Many researchers have discovered the influence on soil microorganisms in paddy fields.

The soil microbial population is involved in a variety of ecological services, including nutrient cycling and organic matter decomposition, as well as the terrestrial carbon cycle [288].

Here in this study, the mud was obtained from an organic paddy field assuming the lowest intensification of mud from alien compounds compared to the other inorganic



Figure 5-10 Removing the larger unwanted particles using sieves and the washed access of water .

fertilized paddy fields (Figure 5-9). The mud obtained from the field contains different unwanted materials like straws, stones, etc. Therefore, the mud is prepared before it is used. It is washed with normal water and sieved using a 2 mm stainless steel sieve to remove the larger and unwanted particles in it. The excess water was removed by using the tubes after sedimented within 24 hours, (Figure 5-10).

5.5.3.1 Mud (solute) to solvent (water): leaf proportion was determined as follows,

The Leaf extract to water was used as a 1:1 ratio. The filtrate was kept constant and the by weight mud was changed (Figure 5-11).



Figure 5-11; Mud solubility in plant extract dissolved in water as the solvent

Table 5-8; Ratio development Solute to solvent

Solution number	Mud (Solute)	Leaf extracted to water (Solvent)	Description of the extraction yield (96 hrs later)	Colouring capability
1	1	1	It was poor to obtain proper filtrations and moderate penetration	Poor
2	2	1	It was poor to obtain proper filtrations and moderate penetration	Poor
3	3	1	It was poor to obtain proper filtrations and moderate penetration	Slightly poor
4	4	1	It was moderate to obtain proper filtrations and moderate penetration	Moderate
5	**5**	**1**	**A clear filtrate can be obtained after 96 hours.**	**Significant**
6	6	1	It was moderate to obtain proper filtrations and moderate poor penetration as lack of carrier solvent	Moderate
7	7	1	It was hard to obtain proper filtrations and very poor penetration as lack of carrier solvent	Moderate
8	8	1	It was hard to obtain proper filtrations and very poor penetration as lack of carrier solvent	Moderate
9	9	1	It was hard to obtain proper filtrations and very poor penetration as lack of carrier solvent	Not significant

10	10	1	It was hard to obtain proper filtrations and very poor penetration as lack of carrier solvent	Significant

Solution Number five was detected as the significant component of the formula (Figure 5-9).

5.5.4 Development of the procedure

For easy reference for the further investigations this protocol is referred as protocol 1; 1:1:1 ratio of fresh green leaves

Protocol 1;Below procedure consists of steps from a to h. with

(a) Matured fresh green leaves are rinsed with normal water to take off unwanted dust particles. Remove the excess water after cleaning.

(b) The extraction efficiency is improved by minimizing the particle size to enhance the penetration of water and dispersion of the plant extracts. The matured fresh green leaves are crushed at approximately 1 mm finer particle size.

(c) Water is used as the solvent. This solvent diffuses into the cell to dissolve the desired plant elements.

(d) Next, the Paddy field mud is obtained from an organic paddy field. The mud is prepared before it is used. It is washed with normal water, sieved, and remove the larger and unwanted particles in it. Then remove the excess water.

(e) Finally, the solution was developed by the combination of the above-mentioned raw materials as follows, it consists of a 1:1:1 ratio of fresh green leaves respectively of *Gliricidia sepium, Tithonia diversifolia* and *Mikania micrantha crushed* into 1 mm finer particles and added to a vessel with water with 1: 1 ratio.

(f) Two separate solutions were developed

- S-1; a solution assorted with mud is with leaves and water in the vessel contains a 1:1:5 ratio of leaves: water: mud.
- S-2; And another solution with only the three plants with the ratio of 1: 1 water: leaves extracts.

(g) The solution was mixed in every 4 hours times, after 48 hours separate the solution using the gravity filtrating techniques, this helps to remove the solid particles and separate the solution.

(h) Keep the extracted solution for another 48 hours under room temperature and then once again filter the solution to remove the sediments and then it's ready for use. The solutions developed under this protocol were evaluated to investigate the hesitation towards wood deteriorating fungus.

5.6 Investigating the performance of the extracts obtained from the plant leaves

Here the study investigates under the following parameters keeping constant;

- The solvent
- The particle of the leaves.
- The solvent-to-solid ration
- The extraction temperature- room temperature
- The extraction duration – a total of 96 hrs under atmospheric temperature

Table 5-9; Solute to solvent ratio on the solution developed with only plant extracts

Solute (leaves)				**Solvent**
G.sepium	*T.diversifolia*	*M. micrantha*	mud	water
				
1	1	1		3

Solute (leaves)			**Solvent**
G.sepium	*T.diversifolia*	*M. micrantha*	water
			
1	1	1	3
	1		1

1	**5**	**1**

Table 5-10; Solute to solvent ratio on the solution (plant extracts) assorted with mud

5.6.1 Solution development comprising the plant extracts.

The solutions were developed under the following composition

Even though the particle size and fermentation hour were concluded at the moment the plant composition with the optimum performance was not yet defined. So, there is a promising need to quantify the performance of solutions developed with only one leaf extract and then reveal the performance of the combinations as in the above.

5.6.1.1 Surface application of the fermented filtrate

From the above extracted and the fermented solution, the impurities are separated by using the gravity filtrations techniques. Three layers of the fermented solutions are then applied on the wood surface as a brush application to understand the coloring capabilities of the solutions (Table 5-11),(Table 5-12),(Figure 5-12).

Table 5-11; Visual observation of the 96 hours fermented extracted solutions.

Leaf type (50 g of dry weight)	**Plant part**	**The solvent-to-solid ration (Leaf: water)**	**Solid-to-solid**	**Abbreviation**
G.sepium	Leaf	1:1		Gs
T.diversifolia	Leaf	1:1		Td-L
T.diversifolia	Flower	1:1		Td-F
M. micrantha	Leaf	1:1		Mm
T.diversifolia and M. micrantha	Leaf	1:1	1:1	(Td-L):Mm
G. sepium and M.micrantha	Leaf	1:1	1:1	Gs: Mm
G. sepium and *T.diversifolia*				Gs:Td-L
T.diversifolia , G. sepium and M. micrantha	Leaf	1:1	1:1:1	Td-L: Gs : Mm
T.diversifolia , G. sepium and M. micrantha	Leaf	1:1	1:1:1	Td-F: Gs : Mm:Td-L
Paddy field mud		1:1		M
T.diversifolia , G. sepium and M. micrantha,Mud		1:1		Td-L: Gs : Mm: M

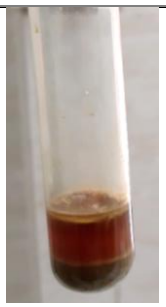
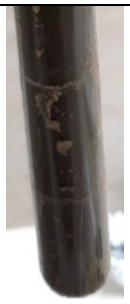
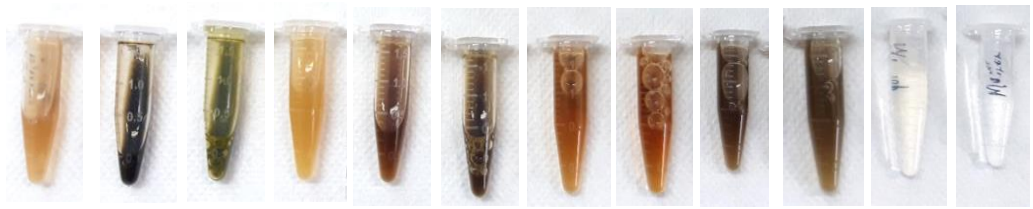
				
Mm	Td-L	Gs	Td-F	(Td-L): Mm

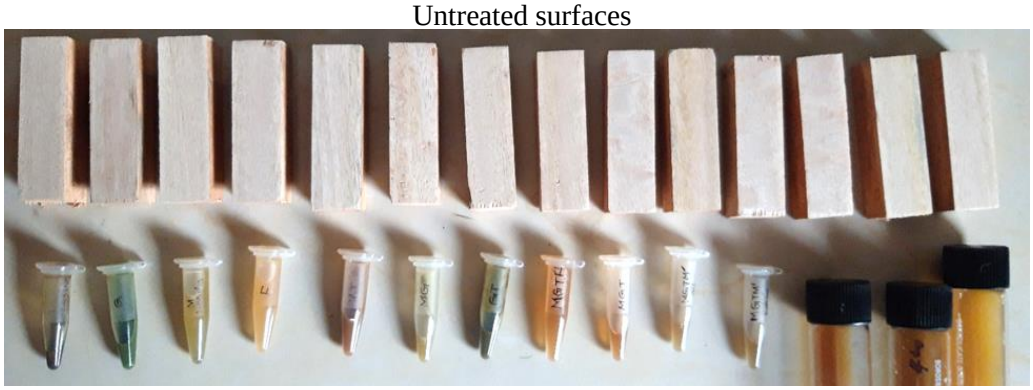
Table 5-12; Visual observation of the 96 hours fermented extracted solutions.

					
Gs: Mm	Gs:Td	Td-F: Gs : Mm:Td-L	Td-L: Gs : Mm	M	Td-L: Gs : Mm: M

5.6.1.2 Results and Discussion



Untreated surfaces



Treated surfaces

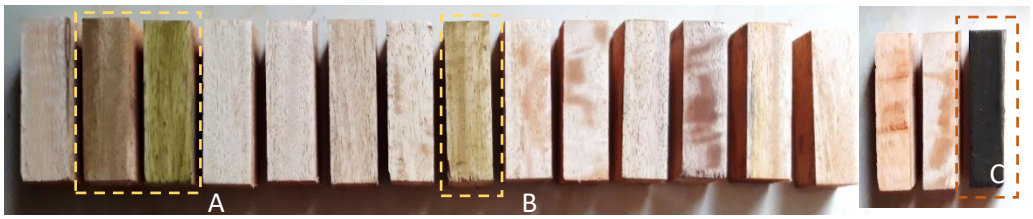


Figure 5-12;Visual observation of the surface application ;A, B, C- Darker colors observed when the impurities are applied

It was observed when the two layers are separated properly as the extracted fraction (solution and the solute carefully without mixing any impurities sedimented at the bottom) presented significantly low coloring capability and a very smooth odorless solution during application. And if the separation is not conducted properly, it will be a reason for a darker color application as the impurities or the sediment settled at the bottom layer affects it. Also, the surface application is not smooth and has a moderate level of odour than the others.

The study has identified the solutions developed assorted with mud have the potential of coloring capabilities. The fraction above the mud layer in M solution showed the lowest coloring capability. The solution with all three plant species assorted with mud; Td-L: Gs: Mm: M; presented significantly higher color capability which was a significant finding. Therefore, the above study dignifies and emphasizes the necessity of better filtering is needed to the study for a proper, smooth application while the solutions developed with mud assorted solutions have a significant potential of wood coloring capability.

5.6.2 Defining the extraction Duration

The solution was filtered after two extraction durations as(Figure 5-13),

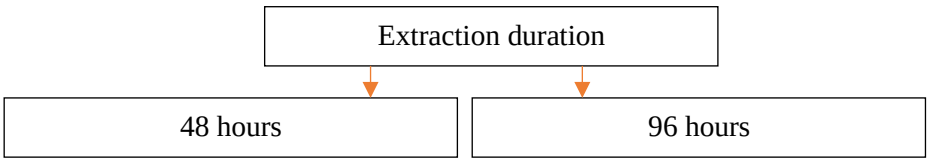
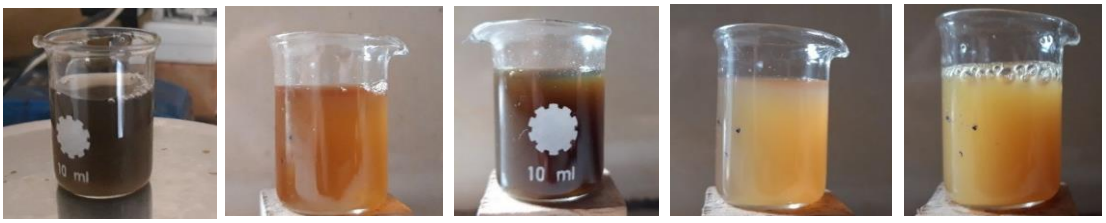


Figure 5-13;The flow chart presenting the extraction duration

The solvent, the solvent-to-solid ratio, the extraction temperature, pressure, and the extraction duration were kept constant, while the plant species altered. As per the visual observations, it can be concluded that when the filtration is not completed or failed when applying the sedimented solute gives the significant color variation(Figure 5-14). However, if proper filtration is processed to separate the sedimented solutes and the solution then the significant color capability is not visually observed on the developed solutions. Further minimizing the particle size may increase the extraction efficiency



FSWM *FSWM300_400_300* **FSWOM** *FSWOM300_00_300* **TD** *TD100_00_100* **MM** *MM100_00_100-* ***GS*** *GS100_00_*

Figure 5-14; visual appearance of the solution

the effort of filtration is not an easy task. Therefore, this study records the particle size to range from 1 mm to 6 mm, (Table 5-13).

Table 5-13; Presents the observations to further determine the extraction duration to be kept before the initial filtration.

Initially filtered after 48 hrs and kept for another 48 hours to ferment and filtered again	**Initially filtered after 96 hrs**
The fresh leaves as mentioned above were ground to break the leaf to approximately around 1 mm to 2 mm particle size and separated and kept for 48 hours, and then after 48 hours the solution was filtered and the extracted solution is further fermented for 48 hours.	The fresh leaves as mentioned above were ground to break the leaf to approximately around 1 mm to 2 mm particle size and separated and kept for 96 hours.
And finally, the extracted solution was applied on the surface of raw (untreated) Mango wood to observe the coloring capabilities of the developed solution.	And finally, the extracted solution was applied on the surface of raw (untreated) Mango wood to observe the coloring capabilities of the developed solution.
Lighter color was observed	Darker color was observed as the solute was applied on the surface
No odor	Contains an odor
A smooth surface was observed.	Rough surface, due to solute impurities applied on the surfaces
No surface mold observed	Minimum visible mold was present on the surfaces of the solutes or the impurities However not on the wood surfaces.
The low duration is taken to obtain a colorless filtrate	A significantly high duration was taken to obtain a colorless filtrate.

Therefore, the study recommends two filtrations' cycles to a particular solvent. First, the solvent should filter after 48 hours, and then the filtrate is further kept to another 48 hours for fermentation. This fermented solution is again filtered after a total of 96 hours.

5.6.2.1 The density of the solution

The density of the solutions is presented as follows, (Table 5-14).

Table 5-14; Density values of the solutions including the standard deviations

Solution name	Abbreviations	Density
T. diversifolia	TD 100_00_100	976.2±1.30
M.micrantha	MM100_00_100	935.6 ±23.64
G.sepium	GS100_00_100	976.6±3.05
Final Solution Without Mud	FSWOM300_00_300	968±20.95
Final Solution with Mud	FSWM300_1500_300	967±1.73

5.6.3 Investigating the most effective fraction of the Extraction yield

The study has identified an extraction procedure in the initial investigations. From here onwards, further investigations were conducted to evaluate the fractions extracted to water and to study the suitable solute to solvent ratio. Below test 1 and test 2 comprise the leaf ratio as a mix of the three following plant species; *T.diversifolia (Td), G.sepium (Gs), and M.micrantha (Mm)* 1:1:1 respectively, (Figure 5-15),(Figure 5 24).

Within the process; the solvent, the extraction temperature, pressure, and the extraction duration, the plant species (Gs:Td: Mm -1:1:1) were kept constant while the solvent-to-solid ratio was altered.

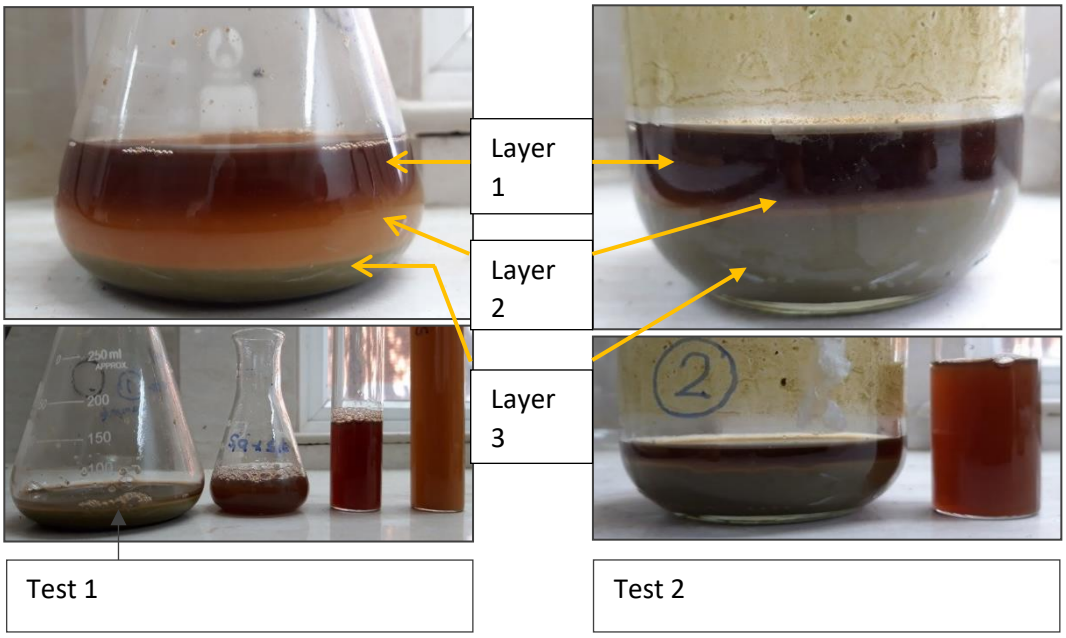


Figure 5-15;the leaves extracted to water fermented to days

Test 1 - Comprise of solute to solvent ratio 3:1; 150 g of total leaves by weight and 50 g of water by weight.

Test 2 - Comprise of solute to solvent ratio 1:0; 150 g of total leaves by weight.

In both cases, the normal tap water was used as the solvent.

Once the solution is filtered after 48 hours the solution is further kept for 72 hours. It was then observed, three separate layers in test 1 and test 2. Then the three layers were separated using micro pipets.

The layers were named in the Figures. The layer 2 observed in test 2 was present in the micro-level so it was not possible to extract the mid-layer. It was very clear that the solvent (water)used in the extraction influences layer two. As there is no present solvent(water) in test 2 layer 2 in test 2 is not available, Figure 5-16).

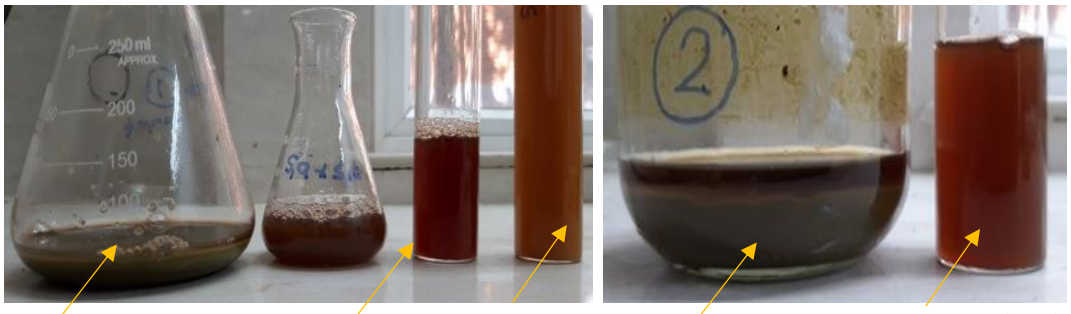


Figure 5-16; Solution with the layers.

5.7 Evaluating the performance of the solution

a) Fungus and mold resistance performance

Evaluation of the performance against fungus (*Schizophyllum commune*) that was grown in; Agar disc diffusion method

b) Termite resistance performance

Performance of the Solution Toxicity against termites (Figure 5-17).

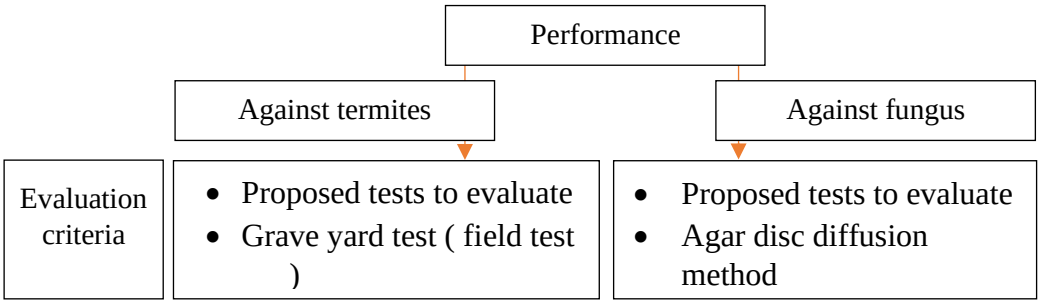


Figure 5-17; The flow chart of two major ways to evaluate the performance of the solutions

5.7.1 Evaluating the wood treated by the above-extracted layers

The above-developed solutions were then used to treat *Mangifera indica* wood. And then the solution effectiveness is evaluated.

5.7.1.1 Materials and methodology

The separated extract fractions were then used to dip 5 mm x 25 mm x 60 mm Mango wood strips to evaluate their performance in natural field conditions (pre-determined termite dense area). The wood specimens are submerged in a 30 ml solution for 24 hours under room temperature with atmospheric conditions, (Figure 5-18).

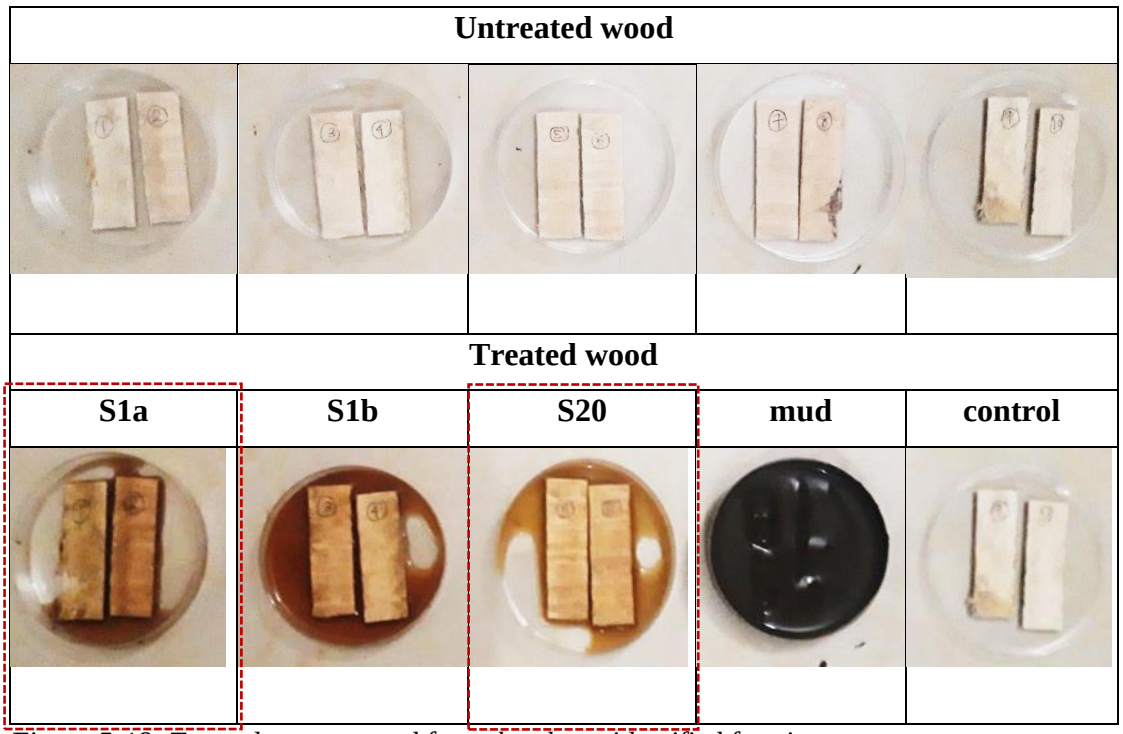


Figure 5-18; Treated mango wood from the above-identified fractions

5.7.1.2 Accelerated field test

Experiment 5-4; Evaluate the performance of the treated wood against natural field conditions in the tropics after 3 months.

The 24 hours submerge wood specimens were then air-dried for and then the sample specimens were dried in the oven for 103 $\pm$ 2 Celsius degree temperature until a constant mass is obtained. The dried specimens were then exposed to the natural field conditions for continuously three months to evaluate the toxicity against mainly on termites and other natural degradable conditions. On which this field test evaluating the durability is based on evaluating the performance compared with the untreated control specimens; where those wood are used as the reference species.

$$Weight\ loss\ percentage = \frac{Initial\ weight - Final\ weight}{Initial\ weight} * 100$$

5.7.2 Results

Weight loss percentage after 3 months were presented as follows (chart 5-1),



Figure 5-19; Field exposure of the samples

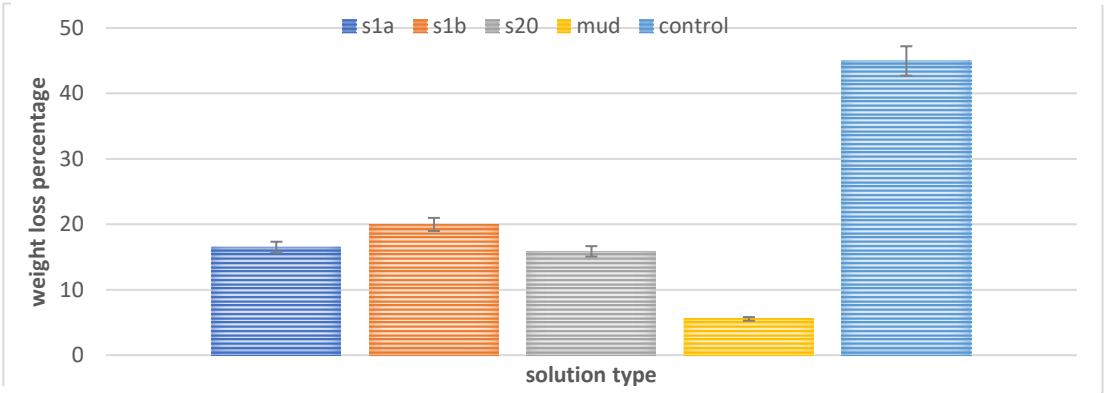


chart 5-1; Weight loss percentage vs solution type

5.7.3 Discussion

The results revealed the highest weight loss percentage on the reference mango wood specimens which were untreated and maintained as control specimens. Meanwhile, the lowest was present from the wood treated with only mud solution. Also, the wood treated with the mud solution visually shows a coloring capability compared with the other extracted solutions. A significant hesitation towards the field conditions was shown from the wood specimens treated with S1a and S2o which represent layer 1, (Figure 5-19). From both the extracted solutions. Further, it can be concluded that when the fermentation time increases in the solutions the solution separates into density different solutions.

5.8 Effect of extraction methodologies and solvent selection for Chemical analysis

The next segment of the study attempts to evaluate the chemical composition of the developed solutions. On behalf of it, the study wants to identify the extraction solution for further chemical investigations. As per literature clarifications, the study identifies Dichloromethane as the best solution for extraction chemical investigations.

5.8.1 Dichloromethane

Methylene chloride, often known as dichloromethane, CH2Cl2 (DCM); halogenated aliphatic hydrocarbon chemical. It's a clear liquid with a lingering ether-like or mildly pleasant odor. Most organic solvents, such as ethanol, ether, phenols, aldehydes, and ketones, are soluble in them. It's moderately soluble in water (2 g/100 ml at 20 °C) [289].

5.8.2 Evaluation on the most effective fraction of the plant extraction

As the defined procedure the fresh leaves as mentioned above were ground to break the leaf to approximately around 1 mm to 2 mm particle size and separately and kept for 48 hours, and then after 48 hours the solution was filtered and the extracted solution is further fermented for 48 hours. The solvent used here was distilled water, the solvent-to-solid ratio 1:1, the extraction temperature – room temperature, pressure- atmospheric pressure, and the extraction duration 96 hours, while the plant species altered.

5.8.2.1 Collection of plant material

The Fresh leaves of these plants were collected from the Colombo district in the western province of Sri Lanka. Leaves by weight were taken and the leaves were dipped in water and kept under the room temperature at 27.0 °C (81°F) for continuous 48 hours for slow water extraction and then again, 48 hours for fermentation. The extracted solution is then ready to use as a preservative solution. The original solution developed as mentioned above was then further extracted to Dichloromethane solution under the below procedure.

5.8.2.2 Extraction procedure

According to the literature and the expert's guides a defined protocol was taken to the study for further analysis, (Figure 5-20), (Figure 5-21).

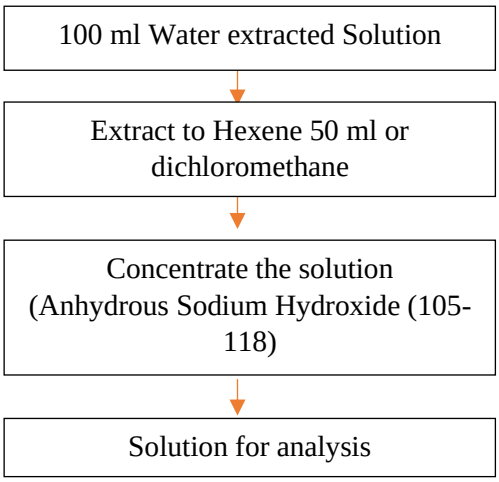


Figure 5-20; Flow diagram representing the dichloromethane extraction procedure

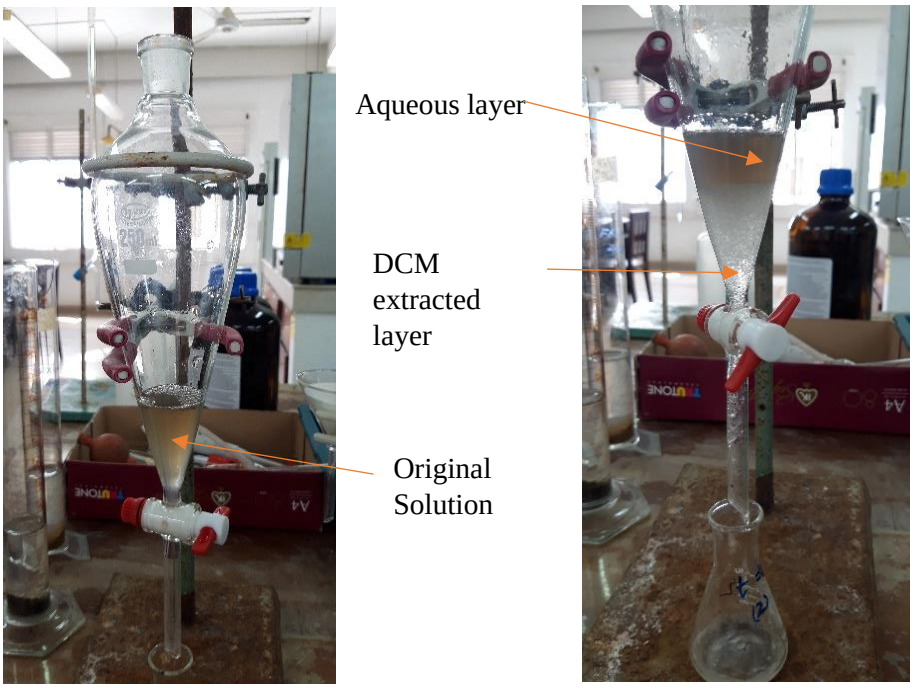
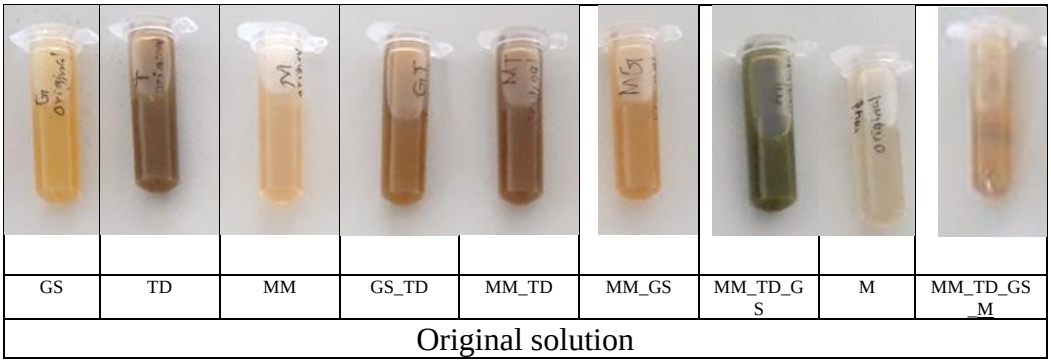


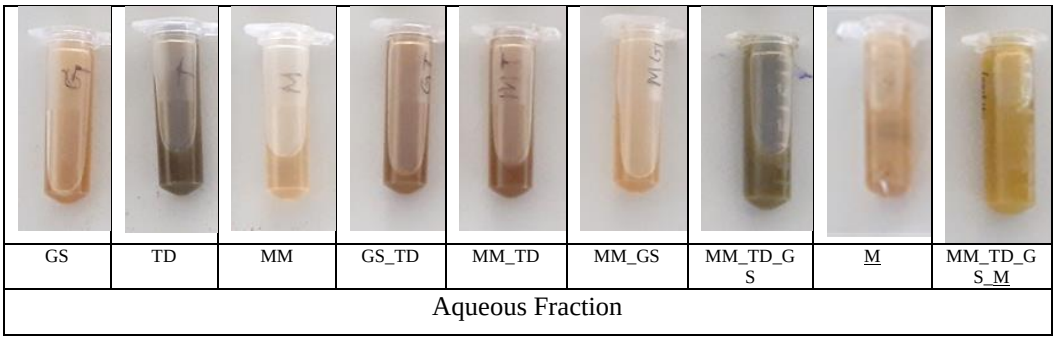
Figure 5-21;Dicloromethane extraction procedure

The extracted solutions are as follows, (Figure 5-22),(Figure 5-23), (Figure 5-24).



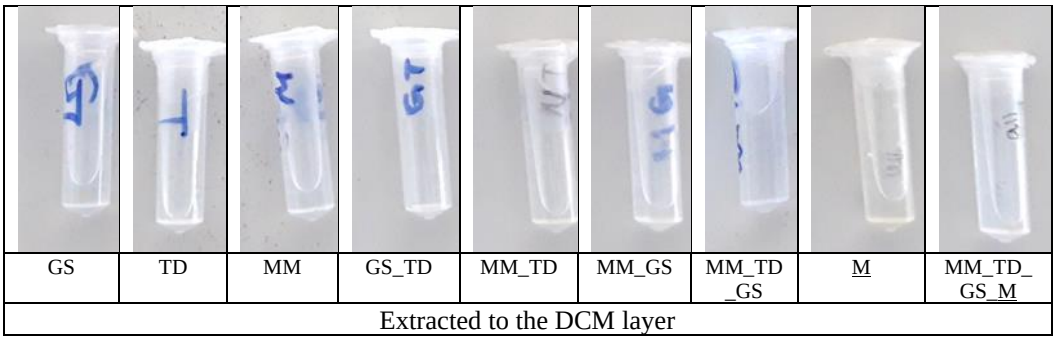
GS	TD	MM	GS_TD	MM_TD	MM_GS	MM_TD_GS	M	MM_TD_GS_M
Original solution								

Figure 5-22; The extracted solution fermented for 24 hours



GS	TD	MM	GS_TD	MM_TD	MM_GS	MM_TD_GS	M	MM_TD_GS_M
Aqueous Fraction								

Figure 5-23 The aqueous layer separated after the dichloromethane extraction



GS	TD	MM	GS_TD	MM_TD	MM_GS	MM_TD_GS	M	MM_TD_GS_M
Extracted to the DCM layer								

Figure 5-24 The fraction extracted to the dichloromethane solution

5.8.2.3 Discussion

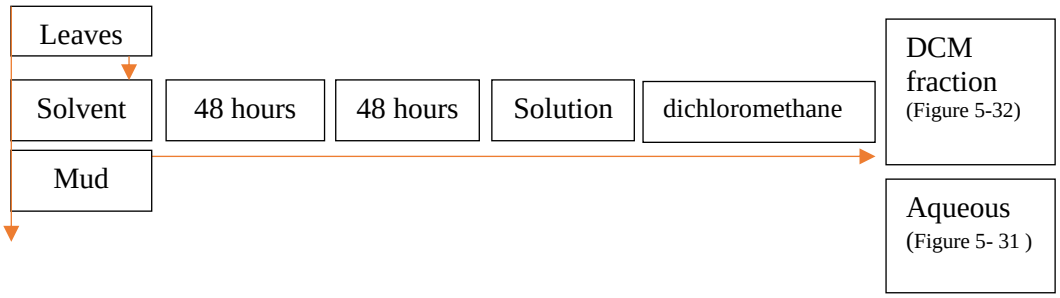


Figure 5-25; Flow chart representing the steps of the process

It was observed the fraction extracted to the DCM layer was colorless. The DCM fraction extracted from the solution MM_TD_GS_M was with the odor while the other layer had the color. Among all the other fractions separated apart from the DCM, layers have a color similar to the original solution (Figure 5-25).

5.9 Evaluation of the performance against fungus (*Schizophyllum commune*) that was grown in; Agar disc diffusion method

This investigates the hesitation of the solution against white-rot fungus. The solutions were obtained from the developed protocol 1 within the study up to now; 4 days of fermentation under room temperature and the atmospheric pressure by varying the plant types; (Figure 5-26).

Experiment 5-5; Agar disc diffusion method to evaluate the antifungal property of the developed solutions

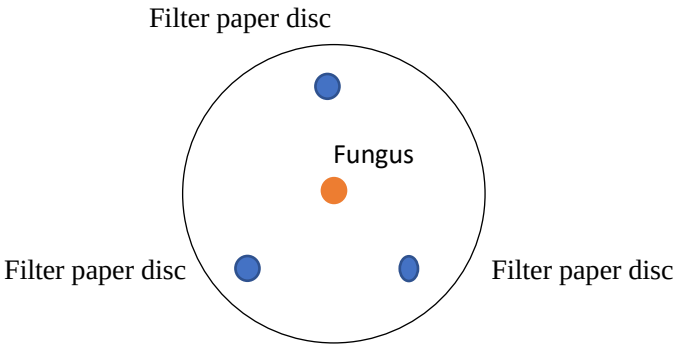


Figure 5-26:Schematic diagram of the practice

5.9.1 Materials and methodology

The solution preparation and the filter paper disc preparation are as follows,

A. Solution preparations

The solutions were obtained from protocol 1 defined in the above study. Three solutions were obtained from a single extract as the original solution, the fraction obtained from the DCM layer, and the other layer separated from the DCM layer,(Figure 5-36).

B. Filter paper disc preparations

5 mm discs were cut from Whatman filter papers. And these filter papers were inserted into a glass vial with a seal cap. The discs are autoclaved to sterilize. The solutions were then filtered using 0.22-micrometer syringe filters before saturating the filter paper discs. 6 ml was added to saturate the filter paper discs.

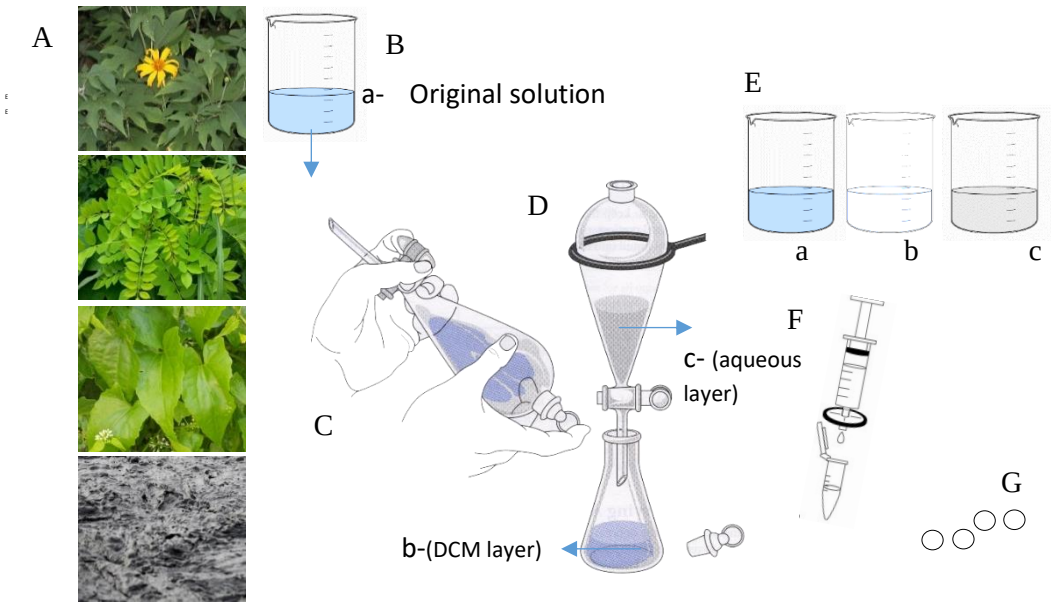


Figure 5-27;A- material matrix (Titonia Diversifolia , Gliricidia Sepium , Mikania micrantha , Mud , B- The solution developed under the protocol 1 , C- The solutions were mixed with Dichloromethane , D- The fractions were extracted using the separating funnel, E – the extracted fraction; a- original solution , b – DCM extracted fraction , c- others , F- Syringe filters , G- punched filter papers submerged with the Solution in E And the filter air papers

5.9.1.1 Antifungal properties were tested against decay fungi.

The extracted fractions are evaluated against fungus to identify the antifungal properties of the solutions. The Solutions were tested against white rot fungi *Schizophyllum commune which* was dominantly observed during the field test. The toxicity was evaluated for continuous 6 days.

A. Agar plate preparation

The PDA (Potato dextrose agar 3.9 %) of the molten agar was autoclaved under the pressurized saturated steam at 121 °C (250 °F) for approximately 15–20 minutes. The solution was then kept until cool and a penicillin antibiotic was added to the solution for the prevention of bacteria growth on the Petri dishes during the evaluation.

Next approximately 15 ml of the medium was poured into Petri dishes, A sterile corn borer or tip was used to make a hole with a diameter of 5 mm is punched at the center of the Petri dish. A volume (20–100 mL) of the fungus culture (4 to 5 days old) is inoculated into the well. The agar plates are then incubated in the appropriate conditions. The fungus diffuses in the agar medium and inhibits growth. This growth of the fungus was measured.



Figure 5-28; Solutions were syringe filtered before introducing to the filter papers .

Measure the radial growth rate over 6 days (mm day-1). Growth rate measurements over 6 days were compared to the control. Triplicate sample dishes were prepared. Sporulation can be also compared to the control.

Mean growth of the fungi was presented from the growth diameter, the fungal growth rate was expressed in growth diameter per day (mm per day) and the Mean antifungal activity percentage of the solution was evaluated. Growth rate measurements over 6 days were compared concerning the control. Triplicate sample dishes were prepared. The control and sporulation can be contrasted. The antifungal impact is estimated using the formula by measuring the diameters of fungal growth.

$$\text{Antifungal activity percentage } = \left[\frac{\text{Dc}-\text{Ds}}{\text{Dc}}\right] \times 100$$

Here the Dc - Diameter of growth in control plate, Ds - Diameter of growth in the plate comprising tested antifungal agent.

5.9.2 Results and discussion

A. The Mean antifungal activity percentage of the solution

The study uses 9 solutions for the evaluations developed under protocol 1. And the study uses 4 controls filter paper treated with the DCM solution, distilled water, and untreated filter papers. Few contaminations were observed on the

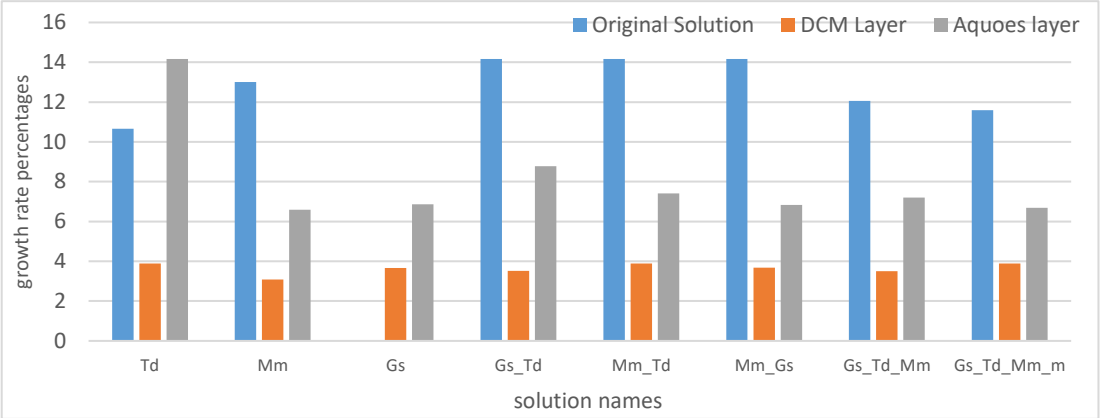


Chart 5-2; the growth rate percentage

agar plates with the filter papers treated with the original solution. And very few contaminations were observed on the agar plates treated with the aqueous layers. However, no contaminations were observed on the agar plates with the DCM treated filter papers. The study conclude that the fraction extracted to the DCM layer presented significant toxicity against *Schizophyllum commune*. It was elaborated that the fraction extracted to the DCM Layer was more toxic compared to the other fraction. Which presented the most justifying factor to investigate the chemistry of the DCM solution extracted fractions.

Compared with all solutions and the fractions the highest antifungal activity was obtained on the fractions extracted to the DCM layer from the solution developed using *Mikania micrantha.* The next highest antifungal activity was presented on the fraction extracted to the DCM layer from the solution developed with the combination of all three plant extracts. It was presented the solutions and the fractions with the combinations of *Mikania micrantha* presented more potentials for the toxicity against *Schizophyllum commune.*

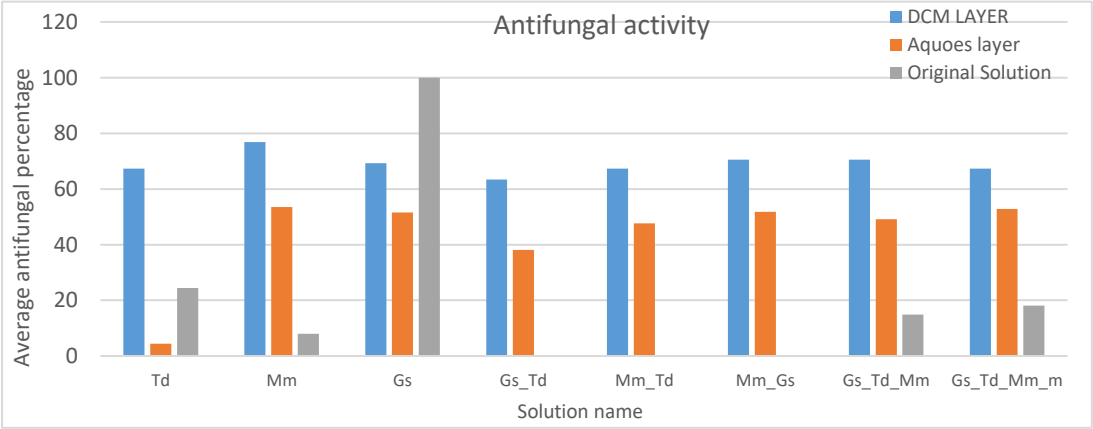
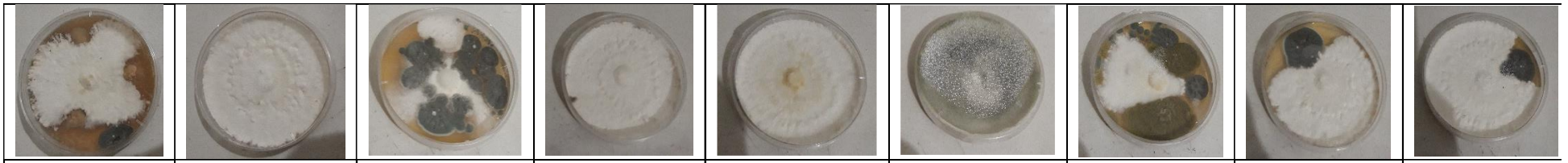


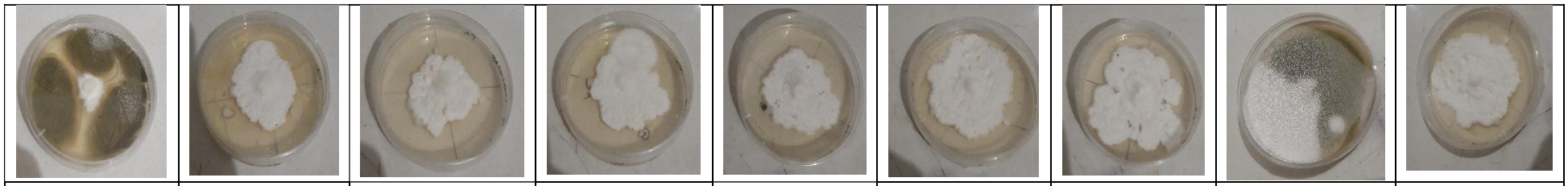
chart 5-3 ; The antifungal activity of the solution and the fractions

Filter papers treated with the originally extracted solutions



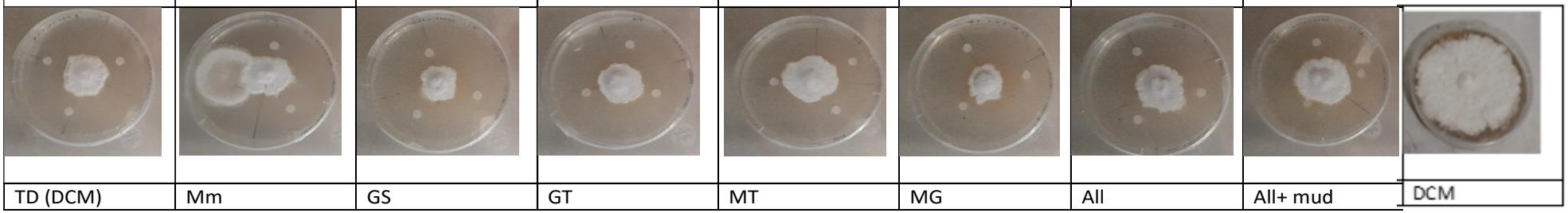
TD original	**mm**	**GS**	**GT**	**MT**	**MG**	**All**	**All+ Mud**	Only mud

Filter papers treated with the aqueous fraction



TD(aques)	**mm**	**GS**	**GT**	**MT**	**MG**	**All**	**Distil water**	Only mud

Filter papers treated with the fraction extracted to the DCM layer



TD (DCM)	Mm	GS	GT	MT	MG	All	All+ mud	DCM

Figure 5-29; The submerged filter apers exposed to the fungus

5.10 Performance of the Solution Toxicity against termites

The main objective of this study was to conduct a solution development assessment through an accelerated field test using filter papers.

Experiment 5-6; Experiment on the performance of solution treated filter paper against termites

This was to identify the concentration and the toxicity to develop the final solutions. As per the previous studies' conclusion, this aims on the solutions developed using all three plant extracts.

5.10.1.1 Materials and methodology

The solution development and the sample preparation were conducted as follows,

A. Solution Development

Here the study evaluates the performance of the solutions developed using all three plant extracts.

Table 5-15; Description of the Solutions

Solution 1 (Abbreviation)	Protocol used	Material matrix
Control (+)	Protocol 1	Distil water
Control (-)	Protocol 1	No solutions (untreated filter papers)
Gs_Td_Mm (Original solution)	Protocol 1	*M.micrantha , T.diversifolia, G.Sepium*
Gs_Td_Mm_m (Original solution)	Protocol 1	M.micrantha , T.diversifolia, G.Sepium , Mud
Gs_Td_Mm_m (DCM Fraction)	Protocol 1	M.micrantha , T.diversifolia, G.Sepium, Mud , DCM extracted fraction
Gs_Td_Mm_m (Aqueous Fraction)	Protocol 1	M.micrantha, T.diversifolia, G.Sepium, Mud, remaining fraction after DCM extraction

B. Sample preparation

The Cellulose, 11 µm (Medium Flow), 180 µm thick most frequently used standard Whatman filter papers were used in the study. The specimens were prepared in the size of 50 mm x 50mm squares. 5 ml solution s were 3 times dipped in the solution until the filter paper get saturated. Finally, the treated filter papers are then kept for air dry until a constant weight was obtained. Then the specimens were weighted for 0.0001g accuracy using an electronic balance. Then the specimens were exposed to a predetermined termite dense area. The 120 mm space was kept in between the two

specimens. Then the saturated air-dried filter papers were weighted in the accuracy of 0.0001g then exposed to the predetermined termite dense area. Five replicates per solution were used to evaluate the field performance and the average values were obtained for the conclusions.

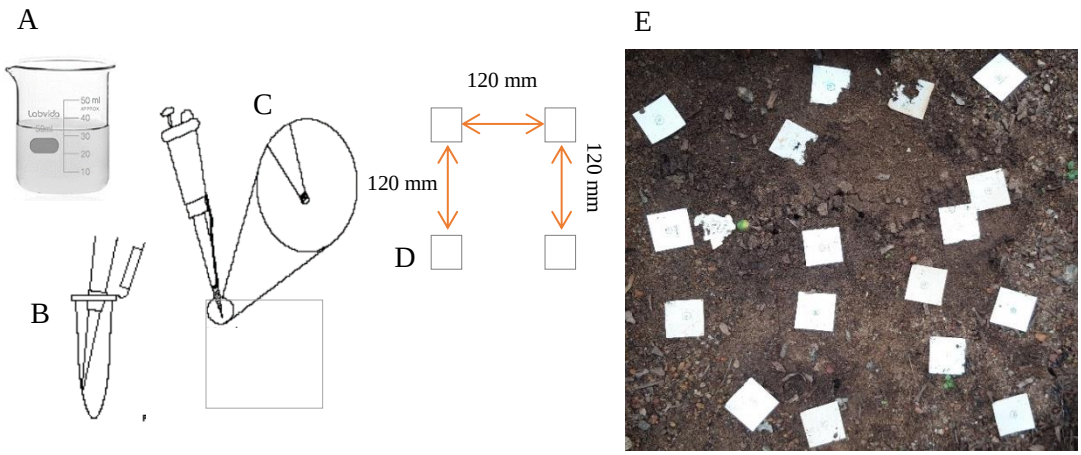


Figure 5-30 ; A- The prepared solutions ,B- 5 ml of the solution, C- the filter papers are saturated , D – the positioning of the filter papers , E- Field exposed treated filter

Subjective rating criteria are used to evaluate wood durability in the field and laboratory. This test uses cellulose material to evaluate the toxicity of the solution. The evaluation criteria were based on the FRIM field evaluation of in-ground durability that evaluates the relative termite and fungal attack on the wood specimen. This test uses a rating tool similar to the IUFRO rating scale by Wong et al 1998, Wong 2000 was recently ascribed as a five-category termite resistance[290]. Each filter paper was also visually evaluated following the firm visual rating.

The following equations show how to calculate mass change (%),

$$AML\% = [(W1 - W2)/W1] \times 100$$

Where W1 = conditioned mass before testing (g), W2 = conditioned mass following testing (g).

Table 5-16; FRIM visual rating scale to evaluate the termite attack

Color reference	Rating	Explanation
	0	Sound
	1	Surface Nibbles
	2	Light Attack
	3	Moderate Attack with boreholes
	4	Heavy /Severe attack
	5	Completely destroyed

5.10.1.2 Results

A. Visual observation on the surfaces infested by the termite attack

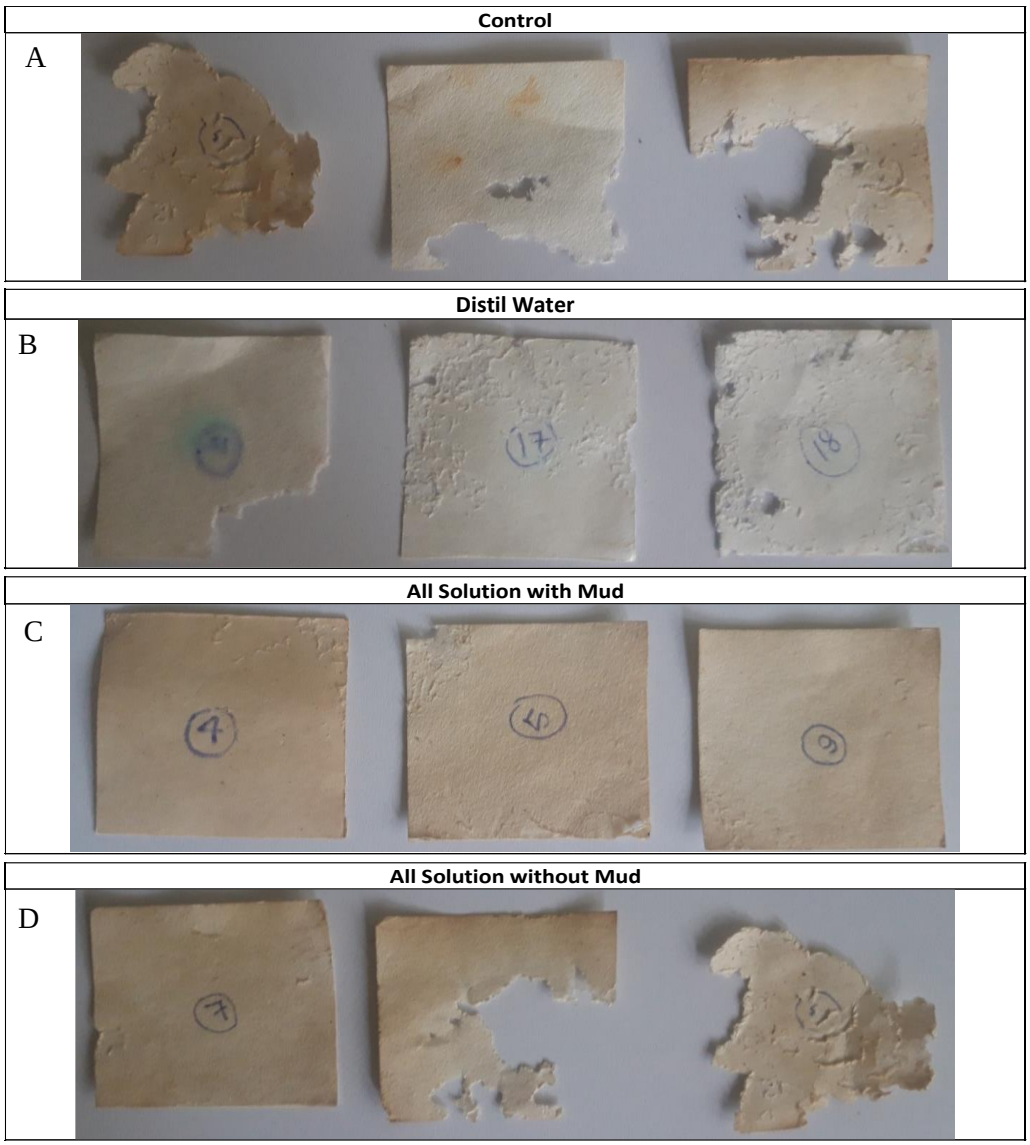


Figure 5-31;A-the control (-), B- The control (+) , C- Gs_Td_Mm_m (original solution), D- Gs_Td_Mm (Original solution)

Among the four solutions above, the solution Gs_Td_Mm_m (original solution) presented significant performance against termites under natural conditions. Therefore, further analysis was conducted. The two fractions were separated using the dichloromethane solution, Gs_Td_Mm_m DCM extracted fraction and the Gs_Td_Mm_m aqueous fraction.

And the most effective fraction was identified from the weight loss percentage.

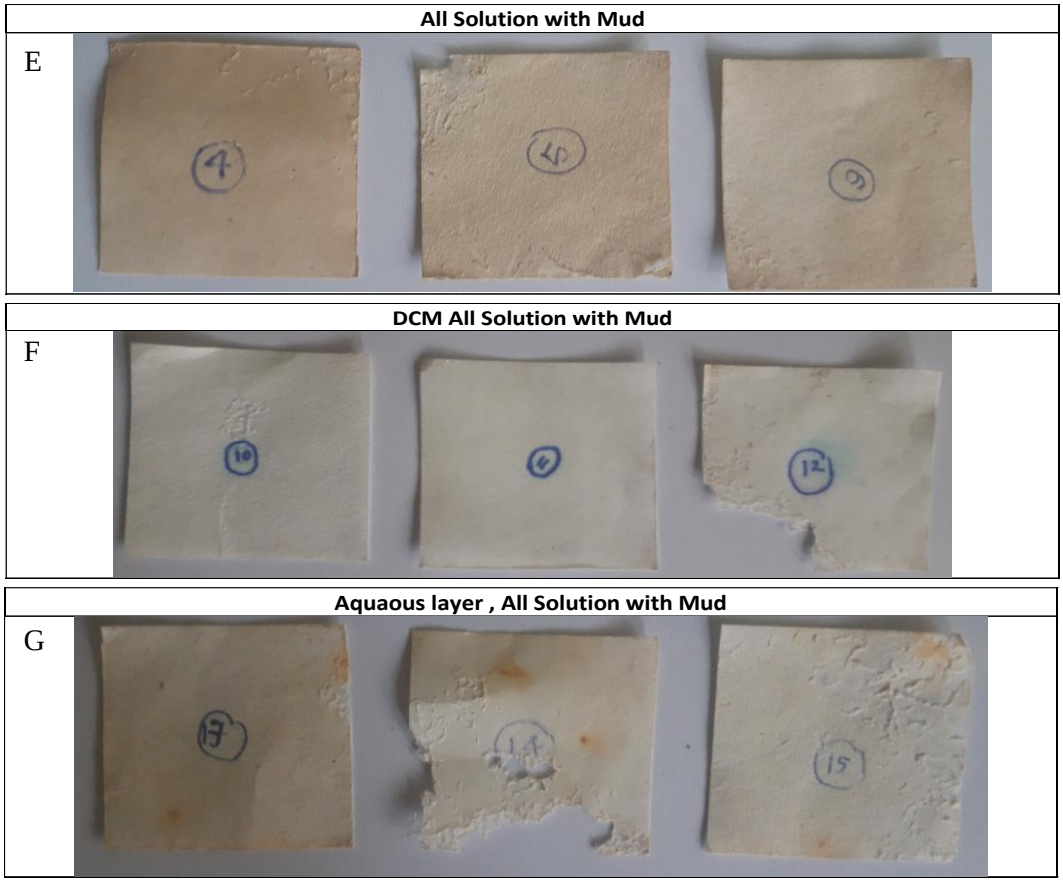


Figure 5-32 ; E- C- Gs_Td_Mm_m (original solution), F- Gs_Td_Mm_m (DCM fraction),G- Gs_Td_Mm_m (D- Aqueous fraction)

B. FRIM visual rating scale for termite attack

The visual rating tool was used to evaluate the termite attack, the results are presented below.

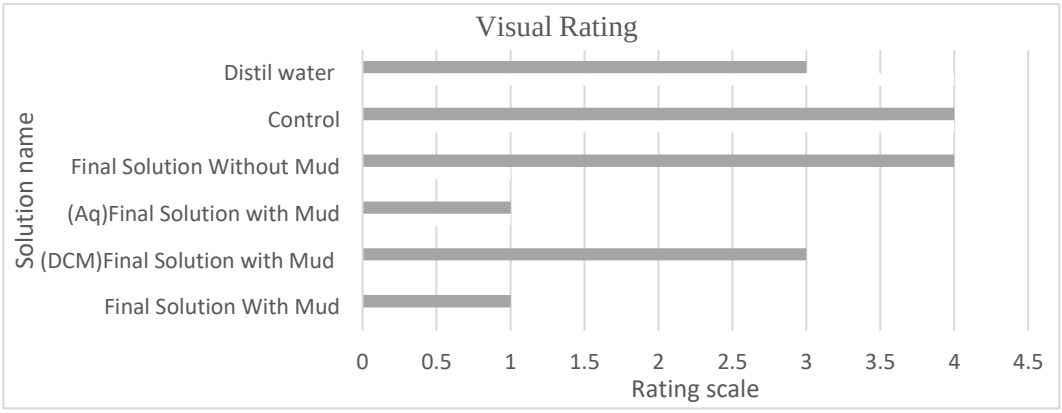


chart 5-4; Visual rating vs the solution type treated on the filter paper

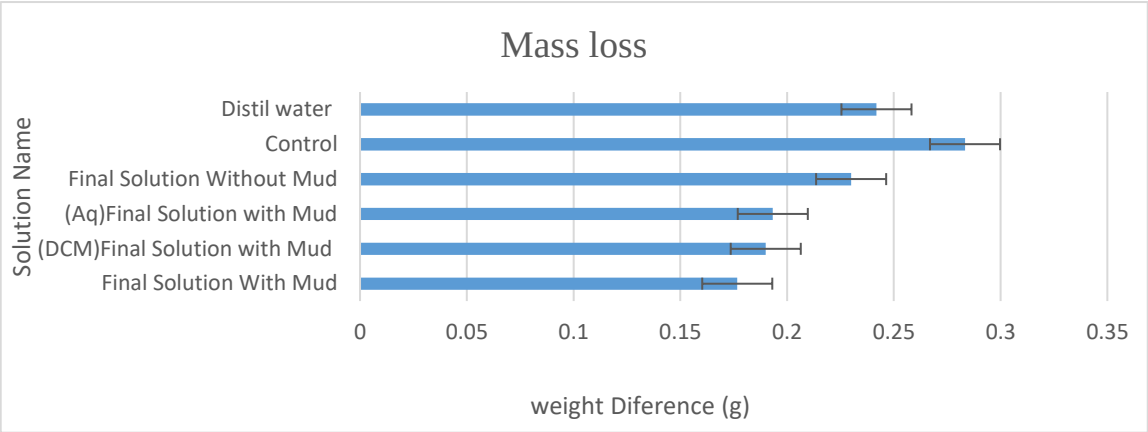


chart 5-5; Mass loss of the treated filter papers .

5.10.1.3 Discussion

Results from this study suggest that the untreated filter papers are highly susceptible to attack by subterranean termites. In addition, the developed solutions have toxicity against the subterranean termites preserving this cellulose material which the filter papers are formed of. At the first two days, only surface nibble was observed in the Gs_Td_Mm when the Gs_Td_Mm_m one specimen treated filter paper was observed with a slight attack. However, with time the Gs_Td_Mm_m remained significantly resistant towards the termites while Gs_Td_Mm presented a severe attack. However, this predicts that the Gs_Td_Mm_m has more leach resistance in outdoor conditions and more significant fixation properties compared to the Gs_Td_Mm solution.

Further attention was paid to the fractions of the Gs_Td_Mm_m. Two fractions of this were evaluated under the same procedure. the two fractions as Gs_Td_Mm_m extracted to the DCM layer and the Gs_Td_Mm_m aqueous layer which was separated after DCM layer was obtained. The majority treated with the DCM fraction was under the rating with the explanation of sound. while one presented a severe attack.

Among all, the highest mass loss percentage was presented from the control (-), the lowest mass lost was presented in the Gs_Td_Mm_m and the lowest was presented from the Gs_Td_Mm.

When comparing the mass loss percentage of the fractions obtained from the Gs_Td_Mm_m, both the aqueous fraction and the DCM presented moderately same level of toxicity against termites with a significant performance compared to the control (-) and the control (+).

This study concludes both the two solutions Gs_Td_Mm_m and the Gs_Td_Mm performed significantly against the termites under outdoor conditions.

- The mass loss percentage was presented as below,

Control(-) > Control (+) > Gs_Td_Mm > Gs_Td_Mm_m

- Concluding the mass loss percentage of the fractions of the Gs_Td_Mm_m

Control(-) > Control (+) > Gs_Td_Mm_m(Aqu.) > Gs_Td_Mm_m(DCM)

Realistic efficacy levels of termiticides as wood preservatives are a significant need when developing solutions as wood preservatives. So, the study extends to further understand the developed solutions treated on wood specimens.

5.10.2 Investigating the performance of the plant extracted solutions

This phase of the study initiates as the primary investigation towards defining the solution composition with the optimum performance. For that, the study needs a clear understanding of the performance of the individual extract of the selected solution.

Experiment 5-7;; Experiment on the performance of solution treated wood specimens against termites

5.10.2.1 Plant material collection

Fresh plant leaves of *Titonia diversifolia, Mikania micrantha, Gliricidia Sepium* were obtained from Piliyandala.

5.10.2.2 Extraction procedure

The above-described solution extraction procedure was used in the below study too. Protocol 1,

Table 5-17;material matrix used to develop the solutions

Plant matrix	Abbreviation	Water (ml)	Leaf(g)	Mud (g)
Titonia diversifolia	TD100_00_100	100	100	0
Mikania micrantha	MM100_00_100	100	100	0
Gliricidia sepium	GS100_00_100	100	100	0
Final Solution Without Mud	FSWOM 300_00_300	300	300	0
Final Solution with Mud	FSWM 300_1500_300	300	300	1500
Mud	M00_300_300	300		1500

5.10.2.3 Treated wood

The defect-free mango raw mano wood specimens were submerged in the extracted and fermented solution under the extraction procedure; Protocol 1.

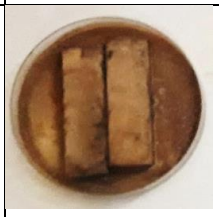
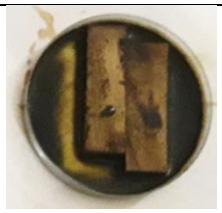
MM100_00_100	GS100_00_100	TD100_00_100	FSWOM300_00_300)	M00_00_300)
				

Figure 5-33; Woos specimens submerged in the solutions

The separated fractions were then transferred into glass containers with the 30 ml of the solution and the wood specimens in the size of 5 x 25 x 60 mm^3 Mango timber strips to evaluate their performance in field conditions (pre-determined termite dense area). The wood specimens are submerged in a 30 ml solution for 24 hours.

5.10.2.4 Accelerated test graveyard test or field test as a screening test

The durability tests underground contact was conducted at a graveyard at the University of Moratuwa, and mini-stake specimens were utilized in place of standard samples according to EN 252 (1989). The mini-stake style permits test samples to be prepared from smaller wood pieces, which can be useful in some cases. Additionally, they are claimed to fade faster and allow for minimum test durations, saving duration and money. Also, it is a good chance that the results from the two sample types will not be similar.

5.10.3 Results of the accelerated field test.

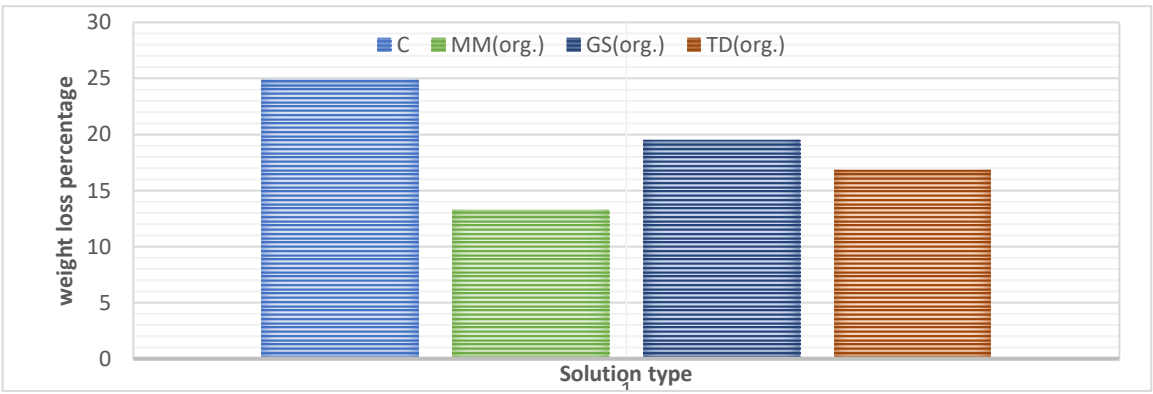


chart 5-6; weight loss percentage vs Solution type

5.10.4 Discussion

The mini-stake style has presented the highest weight loss percentage in the control specimen, where the lowest was presented on the wood treated with a solution

developed with Mikania micrantha plant extracts. Average weight loss percentage was 24.84 %, 19.54%, 16.831%, 13.253 % presenting the control, *G.sepium*, *T.diversifolia*, *M.micrantha* .

5.11 Evaluating the most toxic fraction against termites under natural field conditions

Experiment 5-8; Evaluating the most toxic fraction against termites under natural field conditions;

The above solution is further extracted to the dichloromethane and identified as the most toxic fraction in the graveyard test.

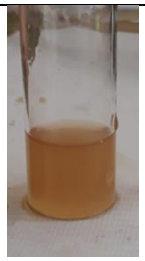
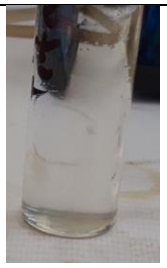
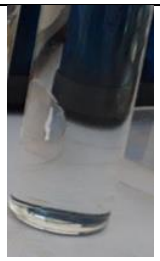
TD100_00_100 (aq)	GS100_00_100 (aq)	MM100_00_100 (aq)	TD100_00_100 (dcm)	GS100_00_100 (dcm)	MM100_00_100 (dcm)
					

Figure 5-34; The fraction extracted to the DCM layer and the layer removed after the DCM fraction was removed (aqueous layer)

These treated timber specimens are then exposed to the field conditions after 8 hours of oven-dry under 103±2 degrees Celsius to obtain constant moisture. Then these weighted specimens (0.001 g accurate) were exposed to the fields (predetermined termite dense area) for three months. It was always conditioned to make sure a down growth is not visible in between the wood specimens. A field positioning of the samples



TD100_00_100 (aq) | GS100_00_100 (aq) | MM100_00_100 (aq) | control



TD100_00_100 (DCM) | GS100_00_100 (DCM) | MM100_00_100 (DCM)

was done in opposite positions to prevent the error percentage and get an average mass loss percentage.

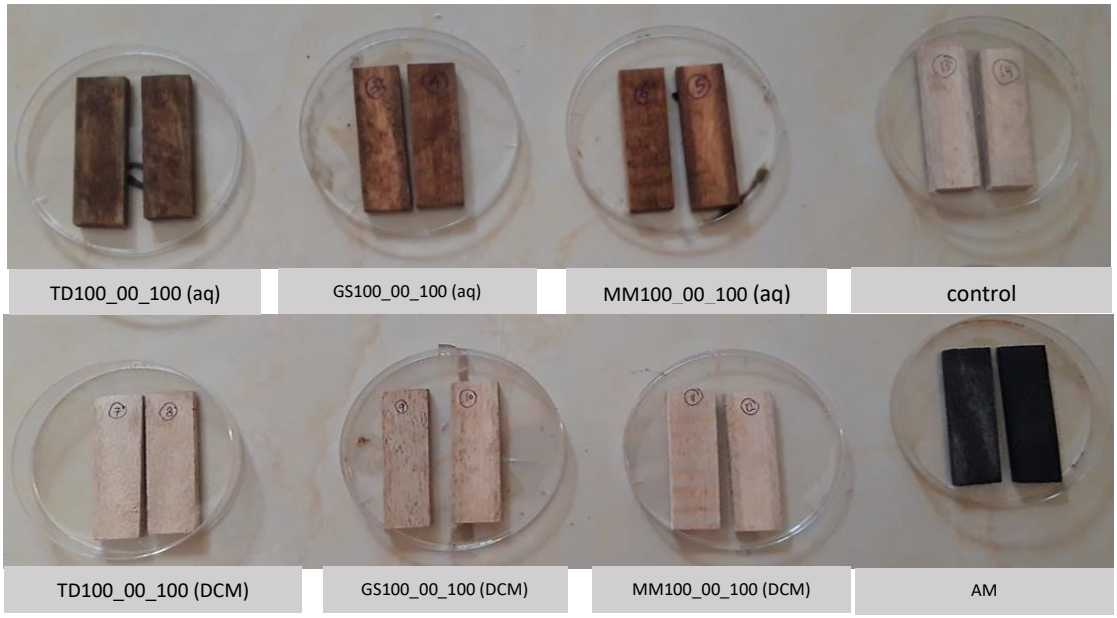


Figure 5-35 ; treated wood specimens out of the developed solutions



Table 5-18; A- The color of the treated wood specimens , the field exposure of the treated wood specimen

5.11.1.1 Results and discussion

The results the graphed as follows,

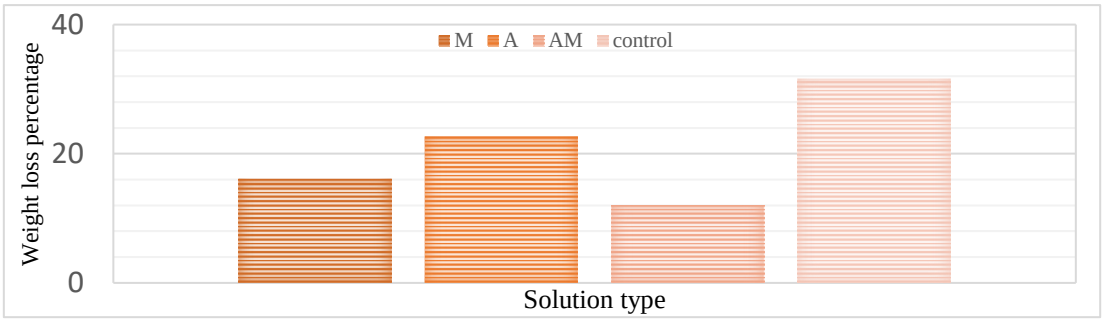


chart 5-7; the weight loss percentage against the solutions

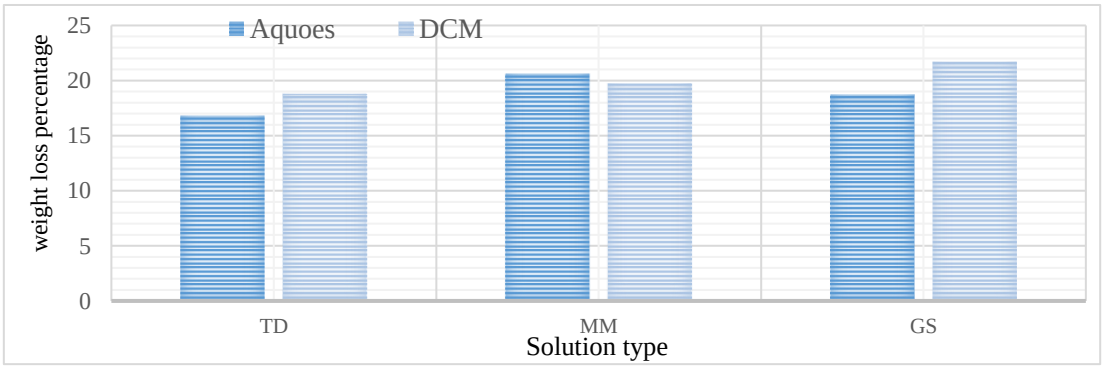


chart 5-10; the DCM extracted fraction vs weight loss percentage

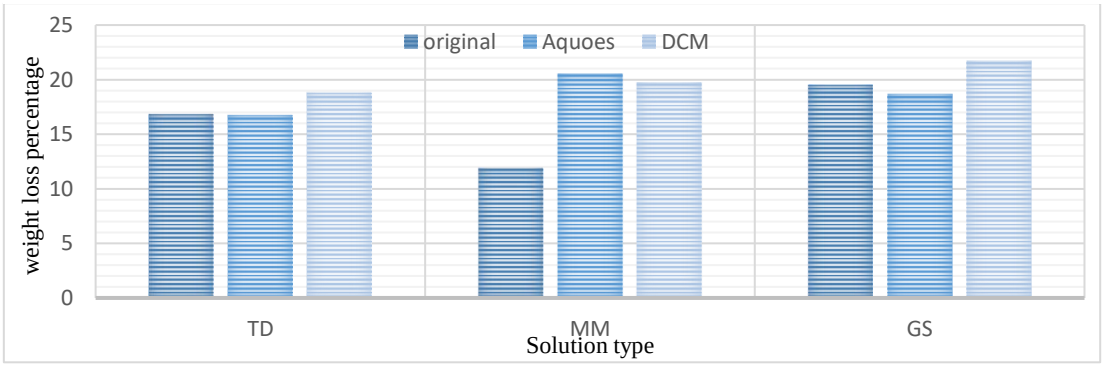


chart 5-8 ; the performance of the original solution vs the extracted fractions

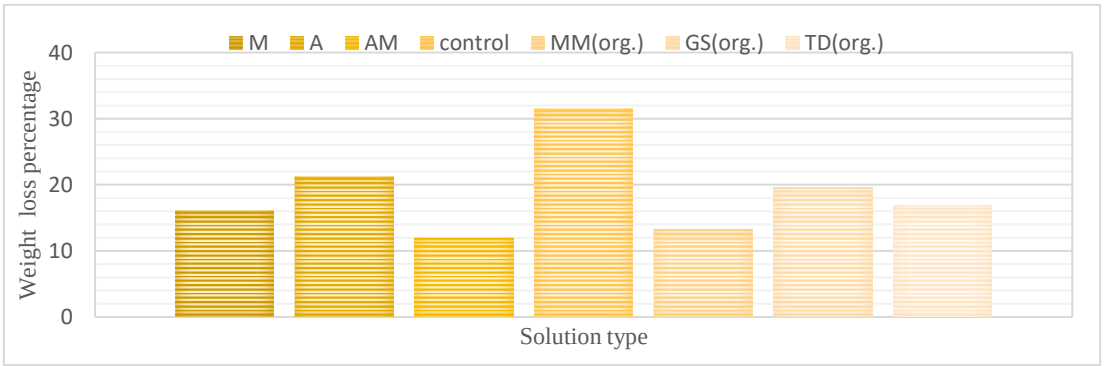


chart 5-9 the comparison among the solutions on the field performance.

5.11.2 Evaluating the toxicity against fungus

Here the study evaluates the optimum concentration of the solution for evaluations against fungus. Based on the literature the study initiated to evaluate 10 % and then raise it to 100 %.

Experiment 5-9; Experimenting on the solution toxicity and the effective solution concentration through food poisoning test.

A. Collection of plant material

Matured *Mikania micrantha, Tithonia diversifolia, and Gliricidia sepium* fresh plant leaves are collected from Moratuwa and transported to the pro-green laboratory.

B. Solution development

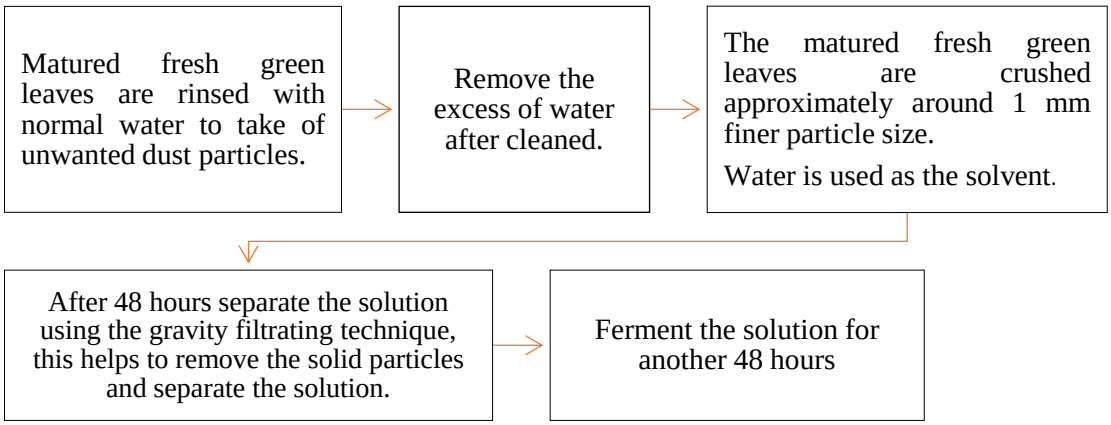


Table 5-19; Combination by weight composition of leaves: water mud

SOLUTION NAME	Plant species	Leave	Water
Td-L: Gs: Mm	*T. diversifolia: M.micrantha: G. sepium(1:1:1)*	1	5

5.11.3 Preparation of culture plates

The culture plates were prepared as follows,

A. Food poisoning Assay

The PDA (Potato dextrose agar 3.9 %) was poisoned by adding the desired concentration of the solution as follows,

Concentration 1 – 100 % of the Td-L: Gs: Mm solution

Concentration 2 – 10 % of the Td-L: Gs: Mm solution

was into the molten agar and was mixed well. Then the poisoned PDA was autoclaved under the temperature of 120 degrees Celsius For 15 minutes. The solution was then kept until cool and an antibiotic was added to the solution for the prevention introduced into Petri dishes, approximately 15 ml. Then, a hole with a diameter of 5 mm has

punched aseptically with a sterile corn borer or a tip, and a volume (20–100 mL) of the fungus culture (4 to 5 days of age) is inoculated into the hole. Then, agar plates are incubated under suitable conditions. The fungus diffuses in the agar medium and inhibits the growth of the fungus was measured.

Measure the radial growth rate over 2 weeks (mm day-1). Growth rate measurement over 1 week compared to the control. Triplicate sample dishes were prepared. The antifungal activity was evaluated,

$$\text{Antifungal activity percentage } = \left[\frac{\text{Dc}-\text{Ds}}{\text{Dc}}\right] \times 100$$

Where Dc – the growth diameter in the control plate, Ds – the growth diameter in the plate containing tested antifungal agent.

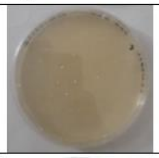
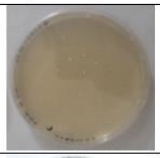
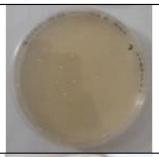
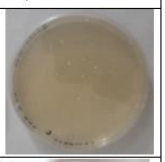
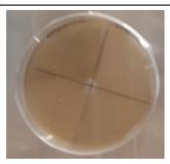
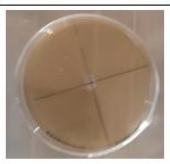
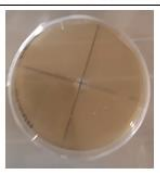
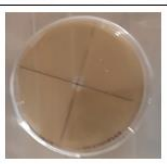
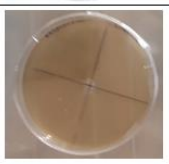
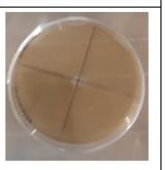


Figure 5-36; The PDA solutions and the poisoned solutions

5.11.4 Results

The study evaluated the results in two ways as Visual Observation and the growth

Table 5-20;Control Petri dishes with no exposed fungus.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Control PDA Plate						
All Solution (100)						
All Solution (10)						

diameter, growth rate per day, and anti-fungal activity as presented below.

Table 5-21; Effectiveness' of the solutions against Talaromyces purpureogenus

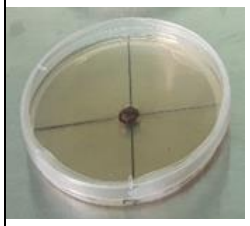
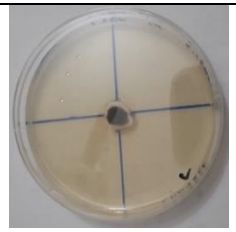
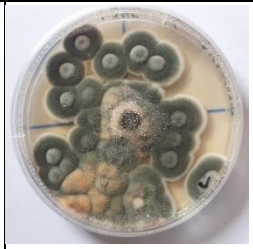
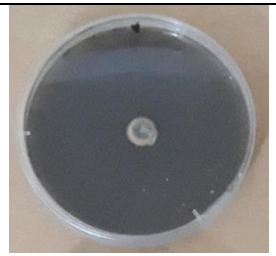
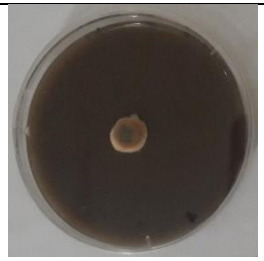
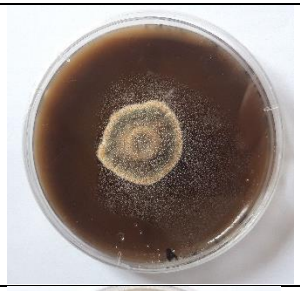
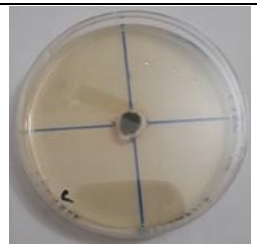
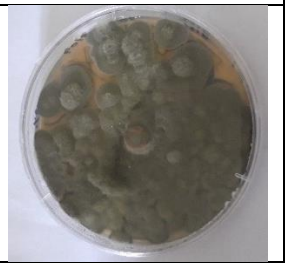
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Control PDA Plate						
All Solution (100)						
All Solution (10)						

Table 5-22; Effectiveness' of the solutions against Aspergillus japonicus

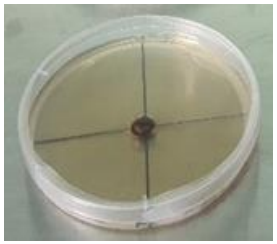
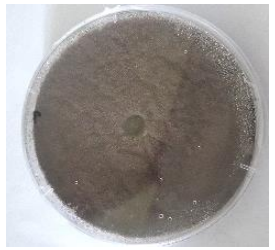
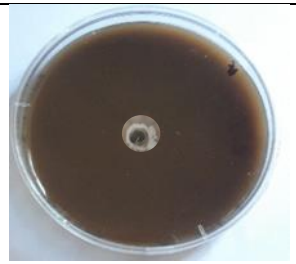
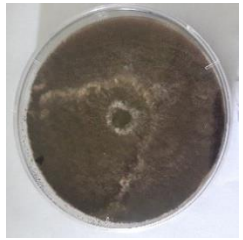
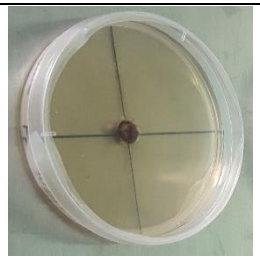
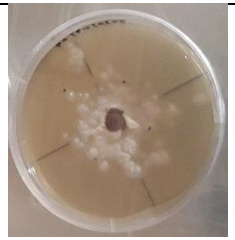
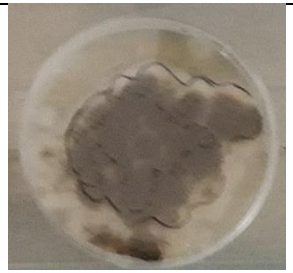
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Control PDA Plate						
All Solution (100)						
All Solution (10)						

Table 5-23; Effectiveness of the solutions against Pleurotus ostreatus

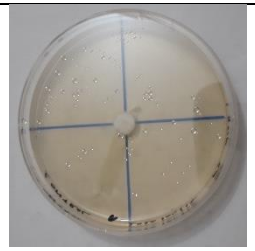
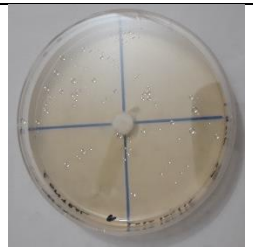
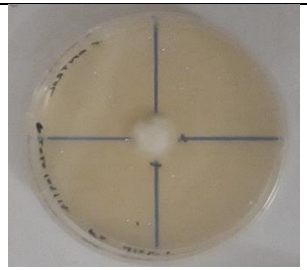
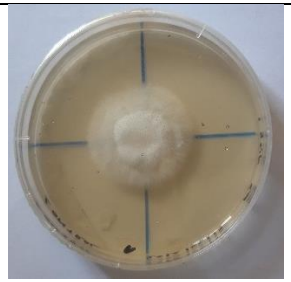
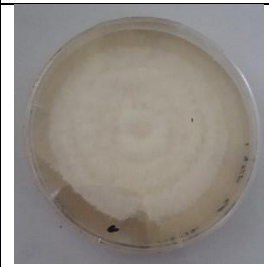
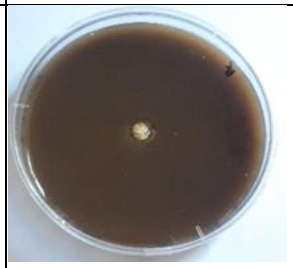
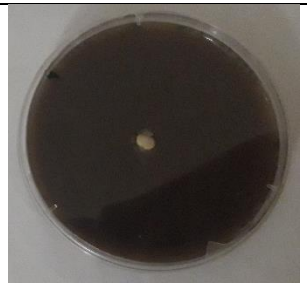
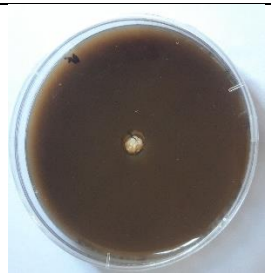
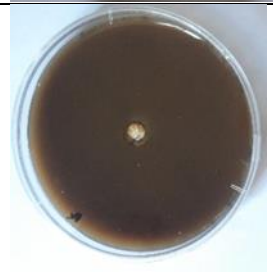
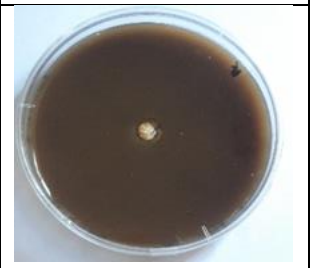
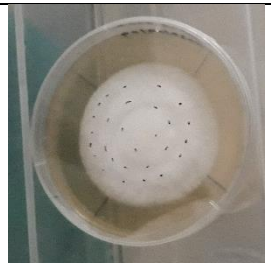
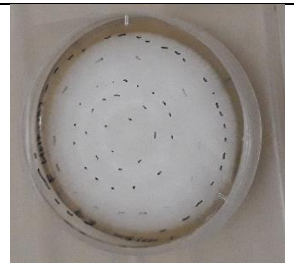
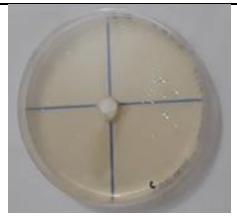
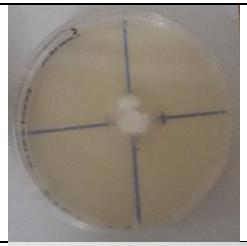
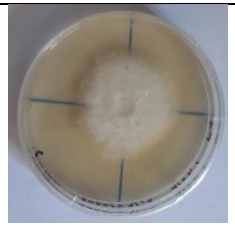
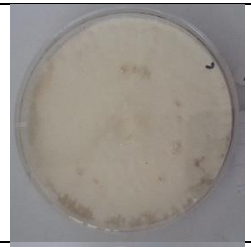
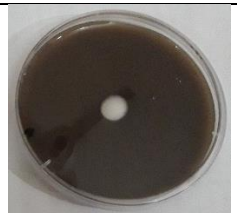
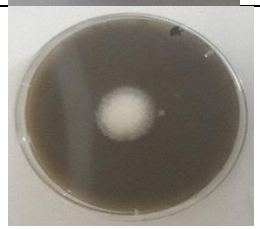
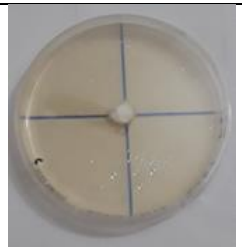
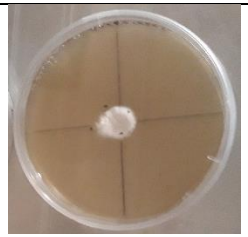
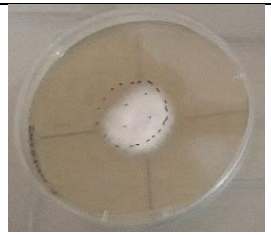
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Control PDA Plate						
All Solution (100)						
All Solution (10)						

Table 5-24; Effectiveness of the solutions against Schizophyllum commune

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Control PDA Plate						
All Solution (100)						
All Solution (10)						

5.11.4.1 Growth diameter per presented as follows,

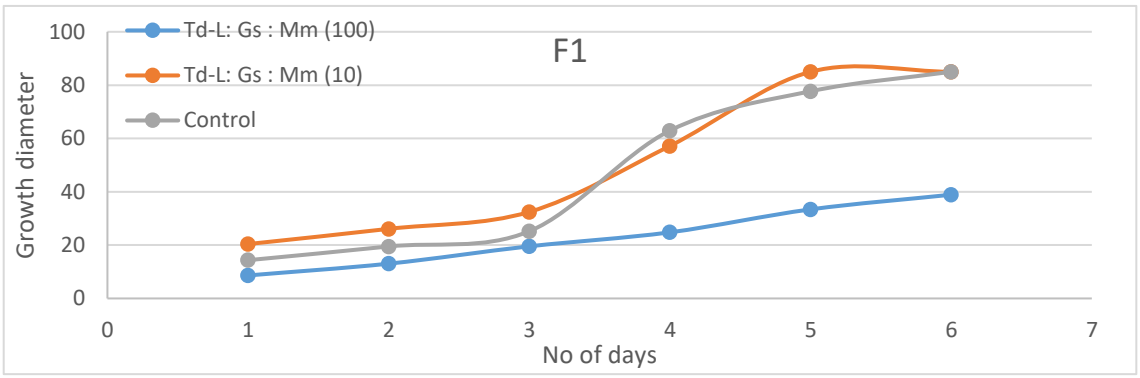


chart 5-12;Performance against Talaromyces purpureogenus(F1)

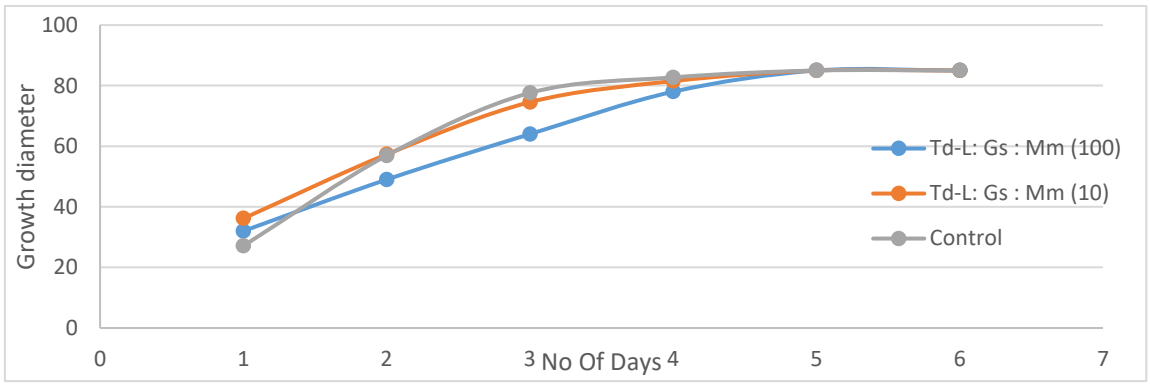


chart 5-11;Performance against Aspergillus japonicus(F2)

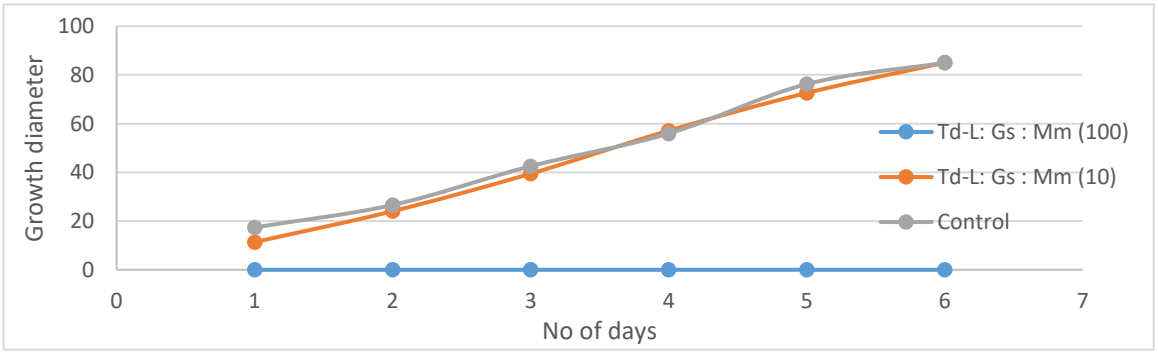


chart 5-14;Performance against Pleurotus ostreatus(F3)

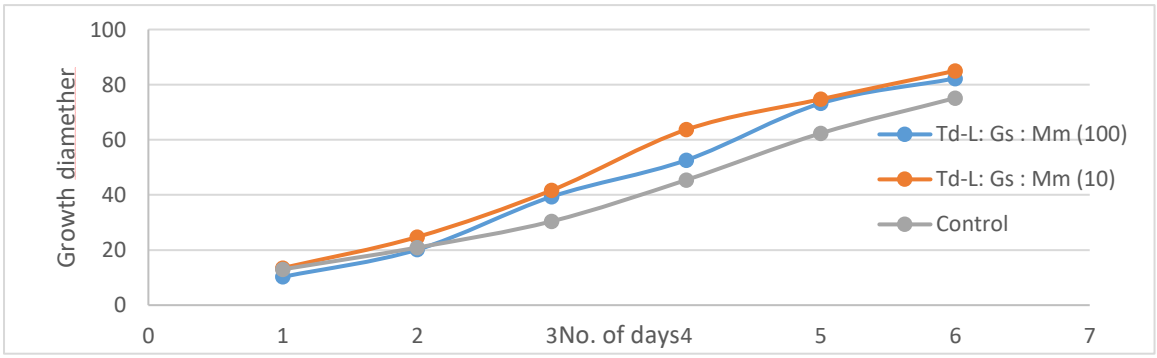


chart 5-13;Performance against Schizophyllum commune(F4)

5.11.4.2 Growth diameter per day was presented as follows,

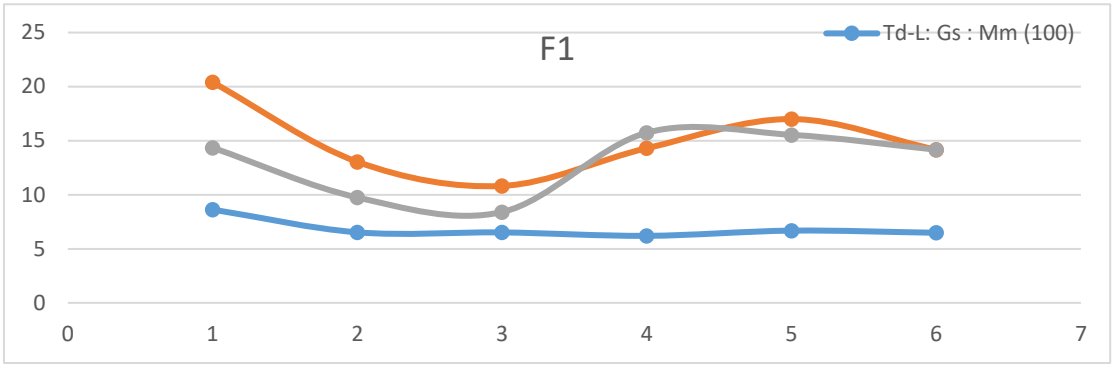


chart 5-18;Growth diameter per day against Talaromyces purpureogenus(F1)

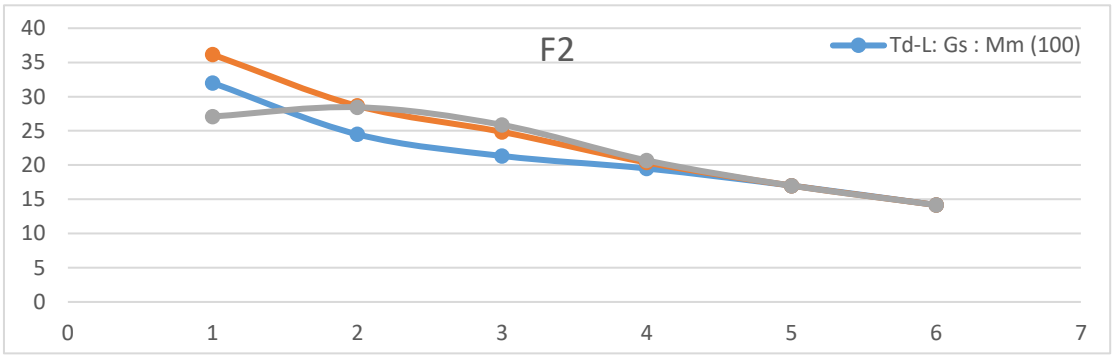


chart 5-17;Growth diameter per day against Aspergillus japonicus(F2)

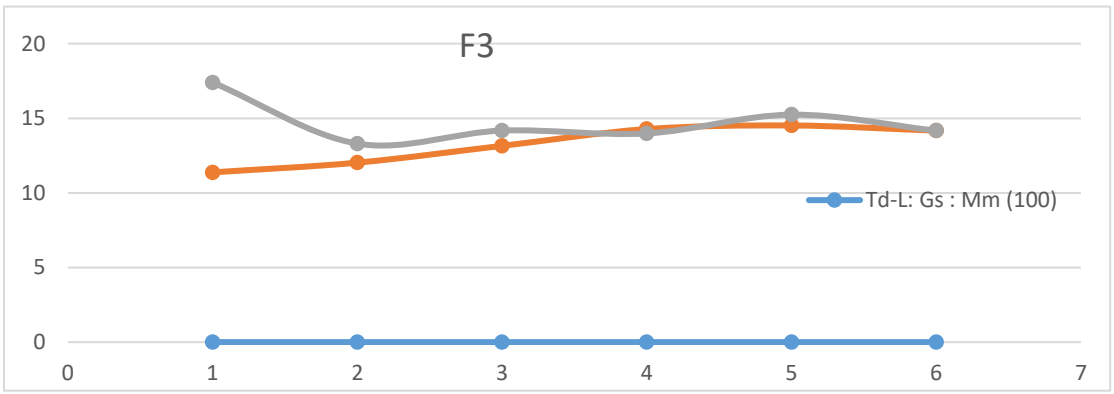


chart 5-16;Growth diameter per day against Pleurotus ostreatus(F3)

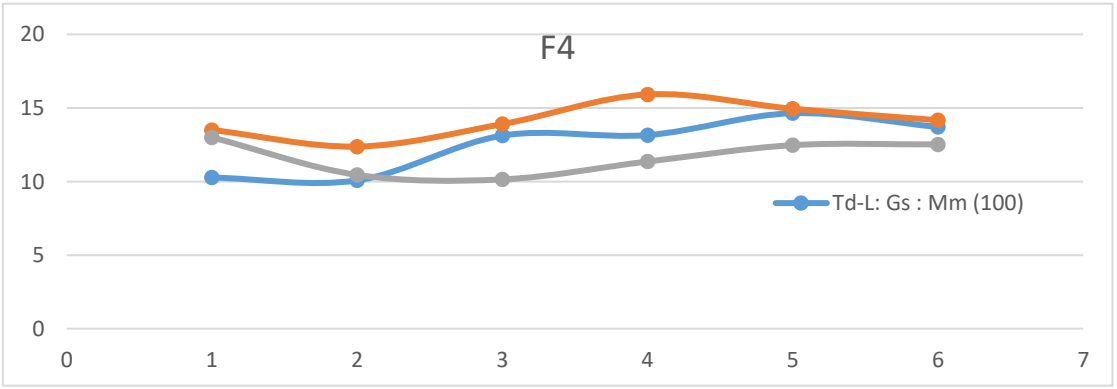


chart 5-15; Growth diameter per day against Schizophyllum commune(F4)

5.11.4.3 Antifungal percentage of the respective solution concentration

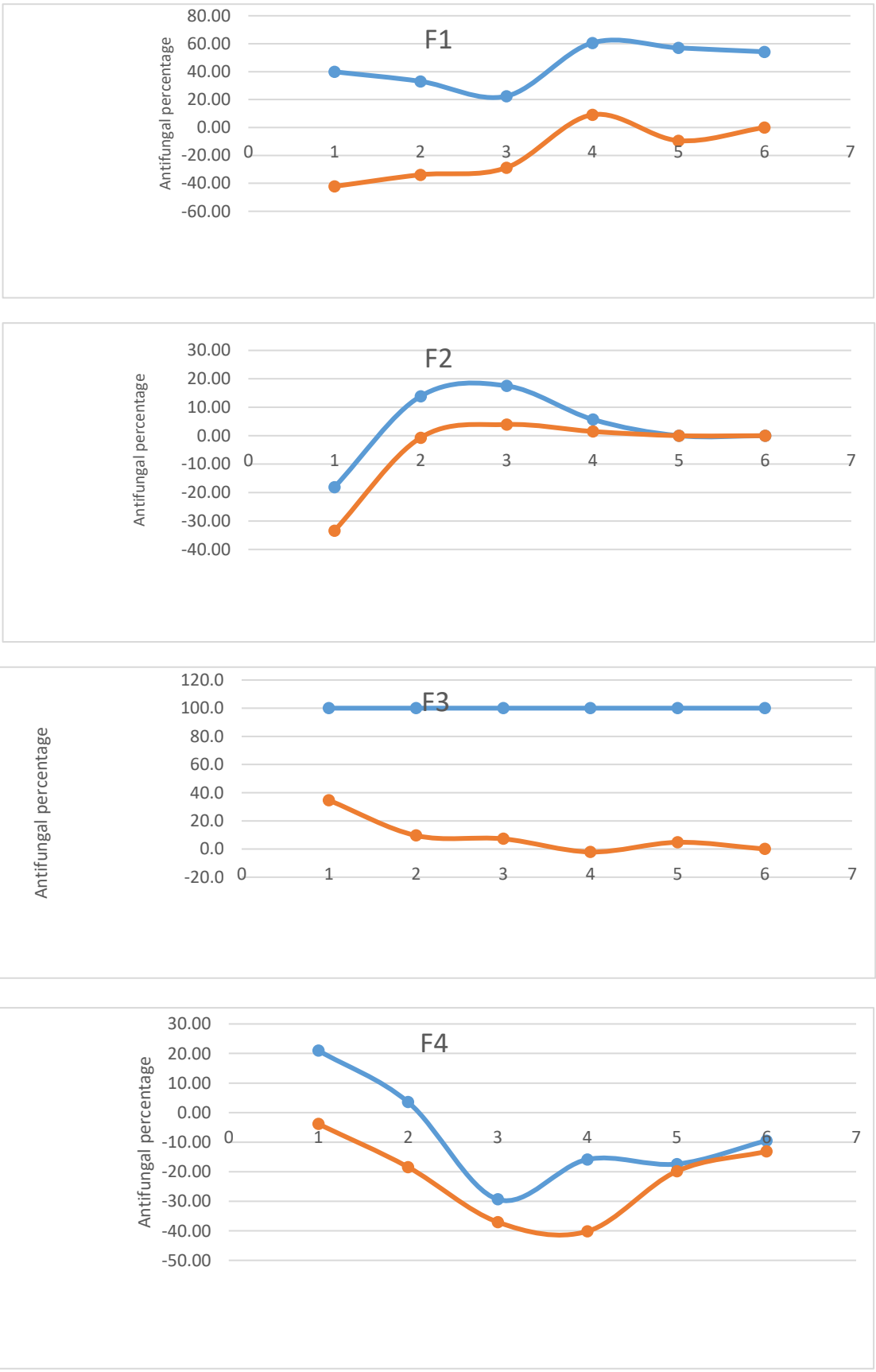


Figure 5-37;Antifungal activity against Talaromyces purpureogenus(F1), Aspergillus japonicus(F2), Pleurotus ostreatus(F3), Schizophyllum commune(F4)

5.11.4.4 Discussion

It was significantly observed the 100 % concentration of the solution is more effective than the 10 % of the solution. Here the study concludes the solution needs further concentration rather than diluting it in even the initial stage to obtain more toxicity towards the fungus. No growth was presented from the solution at 100 against *Pleurotus ostreatus. Td-L:Gs:Mm presented significant antifungal activity at 100 % concentration compared to the 10 % concentration.*

5.12 Evaluation of the antifungal activity of experimental organic wood preservative

This study is to evaluate and compare the effectiveness of the solution developed using natural plant leaf extracts against common wood decay fungi as a solution with the potential for a wood preservative.

Experiment 5-10; Compare the effectiveness of the solution developed using each plant extract

5.12.1 Materials and methods

The study uses the below plant material collection and plant extractions to develop the solutions

A. Collection of plant material

Matured *Mikania micrantha, Tithonia diversifolia, and Gliricidia sepium* fresh plant leaves are collected from Moratuwa and transported to the pro-green laboratory.

B. Solution development

Matured fresh green leaves are rinsed with normal water to take off unwanted dust particles. Then the leaves are crushed at approximately around 1 mm finer particle size. Water is used as the solvent. Next, the Paddy field mud is obtained from an organic paddy field. The mud is prepared before it is used. It is washed once with normal water and sieved and remove from the larger and unwanted particles in it. Then the excess water was removed. Finally, the solutions were developed by the combination by weight of the above-mentioned raw materials as follows; Table 2. Then after 48 hours solutions were separated using the gravity filtrating techniques, this helps to remove the solid particles and separate the aqueous extraction. Further, the solutions were kept for 48 hours at room temperature. Then the effectiveness of the solutions against fungus was evaluated, (Table 5-25).

SOLUTION NAME	Plant species	Le ave	Water	Mud
		Composition		
Td	*Tithonia diversifolia*	1	1	0
Mm	Mikania micrantha	1	1	0
Gs	*Gliricidia sepium*	1	1	0
Td_Mm_Gs	T. diversifolia: M.micrantha: G. sepium(1:1:1)	1	1	0
Td_Mm_Gs_m	T. diversifolia: M.micrantha: G. sepium(1:1:1)	1	1	5

Table 5-25; combination by weight composition of leaves: water mud

C. The density of the solution

The solution density is a term for the relative measurement of an object's mass concerning the space it occupies [291]. The density (ρ) of aqueous solutions is expressed in terms of molar volume (v) by the following expression;

$$\partial = (Mf - Me)/V$$

M_f- the mass of the empty beaker

M_e- the mass of the filled beaker

D. Food poisoning Assay

The PDA (Potato dextrose agar 3.9 %) was poisoned by adding the desired final concentration of the solution as 100 % into the molten agar and was mixed well. Then the poisoned PDA was autoclaved under the temperature of 120 degrees Celsius For 15 minutes. The solution was then kept until cool and an antibiotic was added to the solution for the prevention of antibiotic growth on the Petri dishes during the evaluation. Then, the medium was poured into Petri dishes, approximately 15 ml. Then, a hole with a diameter of 5 mm has punched aseptically with a sterile corn borer or a tip, and a volume (20–100 mL) of the fungus culture (4 to 5 days of age) is introduced into the well. Then, agar plates are incubated under suitable conditions.

The fungus diffuses in the agar medium and inhibits the growth of the fungus was measured.

Measure the radial growth rate over 6 days (mm day-1). Growth rate measurements over 6 days were compared to the control. Triplicate sample dishes were prepared. Sporulation can be also compared to the control. The antifungal percentage was evaluated as follows,

$$\text{Antifungal activity percentage } = \left[\frac{Dc-Ds}{Dc}\right] \times 100$$

Where Dc – Growth diameter in the control plate, Ds – Growth diameter in the plate containing tested antifungal agent.

5.12.2 Results and Discussions

The experiment presents the following results as follows,

5.12.2.1 Density

Plant extract included in the solution	Solution name with the composition plant: mud: water	Abbreviation	Density with the (standard deviation)
Tithonia diversifolia	*Td*100_00_100	Td	976.2 ±1.30
M*ikania* ***m****icrantha*	*Mm*100_00_100	Mm	935.6 ± 23.64
Gliricidia sepium	*Gs*100_00_100	Gs	976.6 ±3.05
Final **S**olution without **M**ud	*FSWOM*300_00_300	FSWOM	968 ±20.95
Final **S**olution **with M**ud	*FSWM*300_1500_300	FSWM	967 ±1.73

Table 5-26; Solution name and its composition

The highest density value was obtained from the solution developed using only *Gliricidia sepium* plant extract with the composition of 1: 1 water and plant extract ratio.

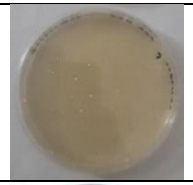
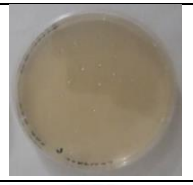
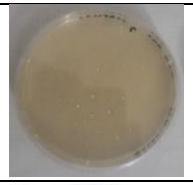
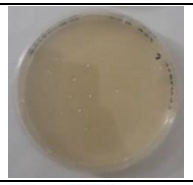
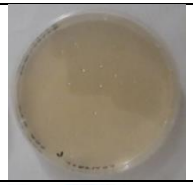
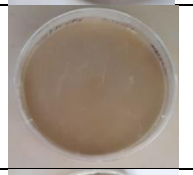
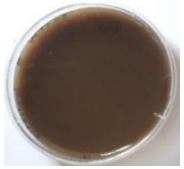
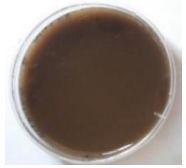
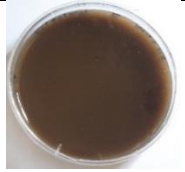
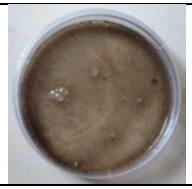
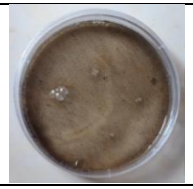
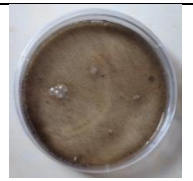
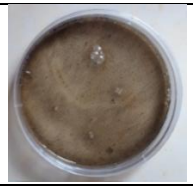
And the lowest density was presented on the solution developed only *Mikania micrantha* plant extract with the composition of 1:1 water and the plant extract ratio. Compare to the FSWOM and FSWM solutions which comprise all three-plant extract combinations 1:1:1, FSWOM presented the highest value, Table 5-26.

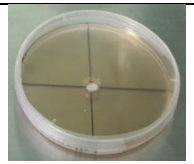
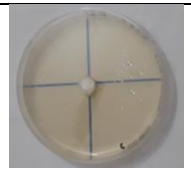
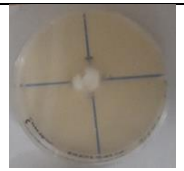
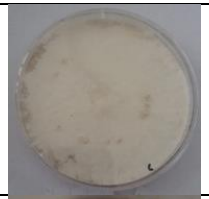
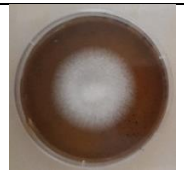
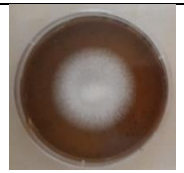
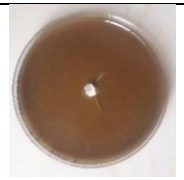
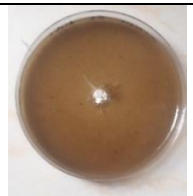
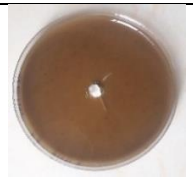
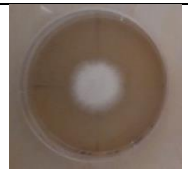
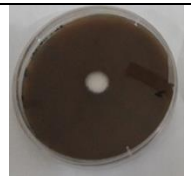
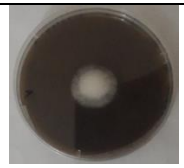
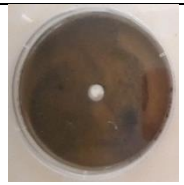
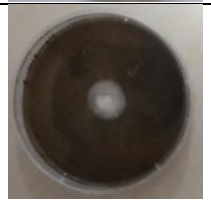
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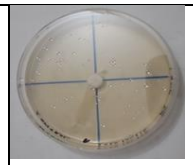
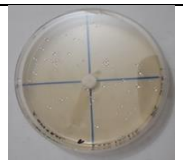
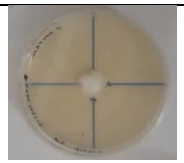
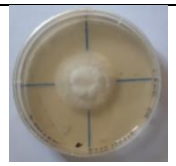
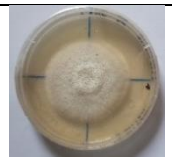
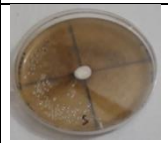
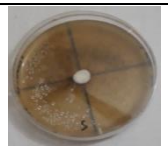
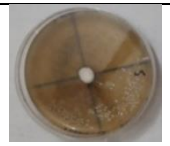
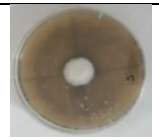
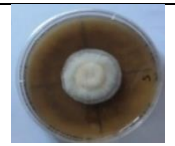
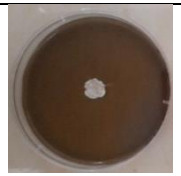
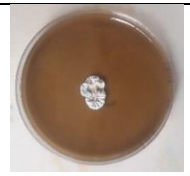
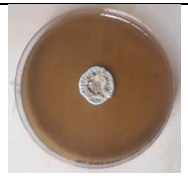
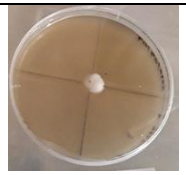
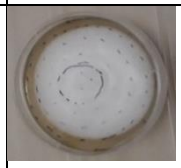
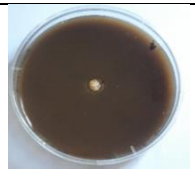
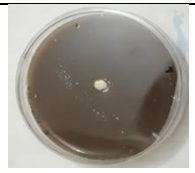
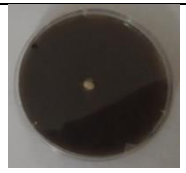
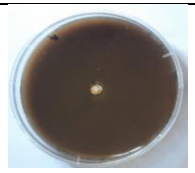
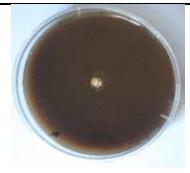
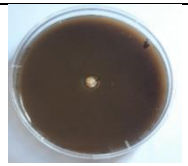
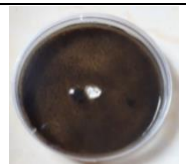
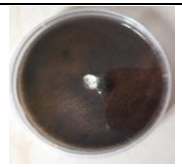
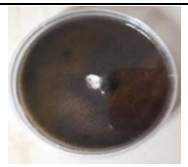
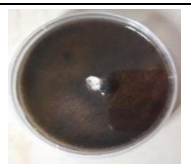
Plant extract : water	Leaf Combination	Leaf :water :mud
1:1	1:1:1	1:1:1:5

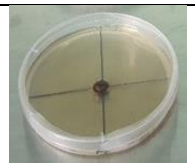
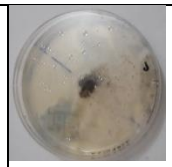
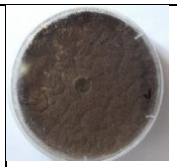
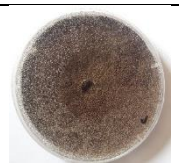
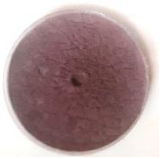
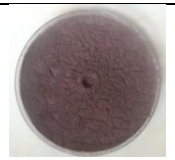
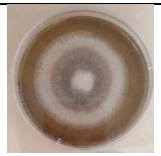
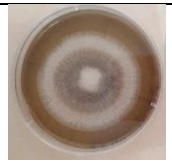
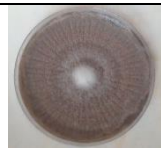
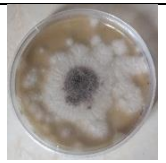
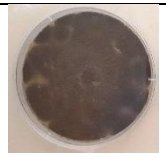
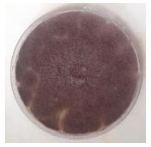
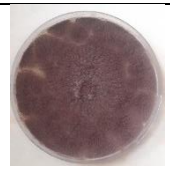
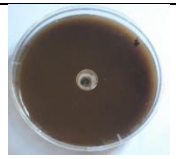
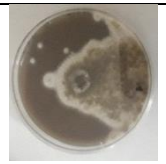
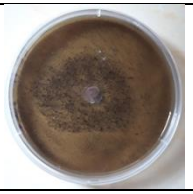
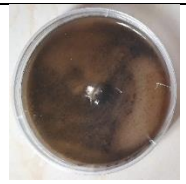
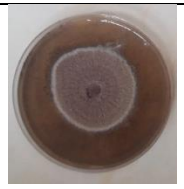
Figure 5-38; Material matrix composition

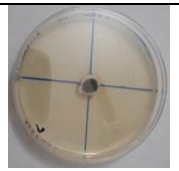
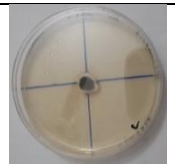
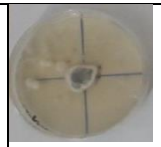
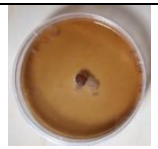
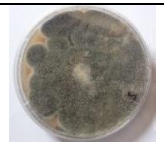
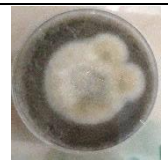
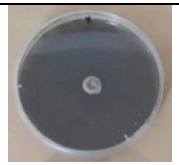
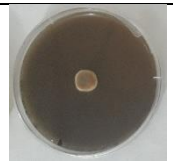
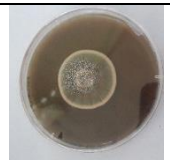
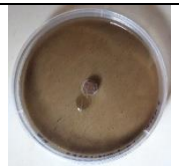
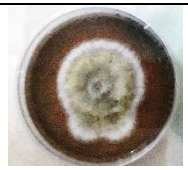
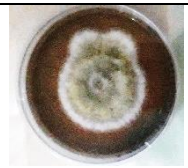
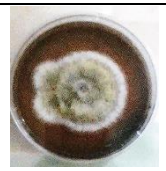
Table 5-27; Control Specimens,

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Control						
Tithonia diversifolia (Td)						
Mikania micrantha (Mm)						
Gliricidia sepium *(Gs)*						
Final Solution without Mud ***(FSWOM)***						
Final Solution with Mud *(FSWM)*						
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6

F4						
Control						
Tithonia diversifolia (Td)						
Mikania micrantha (Mm)						
Gliricidia sepium *(Gs)*						
Final Solution without Mud ***(FSWOM)***						
Final Solution with Mud *(FSWM)*						
F3	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6

Control						
Tithonia diversifolia (Td)						
Mikania micrantha (Mm)						
Gliricidia sepium *(Gs)*						
Final Solution with out Mud ***(FSWOM)***						
Final Solution with Mud *(FSWM)*						
F2	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6

Control						
Tithonia diversifolia (Td)						
Mikania micrantha (Mm)						
Gliricidia sepium *(Gs)*						
Final Solution without Mud ***(FSWOM)***						
Final Solution with Mud *(FSWM)*						
F1	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6

Control						
Tithonia diversifolia (Td)						
Mikania micrantha (Mm)						
Gliricidia sepium *(Gs)*						
Final Solution without Mud ***(FSWOM)***						
Final Solution with Mud *(FSWM)*						

5.12.3 **Antifungal activity against white rots was presented as below,**

5.12.3.1 Growth of *Schizophyllum commune* against the developed solutions

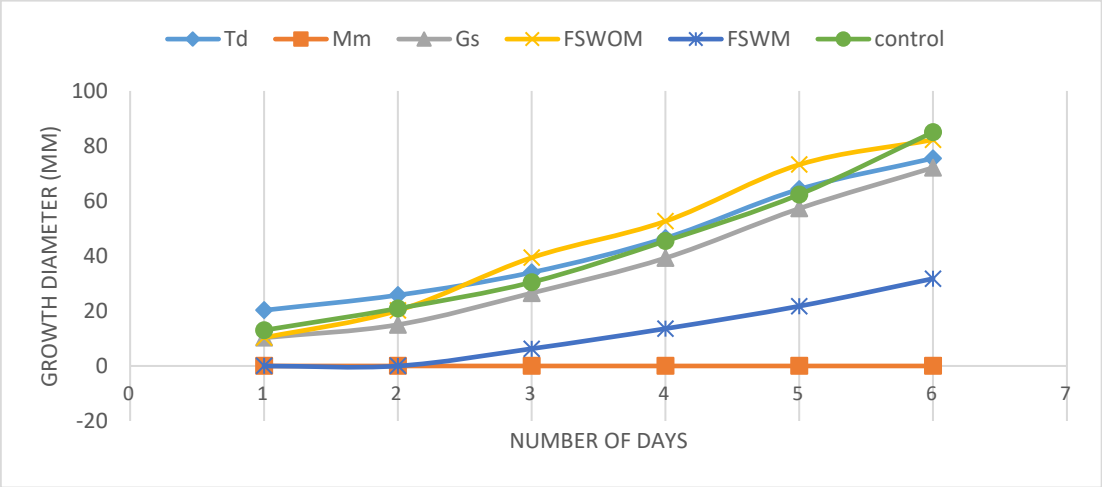


chart 5-20;Growth diameter against Schizophyllum commune

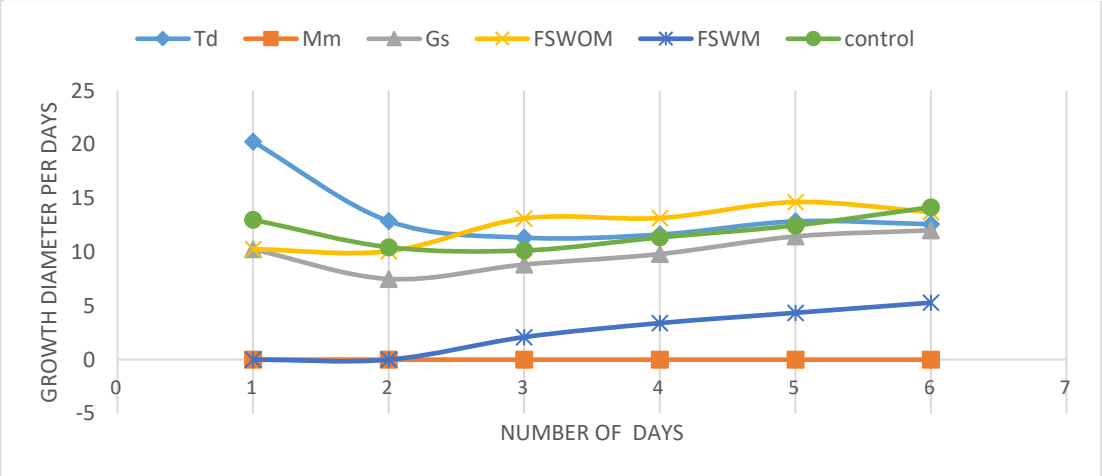


Chart 5-19- Growth diameter per day against Schizophyllum commune

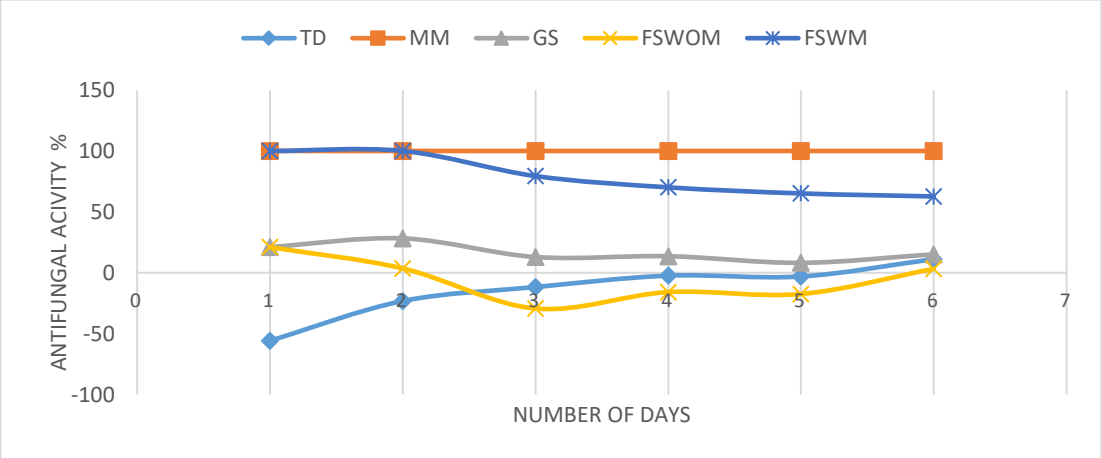


Chart 5-21- Antifungal activity percentage against Schizophyllum commune

5.12.3.2 Growth of *Pleurotus ostreatus* against the developed solutions

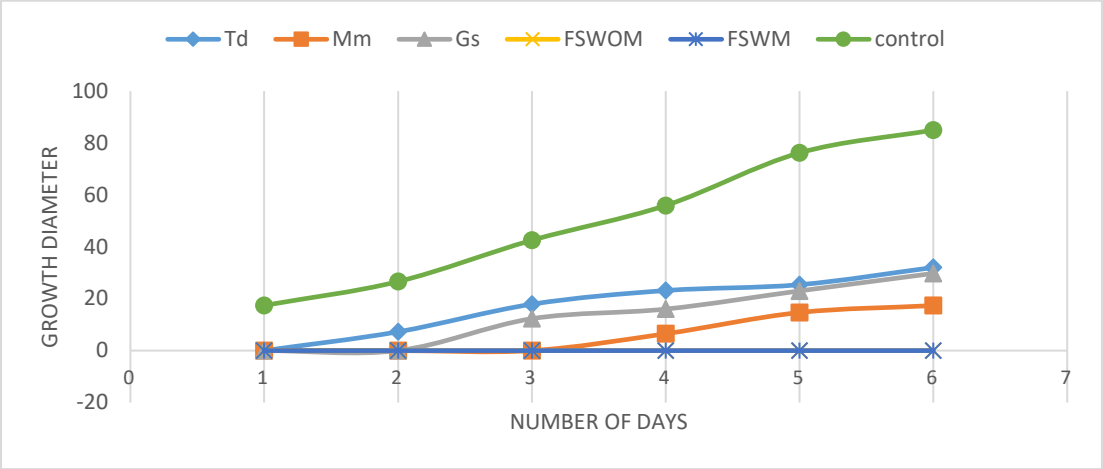


Chart 5-24- growth diameter against Pleurotus ostreatus

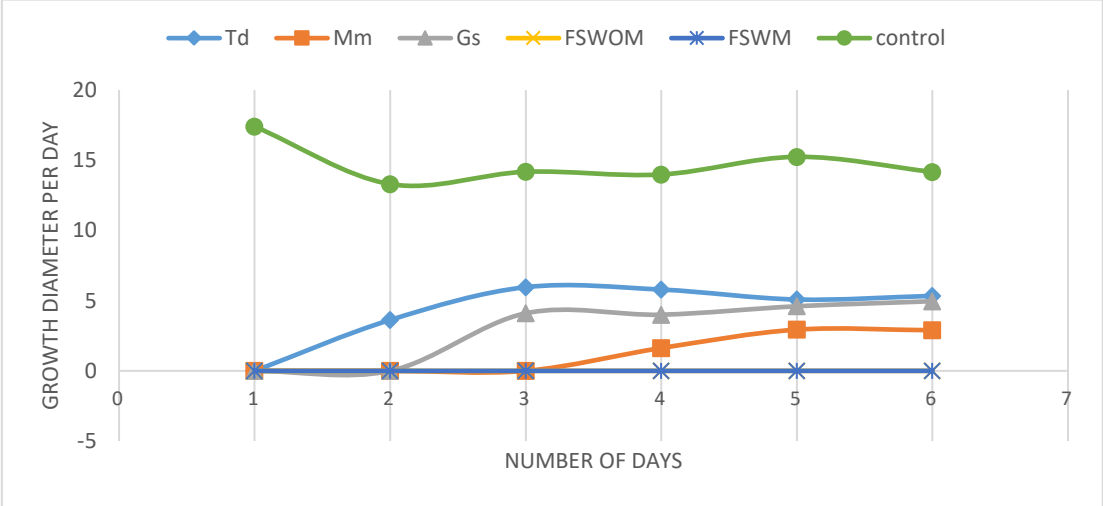


Chart 5-22- Growth diameter per day Pleurotus ostreatus

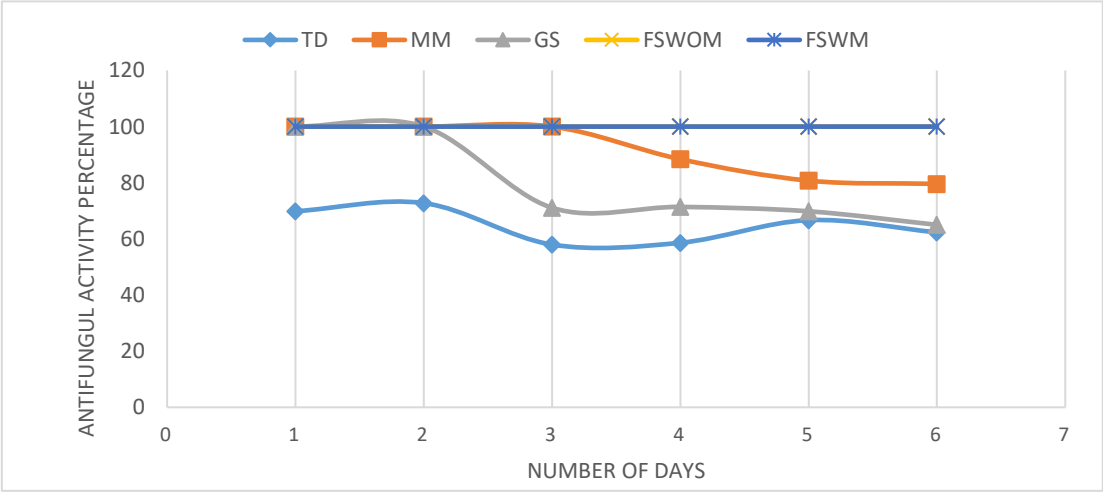


Chart 5-23- Antifungal activity percentage Pleurotus ostreatus

5.12.3.3 Antifungal activity against molds Growth of *Aspergillus japonicus* against the developed solutions

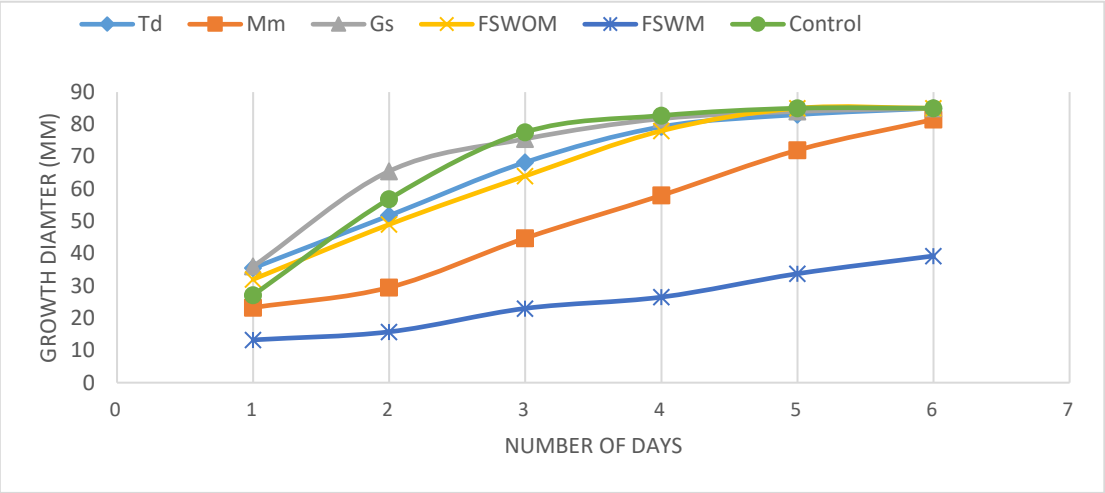


Chart 5-25- Growth diameter Aspergillus japonicus

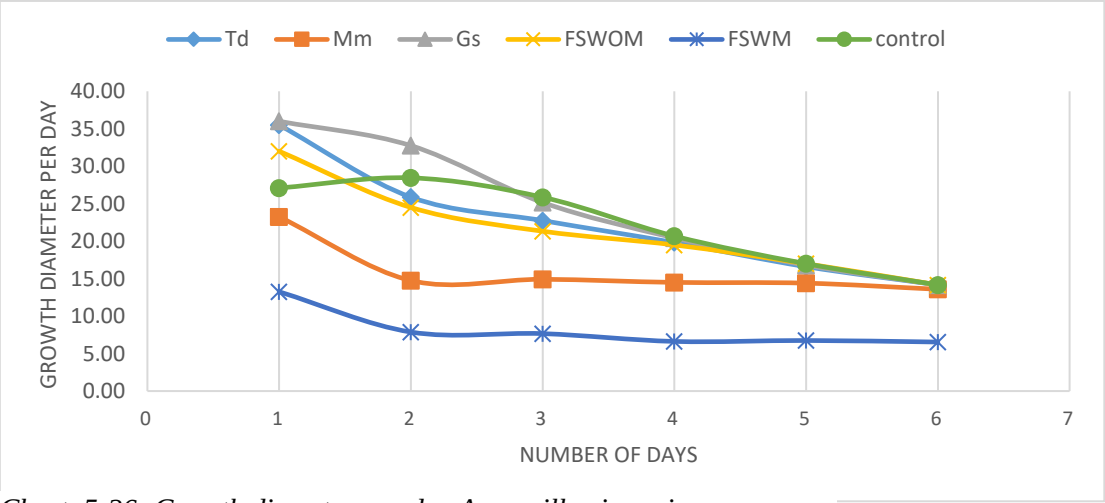


Chart 5-26- Growth diameter per day Aspergillus japonicus

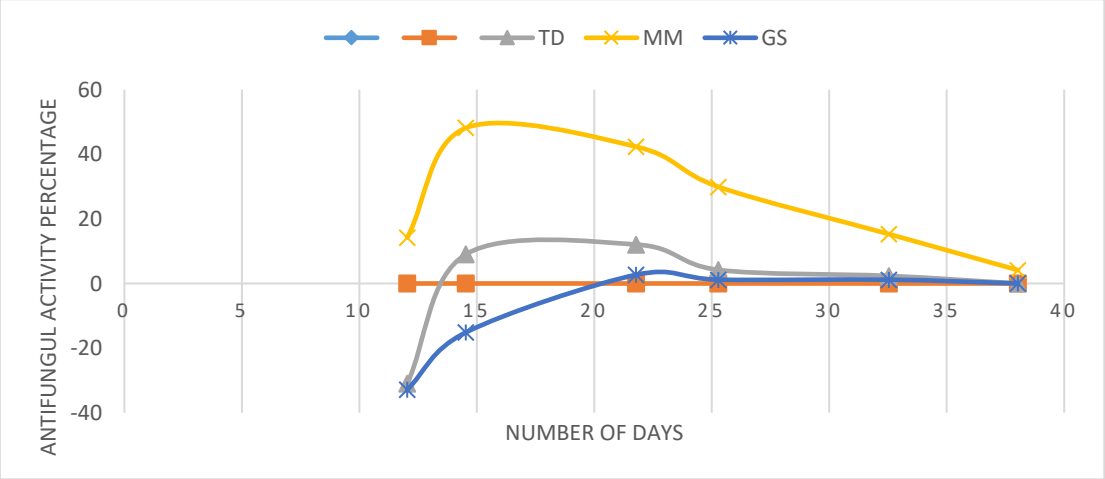


Chart 5-27- Antifungal activity percentage Aspergillus japonicus

5.12.3.4 Growth of *Talaromyces purpureogenus* against the developed Solutions

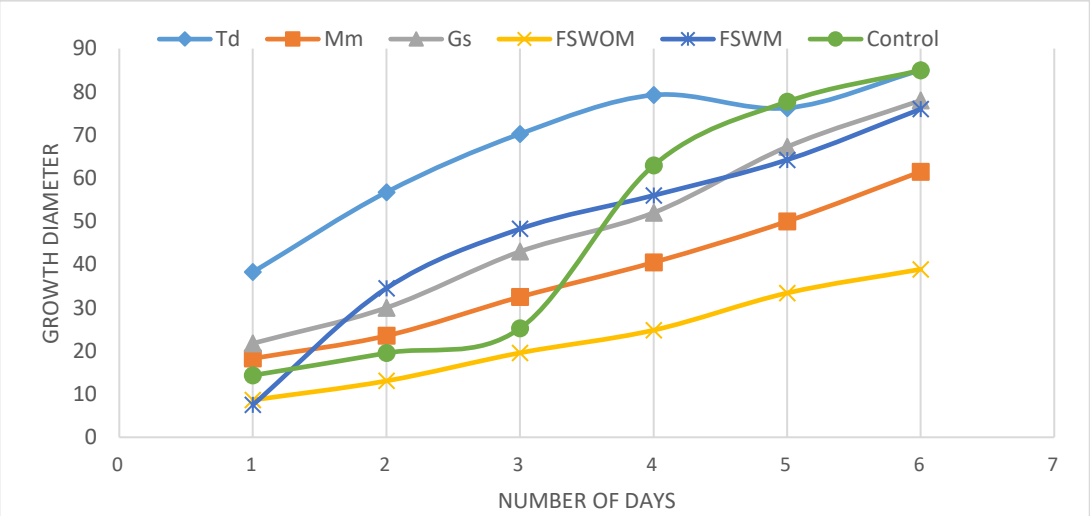


Chart 5-29 - Growth diameter Talaromyces purpureogenus

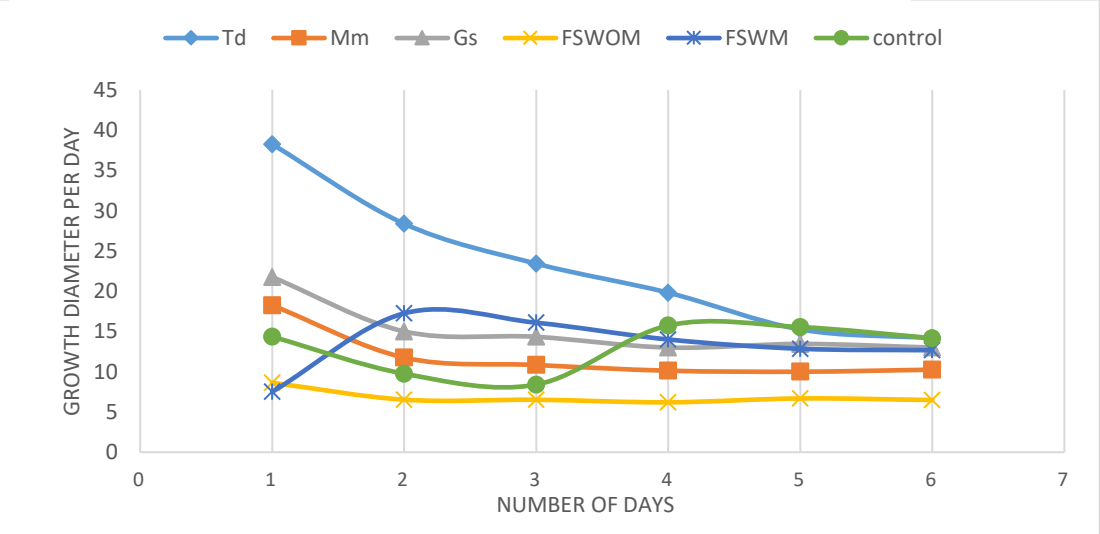


Chart 5-28 - Growth diameter per day Talaromyces purpureogenus

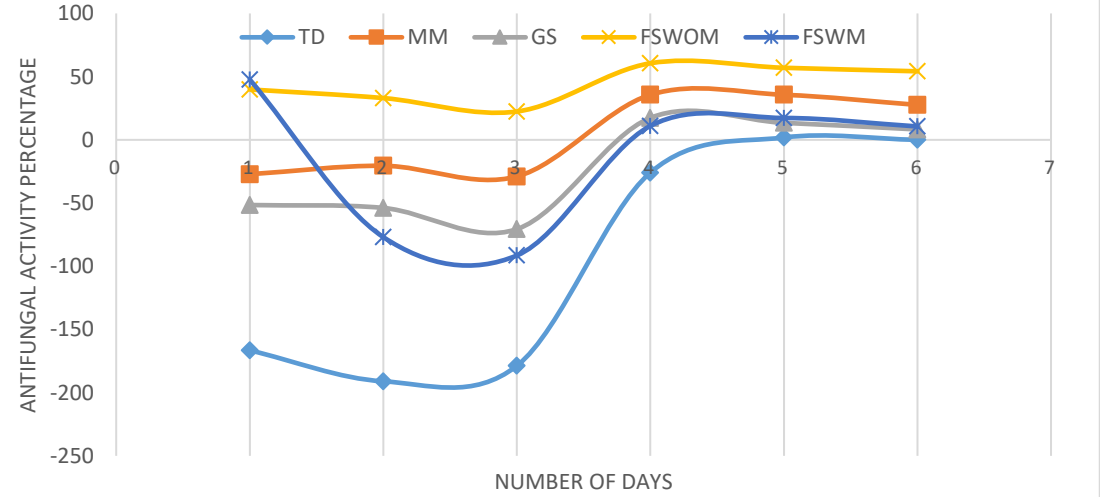


Chart 5-30-Antifungal activity percentage Talaromyces purpureogenus

- **Effect of *Schizophyllum commune and Pleurotus ostreatus***

Mean growth of the fungi was presented from the growth diameter, the fungal growth rate was expressed in growth diameter per day (mm per day) and the Mean antifungal activity percentage of the solution developed using 3 different plant extract species were given; (Chart 5-22),(Chart 5-23), (Chart 5-25). The results disclosed the Control PDA (without poisoning the medium) presented the mean growth per day against *Schizophyllum commune* up to the 6 days as 13,10.45,10.14,11.35,12.47,14.16 mm. Also, the control PDA recorded the values of 17.4,13.4,14.17,13.98,15.24,14.16 mm per day against *Pleurotus ostreatus.*

The highest antifungal activity against *Schizophyllum commune* recorded on the 6th day was the solution MM (100%) and the lowest was recorded on the solution FSWOM (3.25 %). This presented a comparatively 96.75 % higher antifungal activity percentage in the FSWM solution.

The highest antifungal activity against *Pleurotus ostreatus* recorded on the 6th day was the solution FSWM and FSWOM (100 %) and the lowest was recorded on the solution Td (62.32 %). This presented a comparatively 37.68 % higher antifungal activity percentage in both FSWM and FSWOM solutions.

Compared to the above results the solutions with the highest antifungal activity against both the white rots were identified as Solution Mm and the Solution FSWM.

- **Effect of *Talaromyces purpureogenus and Talaromyces purpureogenus***

Reference to the (Chart 5-23), (Chart 5-25), (Chart 5-26), (Chart 5-27), (Chart 5-28), (Chart 5-29). The Control PDA (without poisoning the medium) presented the mean growth per day against *Aspergillus japonicus* up to the 6 days as 27.10, 28.45,25.87,20.68,17.00,14.17 mm per day. Also, the control PDA recorded the values of 14.35, 9.75 ,8.4 ,15.73 ,15.73, 15.54, 14.16 mm per day against *Talaromyces purpureogenus.*

The highest antifungal activity against *Aspergillus japonicus* recorded on the 6th day was the solution FSWM (53.82 %) and the lowest was recorded on the solution TD, GS, FSWOM (0 %). This presented a comparatively 53.82 % higher antifungal activity percentage in the FSWM solution.

The highest antifungal activity against *Talaromyces purpureogenus* recorded on the 6th day was the solution FSWOM (54.23 %) and the lowest was recorded on the solution

Td (0 %). This presented a comparatively 54.23 % higher antifungal activity percentage in FSWOM solution.

Compared to the above results the solutions with the highest antifungal activity against both the molds were identified as Solution the Solution FSWM.

Substantial antifungal activity percentage was presented in the solution developed with the *Mikania micrantha* plant extract names as Mm. the values presented as 27.64 against *Talaromyces purpureogenus, 4.11 % - Aspergillus japonicus, 79.58 % against Pleurotus ostreatus and 100% against Schizophyllum commune.*

FSWM solution presented more than 50 % of antifungal activity against Aspergillus japonicus, Pleurotus ostreatus an *Schizophyllum commune* as 53.82 %, 100 %, 62.64 %. while a low antifungal activity against Talaromyces purpureogenus as 10.58 %.

The significant antifungal activity of M. micrantha has been linked to the presence of numerous types of bioactive chemical substances, including Sesquiterpene lactones, Mikanolide, deoxymikanolide, dihydromikanolide, and scandenolide. The presence of glycosides and quinones, according to a study, is responsible for the antifungal activity. Where they have an inhibitory effect on the germination of spores by a variety of fungus species [292], [293], [294].

5.12.4 Discussion

Plant-derived phytochemicals could be useful in the wood preservation industry because of their antimicrobial potencies, toxic nature towards wood deteriorating agents, and bioavailability. Plants like *Mikania micrantha* used in the study Eco-friendly biological control and innovative genetic engineering technologies should be used to reduce substantial loss due to its invasive nature.

This study evaluated antifungal resistance of experimental wood preservatives based on plant leaves extracts. Solutions developed using three different plant extracts *of Gliricidia sepium, Tithonia diversifolia,* and *Mikania micrantha* under different combinations, under the same concentration were evaluated.

Developed solutions were investigated against *Schizophyllum commune, Pleurotus ostreatus,* and *Aspergillus japonicus, Talaromyces purpureogenus* for 6 days. Five combinations of preservative solutions were developed as Td, Mm, Gs, FSWOM, FSWM. FSWM solution presented more than 50 % of antifungal activity against *Aspergillus japonicus, Pleurotus ostreatus,* and *Schizophyllum commune as* 53.82 %, 100 %, 62.64 %. While it seemed low effective against *Talaromyces purpureogenus* as

10.58 %. Comparatively, a substantial antifungal activity percentage was presented in the solution developed with the *M. micrantha* plant extract Mm; 27.64 % against *Talaromyces purpureogenus*, 4.11 % - *Aspergillus japonicus*, 79.58 % against *Pleurotus ostreatus,* and 100% against *Schizophyllum commune*.

The current study suggests that the solution developed with the combination of all three plant extracts comprising a mud mix as a potential organic wood preservative against wood decay fungi as an alternative to chemical preservatives.

- Antifungal properties of an experimental wood preservative were tested against decay fungi.
- Preservative solutions were developed using Mikania micrantha, Gliricidia sepium, Titonia diversifolia.
- The highest antifungal activity against both the white rots was identified as Solutions with only *Mikania micrantha* and the solution with all three plant extracts combined with mud solution Mm and the Solution FSWM.
- These developed solutions with all the three plant extracts have the potential toxicity to be utilized as an alternative wood preservative solution against fungi.

5.13 Leaching characteristics of the wood treated with the plant extracts

When water enters a significant bulk of solid material as a contaminated liquid, leachate is produced. To acquire important information on their leach resistance, a continuous water immersion CEN/TS 15119-2 was based on the sequential extraction technique.

The present study aimed to observe the tannin leachate after being exposed to water and compare the leachate with untreated timber and two commercially available wood preservation technique. *M. micrantha, G. sepium, and T. diversifolia* plant species were utilized to develop the solutions. 25 mm x 25 mm x 25 mm *Mangifera indica* defect-free timber blocks were dipped in the solutions for 72 hours. The blocks were oven-dried at 103± 2 ℃ for 24 hours and sample size 25 mm x 12.5 mm x 5 mm was subjected to sequential and continuous water immersion procedure for 24 hours at room temperature. Ferric chloride color indicator was to characterize the tannin presence at the leachate and the leached timber specimens were then oven-dried at 103± 2 ℃ for 24 hours and exposed to subterranean termites for 3 months.

Literature records the retention of organic biocides inside treated wood tissues is challengeable [295]. Therefore, the literature significantly states the importance of evaluating the leachate when developing a wood preservative solution. The potential pollution from this waste has been evaluated through leaching studies, the repeated test series are based upon continuous water immersion (CEN/TS 15119-2) leaching tests[296].

Experiment 5-11; characterize the behavior of wood leachate generated from the treated wood

And visually observe the color variation of the leachate. Consequently, the present study monitors the leachate induced by precipitation on *Mangifera indica* wood treated solutions developed with plant extract and compares the performance concerning industrially available two types of wood preservatives based on continuous observations and monitoring data of leachate quality. Temporal variations in leachate quality were examined visually and quantified by using color indicators. Colorimetric tests are performed to visually evaluate the presence of tannin and mass loss percentage of the treated wood exposed to subterranean termites under natural environmental conditions was observed to evaluate the toxicity retains even after continuous leachate.

5.13.1 Experimental methods

A. Preservative Solution developments

The solutions were prepared as per the following mentioned table below; (Table 5-33), Plant Collection; The fresh plant leaves of *M. micrantha*, *G. sepium*, and T. *diversifolia* were collected during the maturated stage in Piliyandala, Colombo district natural habitats. The samples were rinsed with normal tap water to remove the dust alien particles dust or others etc., then the fresh leaves were obtained by weight percentage as the above chart to develop separate solutions. The fresh leaves were ground and then kept for 48 hours. Then the solutions are gravity filtered using cotton clothes to separate the solute and the solvent and then again, the solution is kept for another 48 hours and then the solutions are ready and stored in glass jars until use.

B. Preparation of test specimens

Aqueous extraction of the plants was obtained as per the above-given table 1. Test specimens of *Mangifera indica* (hardwood;25 × 25 × 25 mm^3 timber blocks) were treated by soaking with 100% (w/w) of the solutions developed by the plant extracts for 72 hours. The weight of each specimen was measured before and after (oven-dried)

treatment. The treated wood was then oven-dried at the temperature of 103 ± 2 for 24 hours. The percentage of gross chemical uptake of the agent was calculated from the difference in the weights of the specimen before and after treatment. The dried woodblocks were cut into smaller pieces of 25 mm x 12.5 mm x 5 mm to improve contact with the reagents.

C. Sample Dissolution Methods- leaching procedures

The laboratory leaching test was carried out following the CEN/TS 15119-2:2008 standard for continuous water immersion of the sample. Each specimen was placed in its container, which was then filled with deionized water. Three specimens were placed in each glass test tube and three replicates were maintained per treatment and a blank sample was maintained parallelly. The test is repeated as follows; the deionized water was replaced after 6-hour, 1 day, 2 days, 3 days, 4 days, 5 days, 6 days, 7 days, and 8 days of leaching (Bahmani et al., 2016). The leachate is then thoroughly mixed to obtain as homogeneous a sample as possible. All the procedures were carried out on a minimum of three samples and a blank sample. Then the wood samples were added to a test tube with 30 ml of distilling water. A sequential extraction procedure was also applied to obtain the color variations every 24 hours. And every 24 hours' time the

	abbreviation	**Composition of the solution**		
	Solution abbreviation	**water (ml)**	**leaf (g)**	**mud (g)**
Tithonia diversifolia	TD100_00_100	100	100	0
Mikania micrantha	MM100_00_100	100	100	0
Gliricidia sepium	GS100_00_100	100	100	0
Tithonia diversifolia* + *Mikania micrantha	TD_ MM	200	200	0
Tithonia diversifolia* + *Gliricidia sepium	TD_ GS	200	200	0
Mikania micrantha* + *Gliricidia sepium	MM_ GS	200	200	0
Final Solution Without Mud	FSWOM300_00_300	300	300	0
Final Solution with Mud	FSWM300_400_300	300	300	600

Table 5-28;Description of the material matrix and the composition of the solutions .

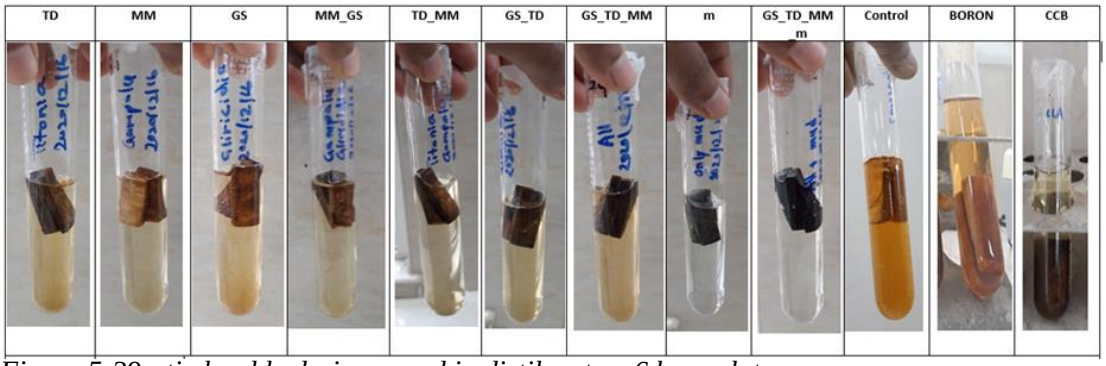


Figure 5-39 - timber blocks immersed in distil water ;6 hours later

leachates were removed after recorded and then it was renewed with distilled water. It was continuously observed visually until a colorless solution was obtained;

D. Ferric test for tannin detection

A quantity (10 ml) of the extract was obtained from the 24 hours solution leached out to the water. The solution was mixed to obtain a homogeneous solution and filtered. The filtrate was subjected to the following tests. Qualitative characterization of tannins was performed on *Mangifera indica* treated timber samples with chemical and colorimetric tests: ferric. Results were evaluated visually. The reagents used were ferric chloride. Ferric reagent was an aqueous solution of 2%(w/v) ferric chloride (FeCl3). A Ferric chloride test was performed as follows. 2 drops of ferric chloride were added to a 5ml filtrate; if the solution presents a transient greenish to black color that indicates the presence of tannins[297]. Pizzi (2004) reported that the products of condensed tannins are in green black color whereas for the hydrolyzable tannins they will become blue-black products.

Experiment 5-12; Tannin detection of the leachate generated using Ferric chloride test

E. Accelerated field test

A leached wood sample was then exposed to a subterranean termite attack to evaluate the potential toxicity in the field. Trials were set up in each of the solutions developed using the plant extract and industrially available preservative, of *Mangifera Indica*.

Experiment 5-13; Investigate the mass loss percentage of the wood specimens after exposing them to continuous water immersion.

It was assessed by the samples placed on a soil bed with dense subterranean termites' area and exposed for 3 months. Five replicates per solution were evaluated.

$$wieght\ loss\ \% = (Initial\ weight - present\ weight) * \frac{100}{(initial} weight)$$

5.13.2 Results

The results disclose the gross chemical uptake and the toxicity performance,

A. Gross chemical

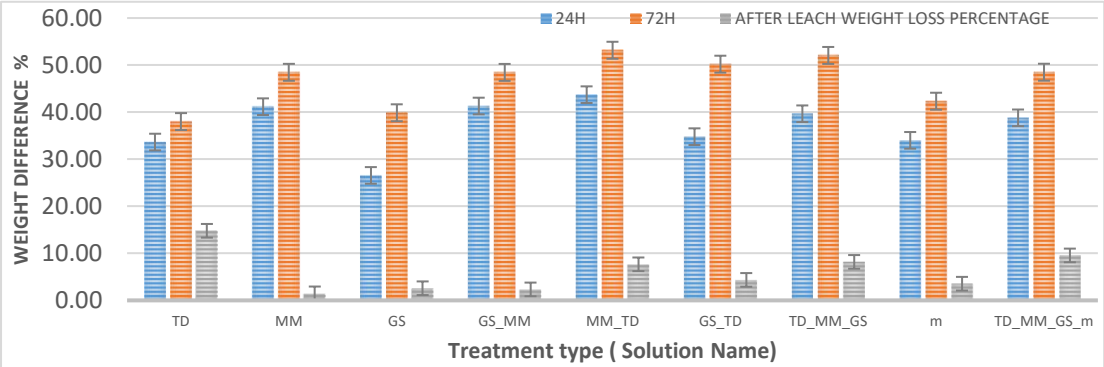


Chart 5-31;Obtained weight difference percentages among the solutions

A significant chemical uptake was recorded from the results obtained after 72 hours of soaking compared to the 24 hours soaking duration. Among the developed solutions MM_TD presented a significant chemical uptake when the lowest chemical uptake percentage was presented from the GS. It was presented that the solutions without *Gliricidia sepium* plant extracts presented substantial values of chemical uptake. The weight gain percentage and the weight loss percentage after leachate were presented as above (Chart 5-31).

The highest weight loss percentage was presented from the timber blocks treated with TD solution and the lowest weight loss percentage was presented from the sample treated with the MM. The leachate generated due to continuous immersion of 6 hours, 1 day, 2 days,3 days, 4 days, 5 days, 6 days, 7 days, 8 days were recorded every 24 hours. The visual observations exhibited a drastically deviating color variation compared to the (clear /colorless /distill water) control sample. Then the leached solution was separated and renewed with new distilled water after every twenty-four hours. Finally, all the timber samples exposed to continuous immersion presented a gradually decreasing appearance and on the 8 days, the solutions presented the lowest color variation among the solutions; Figure 2. The highest leach resistance was presented on the timber treated with the solutions mixed with mud compared to all solutions and the control untreated sample. Also, when compared to the industrial available treatments the timber treated with m and the TD_GS_MM_m solution presented a significant discoloration property compared to Boron treated timber and a chromated copper boron treated timber from the first 24 hours immersion.

B. Tannin presence in the leachate

The Ferric test is designed to detect phenolic chemicals, not just tannins. It works on the basis that when phenolics react with iron salts, a blue or green-black (or grey) product is formed. The phenolic content of the sample was found to be positive. As a result, the phenolics found can be fairly assumed to be tannins. It was observed with time the tannin leachate gradually decreases. Hence though the lowest color variation was detected on the 8 days still the moderate tannin leachate was presented on the solution as indicated from the ferric chloride solution.

Table 5-29; Solution Composition

Plants extracts used to develop the solutions	**Abbreviation**	**Initial weight**	**72 hours gross chemical uptake**	**After leach weight loss percentage**	**Weight loss percentage due to the termite attack**
T. diversifolia	*TD*	16.23 ± 1.02	38.00	14.79 ± 1.36	25.29 ± 2.72
M. micrantha	*MM*	17.39± 1.02	48.47	1.49 ± 0.64	9.93 ± 3.27
G. sepium	*GS*	2.58 ± 1.03	39.87	2.58 ± 1.31	10.37 ± 0.28
G. sepium + M.micrantha	*GS_MM*	14.97± 1.01	48.45	2.33 ± 0.90	12.72 ± 4.40
M. micrantha + T. diversifolia	*MM_TD*	15.74 ± 1.02	53.16	7.66 ± 3.31	18.18 ± 2.86
G. sepium + T. diversifolia	*GS_TD*	17.04 ± 1.02	50.20	4.35 ± 1.87	15.69 ± 4.15
All	*TD_MM_GS*	15.51 ± 1.01	52.06	8.18 ± 2.47	15.40 ± 3.75
Only mud	*m*	16.25± 1.02	42.33	3.54 ± 0.88	8.30 ± 0.71
All + mud	*TD_MM_GS_m*	15.55 ± 1.01	48.49	9.55 ± 5.48	19.91 ± 2.22
Control	*C*	15.66 ± 1.03	NA	18.56 ± 2.23	29.09 5.07

C. Mass loss percentage

The presents the weight loss percentage comparisons among the solutions.

Results of the mass loss percentage presented as below,

The lowest mass loss percentage (5 % to 10%) was presented from the timber treated with the only mud solution and the timber treated with the solution developed using *Mikania micrantha* plant extract. Next, the lowest mass loss percentage (10-15%) was presented with the timber treated with the solutions developed with GS (*Gliricidia sepium* plant extract) and GS_MM (*Gliricidia sepium* and *Mikania micrantha* plant

extract). The solutions TS_MM, GS_TD, TD_MM_GS, TD_MM_GS_m presented the weight loss in between 15 to 20 percent. The highest mass loss percentage was obtained from the solution TD (*Tithonia diversifolia* plant extract). Among all the timber specimens' samples, the control untreated *Mangifera indica* presented the highest weight loss percentage. The wood treated with chromated copper boron solution recorded a mass loss percentage of (10-15%). The Boron treated wood presented a mass loss percentage around (15 – 20 %) percentage. The specific untreated control samples presented the lowest hesitant towards environmental conditions. So, this concludes the highest toxicity against termites under natural conditions was presented on the wood treated with solution m, Solution MM and the Industrially available Chromated copper boron treated wood. And the lowest hesitation towards the termites in natural conditions was presented with the wood treated with the solution TD _MM. Further, this can be concluded that specific to the control sample the timber treated with the solution developed with only *Mikania micrantha* plant extract contains the highest toxicity against termites even after 8 days of continuous leachate.

5.13.3 Discussion

Leachate is produced when the water in contact with wood waste dissolves the soluble organic and inorganic components, resulting in an aqueous solution of wood extractives. Timber is usually treated with wood preservatives to protect them from wood deterioration during its service. Many researchers reveal the toxicity against the wood deteriorating agents involve during the service. However, the attention towards leach resistance during service and after service is inadequate. Overall, this study found the potential of developing a wood preservative using plant extracts and mud solutions, and then the study evaluates their leach resistance and its performance against termites after it was leaching for days. The results detected a discoloration on the leachate generated every 24 hours.

From these experiments, it presents that the solutions developed with *M. micrantha* plant extract are significant in toxicity even after continuous leaching and the solutions developed using mud contain a significant leach resistance. The relationship between the 72 hours gross chemical uptake percentage and the weight loss percentage after leachate was not significant.

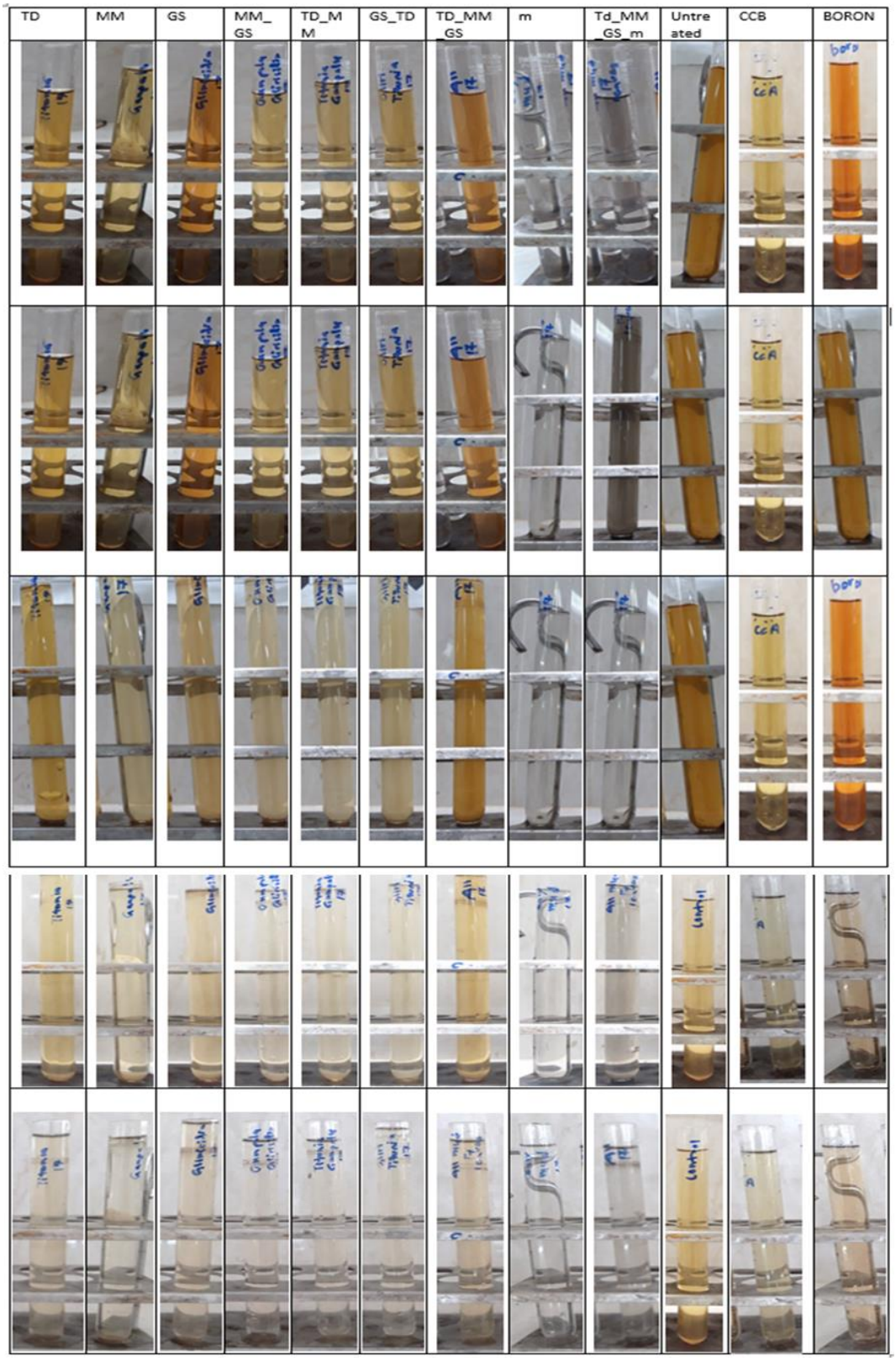


Figure 5-40;Visual observation of the color variation presented on 6 hours later, 1 day later, 3 days later, 6 days later , 8 days later

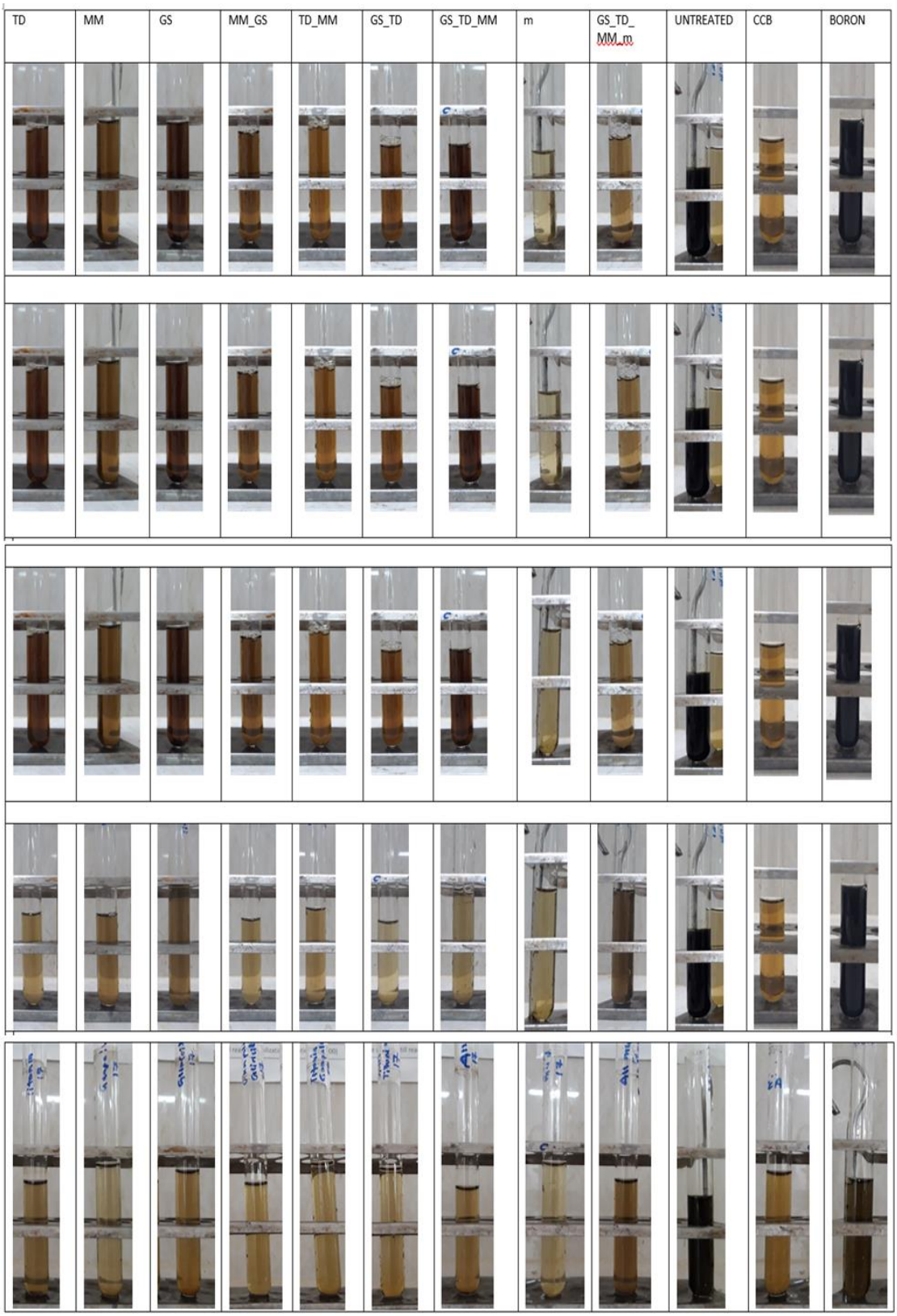


Figure 5-41; Visual observation of the color variation presented on 6 hours later, 1 day later, 3 days later, 6 days later, 8 days later after the color indicator was added to the solution

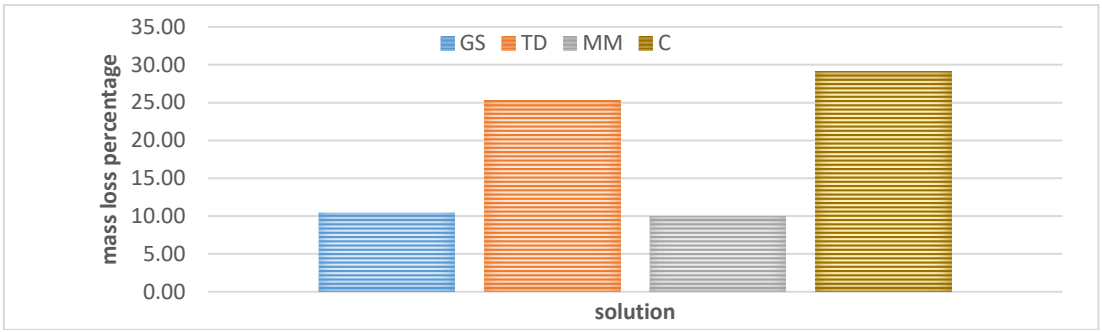


chart 5-35 Comparison of the weight loss percentage GS: TD:M M: C

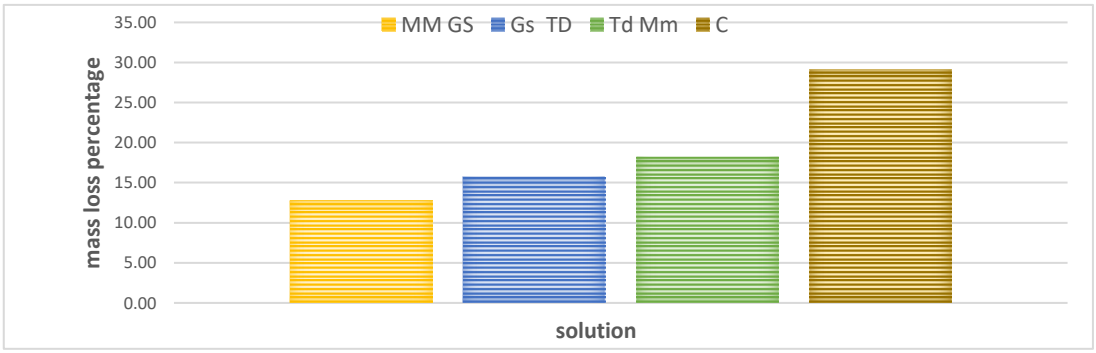


chart 5-34;Comparison of the weight loss percentage A: AM: m: C

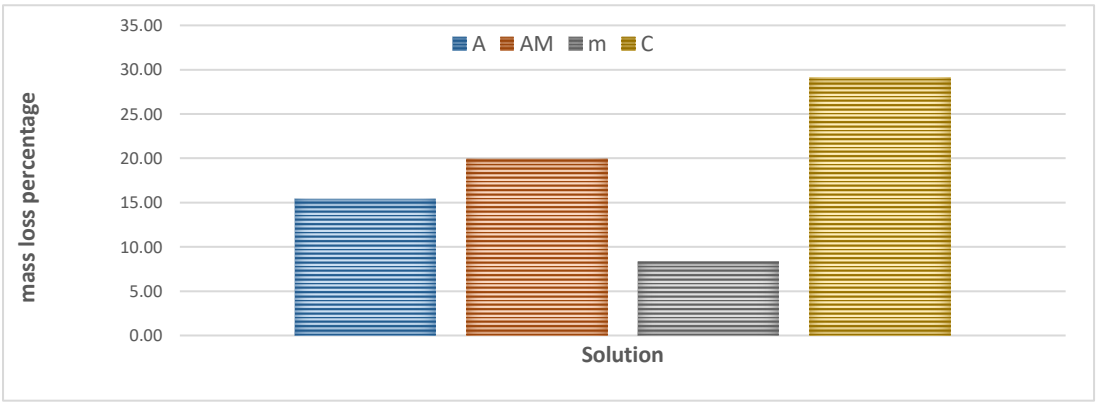


chart 5-33;Comparison of the weight loss percentage A: AM: m: C

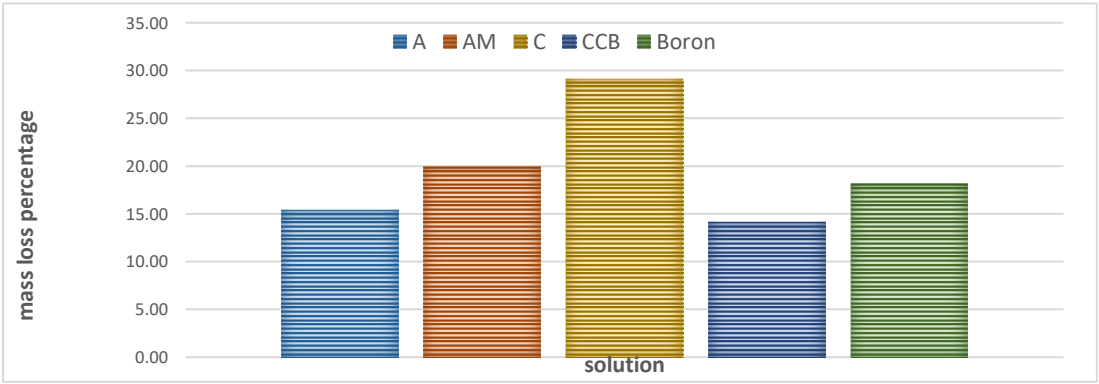


chart 5-32; A comparison of the weight loss percentage

5.14 The Composition Development with optimum performance

This phase aims to identify the best composition from the tests done up to now. Individual performance of the solution was evaluated. Here the study is based on the following findings,

- Spectroscopic screening on the treated wood
- Field Evaluation of Potential toxicity Against the Invasive Subterranean
- Termite (Isoptera: Rhinotermitidae) in tropics
- Evaluating the performance of the solution against fungus
- Accelerated field test
- Performance of the Solution Toxicity against termites
- Long-term exposed graveyard test.

Protocol 1 was evaluated by keeping the leaves composition 1:1:1

Whereas the water as the solvent and the organic prepared paddy field mud and the extraction was conducted further down the room temperature under the atmospheric pressure leaf composition was as follow,

Table 5-30; The composition of the material matrix

			*Solution*
1	1	1	Gs_Td_Mm

Micrantha: G. Sepium: T. diversifolia 1:1:1.

Table 5-31; The material matrix assorted with mud.

				*Solution*
1	*1*	*1*	*5*	*Gs_Td_Mm_m*

Based on the spectroscopic determinations of the initial investigations has made conclusions that combining plant extracts are more toxic rather developing a solution

with only a single plant extract. Also, the Mikania micrantha plant extract has resented more effective against white-rot fungus as well as in the field performance as an accelerated field test and the long-term exposed graveyard test. Also, *Mikania micrantha* treated wood at the initial stage has also presented the minimum strength loss. Therefore, comparative to all three studies identifies the *Mikania micrantha* plant extract is to be raised.

With those conclusions, the solution was developed as follows to define the exact final composition (Table 5-32).

Table 5-32 the composition was developed as follows,

Td	Gs	Mm	Solution	
1	1	1	Gs_Td_Mm	Protocol 1
1	1	2	Gs_Td_Mm (test)	Protocol test
1	1	3	FSWOM	Protocol 2

Referring to the same evaluation procedure the study identifies as protocol 2 is significantly effective compared to protocol 1 (more than 50% effective against fungus and termites), Yet the protocol test did not present a significant performance compared to protocol 1.

Based on the above finding presented, the study identifies protocol 2 under the same material matrix with the keeping the leaves composition 3:1:1.

Whereas the water as the solvent and the organic prepared paddy field mud and the extraction was conducted further down the room temperature under the atmospheric pressure leaf composition as follow

Micrantha: G. Sepium: T. diversifolia 3:1:1.

5.15 Summary

The increasing demand for timber wood treatments plays a major role[298]. Concerning those high toxic preservatives that have been used as a result of that, it has now created a threat to the environment. To mitigate this complication the objective is to explore the preservative solutions comprising plant extracts. Many scientists have been looking into the plant and microbial extracts, essential oils, pure secondary metabolites, and freshly synthesized compounds as possible antibacterial agents recently[299]. Other procedures, such as poisoned food techniques, are utilized specifically for antifungal testing. The poisoned food approach is commonly used to assess mold antifungal activity [300].

This chapter mainly focuses on the development of the solution. Here the study identifies and defines the following areas,

1. Define the parameters affecting the extraction protocol;

Temperature, extraction duration, solute to solvent ratio, particle size, the effect of extraction cycle, Solvent, preparation of the materials.

2. Define the best fermentation time and the filtration techniques and define the best solution extraction protocol with the optimum toxicity.

Many organic preservatives have been immerged using plant extracts. However, they have a lack of awareness among the wood industry as they comprise of few shortcomings of permanency, toxicity, leach resistance, environmental acceptability, or cost are some of the factors to consider. The smaller the material's particle size, the shorter the solvent's path must travel, reducing the time required for maximal phytochemical extraction. A smaller particle size led to a higher extraction extent; a typical value of 0.2 mm is accordingly recommended. The study identifies water as a potential solvent.

Literature has proved a long extraction period may not be suitable for all nutraceutical components Obtaining a specific and accurate extraction protocols is so sensitive and challengeable with these researches. The solvent, the solvent-to-solid ratio, the extraction temperature, pressure, and the extraction duration were kept constant. 50 g of fresh leaves were used for extraction. The solvent-to-solid ratio is 1 :1, the extraction was conducted under room temperature and the extraction duration was in 10 minutes, 24 hours, 72 hours, and 96 hours respectively.

The visual observation and the visual rating revealed the extraction efficiency is significant among the plant species where the fastest leaf digestion was observed in

Titonia diversifolia then in *Mikania micrantha* and the lowermost leaf digestion to water was observed in *Gliricidia sepium*. However smaller the particle sizes the time allocated to the gravity filter is higher and it's challengeable

The application of the solution with an improper filtration effect on an applied surface (rough textures as not a smooth application) and un-uniform colors and the main issue was highlighted due to potentials of molds growth on the applied surface if there were impurities. The study defines Protocol Number 1. The study has identified the solutions developed assorted with mud have the potential of coloring capabilities.

The solution with all three plant species assorted with mud; Td-L: Gs: Mm: M; presented significantly higher colour capability which was a significant finding.

Further minimizing the particle size may increase the extraction efficiency the effort on filtration is not an easy task. Therefore, this study records the particle size to range from 1 mm to 6 mm. As per literature clarifications, the study identifies Dichloromethane as the best solution for extraction chemical investigations.

Effect of extraction methodologies and solvent selection for Chemical analysis. Evaluation of the performance against fungus (*Schizophyllum commune*) that was grown in; the Agar disc diffusion method. Performance of the Solution Toxicity against termites. Results revealed that the Gs_Td_Mm_m has more leach resistance in outdoor conditions and more significant fixation properties compared to the Gs_Td_Mm solution

CHAPTER 6 : A COMPARISON OF THE PERFORMANCE OF DEVELOPED SOLUTION

6.1 General

This chapter presents the outcome achieved from the experiments of the last chapters. This can be introduced as a method of protecting low resistant wood from decay fungi, termites and also has the capability of leach resistance using a solution developed as a wood preservative. The formulations comprise of leaf extracts obtained from *Gliricidia sepium, Tithonia diversifolia*, and *Mikania micrantha*. The fresh plant leaves were rinsed with normal tap water and ground down to approximately 1 to 6 mm particles and then the formulations were developed to 1:1:3 ratio of the above respectively plant leaves by weight. The solution is also comprised of mud which is obtained from paddy fields. The paddy field mud was prepared before it is used in this formulation. This chapter concludes the performance of the two distinct solutions assorted with mud and without mud.

6.2 Development of the final solution

As discussed, and elaborated in the last chapter the study identifies two solutions as below; (Figure 6-1),

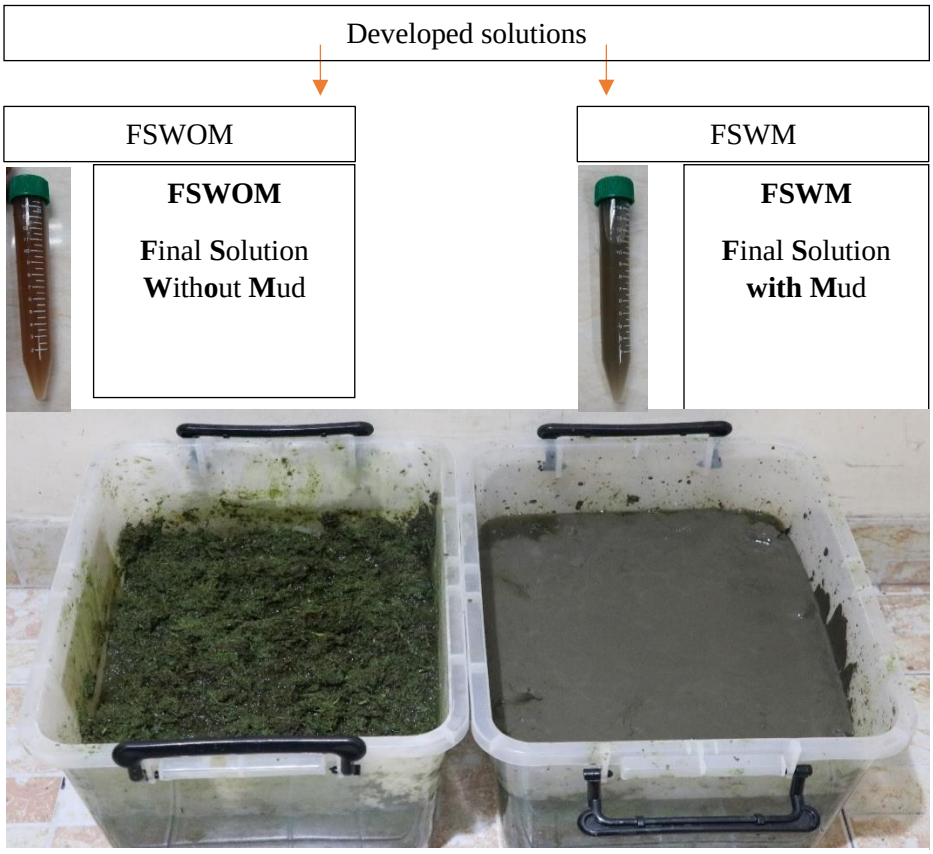


Figure 6-1; Developed solutions from the leaf extracts

6.2.1 Experimental program

As per the results obtained from the last chapters, two unique experimental procedures were developed for the two solutions, FSWOM (Final Solution without mud), FSWM (Final solution with mud).

6.2.1.1 Solution FSWM

A. Development of the solution;- Protocol 2- For FSWM

Matured fresh green leaves are rinsed with normal water to take off unwanted dust particles. The excess water was removed after cleaning; The extraction efficiency is improved by small particle size due to the enhanced penetration of water and diffusion of the plant extracts. The matured fresh green leaves are crushed at approximately between 1 to 6 mm finer particle size to achieve the better results of the extraction; Water is used as the solvent.

Next, the Paddy field mud is obtained from an organic paddy field. The mud is prepared before it is used. It is washed with normal water, sieved, and remove the larger and unwanted particles in it. Then remove the excess water;

Finally, the solution was developed by the combination of the above-mentioned raw materials as follows, it consists of a 1:1:3 ratio of fresh green leaves respectively of *Gliricidia sepium, Tithonia diversifolia,* and *Mikania micrantha crushed* into 1 mm finer particles and added to a vessel which contains 1:1:5 ratio of leaves: water: mud.

Example: 100 g of *G. sepium* leaves, mixed with 100 g of *T. diversifolia* leaves mixed with 300 g of *M. micrantha* leaves added to a vessel with 500 ml water and 2.5 kg of mud.

The solution was mixed in every 4 hours times, after 48 hours the impurities or the solute is separated from the solution using the gravity filtrating techniques, this helps to remove the solid particles and separate the solution; Once then the extracted solution is kept for another 48 hours under room temperature and then once again filter the solution to remove the sediments and then it's ready for use.

1. Solution FSWOM

A. Development of the solution;- Protocol 3- for FSWM

The matured fresh leaves of the above-mentioned three plant types were cleaned with normal water to take off the dust particles. Then the excess water was removed. Then the leaves are crushed approximately around 1to 6 mm finer particle size to achieve

better results of the extraction. Water was used as the solvent. Finally, a ratio of 1:1:3 by weight ratio of green leaves respectively *G. sepium*, *T. diversifolia*, and *M. micrantha* was chopped into the above-mentioned particle size and then 1:1 by weight ratio of water is added to the vessel; (Water: All three types of leaves).

Example: 100 g of *G. sepium* leaves, mixed with 100 g of *T. diversifolia* leaves mixed with 300 g of *M. micrantha* leaves added to a vessel with 500 ml.

Once after every 4 hours, the solution was stirred, then the solution is kept to ferment for 48 hours, and was separated using the gravity filtrating techniques, this helps to remove the solid particles and separate the solution.

The extracted solution is kept for another 48 hours for further fermentation at room temperature and then filtered through the gravity filtrating techniques once again finally, it's ready for use; the solution was named FSWOM for easy reference.

6.2.2 Experiment for the gross solution uptake

Two techniques were used to treat the wood as pressure treatment and non-pressure treatment.

6.2.2.1 Method 1 – pressure treatment

The timber specimens were placed into cylindrical containers. After adding preservative solution, the pressure was applied for 8 hours under a glass desiccator. Then the specimens were removed at atmospheric pressure. The treated woodblocks were immediately weighed. This determines gross solution uptake. Retention was calculated (kg/m3). The retention of the extractive solution on wood specimens (kg/m3) was calculated based on the following equation (TS 5723, 1988).

$$\boldsymbol{R = \frac{(M1 - M0)}{V} \times C \times 10}$$

Here, M_0: weight before treatment (g), M_1: weight after treatment (g), C: Concentration of solutions, V: volume of wood blocks (m_3).

6.2.2.2 Method 2 – Treatment techniques (Soaking)

The samples were submerged in the solutions for 24 hours. The treated woodblocks were immediately weighed to determine gross solution uptake. Retention was calculated (kg/m3).

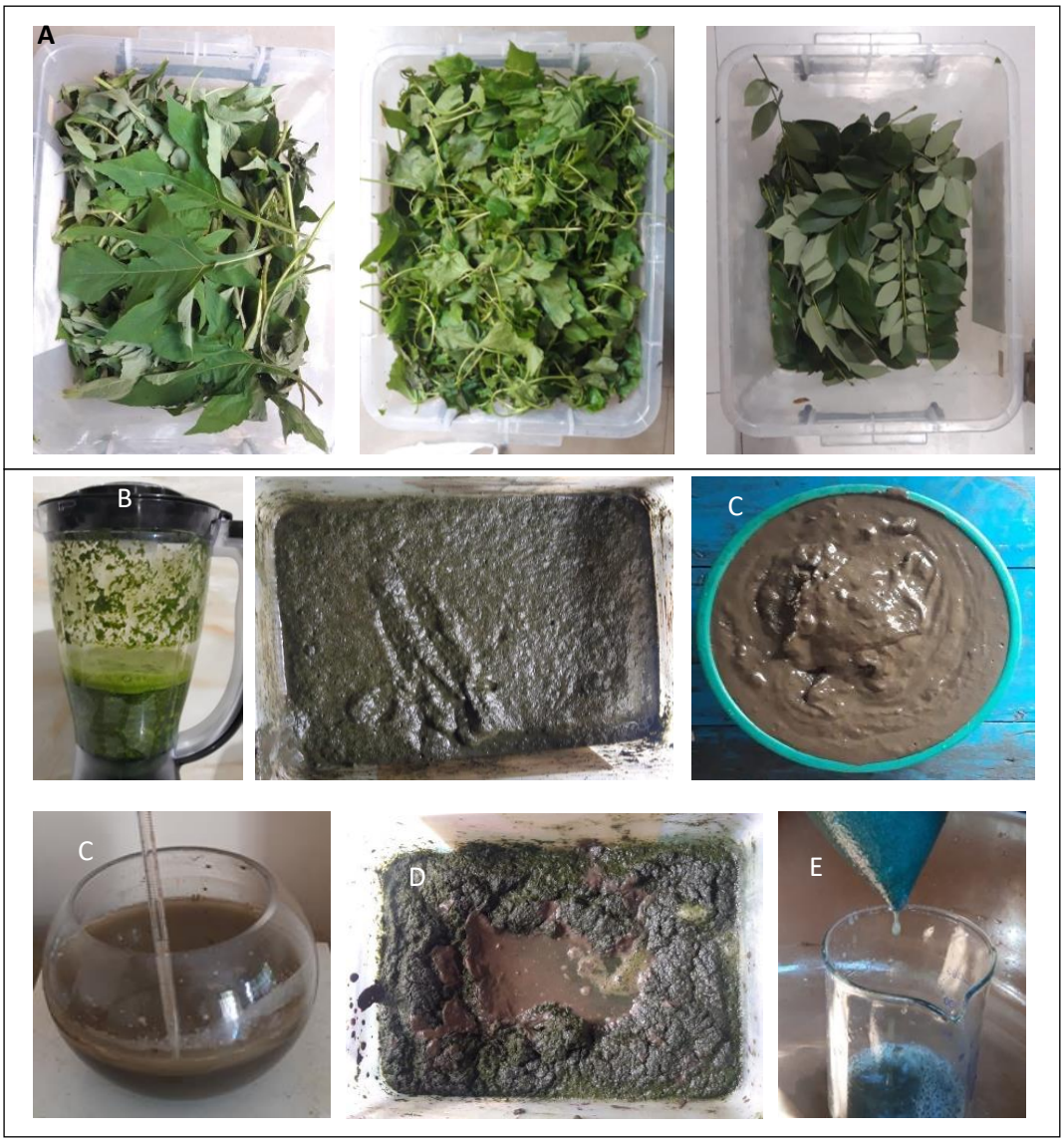


Figure 6-2; Cleaned Matured fresh green leaves, B- The leaves were crushed using blenders, C – the sieved paddy fields mud to remove the large particles and washed using normal tap water, and then the extra water is removed after the mud is sedimented, D- proper mix of the material matrix , E- Filtered solution

A. Chemical Retention

FSWM	FSWOM
Chemical retention of 24 hours in soaking presents as 0.046% and the retention value obtained from pressure treatment was 0.0684%. The pressure treatment increased the retention value from 32.745 %;	The results disclosed the; Chemical retention of 24 hours in soaking presents as 0.046% and the retention value obtained from pressure treatment was 0.0684%. The pressure treatment increased the retention value from 32.745 %.

6.2.3 The density of the solution

FSWM	FSWOM
The density of the solution is 967± 17.65 kg m-3	The density of the solution is 968 ± 20.95 kg m-3; Figure2

6.2.4 Visual observation of the penetration

This phase aims to visually evaluate the penetration that is visualized to the naked eye. Accurate quantitative comparisons of penetrating properties are not practicable, it is possible, with materials that are coloured or can be made to give colour reactions, to make rough comparisons, and to learn whether the new material is significantly different. (Figure 6-3); indicates the visual appearance observed after the treatment.

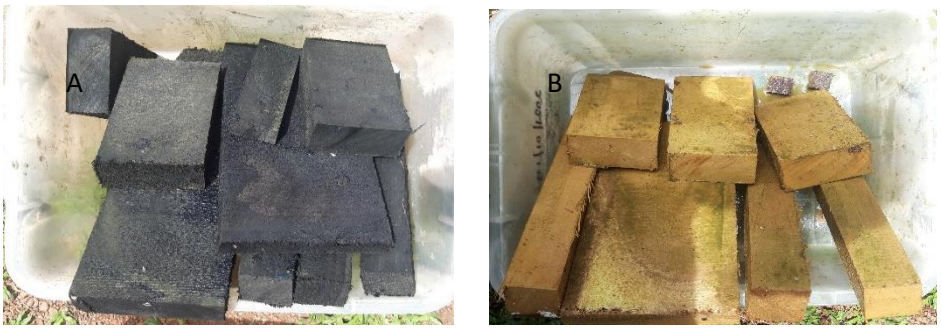


Figure 6-3 ; A- Treated with FSWM and B- treated with FSWOM

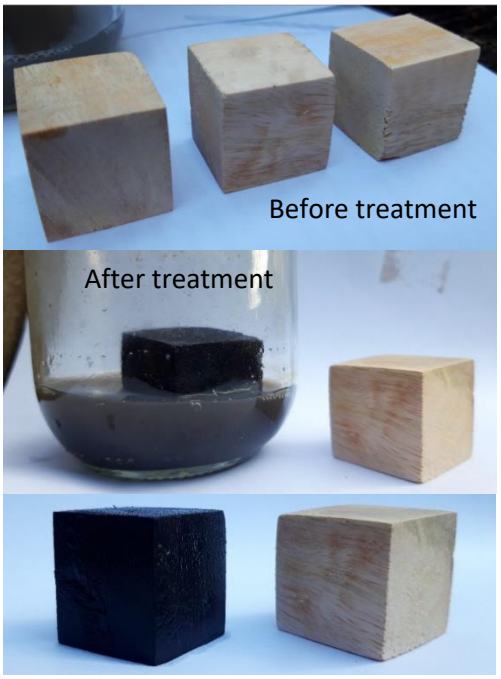
6.2.4.1 Physical appearance.

FSWM	FSWOM
The FSWM has a direct influence on the wood color. The wood color has changed from golden brown to black or grey shade.	The FSWOM has no significant impact on the wood color.

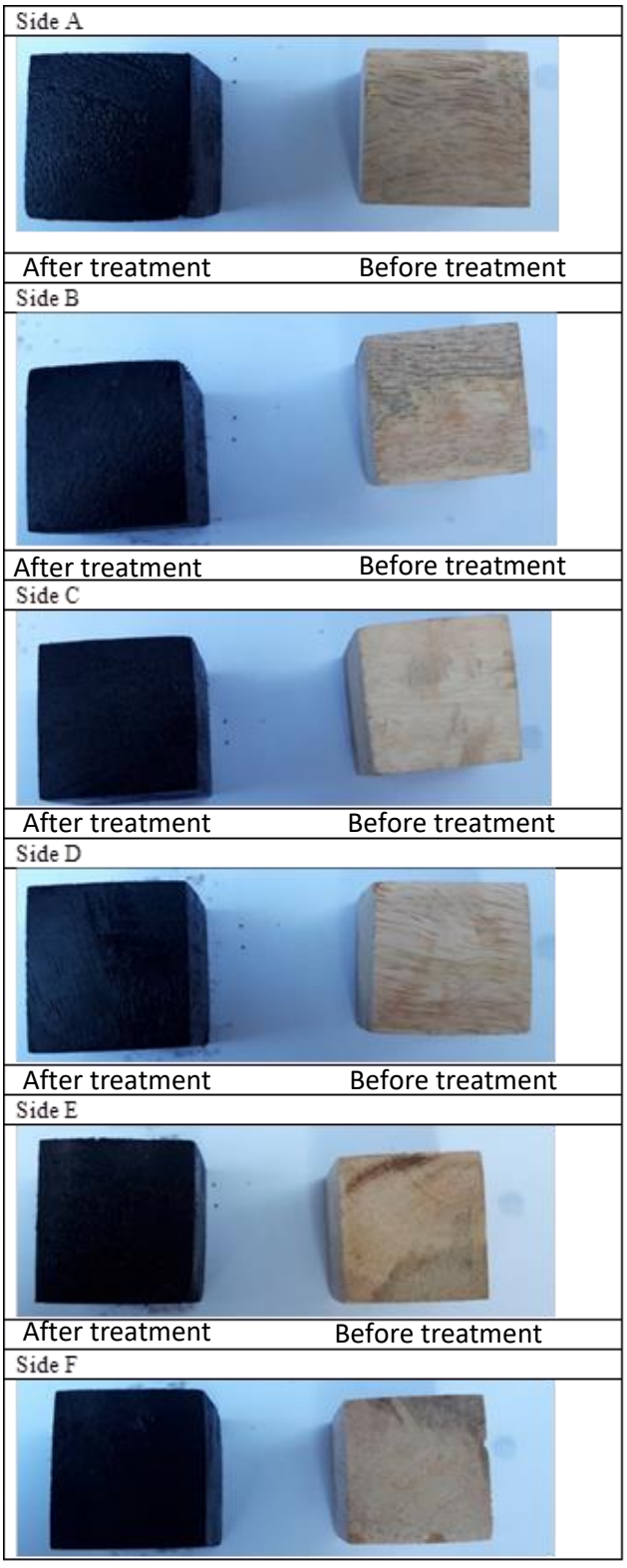
When comparing the FSWM solution with FSWOM, the FSWM has a significant wood coloring capability within the time below one second.

The 96-hour fermented solution has the optimum coloring capability with the minimum time duration. This also can be an indicator to notify the solution is ready for use.

The visual observation of the coloring capability of the FSWM was presented as below,



A



B

Figure 6-4; A-Physical appearance after treatment of M. indica, B- visualizing the treated surfaces compared to the non-treated Surfaces



Figure 6-6;Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section A-A') - FSWOM



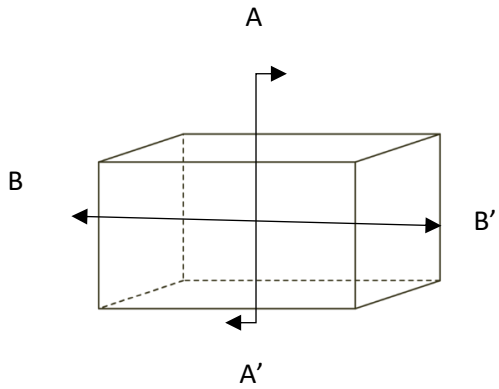


Figure 6-7;Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section B-B')-FSWOM



Figure 6-9; Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section A-A') - FSWM



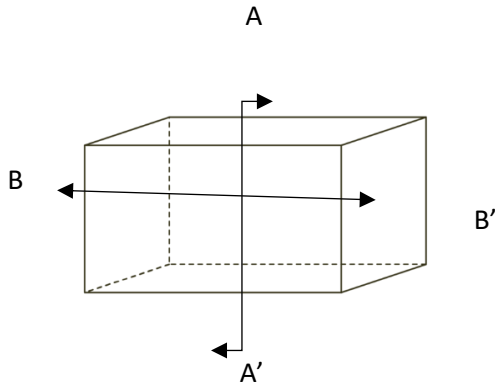


Figure 6-8;Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section B-B')- FSWM

6.2.5 EDX analysis (Energy-Dispersive X-Ray Spectroscopy)

The elemental composition of a sample is determined through EDX analysis, which provides a more quantitative result than SEM analysis alone. Concluding the Test further analysis was performed to examine the three stated toxic elements present in preservatives as per the literature utilizing Sulphur(S), Copper (Cu), Zink (Zn) in the wood specimens treated from FSWM solution; (chart 6-1).

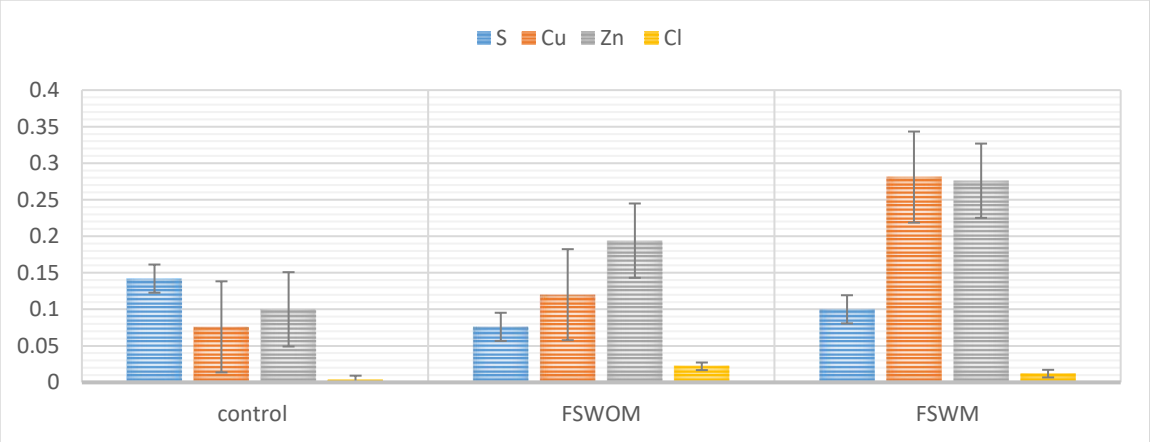


chart 6-1;Atomic percentage comparison of treated and untreated wood specimens

6.2.6 Experiment on the toxicity performance

The average service life of timber specimens was used to assess their durability. The findings of field trials are used to examine the actual performance of each specific species against fungal and termite attacks, which are commonly used to determine the durability of timbers.

Based on the literature, the Graveyard test is the most approved scientific study for measuring the durability of lumber. The study presents two types of natural durability tests based on the expose duration, (Figure 6-10).

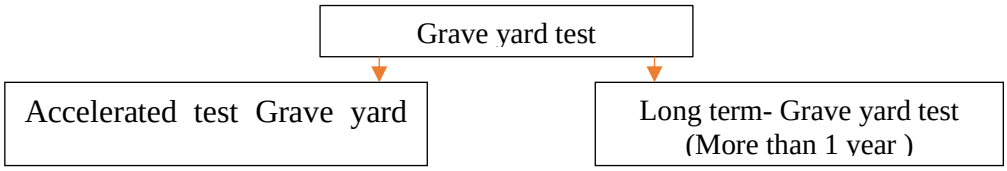


Figure 6-10; classification of the grave yard test based on the exposure time

Here the study evaluates the performance of the solution used as the wood preservatives as a preliminary investigation before treating them to wood. The study, therefore, uses treated filter papers for accelerated field tests.

6.2.7 Accelerated Test 1 - *Filter paper test*

Conclusions were based on the assumption that the weight loss percentage caused due to the fungus infection was negligible. Therefore, the weight loss was entirely affected

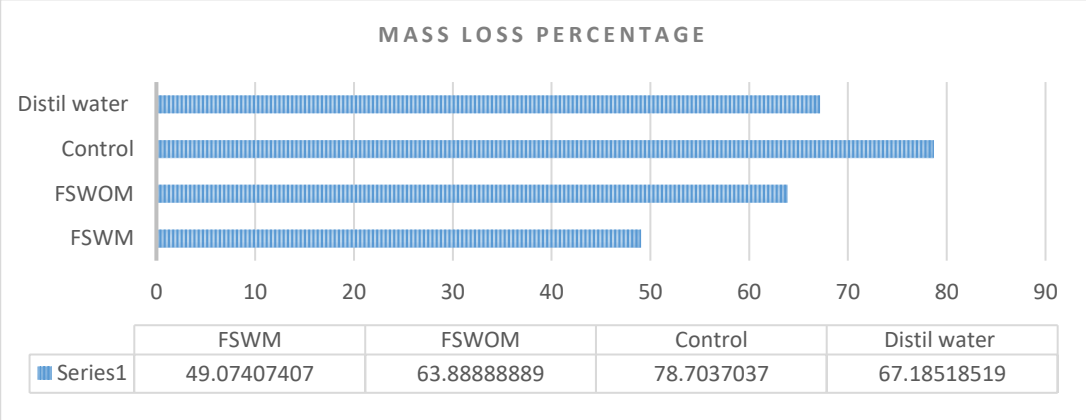


chart 6-2; Average mass loss percentage of the treated filter papers

due to the termites. Hence with that assumption, the significant toxicity performance with the minimum weight loss percentage was presented on the FSWM treated filter papers compared to the FSWOM filter papers.

6.2.8 Antifungal properties of the two solutions

The solution FSWM and FSWOM are evaluated against fungus to identify the antifungal properties using the food posing test as described in Experiment 5-9, Experiment 5-10. FSWM was evaluated on *S. commune*, *P.ostreatus*, and the common molds *A. japonicus*, *T. purpureogenus* for continuous 6 days.

FSWM	FSWOM
The highest antifungal activity against *Aspergillus japonicus* recorded on the 6th day was the solution FSWM (53.82 %). The highest antifungal activity against *Pleurotus ostreatus* recorded on the 6th day was the solution FSWM (100 %). FSWM solution presented more than 50 % of antifungal activity against *Aspergillus japonicus*, *Pleurotus ostreatus*, and *Schizophyllum commune as* 53.82 %, 100 %, 62.64 %. While a	The highest antifungal activity against *Aspergillus japonicus* recorded on the 6th day was the solution FSWOM recorded in between 45 – 55 %. The highest antifungal activity against *Pleurotus ostreatus* recorded on the 6th day was the solution FSWOM was 100 %. FSWOM solution presented more than 45 % of antifungal activity against *Aspergillus japonicus*, *Pleurotus ostreatus* (98 -100 %), and *Schizophyllum*

low antifungal activity against *Talaromyces purpureogenus* is 10.58 %.	*commune as* (90-100) %, While a low antifungal activity against *Talaromyces purpureogenus* as (8- 12) %.

6.2.9 Performance of the treated wood (wood mass loss assay)

Here the study performed the BS EN 350 standard procedure to evaluate the accelerated wood decay test evaluated based on the average weight loss of the test samples finally compared with the untreated mango specimens after exposing them for 16 weeks against decay fungi. The x values refer to the wood types were calculated as follows,

$$Xvalue = (\ Averg.mass\ loss\ )/(Averg.mass\ loss\ control)$$

Table 6-1; Source [301]; Durability classification of the timber referred to the EN BS 350 .

Rating	Classification	X – Value reference to EN 350	Graveyard (timber trade leaflet no.28)
1	Very durable	< 0.15	> 10 years
2	Durable	>0.15 – 0.30	5-10 years
3	Moderately durable	>0.30 – 0.60	2-5 years
4	Slightly durable	>0.60 – 0.90	Not specified
5	Not durable	>0.90	< 2

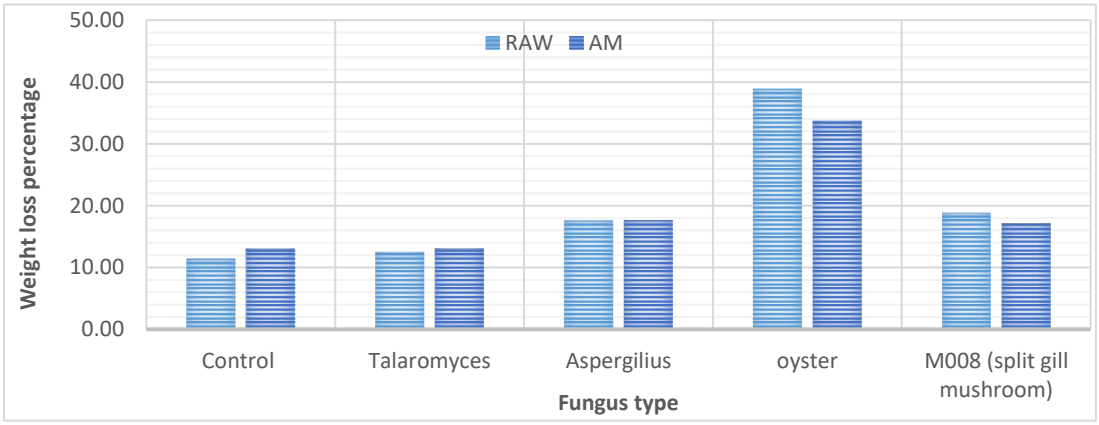


chart 6-3;FSWM against the fungus and compared with the untreated mango wood specimens

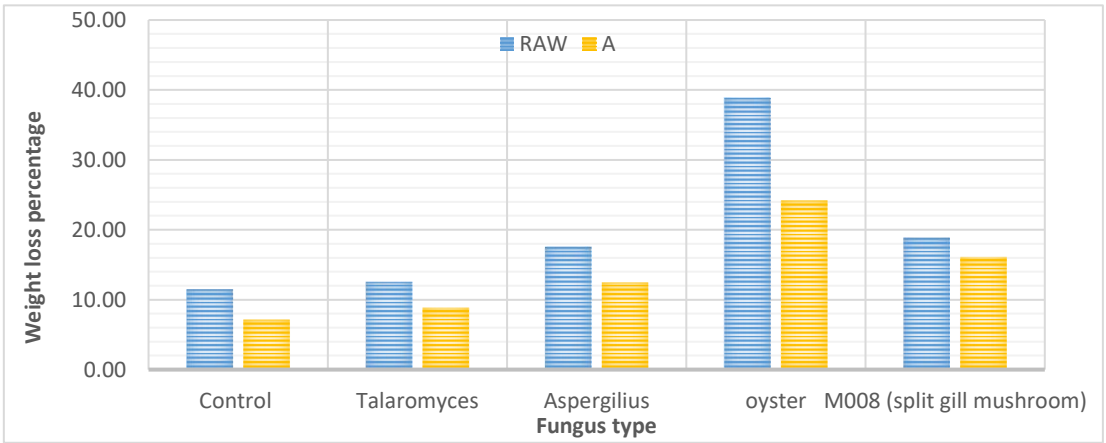


chart 6-4;FSWOM against the fungus and compared with the untreated mango wood specimens

Reference to the BS EN 350 the results were conclude as follows,

Table 6-2; Results conclude based on the standard , the durability classification

FSWM	**FSWOM**
X_{FSWM} > 0.15-0.3	X_{FSWOM} > 0.15-0.30

The timber trade leaflet no.28 denotes[301], both the wood treated under this solution can be further raised to moderately durable wood which can estimate the lifespan up to 5- 10 years under natural conditions.

FSWM was evaluated and compared with the industrially available Boron treatment and chromated copper boron treatment.

Table 6-3; The FSWM solutions treated wood specimens against the four fungus types

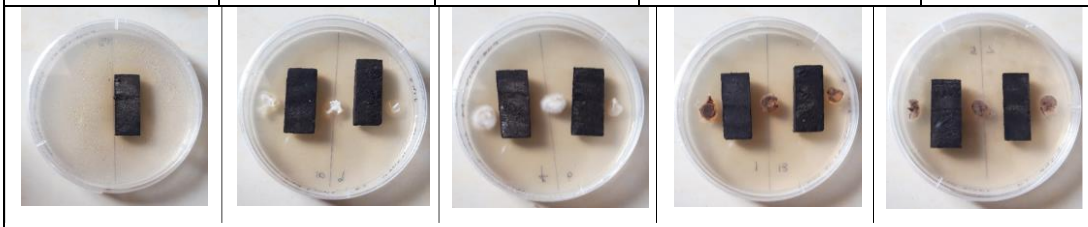
Control	P. ostreatus	S.commune	T. purpureogenus	A.japonicus
				

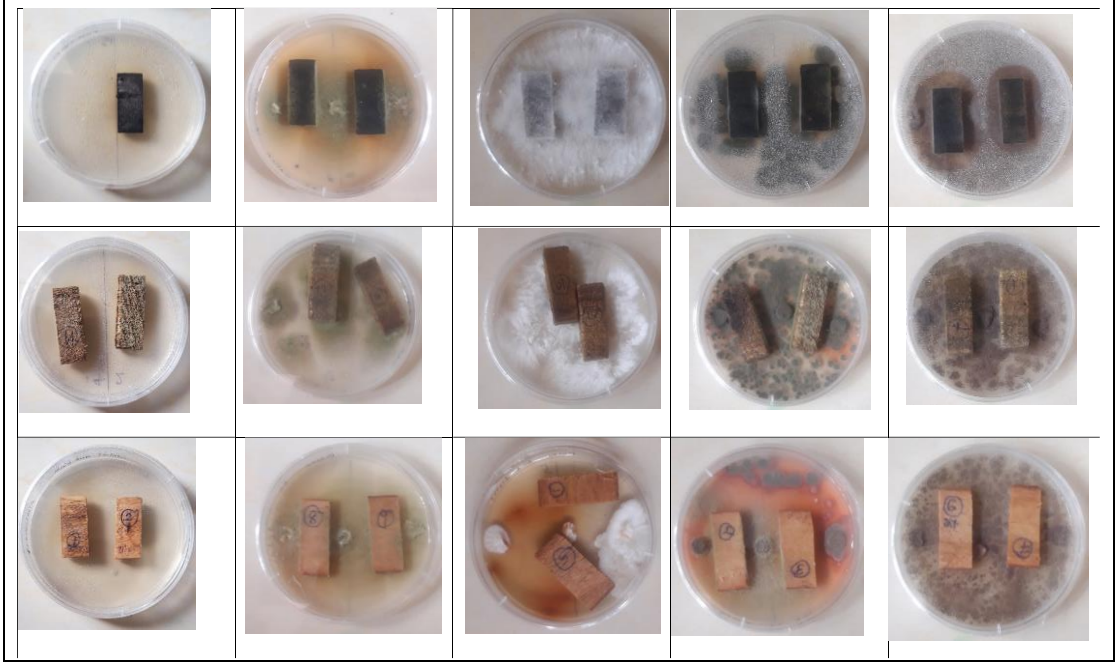
Table 6-4,; The Boron treated wood specimens against the four fungus types

Control	P. ostreatus	S.commune	T. purpureogenus	A.japonicus
				

Table 6-5; The CCB treated wood specimens against the four fungus types

Control	P. ostreatus	S.commune	T. purpureogenus	A.japonicus
				

Table 6-6; The visual observation against the fungus after 6 days

Control	P. ostreatus	S.Commune	T. purpureogenus	A.japonicus
				

The x values are presented as follows,

Table 6-7; FSWM treated mango wood, CCB treated mango wood, Boron treated mango wood

FSWM	**CCB**	**Boron**
X_{FSWM} > 0.15-0.3	X_{CCB} > 0.15-0.30	X_{Boron} > 0.15-0.30

As per the BS EN 350 the X values obtained after the above test declare the expected living space as 5 to 10 years. The given durability rating will be 2. Also, the study further concluded that the mango wood treated with the CCB and Boron was significantly resisted to *S.commune* where no fungus was grown on the surface of the treated wood. While the *S.commune* was grown on the surface of the wood treated with FSWM. Therefore, the study recommends developing the FSWM further until the negligible fungus growths similar to the CCB and boron treatment.

6.2.10 Investigating the leachate of the solution

Leachate is produced when the water in contact with treated wood dissolves the soluble organic and inorganic components, resulting in an aqueous solution of wood extractives.

6.2.10.1 Visual observation of the leachate generated

A continuous water immersion based on the sequential extraction procedure is an attempt to gather significant information about their leach resistance, as the presented Experiment 5-11. The laboratory leaching test was done according to CEN/TS 15119-2:2008 standard which was established for continuous water immersion of the sample.

The FSWM and FSWOM solution-treated wood were evaluated to detect the color disparity caused due to chemicals leached out of the wood.

Then the leachate obtained from the FSWM and FSWOM was compared with untreated timber and two commercially available wood preservation treatments such as Chromated copper boron treatment and boron treatment.

A Ferric chloride color indicator was used to characterize the tannin presence at the leachate; referred as in Experiment 5-12.

FSWM	**FSWOM**
The results disclosed the highest discoloration was obtained at the first 24 hours. And the discoloration gradually decreases with time. The leachate generated by the timber treated with the FSWM presented a significantly low discoloration compared to untreated and boron-treated timber.	The results disclosed the highest discoloration was obtained at the first 24 hours. And the discoloration gradually decreases with time. The leachate generated by the timber treated with the FSWOM presented a significantly low discoloration compared to untreated and boron-treated timber.

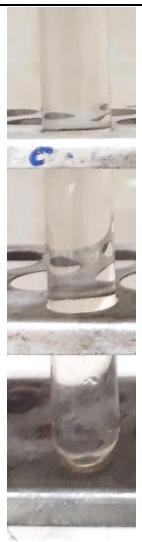
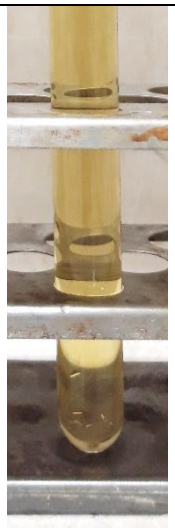
Control	FSWOM	FSWM	CCB	Boron
				

Figure 6-11;Leachate observed on the treated wood

6.2.11 Ferric test for tannin detection

Table 6-8; the color variation after ferric chloride color indicators were used.

control	FSWOM	FSWM	CCB	Boron
				

The leachate generated from the control specimen and the Boron treated wood specimens presented a significant color variation resenting the highest tannin leachate. The FSWM presented the significantly low tannin leachate However higher than the leachate generated from the CCB treated wood specimen.

6.2.12 Experiment on the performance of the treated wood after leachate against termites (Accelerated field test)

A leached wood sample was then exposed to a subterranean termite attack to evaluate the potential toxicity in the field. Trials were set up in each of the solutions developed using the FSWM and industrially available preservative-treated on Mangifera *Indica*. It was assessed by the samples placed on a soil bed with dense subterranean termites' area and exposed for 3 months. Five replicates per solution were evaluated;

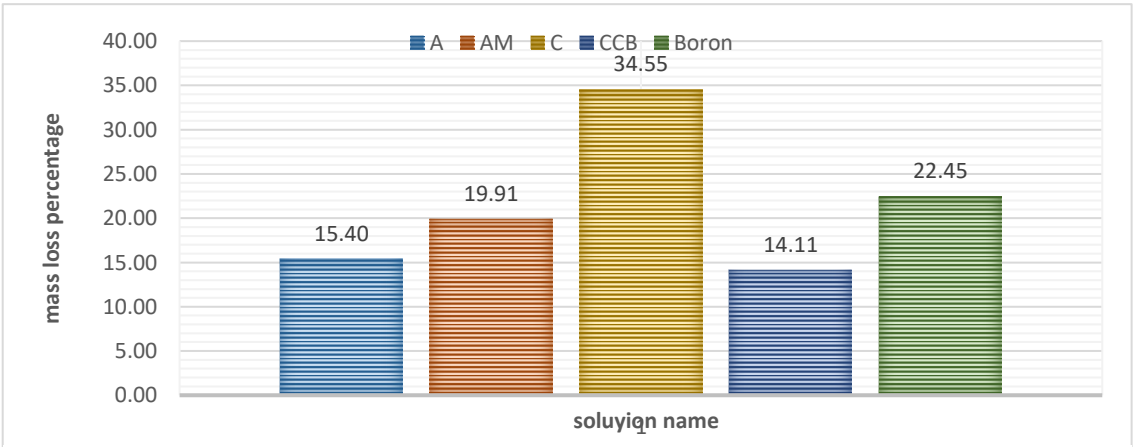


chart 6-5; The mass loss percentage of the treated wood specimens

6.3 Study of heavy metal leaching in the treated wood

The CEN/TS 15119-2:2008 standard for continuous water immersion of the sample was followed during the leaching test. The pH of the leachate, temperature, the duration of leaching, and the kind of leachate were all explored as factors affecting metal leaching from wood.

During European robustness research, laboratory leaching tests on treated wood were conducted as part of a tank leaching test's validation protocol proposed for building goods to detect the possible release of harmful compounds that can be transported to soil and groundwater. According to the European Biocidal Products Regulation, the release of chemicals from materials treated with biocidal products must also be determined. For this reason, a similar leaching test protocol for treated wood has previously been standardized. Additional studies were carried out to look into the unanticipated influences of the L/A relation on copper leaching[302].

When it comes to the leaching of inorganic and organic components of wood preservatives from treated wood, the type of preservative, leaching mechanisms, environmental impact, and test conditions have all been investigated for many years [363]. The development of new forms of preservatives has been fuelled by a desire to reduce leaching.

6.3.1 Materials and methodology

Leachate generated from the treated wood decreases gradually. The highest color variation was obtained on the leachate obtained from 24 hours.

The available element content at the leachate generated at the first 24 hours was determined using the ICP-MS (inductively coupled plasma-mass spectrometry) approach is an analytical technique for measuring components in biological fluids at trace levels. The leaching test accordance with the CEN/TS 15119-2:2008 standard for continuous water immersion. The majority of leaching from treated wood happens during the initial exposure to the leaching medium, whether in in-service or in laboratory experiments. Mercury (Hg), lead (Pb), and cadmium (Cd) are three heavy metal toxins that have no known biological function.

Based on leaching tests for analysis of the heavy metals carried out with the wood sections (chopped to 1 cm wood sections) from the treated wood values indicated as illustrated in the following charts.

6.3.2 Results and Discussion

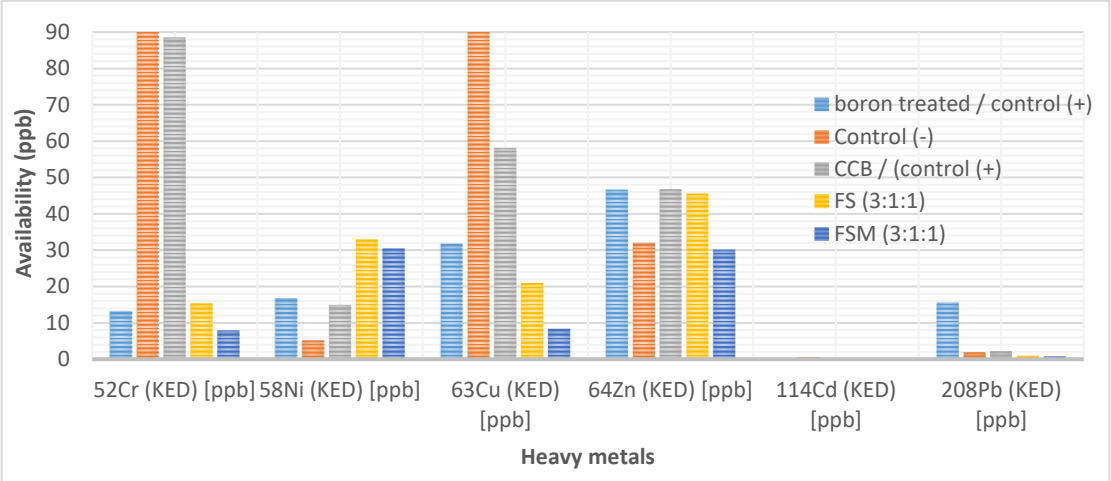


chart 6-6; The evaluation of the leachate generated.

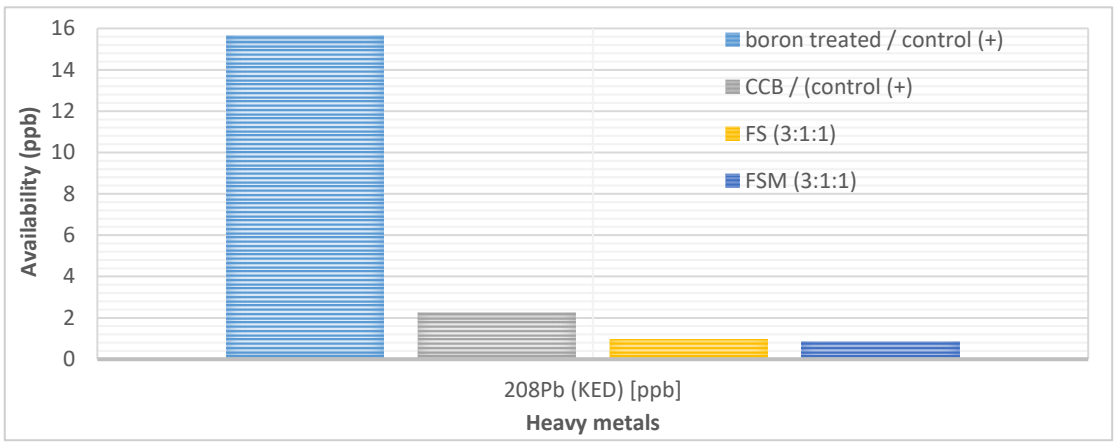


chart 6-7; analysis of Pb

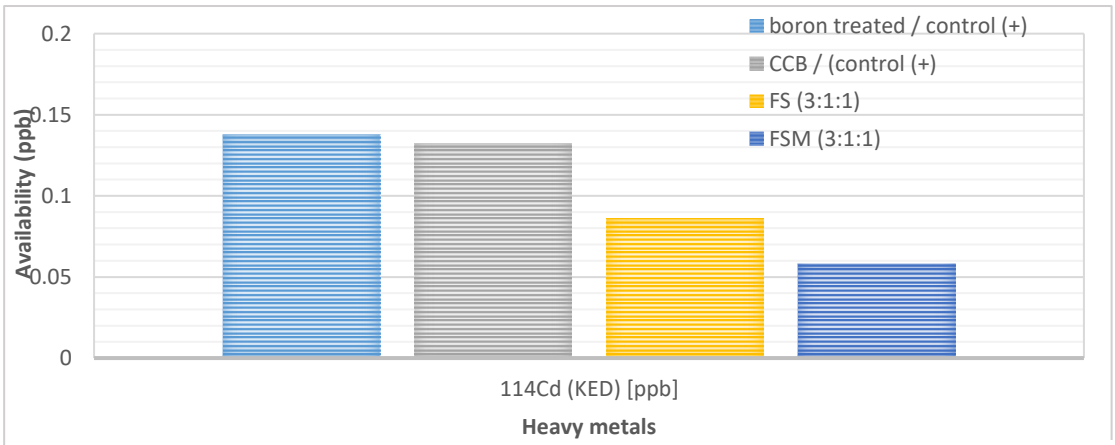


chart 6-8 Cd analysis

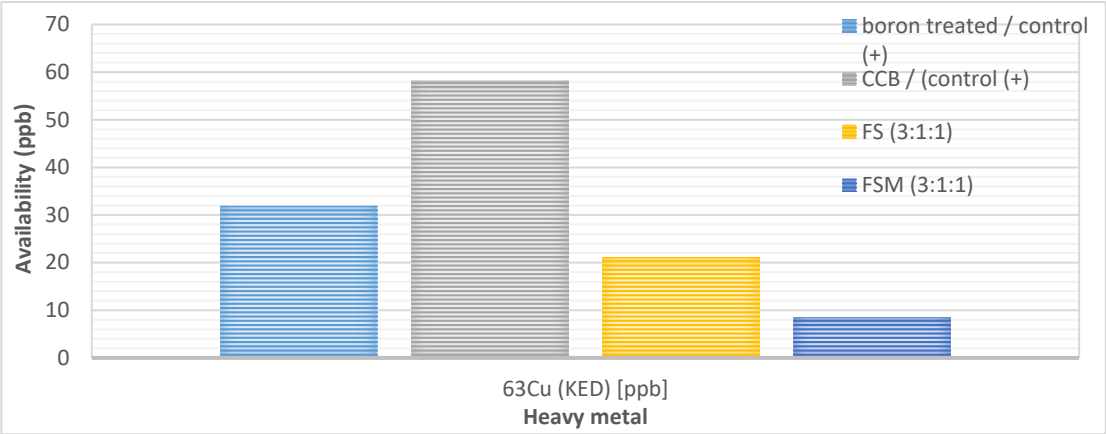


chart 6-9; Cu analysis

The significantly low availability of lead, copper, cadmium was observed in FSM which denotes the wood treated with Final solution with mud developed under the protocol 2. Compared to both CCB (Chromated copper boron) and Boron treatment highest availability of Pb, Cu AN Cd was observed on the wood treated with Boron treatment. But comparing the industrial available treatment methods and the developed solutions, this FS (final solution with only plant extracts) and the FSM (Final solution with mud) presented significantly low availability of Pb, Cd, and Cu in the generated leachate.

6.4 Mechanical performance after treatment

Wood-frame buildings have remained cost viable with other types of building due to its ability to be built with minimal equipment. Where architectural considerations are relevant, however, exposed wood's beauty and warmth hard to compare with other construction materials.

However, it is susceptible to deterioration, fungal stains, and insect infestation. Under this preservative solution and long-term soaking process, soaking saturates with a preservative solution by being immersed continuously the sugars in mango wood come into touch with cell wall components, they undergo hydrolytic reduction, which reacts with the cell wall components. These causes in reducing wood strength; the experimental procedure was similar to the Experiment 4-3.

6.4.1 Material and methodology

The mango wood specimens were prepared from the solution developed under the developed protocol no.2. The properties are determined under BS EN 384:2016 and BS 373:1957. The UTM-100 PC standard machine under state timber cooperation facilitates to perform the destructive tests.

The results were evaluated from the same equations referenced in chapter 4, subheading 4.9 (Causes for the Mechanical performance)

6.4.2 Results

This timber falls under class three category under the classification of State timber cooperation. The fracture modes are presented. The authors acknowledge the state timber cooperation to giving the techniques support to succeed the below test series.

The fracture modes were presented as follows,



Figure 6-12; A – control wood specimen , B- FSWOM treated specimen, C- FSWM wood specimen

The mechanical performance results are concluded as above charts. The minimum strength loss has caused from the FSWOM compared to the FSWM.

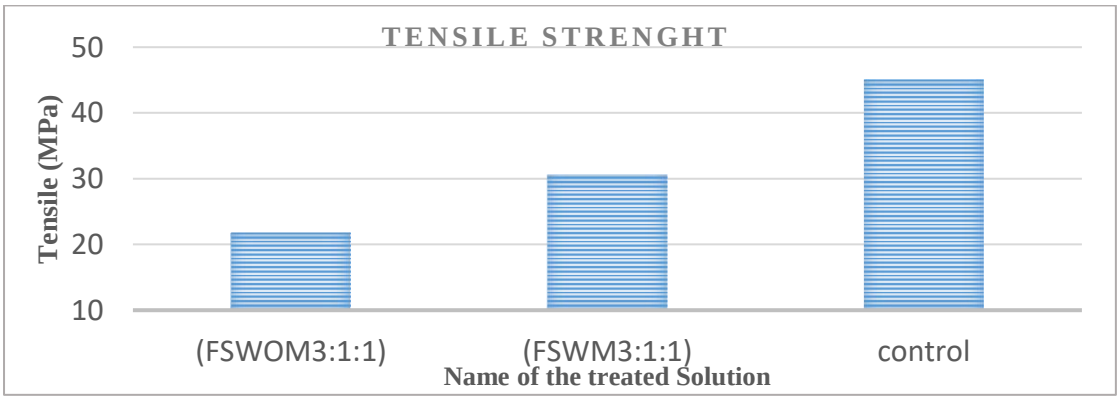


chart 6-10 ; The name of the treated solution Vs. the Tensile strength

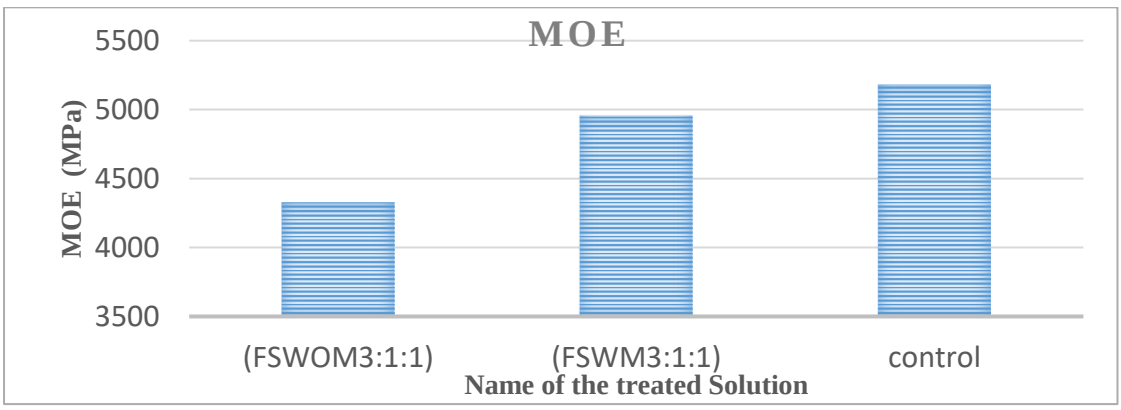


chart 6-11; The name of the solution Vs. the Modulus of Elasticity

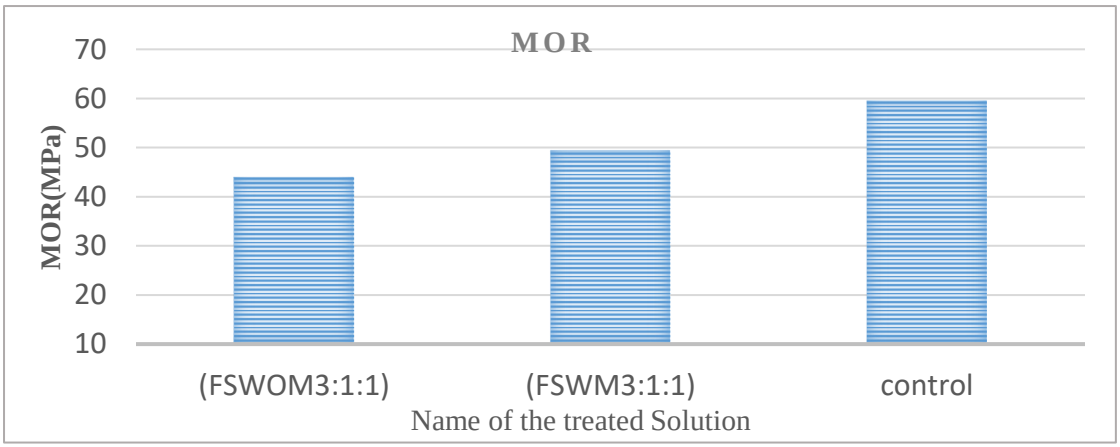


chart 6-13; The name of the solution Vs. the Modulus of elasticity

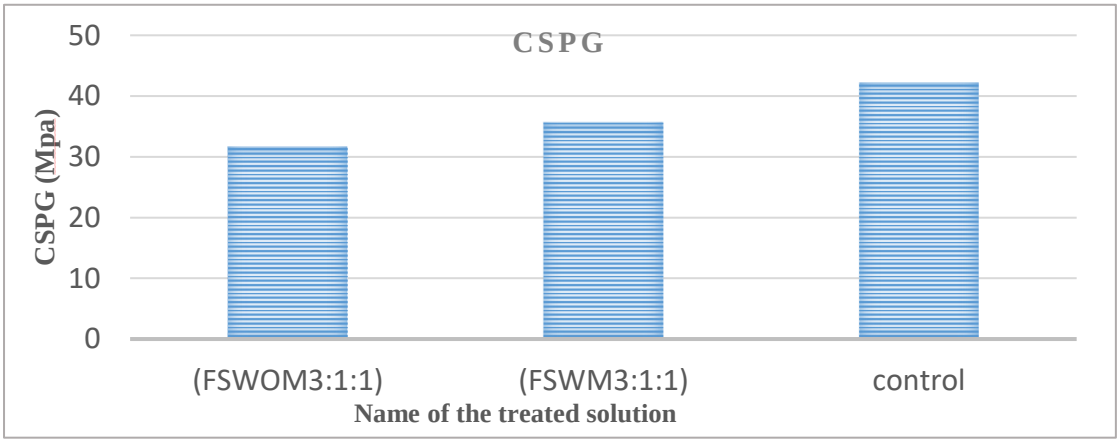
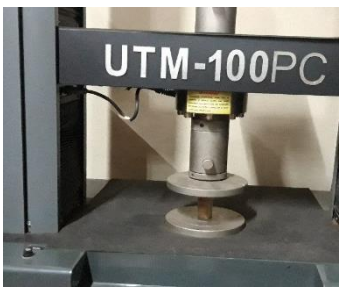


chart 6-12; The name of the solution Vs. Compression strength parallel to grain







6.4.3 Discussion

Figure 6-13; The name of the preservative Vs Mechanical Parameters

The mechanical performance of the treated wood was as below

- Tensile strength – FSWOM < FSWM < Control
- MOE strength – FSWOM < FSWM < Control
- MOR strength – FSWOM < FSWM < Control
- CSPG – FSWOM < FSWM < Control

The minimum strength loss was observed in the wood treated by FSWM solution.

6.5 Rapid Identification of Cu presence on Treated Woods Using chemical stain method

The presence of the chemicals penetrated can be whose presence can be made visible by spraying the treated surface with chemicals that produce colored compounds when they react with the preservatives. Chrome Azurol S solution, which reacts with copper to give a blue color and allows for a visual estimate of preservative penetration. The study considers 5 replicates were used for the visual investigations. (AWPA 2012d).

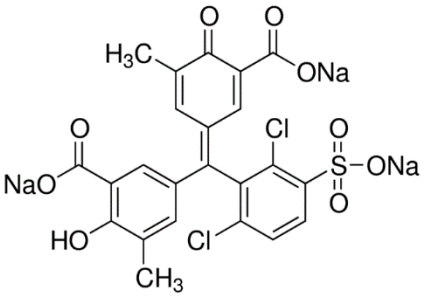


Figure 6-14; The structure of the C23H13Cl2Na3O9S

Table 6-9; the material matrix of the color indicator

Component	**Quality**
Chromazurol S	0.5g
Distilled water	26.0ml
Sodium acetate	10.0g
Ethanol	40.0 ml
Mono- ethylene glycol	33.0 ml

6.5.1 Materials and Methodology

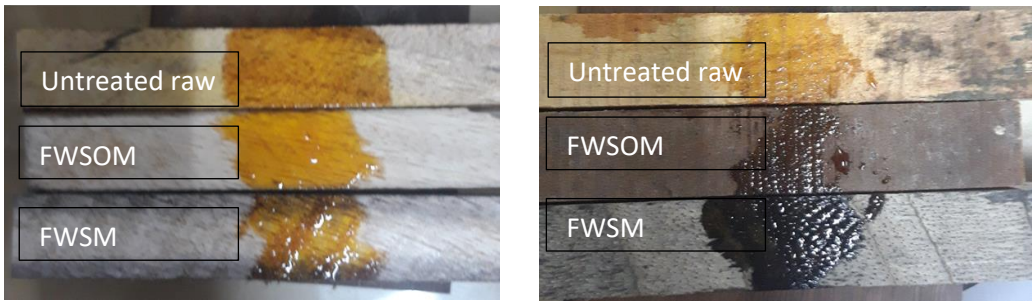


Figure 6-15; Chrome Azurol S solution was sprayed on the wooden surfaces

This was compared along with the raw untreated wooden samples , wood treated with FSWOM and FSWM .

6.5.2 Results and discussion

FSWM solution presented copper on the treated surface representing a significant color change.



Figure 6-16;Visual observation when the colour indicator sprayed on the surface

6.6 Comparison on the mechanical performance with industrial available preservative

The FSWM , FSWOM vs Impregnated mango wood and the 24 hours dipped boron treated mango wood presents the mechanical performance as follows; Mechanical property difference comparison is presented as follows

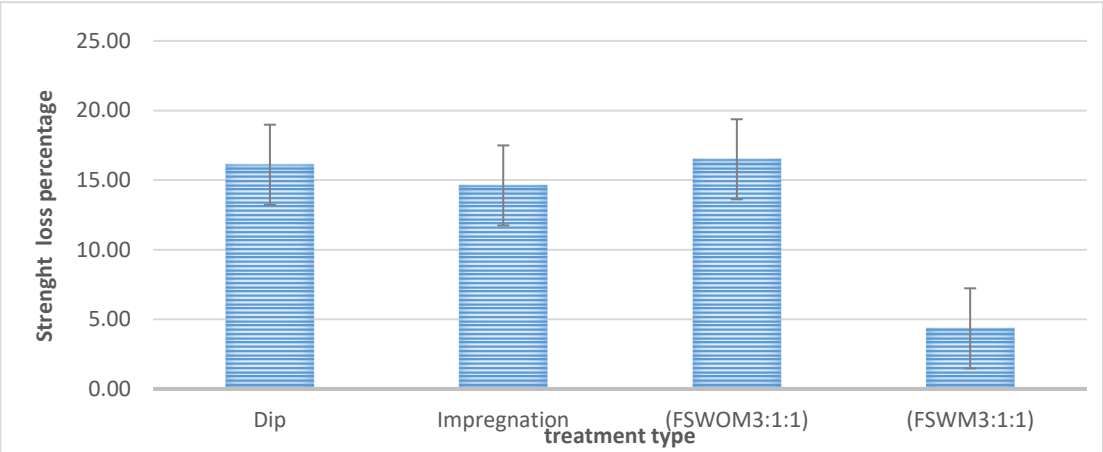


Figure 6-17; Mechanical property difference compared to the control Sample

- Strenght losss percentage – Dip (Boron) >FSWOM > Impregnation (Boron) > FSWM

6.7 Evaluating the water absorption percentage

In the building sector, water absorption and thickness swell of timber owing to contact with water is a major issue. The following codes were referred to BS373, 1957, Methods of testing small clear specimens of timber EUROCODE5, 1995. Structural Timber Design.

Experiment 6-1; Evaluate the water absorption percentage on the treated wood and the untreated wood.

6.7.1 Materials and methodology

The wood treated with the FSWM was evaluated as follows. 50 ×50 × 50 mm3 treated timber cubes and controls samples were used to do a comparison. The negative control sample was the untreated timber specimen and two positive timber samples were used as specimens treated with Chromated copper Boron solution and the boron treatment. Initially, the samples were oven-dried at the temperature of 102 ± 3 degrees Celsius temperature for 24 hours, and weight after oven-dry was obtained. Then the dried specimens were submerged in the water bath and the weight was measured every 24 hours.

Finally, the weight gain Vs time was plotted; The water absorption capacity of the timber after 10 days was presented as follows,

6.7.2 Results of the water absorption

Table 6-10-Water absorption after 10 days

Treatment type	Water absorption % after
FSWM	70.38 ± 2.31
Boron	103.7 ± 2.41
CCB	101.8 ± 2.02
Control	102.3 ±2.10
FSWOM	79.21 ± 2.33

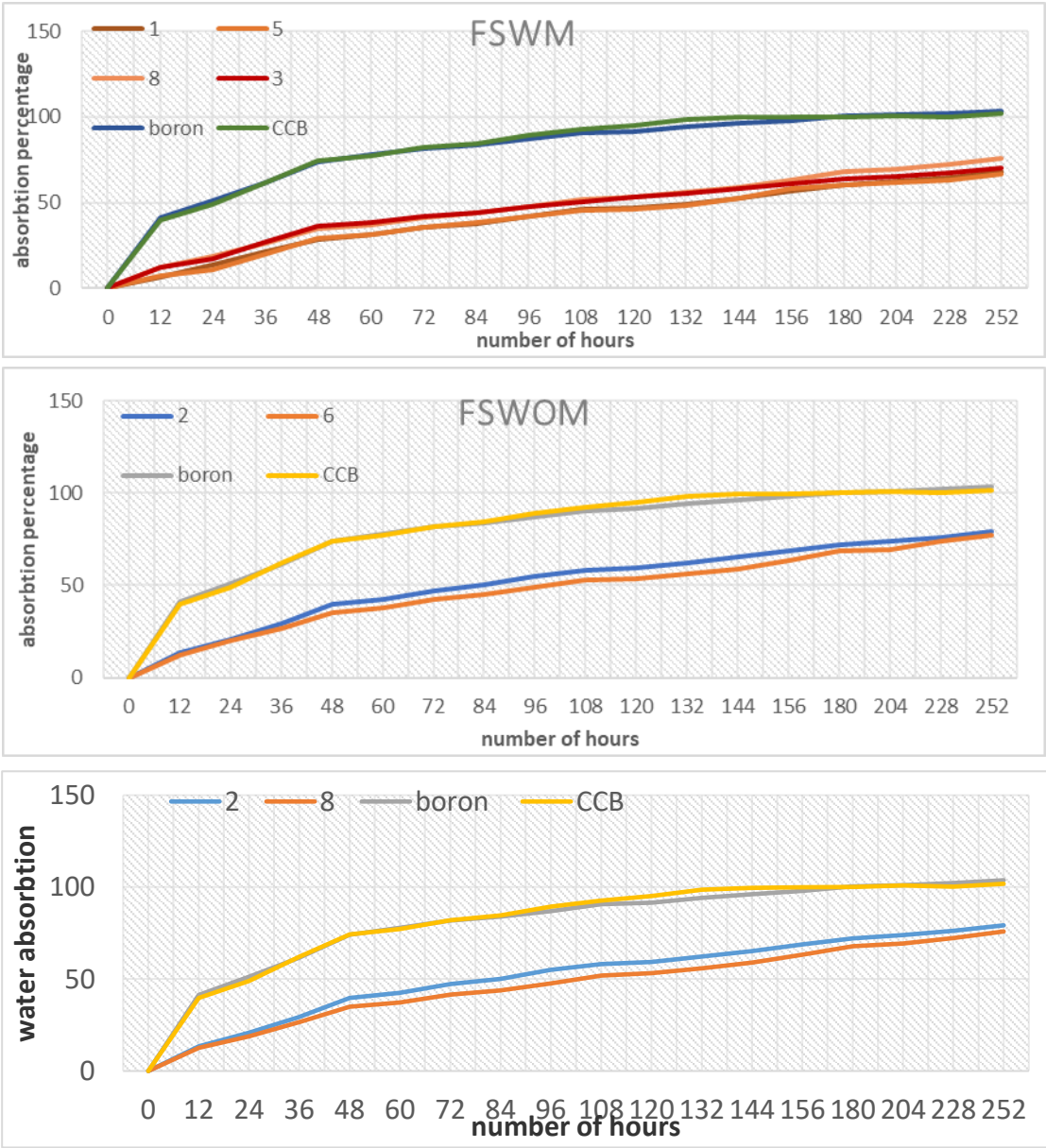


chart 6-14; A- FSWOM vs CCB and Boron treatment , FSWOM Vs CCB and Boron treatment , C- FSWOM and FSWM vs CCB and Boron treatment

6.7.3 Discussion

The *Mangifera indica* wood treated with FSWM presented the lowest water absorption capacity compared to the other control samples. Generally, literature states high strength

timber materials have less water absorption. The specimens treated with FSWM have high strength capacity compared to the *Mangifera indica* treated with Boron treatments as well as chromated copper boron treatment. With time water absorption percentage was tend to be constant.

6.8 Effect of pressure exerted on the chemical retention during wood treatments

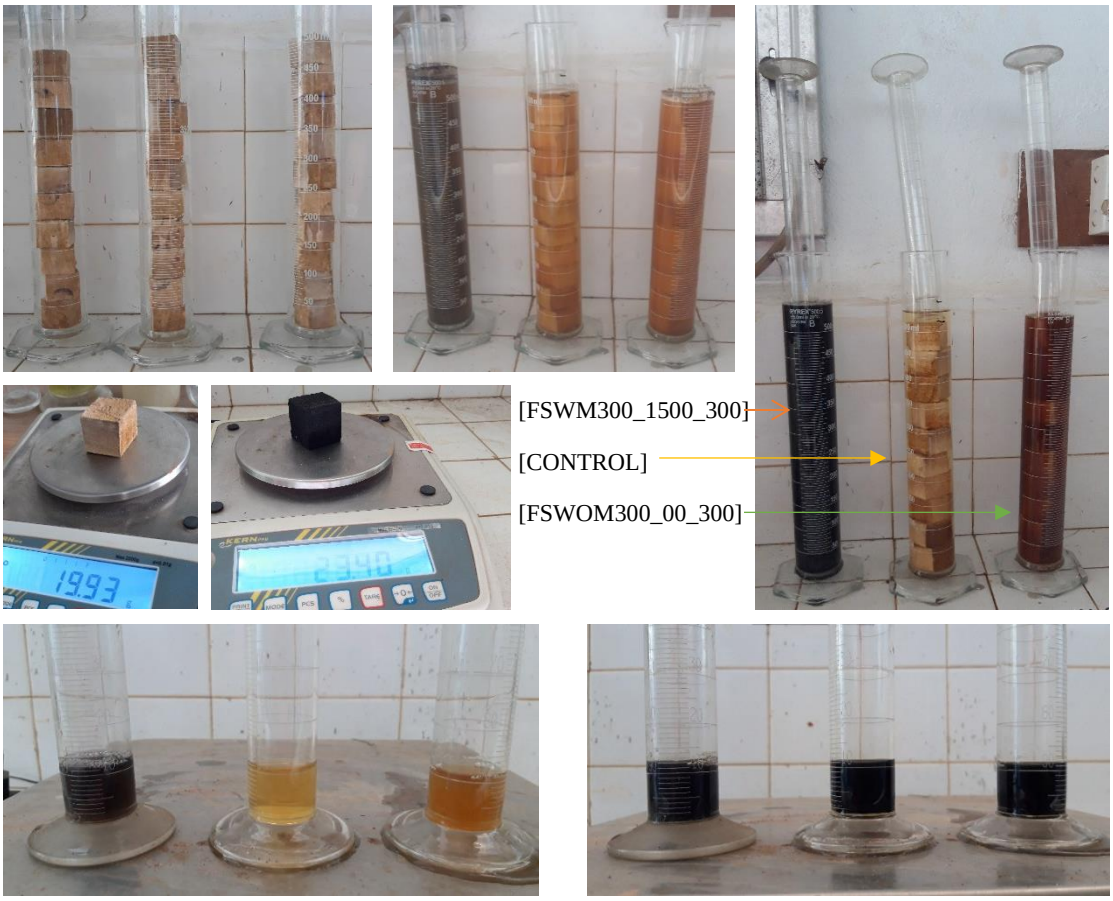


Figure 6-18; Treatment process using I l volume measuring cylinders .

To analyze the effect of pressure exerted on the chemical retention during wood treatments.

6.8.1 Materials and methodology

500 ml glass measuring cylinders were used for the treatment process. Initially, 25 x 25 x 25 mm defect-free timber specimens were prepared. And then the specimens are weighed before the test (0.001g). 10 replicates per solution were used for this test as follows. 300 ml of each solution was added per glass measuring cylinder with the wooden specimens. Then a control was maintained by adding 300 ml of distiled water.

Glass rods were placed at the top to prevent the specimens from floating and to keep them submerged until the treatment duration is completed. the specimens were treated for 72 hours. A Ferric chloride test was performed. The solution presented tannins in the solutions; (Figure 6-18).

6.8.2 Results and discussion

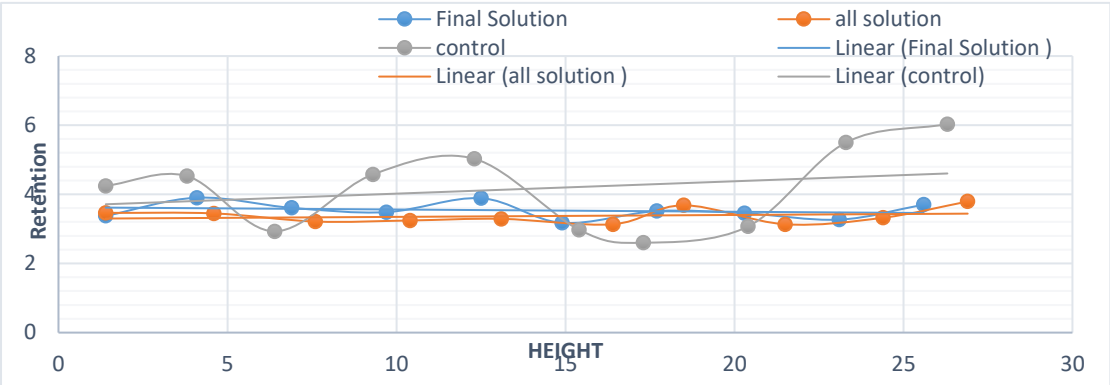


chart 6-16 ; retention values vs height

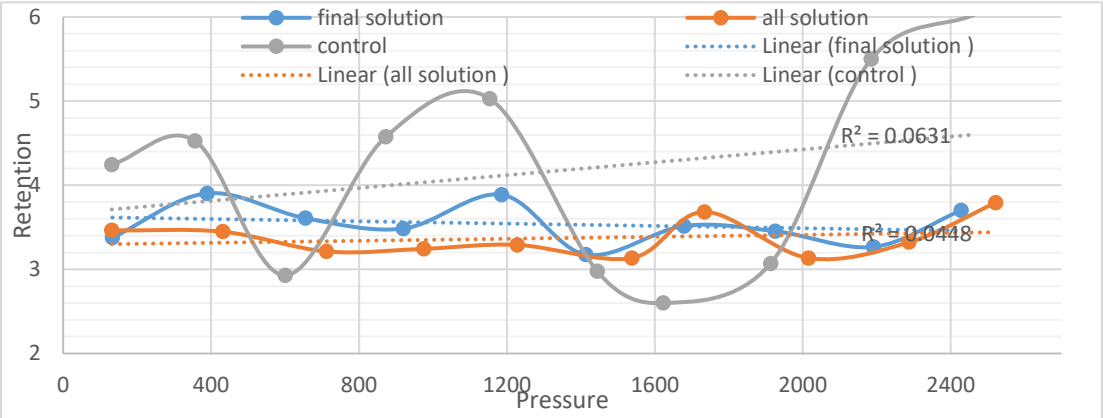


chart 6-15; Pressure was retention

The results disclosed that the height was not significant with the retention values when the wood is treated under high moisture conditions (very raw, wood soon after the tress is sawn into the lumber)

6.9 GC-MS analysis of bioactive compounds of Experimental level wood preservative

Here the study investigates to see if any plant extracts could be used as preservatives against wood degrading chemicals. Traditionally, natural extracts have been discovered throughout history to protect the wood in the tropics. Here the study determines the phytochemical composition in the leaf's extracts using Dichloromethane extraction and report. Finally, this phase of the study identifies and reports the functional components

using the IR technique. The phytochemical compounds in the extracts were then screened by the Gas chromatography-mass spectrometry method.

Experiment 6-2;6.10 GC-MS analysis of bioactive compounds of Experimental level wood preservative

6.9.1 Gas chromatography-mass spectrometry

GCMS analysis is a common confirmation test; a significantly effective chemical analysis. Literature states, the medicinal value of plants can be determined via GC-MS analysis of phytoconstituents in plants [303]. Gas chromatography (GC) and selective detectors are commonly used to quantify pesticides.

The initial stage in the GCMS procedure was to inject the sample into the injected location or the port of the gas chromatography instrument. The Gas chromatography equipment vaporizes the sample before separating and analyzing its constituents. The "retention time" is the time that passes between elution and injection. The retention time was used to distinguish between various substances [303]. The syringe filters were used to inject the liquid sample into the injecting port, after which the instrument vaporized the sample and analyzed the individual components. For each component, a spectrum with a specified spectral peak is formed and recorded[304].

Various groups are exploring the biocidal and non-biocidal properties of extractives contained in plant species to develop organic preservatives with higher efficacy and cheaper cost. The study's top priorities were to assess the extraction yield and perform biochemical analysis using gas chromatography-mass spectrometry.

This research reports the synthesis of bioactive components using plant extracts and testing its efficacy as a wood preservative. Leaf extracts of *M. micrantha, T.diversifolia,* and extract of *G. sepium* were used to develop the wood preservative solution. The confirmed compounds were identified using peak area, retention duration, and molecular formula.

6.9.2 Materials

A. Collection and preparation of plant material

M. micrantha, T. diversifolia, fresh plant leaves are collected from Moratuwa and transported to the pro-green laboratory. After complete washing and removal of unwanted elements, fresh matured leaves were placed in an airtight container to avoid the effects of humidity and then stored at room temperature until further use. Then the

fresh leaves were blended to make finer particles. The water was added as per the below table.

B. Preparation of wood preservative solution

About 100 g of the fresh plant leaves were ground to 1 mm particle size and then were soaked in 100 ml distiled water for 48 hours. Then Whatman No.1 filter papers were utilized to isolate the extract yield. The filtrates then were further kept for another 48 hours at room temperature, under atmospheric pressure. It was again filtered again from Whatman No.1 filter paper and centrifuged for 15 minutes.

C. Preliminary phytochemical screening through GC-MS analysis

The components discovered in the extract were studied in this investigation were identified using GC-MS. Before analyzing the extract using gas chromatography and mass spectrometry, the oven temperature was set to 100 degrees Celsius, as well as the gas's flow rate, as well as the electron gun, was programmed. Micro-syringes were used to inject around 1 μL of Dichloromethanel extract into the GC-MS. The signal created as soon as a compound eluted from the GC column into the detector was represented by the respective peak in the chromatogram. The signal strength was utilized to quantify the component in the injected material. The x-axis showed the retention duration, while the y-axis represented the signal strength.

As they eluted from the gas chromatography column and entered the electron ionization (mass spectroscopy) detector, distinct compounds were hit with a stream of electrons, breaking into shards. It was possible to obtain pieces of charged ions with a specific mass. The mass/charge (M/Z) ratio was calibrated using the graph obtained, known as the mass spectrum graph, which is a molecule's fingerprint.



Mikania micrantha (Mm)

Tithonia diversifolia (Td)

Gliricidia sepium (Gs)

Organic Paddy field

(m)

100 ml Water extracted

Extract to Hexene 50 ml or dichloromethane

Concentrate the solution (Anhydrous Sodium Hydroxide (105-118)

Solution for analysis

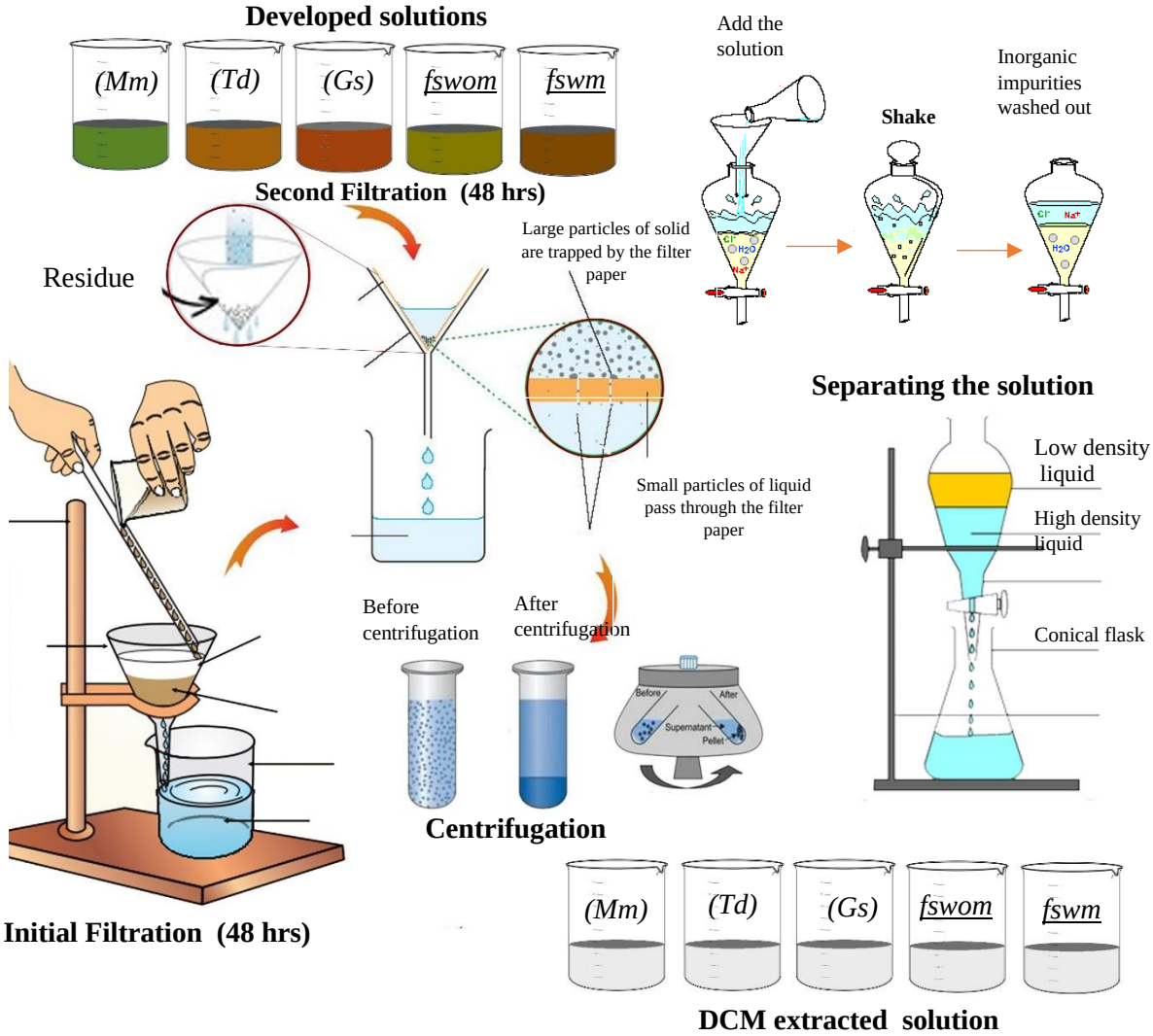


Figure 6-19; the sample preparation process for GC analysis .

6.9.3 Results of GC analysis

GC/MS analysis of dichloromethane extract of the solution developed with the *M. micrantha,* leaves revealed the existence of ([1,1'-Biphenyl]-2,3'-diol,3,4',5,6'-tetrakis(1,1-dimethylethy)-, Trans-(2-Decenyl) succinic anhydride, 2,4-Di-tert-Howeverylphenol, 1H-indole,4-methyl-, Benzene,1,3-bis(1,1-dimethylethyl)-, Naphthalene , Phenol,4-ethyl- .

GC/MS analysis of dichloromethane extract of the solution developed with the combination of *G. sepium* leaves revealed the existence of *Triethylene glycol* monododecyl ether, 2,4-Di-tert-Howeverylphenol, Coumarin.

GC/MS analysis of dichloromethane extract of the solution developed with the combination of *T. diversifolia* leaves revealed the existence of [1,1'-Biphenyl]-2,3'-diol,3,4'5,6'-tetrakis(1,1-dimethylethyl)-,7a-Isopropenyl-4,5-dimethyloctahydroindene-4-carboxylic acid, Trans-(2-Decenyl) succinic anhydride, 2,4-Di-tert-Howeverylphenol, 1,3-Benzenediol,4-ethyl-, Indole

GC/MS analysis of dichloromethane extract of the solution developed with the combination of *M. micrantha, T. diversifolia, G. sepium* leaves revealed the existence of (S, E)-4-Hydroxy -3,5,5-trimethyl-4-(3-oxoHowever-1-en-1-yl) cyclohex-2-enone, 2,4-Di-tert-Howeverylphenol, Coumarin, Phenylethyl Alcohol, Benzyl alcohol, Tolunene.

1. *Mikania micrantha* Solution 100g to 100 ml water developed under protocol 2

Compound	Formula	Retention time
[1,1'-Biphenyl]-2,3'-diol,3,4',5,6'-tetrakis(1,1-dimethylethy)-	C28H42O2	8.150
Trans-(2-Decenyl)succinic anhydride	C14H22O3	8.371
2,4-Di-tert-Howeverylphenol	C14H22O	9.621
1H-indole,4-methyl-	C9H9N	11.787
Benzene,1,3-bis(1,1-dimethylethyl)-	C14H22	13.489
Naphthalene	C10H8	18.904
Phenol,4-ethyl-	C8H10O	22.752

Compound	Properties	Ref:
[1,1'-Biphenyl]-2,3'-diol,3,4',5,6'-tetrakis(1,1-dimethylethy)-	Biphenyles pesticides	[381]
Trans-(2-Decenyl)succinic anhydride	1. Larvicidal 2. ovicidal, 3. Repellent 4. oviposition deterrent activities	

2,4-Di-tert-Howeverylphenol	adulticidal, larvicidal, ovicidal, repellent, and oviposition deterrent activities against the spider mite, Antifungal Activities, Antiviral	[382]
1H-indole,4-methyl-	Antifungal Activities	[381]
Benzene,1,3-bis(1,1-dimethylethyl)-	1. Larvicidal 2. Ovicidal 3. repellent, and oviposition deterrent activities	[382]
Naphthalene	Antifungal Activities, Antiviral	[380]
Phenol,4-ethyl-	Antifungal Activities	

2. *Gliricidia sepium* Solution 100g to 100 ml water; developed under protocol 2

Compound	**Formula**	**Retention time**
Triethylene glycol monododecyl ether	C18H38O4	21.673
2,4-Di-tert-Howeverylphenol	C14H22O	13.489
Coumarin	C9H6O2	12.680

Compound	Properties	**Ref.**
Triethylene glycol monododecyl ether	Unknown	
2,4-Di-tert-Howeverylphenol	adulticidal, larvicidal, ovicidal, repellent, and oviposition deterrent activities against the spider mite, Antifungal Activities, Antiviral	[383]
Coumarin	insecticide activity, anti-inflammatory, anticoagulant, antibacterial, antifungal, antiviral, anticancer, antihypertensive, antitubercular, anticonvulsant, antiadipogenic, antihyperglycemic, antioxidant, and neuroprotective properties.	[384], [385]

3. *Tithonia diversifolia* Solution 100g to 100 ml water; developed under protocol 2

Compound	**Formula**	**Retention time**
[1,1'-Biphenyl]-2,3'-diol,3,4'5,6'-tetrakis(1,1-dimethylethyl)-	C28H42O2	22.752
7a-Isopropenyl-4,5-dimethyloctahydroindene-4-carboxylic acid	C15H24O2	20.25
Trans-(2-Decenyl) succinic anhydride	C14H22O3	18.924
2,4-Di-tert-Howeverylphenol	C14H22O	13.494
1,3-Benzenediol,4-ethyl-	C8H10O2	11.798
Indole	C8H7N	10.389

Compound	**Properties**	**Ref.**
[1,1'-Biphenyl]-2,3'-diol,3,4'5,6'-tetrakis(1,1-dimethylethyl)-	Biphenyles pesticides	[380]
7a-Isopropenyl-4,5-dimethyloctahydroindene-4-carboxylic acid	Antifungal Activities	
Trans-(2-Decenyl) succinic anhydride	larvicidal, ovicidal, repellent, and oviposition deterrent activities	

2,4-Di-tert-Howeverylphenol	, larvicidal, ovicidal, adulticidal repellent, and Antifungal Activities, Antiviral	[382]
1,3-Benzenediol,4-ethyl-	larvicidal, ovicidal, repellent, and oviposition deterrent activities	
Indole	-	

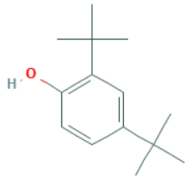
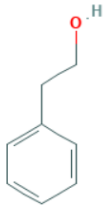
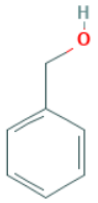
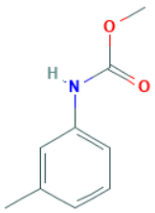
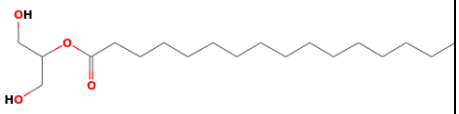
4. Final solution without mud solution (leaf extracts) 3:1:1 ; developed under protocol 2

Compound	Formula	Retention time
(S,E)-4-Hydroxy -3,5,5-trimethyl-4-(3-oxoHowever-1-en-1-yl)cyclohex-2-enone	C13H18O3	16.645
2,4-Di-tert-Howeverylphenol	C14H22O	13.500
Coumarin	C9H6O2	12.525
Phenylethyl Alcohol	C8H10O	7.183
Benzyl alcohol	C7H8O	5.982
Tolunene	C7H8	2.325

Compound	Properties
2,4-Di-tert-Howeverylphenol	2,4-DTBP is a toxic lipophilic phenol, antioxidant and anti-inflammatory activities, cytotoxicity in human cells and animals, insecticidal and nematicidal activities, antimicrobial activities, and phytotoxicities.
Coumarin	insecticide activity, anti-inflammatory, anticoagulant, antibacterial, antifungal, antiviral, anticancer, antihypertensive, antitubercular, anticonvulsant, antiadipogenic, antihyperglycemic, antioxidant, and neuroprotective properties.
Phenylethyl Alcohol	as a fragrance and an antimicrobial preservative in cosmetic formulations (Suspect this as the compound responsible for the odor),
Benzyl alcohol	A toxicologic and dermatologic review of benzyl alcohol when used as a fragrance ingredient is presented. Benzyl alcohol is a member of the fragrance structural group Aryl Alkyl Alcohols and is a primary alcohol.
Tolunene	

6.6.3.5.**Final solution with mud solution (leaf extracts) 3:1:1; developed under protocol 2**

The identified compounds representing its formula , molecular weight and the chemical structure respect to the retention is summaries as follows,

Compound	Formula	Molecular Weight (g/mol)	Chemical Structure	Retention time
2,4-Di-tert-Howeverylphenol	$C_{14}H_{22}O$	206.32		13.497
Phenylethyl Alcohol	$C_8H_{10}O$	122.16		7.183
Benzyl alcohol	C_7H_8O	108.14		5.984
Carbamic acid, methyl-Phenyl ester	$C_8H_9NO_2$	165.19		5.228
Hexadecanoic acid, 2- hydroxy-1-(hydroxymethyl) ethyl ester	$C_{19}H_{38}O_4$	330.5026		24.005

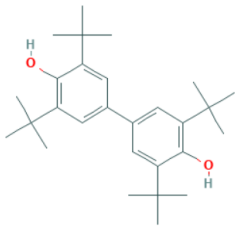
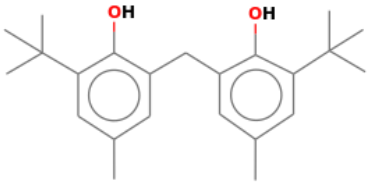
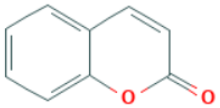
[1,1' – Biphenyl]-2-3'-diol,3,4',5,6'-tetrakis(1,1-dimethylethyl)-	$C_{28}H_{42}0_2$	410.6		22.76
Phenol,2,2'-methylenebis[6-(1,1-dimethylethyl)-4-methyl)-	$C_{23}H_{32}0_2$	340.4990		23.277
Coumarin	$C_9H_6O_2$	146.14		12.534

Figure 6-1 – GC MS results presenting the Chemical compound, Formula, Molecular Weight, Chemical Structure, Retention time

Compound	Properties	Ref:
2,4-Di-tert-Howeverylphenol	2,4-DTBP is a toxic lipophilic phenol, antioxidant and anti-inflammatory activities, cytotoxicity in human cells and animals, insecticidal and nematicidal activities, antimicrobial activities, and phytotoxicities.	[4]
Phenylethyl Alcohol	as a fragrance and an antimicrobial preservative in cosmetic formulations (Suspect this as the compound responsible for the odor) ,	[306],
	PEA is an aromatic alcohol that occurs naturally in many plants. It has a floral odor with a rose character. Contaminants in PEA may include P-phenethyl chloride, diethylene glycol chlorohydrin, a-Phenethyl Alcohol, benzyl alcohol, and dibenzyl.	
Benzyl alcohol	A toxicologic and dermatologic review of benzyl alcohol when used as a fragrance ingredient is presented. Benzyl alcohol is a member of the fragrance structural group Aryl Alkyl Alcohols and is a primary alcohol.	[307]
Carbamic acid, methyl-Phenyl ester	Used in pesticides	[308]
Hexadecanoic acid, 2- hydroxy-	antioxidant, anti-inflammatory, and	[8]

1-(hydroxymethyl) ethyl ester	anthelmintic activities / Hemolytic, pesticide, flavor, antioxidant.	
[1,1' – Biphenyl]-2-3'-diol,3,4',5,6'-tetrakis(1,1-dimethylethyl)-	Biphenyl's pesticides	[9]
Phenol,2,2'-methylenebis[6-(1,1-dimethylethyl)-4-methyl)-	Antioxidant, as a binder in polymers. The chemical is not listed on the Hazardous Substances Information System	[383]
2,4-Di-tert-Howeverylphenol	adulticidal, larvicidal, ovicidal, repellent, oviposition deterrent activities against the spider mite, Antifungal Activities, Antiviral Activity, Antibacterial Activities, this has potential as a natural and environmentally friendly herbicide for weed management, Allelopathy, and Autotoxicity	[10]
Coumarin	insecticide activity, anti-inflammatory, anticoagulant, anticancer, antitubercular, anticonvulsant, antiadipogenic, antihyperglycemic, antioxidant, and neuroprotective properties. antibacterial, antifungal, antiviral	[11], [12]

The solutions were evaluated separately to further get an understanding of where the component has been initiated to the developed FSWOM and FSWM.

6.9.4 Discussion

The best technique for identifying volatile matter, long-chain, branched-chain hydrocarbons, alcohols, acids, esters, and other compounds is GC-MS. Phenols, ketones, hydrocarbons, Aldehydes, Esters, and acids have been presented in the leaf extract solutions. The active principles are listed, along with their retention time (RT), molecular formula, molecular weight (MW), peak area (percentage), and biological activity. For the past few years, the gas chromatography-mass spectrometry approach has been used to profile metabolites in plant species.

By comparing the retention periods of a series, the compounds' retention indices (RI) were determined, and the identification of each component was confirmed by comparing its retention index to data in the literature. From the results, it is evident that the combination of the three plant species under the 96-hours of water extraction

contains various photo components and is recommended as a solution that contains toxic components against wood deteriorating agents.

6.10 Practical Application

The developed preservative solution which presented higher toxicity with minimum strength loss percentage was used to treat which was used for roof elements. The investigated.

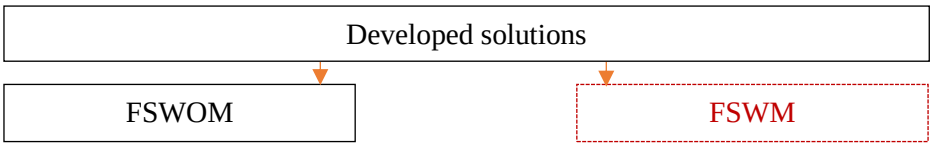


Figure 6-20;Identified solution under protocol 2

Protocol 2 was applied for this application.

The uses quantities were as follows,

Table 6-11; the material matrix used for the extraction was as follows,

Solute				**Solvent**
Plant leaves			mud	
M.micrantha	G.sepium	T.diversifolia	Preprepared	
75 kg	25 kg	25 kg	625 kg	125 kg
3	1	1		
1			5	1

The solution was prepared as per protocol 2. Three numbers of mango wood logs were taken from a wood sawmill in Badulla which was transported from Soranathota, Mahiyangana. It was just after the 2 days cut down from the tree. Then the wood log was sawn down to the lumber with the size of 50 mm x 100 mm x 2438.4 mm. the surfaces were slightly smoothened with the sizing machine.

An equal number of defect-free lumber was prepared per sawn wood log. All the specimens were in high moisture conditions before the treatment. The preservative solution was prepared 4 days before the lumber preparation.

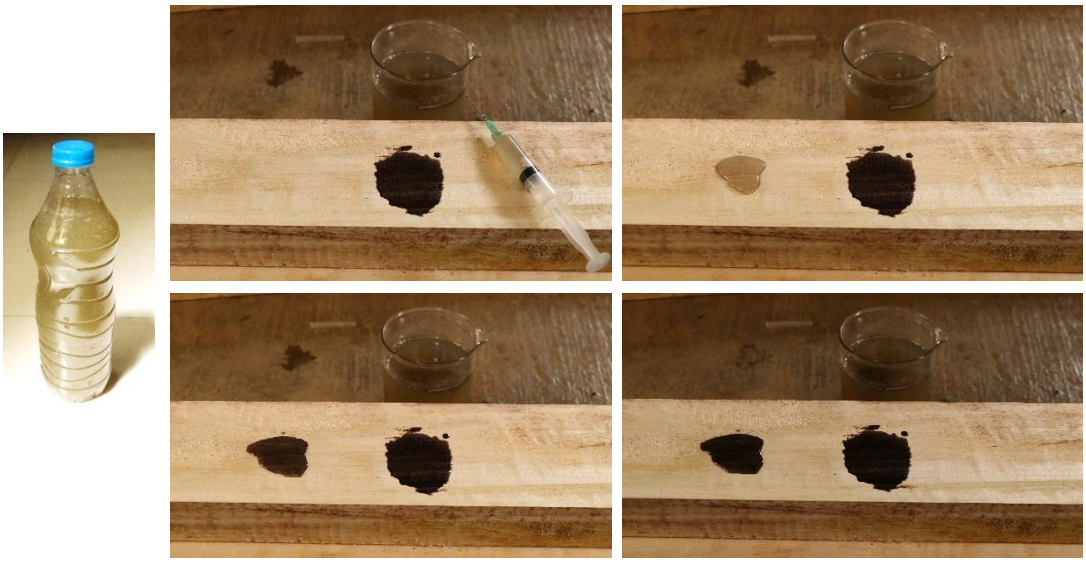


Figure 6-21; The Initial visual observations performed to identify whether the solution is ready for the treatment .

The process was documented as follows, Figure 6-21,

a) Significant color variation was used as an indicator as proof to determine a proper fermented solution.

b) The tank was prepared in the size of 600 mm x 3048 mm x 762 mm, Figure 6-22. The sample



Figure 6-22; 50 mm x 100 mm x 2438 mm timber submerged in the solution (Similar industry available dipping technique)

specimens were submerged in the solution and were kept for another 4 days of treatment duration. The authors propose and recommend the treatment duration can be reduced if the treatment could be completed under pressure treatment. The research study has proved 4 days of treatment duration leads to penetrated the visually shown penetration for 5 to 9 mm in depth, Figure 6-23.



Figure 6-23; The treated timber taken out after 4 days , b – treated wood was then washed from the normal tap water to remove the impurities

The timber was then air-dried for 2 weeks and then was sanded using the following sandpapers; 60,80, 120, 300. Three coats of polyurethane varnish were applied to



Figure 6-24; The appearence were further enhanced using the clear vanish application

enhance the surface appearance before introducing it for application, Figure 6-24.

- Application to the roof in a residential building located in Badulla




6.11 Summary

The extensive use of wood in building construction has both an economic and an aesthetic basis. At present it is at the heart of modern construction owing to its less environmental impact and as it leads towards sustainability. However, as a naturally occurring organic material, wood is susceptible to deterioration, fungal stains, and insect infestation, all of which can shorten the useful life of a structure or product. A preservative solution comprised of fresh leaf extracts of *Gliricidia sepium*, *Tithonia diversifolia*, and *Mikania micrantha* was fermented for 72 hours and then after proper filtrations, the developed solution was evaluated to investigate its performance. This preservative solution and long-term soaking process, soaking saturates with a preservative solution by being immersed continuously effect on formulations react with the cell wall components. Then the wood undergoes a hydrolytic reduction upon contact by sugars present in the wood. This preservative solution and techniques influence the minimal strength loss while improving significant resistance towards wood deteriorating agents.

This results a solution with chemical compounds of 2,4-Di-tert-Howeveryl-phenol, Phenylethyl Alcohol, Benzyl alcohol, Carbamic acid, methyl-Phenyl ester, Hexadecanoic acid, 2- hydroxy-1- (hydroxymethyl) ethyl ester, [1,1' – Biphenyl]-2-3'-diol,3,4',5,6'-tetrakis(1,1-dimethylethyl)-, Phenol,2,2'-methylenebis[6-(1,1-dimethyl ethyl)-4-methyl)-, Coumarin. These compounds are highly responsible for insecticide activity, anti-inflammatory, antibacterial, antifungal, antiviral, antiadipogenic, antioxidant properties. This formulation provides the optimum toxicity against white-rot fungus and the termites and minimum strength loss with minimum leachability.

Also, this involves low embodied energy during the extraction process of the preservative solution as well as the treatment techniques.

One of the significant facts taken into consideration within the development of this organic preservative is to pay attention to the impact of protection agents on human and environmental health. Which is highly significant towards the insight and use of the product.

The main advantage obtained from this organic preservative solution; all the materials obtained are their negligible environmental impact.

Currently, due to many economic reasons or other possibilities, the majority of treated wood products are still dumped or burned. This chapter emphasizes the insight into the impact of toxic treated chemicals through their leaching into groundwater or waterways have elevated serious concerns over the usage of such chemicals and the current practice of disposing of treated wood products. The results have declared the wood treated with the following wood preservative had maintained low leachability and low percentages of heavy metals during leaching.

Fast or Strong-growing plants like *M. micrantha, T.diversifolia, G. sepium* can make it easier to produce certain active chemicals in large quantities to meet demand. Cost-effectiveness of proposed materials and methodology; soaking in the preservative solution. The preservative techniques are themselves cost-effective. Also, the plant species selected within this invention are not native to a specific location, and *M. micrantha* tends to spread to a degree believed to cause damage to the environment. Also, the paddy field mud can be obtained from any of the organic paddy fields after a pre-preparation. The treated *M. indica* wood can be introduced for structural application for building constructions by introducing this organic preservative solution and method that leads towards more sustainability.

CHAPTER 7 : CONCLUSION AND RECOMMENDATIONS

Wood is a building material, standings of its rich and storied history. Properties of any structural material would change over time, especially in tropical countries. Wood is a hygroscopic and anisotropic structure built up of organic compounds. Similarly, insects, fungus, and bacteria influence the molecular structure which is very sensitive to biological destruction in wood. The ecological responsiveness has led to an amplified interest in intensifying new, alternative wood preservatives and *techniques* with minimum environmental impact. Plant derivatives have been applied by generations in some regions of the world to improve the physical and chemical properties of wood to extend the service life. However, with time the utilization of plant-derived goods or extracts was minimally attractive in the timber protection industry while synthetic and inorganic substances were introduced because they proved to be more efficient against wood-degrading agents such as fungus and termites. However, organic biocides or preservatives must now have become a pressing need to replace synthetic and inorganic preservatives due to their lesser toxicity towards human health, non-targeted organisms, and unfavorable impact on the environment. Therefore, the interest has been raised towards finding low-cost, environmentally friendly methods for treating the wood.

A technique on treating timber in a commercially and environmentally acceptable manner aesthetically enhanced by such a method will present significant advances in the art of construction.

7.1 Conclusion

This study investigates the traditional methods and knowledge referring to the preservation of timber used in traditional vernacular constructions for their structural applications. The preservation of these structures is yet in an appreciable status even in harsh tropical conditions like Sri Lanka. Prolonged sustenance of wood in utility applications directly influenced the control of overexploitation of forests for timber production and kept the balance between the interaction between nature and the culture in the past. This study intends to investigate the question of how did the ancient people thought and act on wood preservation in their applications.

The below diagram presents the conceptual chapter analysis of the overall study sequence.

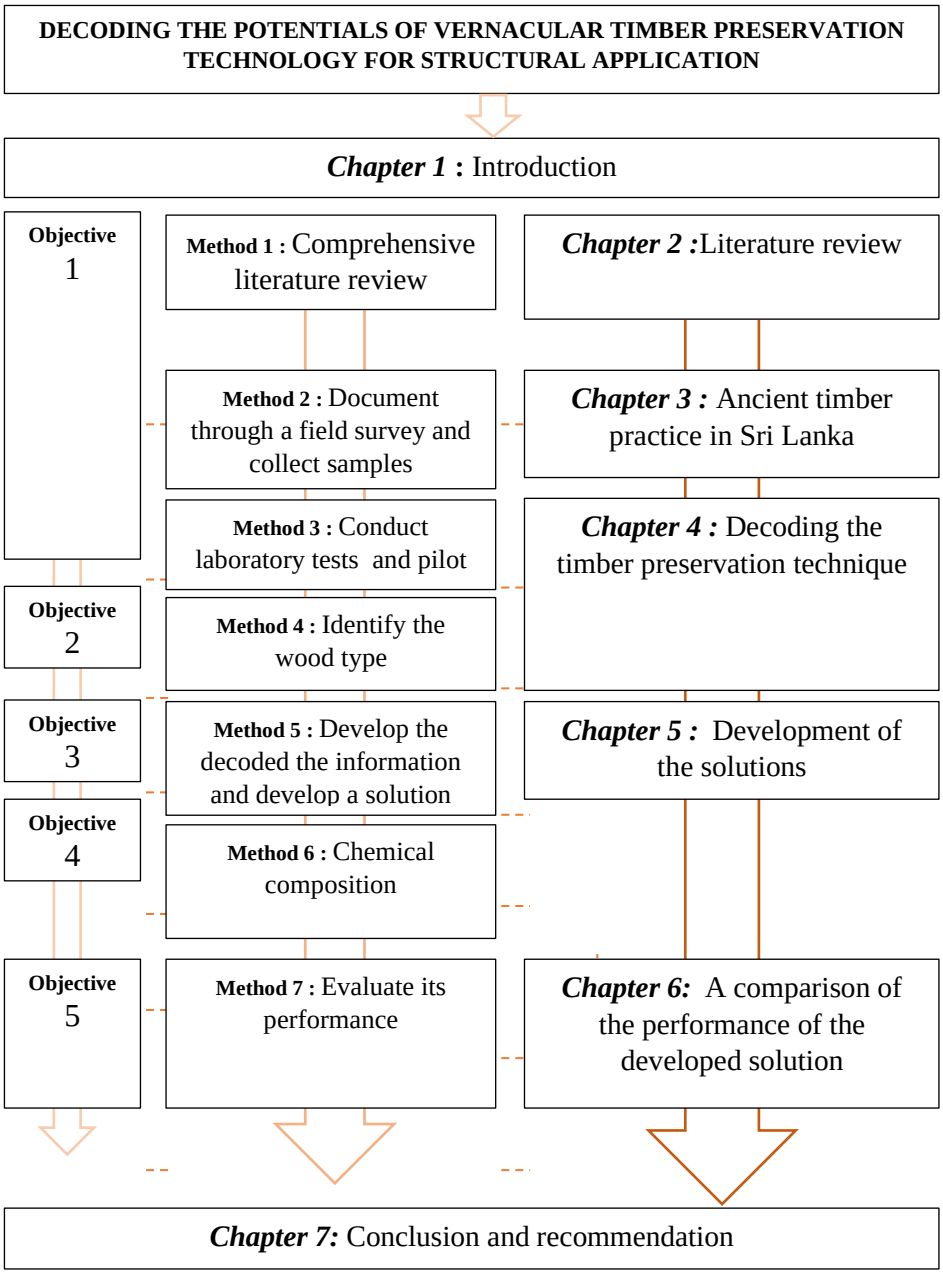


chart 7-1;Flow diagram presenting the objectives and the chapter breakdown

Table 7-1; The summary of the experiments planned within the study.

1	Chapter 4	Experiment 4-1, Experiment 4-2, Experiment 4-3 Experiment 4-4, Experiment 4-6, Experiment 4-7, Experiment 4-8
2	Chapter 5	Experiment 5-1, Experiment 5-2, Experiment 5-4 Experiment 5-5, Experiment 5-6, Experiment 5-7, Experiment 5-8 Experiment 5-9, Experiment 5-10, Experiment 5-11, Experiment 5-12, Experiment 5-13
3	Chapter 6	Experiment 6-1, Experiment 6-2

There are remarks of diverse types of timber structures in our country. This study examines several case histories focusing on the culturally varied and ecologically

diverse traditional buildings with wood used for constructions. There are two main sources to gather information on these cases conceptual-expressive sources and empirical -expressive. To reveal the science the study selects the empirical sources with existing physical proof namely Archeological evidence. Along with it, this study limits on structure in the construction based on the purpose of shelter. *Ambalama* is a kind of architectural manifestation that remained intact that helps to understand the knowledge of traditional timber applications in Sri Lanka.

- The results tabulated from the survey presented significant wood processing techniques and wood preservation techniques that were practiced by the ancestors.
- Medieval constructors had a clear understanding of the physical and mechanical properties of wood during application.
- This was obvious when investigating the existing timber components studied. This study has identified four types of sawing orientations.
- The study identifies clues and factors to suspect and create an assumption on whether did the constructors used any preservatives other than using durable wood.
- An experimental study was further planned on reinventing an eco-efficiency timber preservation technology from lessons learned from history.
- Old buildings comprise a set of authentic information that the future should reveal. They have materialized centuries ago that uphold the respect and the technologies from those who lived in different social structures in a particular context in Sri Lanka.
- A field survey was conducted to collect maximum timber samples; to decode and emphasize the worth of the existing information.
- Survey results and analytical examinations conveyed knowledge that is not yet decoded who had experience in traditional vernacular timber construction practice. However, still, there should be useful ideas to be taken from their solutions. Therefore, results discuss the high necessity of decoding and scientifically proving the value of the existed traditional vernacular practice in Sri Lanka that leads to another environmental innovation in the future that navigates on societal transitions through evidenced knowledge.
- Through the island-wide survey, the study has identified three potential plant species to obtain the extracts to formulate a preservative solution.

- Considering the nutritional value, fast-growth or growth performance, high regeneration capacity with high potential for forage productions three plant species namely *Mikania micrantha*, *Titonia diversifolia*, and *Gliricidia sepium* were selected as potential plant sources for further investigations in this study.
- Further, the study focuses on developing two solutions using the same material matrix with and without pre-prepared. organic paddy field mud.
- The study denotes that rather than developing solutions with each plant extract it has presented optimum toxicity when the solutions developed with the combinations of the three plant types.
- Many organic preservatives have been immerged using plant extracts. However, they have a lack of awareness among the wood industry as they comprise of few shortcomings of permanency, toxicity, leach resistance, environmental acceptability, or cost are some of the factors to consider.
- Based on literature findings the study proposes to minimize the particle size and to select an appropriate solvent to maximize the extraction developed using the *G. Sepium, T. diversifolia, M. Micrantha*.
- The study identifies through literature that the temperature, time, particle size, and extraction cycle are the most important elements that influence extraction efficiency in terms of yield and quality.
- The study identifies water as a potential solvent.
- The visual observation and the visual rating revealed the extraction efficiency is significant among the plant species where the fastest leaf digestion was observed in *Titonia diversifolia* then in *Mikania micrantha* and the lowermost leaf digestion to water was observed in *Gliricidia sepium*.
- However, when the particle size decreases of the solute used for the extraction, the time allocated to the gravity filter increases and it is also challengeable.
- The study has identified the solutions developed combining the plant extracts assorted with mud have coloring capabilities.
- The solution with all three plant species assorted with mud; Td-L: Gs: Mm: M; presented significantly higher color capability which was a significant finding.

- Further minimizing the particle size may increase the extraction efficiency the effort on filtration is not an easy task. Therefore, this study records the particle size to range from 1 mm to 6 mm.
- The current study suggests that the solution developed with the combination of all three plant extracts assorted with mud has the potential to use as an organic wood preservative against wood decay fungi and insects.
- Also, when compared to the industrial available treatments the timber treated with m and the TD_GS_MM_m solution presented a significant discoloration property compared to Boron treated timber and a chromated copper boron treated timber from the first 24 hours immersion.
- Results revealed that the Gs_Td_Mm_m has more leach resistance in outdoor conditions and more significant fixation properties compared to the Gs_Td_Mm solution.
- Besides, the study proposes wood preservatives developed using *Mikania micrantha, Gliricidia sepium,* and *Tithonia diversifolia* plant that is economically and environmentally way which is presently underutilized and sustains high levels of condensed tannins.
- Complexes of tannin extracted to water from the plants effectively protect wood against fungal and termites and also reduce the leachability during service and low levels of heavy metal leaching out. Improving the serviceability of low-durable wood under this preservative and preservation process is a more sustainable choice. Therefore, Overall deforestation is reduced by using domestic or low durable wood. These research findings remarkably lead the low-durable-treated wood to be utilized in the timber construction sector as a sustainable construction material.
- Developing wood protection technologies based on the use of natural chemicals as biocides opens up an array of opportunities for developing effective, environmentally friendly protection systems. Such natural compounds can be obtained cost-effectively, for many engineering approaches which can be employed for economic production.

The study reinvents a solution namely FSWOM and FSWM based on the knowledge obtained from the history. Both the solutions are filed for local patents under the reference numbers 21896 and 21911

7.2 Future Works



Figure 7-1; Future expectation for mass-scale production

Further in-depth investigations should be carried out to reveal the chemistry and the phenomena caused within the wood due to this preservation. And reveal the technique to isolate the chemical compounds for further use.

- Evaluate the Ph values on leachate generated from the wood treated with organic wood preservative solutions.
- Corrosion of fasteners in wood treated with natural and artificial preservatives
- Investigate the effectiveness of the surface application of organic preservatives coupled with petroleum oil and natural oil.
- Investigate the solution and the sediments taken off after treatment to develop as a fertilizer.
- Further, a deep chemical analysis on the formulation of these developed preservatives and identify the best way to isolate the most effective compound.

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